BOTANY
OF SUGARCANE

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TO THE MEMORY OF
MY PARENTS AND MY SISTER EMMY
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PREFACE

This volume aims at giving an inventory of our present knowledge of the botany of the sugarcane plant. Sugarcane compares unfavorably with several other commercial crops as far as reference works are concerned. It is true that several books on local methods of cane growing are available but they rarely refer to experience and research in other countries. This may be largely due to the increasing activities of sugarcane research institutes the world over which render a general review extremely difficult. Curious to relate, the situation as far as the manufacture of sugar is concerned, is quite different since in this field several reference books are available.

The reader will notice that the attention paid by research workers to various aspects of the botany of cane differs widely. While some problems have been studied very carefully, others have been neglected or even ignored. As far as the former group is concerned, I have attempted to present a synthesis of the divergent and often contradictory results; as to the latter group, the urge for research has been emphasized.

Whenever possible, salient parts of original articles have been cited more or less literally, both in the form of illustrations or tables, and in the form of statements. The sources of these citations are indicated by literature references.

Although this volume deals essentially with the botany of sugarcane, many excursions have been made into adjacent fields of study in order to elucidate the importance of botanical research in its application to cane culture, to the control of pests and diseases, and to cane breeding.

Considerable care has been taken in dividing and subdividing the contents of this book in order to facilitate quick reference. Such a detailed subdivision has the drawback that subjects sometimes are split up and dealt with under different subheadings. An attempt has been made to minimize this disadvantage by the liberal use of cross references.

Kandy (Ceylon), July 1951

C. van Dillewijn
I want to express my gratitude to all who in one way or other have assisted in the preparation of the manuscript.

In the first place I thank my former associates of the Sugar Experiment Station, Cheribon, especially Mr. S. W. Leigh, B. Sc., whose wide experience and solid knowledge of problems relating to cane culture have been of great value to me.

In the U.S.A. I had the privilege of spending more than a year in the Division of Sugar Plant Investigations of the Bureau of Plant Industry, Beltsville, Md. To Dr. E. W. Brandes, at that time in charge of the Division, I am grateful for liberal assistance and valuable suggestions. During his absence, Dr. G. H. Coons showed himself a perfect host. To Mrs. L. E. Campbell I am indebted for assistance in tracing literature.

Several staff members of the Division have looked over the manuscript. Dr. E. Artzschwager read the chapters on morphology and anatomy, Dr. E. W. Brandes those on germination, tillering and growth, Dr. G. Arceneaux those on physiology in general while Mr. C. O. Grassl went through the entire manuscript. To all these colleagues I am indebted for valuable suggestions which have undoubtedly improved the manuscript. The responsibility for the final edition rests entirely with the author.

To Dr. P. Honig I am grateful for his sincere interest, constructive ideas and encouragement which were of particular help when, at times, the task undertaken seemed too heavy.

Thanks are due to all institutes and individuals who provided me with publications and reprints. In view of the increasing difficulty of tracing the widely scattered literature on sugarcane their cooperation will be appreciated in the future as well.

Most of the illustrations in this volume are borrowed from other publications as indicated by the references in the legends. Permission to reproduce copyright material was readily granted and particular mention must be made of the many illustrations borrowed from Hawaiian publications by courtesy of the Hawaiian Sugar Planters' Association.

Thanks are due to Miss R. Somersan, Ankara, who typed the first draft, and to Mrs. H. de Huarte, Beltsville, Md., U.S.A., who took great care in preparing the final copy of the manuscript.
INTRODUCTION

In the following paragraphs an attempt is made to analyze the role of research in sugarcane, the dissemination of its results, and other related subjects. 1)

Research

Perhaps more research has been devoted to sugarcane than to any other commercial crop, and there is little doubt that this activity has paid large dividends to the sugar industry, both in the form of higher yielding varieties and of improved growing methods. The cane industry in almost any country has, at one time, been faced with the threat of complete ruin as a result of devastating diseases (sereh in Java, mosaic in many other countries), and the situation has only been saved by the introduction of resistant or tolerant varieties. At present the sugar industry has at its disposal a series of varieties in reserve which in case of an epidemic disease can replace the standard varieties within a short time.

Considerable results, although perhaps less spectacular, have also been obtained from the systematic search for improved culture methods. They permit of saving much labor by using mechanical devices, guarantee better germination by controlling diseases during the early stages of development, and result in a better stand of cane which is reflected in better yields.

The high standard of research in the cane sugar industry is largely due to the splendid work of governmental and private experiment stations. The latter are entirely run by the sugar industry; some of the best examples are those of Hawaii and of prewar Java.

Dissemination of knowledge

Research, however, is only the first step on the road to efficiency, the second is the dissemination of the results obtained, and the third their application in daily field practice. When comparing the results obtained in the institutes of research and the methods actually applied, a striking discrepancy is found. It is obvious that in many cane growing countries field practice has failed to keep pace with scientific progress, and in fact is lagging far behind.

Knowledge may be disseminated verbally and in writing. Publications on sugarcane have become very numerous and they are scattered over such a variety of periodicals that it is hardly possible to keep in touch with progress. Owing to this fact it may happen that research on a certain problem is started in one country in ignorance of the fact that this problem has already been solved elsewhere. There seems to be a need for two kinds of review publications: reference works which give an inventory of our present knowledge, and abstracting periodicals which provide a systematic review of current publications on sugarcane.

1) Several of the views expressed in this introduction have been discussed in an article in SUGAR (January, 1950).
The organization of extension activities differs greatly in various countries. *It should be clear that from a purely economic point of view, the results of research are to be considered as non-existent as long as they are not applied in the field.* There are a few cane growing countries where the results of research are readily translated in terms of field practice but in many countries there is a gap between research and its application.

"Planters' feeling" and tradition

The role played by these two factors, be it consciously or unconsciously, can hardly be overestimated. What is vaguely called "planters' feeling" is supposed to be a kind of intuitive knowledge not based on experiments or reasoning. Young field assistants are often greatly impressed by the "planters' feeling" of older colleagues, particularly if the latter have been successful. In this case it is extremely difficult to determine as to how far the success has resulted from experience and reasoning, and how far from "planters' feeling". On several occasions I have been in a position to test the value of "planters' feeling" and I have been so impressed by the result that I feel it might be of more than personal interest.

The first case relates to Java where prior to 1913 each region and almost every plantation had its particular system of cane culture. Field experiments at that time were rare and since growing conditions varied more or less from one plantation to another, the possibility of differences in cultural requirements was not excluded. At that time it was common to find that adjoining cane fields belonging to two different plantations were handled quite differently although growing conditions were almost identical. This fact raised suspicion.

In the years after 1913 hundreds of field experiments were started with a view to studying each phase of cane culture thoroughly over the entire Java cane belt. The results of the experiments revealed an unexpected degree of uniformity as far as the cultural requirements of cane were concerned. It is true that differences occurred but the overall variation in the Java cane belt was gradually narrowed down to such a degree that the results practically approached uniformity. *This experience strongly indicates that "planters' feeling" or whatever passes under this name may be a most dangerous and misleading guide.*

It might be interesting to speculate about the lesson which this Java experience contains for cane culture in general. To what extent does it apply to the world cane belt as a whole?

As in the case of Java before 1913, we find that each country displays its own characteristic cultural methods which often differ widely from those in other countries. It is true that differences in soil, climate and labor conditions are partly responsible for differences in cultural methods but suspicion is raised by the fact that differences in methods also occur between countries where growing conditions are greatly comparable. One wonders whether, as in the case of Java, many of these differences would not disappear once they were subjected to rigorous field tests. The following experiences seem to point to this direction.

The quantity of planting material used in various countries differs widely. In many cases cuttings are planted in one and a half, and even in two running rows while in others cuttings are planted in a single row at distances of one or two feet in the row. In the former up to one quarter of an acre of fully developed cane has to be sacrificed in order to plant one acre of
INTRODUCTION

new field; in the latter the quantity required is only a fraction of the former. The writer had several opportunities to lay out experiments about the quantity of planting material required in tropical and subtropical cane growing countries where the use of great quantities was customary. Without exception a drastic reduction in the quantity of planting material did not affect the yields provided the quality of the cuttings was adequate. The next step was to trace the origin of the traditional system. It was found that it dated from times when varieties were susceptible to various diseases which affected germination. In order to make up for the low rate of germination, liberal quantities of cuttings had to be planted. With the highly resistant and readily germinating varieties now available, there is no longer any need of using such large quantities. This experience indicates the adverse effect of tradition on the development of efficient methods.

Another example demonstrating the influence of tradition and “planters’ feeling” relates to Java. In this island cane is planted in Reynoso ditches which used to be about 50 cm wide leaving a ridge of about 65 cm between adjoining ditches. The curious fact about this system is that at the time of planting less than 50 per cent of the soil surface is cultivated. It was generally believed that this was the minimum and that any further reduction in width of the ditches would result in decreased yields. So strong was this conviction that it was hardly possible to persuade planters to test this practice experimentally. The results of the experiments were striking: narrowing down the width of the ditches from 50 to 30 cm did not, in general, affect sugar yields although the actual area of land surface cultivated was not much more than 25 per cent. As a result of these experiments the system of narrow ditches has been readily adopted on a large scale in Java. Its main advantages are obvious: savings in labor cost and increased speed of ditching.

The examples presented draw attention to two fundamental aspects of efficiency in cane growing. First the necessity for giving a fair trial to improved methods developed abroad, particularly in those countries where growing conditions are more or less similar. In addition it would seem to be a sensible policy to reconsider and retest from time to time standard practices, especially those which are taken as a matter of course.

Efficiency in the factory and in the field

A comparison of the position in the factory and in the field reveals a series of striking differences. In both sections of the industry full attention is paid to research but here the similarity ends. While a series of excellent books on the manufacture of sugar is available, no recent book covering the entire field of cane growing does exist. It is true that several books have been published on cane growing in individual countries but these are largely restricted to a description of local conditions and practices, and do not take into account the fundamental principles as revealed by research the world over.

A great difference is also found in abstracting activities. At least one or two periodicals are entirely devoted to reviewing current publications on the manufacture of sugar while there is no periodical which completely covers all publications relating to cane growing. Similar wide differences exist in the application of the results of research. In order to
elucidate this point it will be necessary to compare in a general way the efficiency in the factory and in the field. In the factory sugar (contained in cane) is introduced at one end and commercial sugar is delivered at the other. The difference between the quantity introduced and the quantity delivered is a criterion of the efficiency of the manufacturing process. Generally speaking, the efficiency in the factory is high.

In the field there is not such a simple criterion but some idea of the efficiency in the field can be gained by comparing actual sugar yields with those that could be produced by applying efficient methods.

The sugar yield of a field is largely governed by five factors: solar energy (heat and light), moisture (rainfall and irrigation), soil condition, availability of labor, and cultural methods. When adequate cultural methods are applied and when full advantage is taken of the other factors mentioned, the potential yield can be attained, viz. the maximum yield attainable under the conditions given. The potential yield, however, is only of theoretical importance. The sugar industry, being an economic enterprise, is concerned with the economic yield which is the yield that gives the lowest cost price. The economic yield is always lower than the potential yield.

From the factors mentioned it is possible to calculate approximately the economic yield for each country. A comparison of the economic and the actual yield provides a criterion of the efficiency in the field. In prewar Java, for instance, the average sugar yield had approached 18 tons per hectare. Since the economic yield of that island is estimated at 20 tons, it follows that the field efficiency at that time was 90 per cent. In Hawaii the field efficiency is of the same order of magnitude. In most other countries the efficiency is lower, often much lower, and efficiencies of 50 per cent are not rare. The discrepancy between the efficiency in the factory and in the field is obvious. Whereas in the factory every effort is made to recover as much sugar as possible, in the field only a fraction of the economical yield is obtained. It seems as if the scale where the cane is weighed before entering the factory, forms a boundary between low and high efficiency.

What is the reason for the discrepancy between field and factory? It is to be found in the gap between research and practice which is so much wider in the field than in the factory. This includes the inaccessibility of literature and the inadequacy of extension work. Another factor is the general tendency of underestimating agricultural knowledge. As a rule the qualifications required for factory personnel seem to be higher than those for field employees which is not consonant with the complexity of field problems. In this connection it is well to keep in mind that, after all, sugar is produced by the plant in the field and that in the factory it is only extracted and refined. The field costs associated with each bag of sugar are several times the manufacturing costs. Consequently the field offers greater opportunities of reducing the cost price of sugar than does the factory. If the ratio of field costs to factory costs is 3 to 1, a saving of 20 per cent in field costs would reduce the cost price of sugar by 15 per cent while a similar saving in manufacturing costs would lower the cost price of sugar only by 5 per cent.
Cane growing as a science

From the foregoing it follows that the greatest possibilities of reducing the cost price of sugar are to be found in the field. They can be materialized by bridging the gap between research and field practice as has been done to a great extent in the factory. During the past twenty five years research in sugarcane has made more progress than in any previous period, and it is felt that if the results of research were applied in practice, cane growing might become a science, reducing the influence of tradition, planters' feeling and guesswork to a minimum.

A close approach to this ideal situation is to be found in Hawaii; it also applied to pre-war Java where every stage in cane growing was based on the result of numerous field experiments.

An example of what can be achieved in this respect is provided by the method of foliar diagnosis. As in the case of the human body where the nutritional status is tested from time to time by analyses of blood, etc., foliar analysis gives an idea of the nutritional state of the cane plant. The crop log, developed in Hawaii, goes even farther and includes also the water requirement and the ripening process in its system. By sampling cane at regular intervals, it becomes in this way possible to guide a crop safely through all stages of development.

Several other examples could be cited which indicate that research has reached a stage which permits of growing cane in a scientific and efficient way thus reducing the cost of sugar to a minimum. The main problem is how to translate the acquired knowledge into field practice. The present volume is intended as a modest contribution in that it surveys what is known of the cane plant, its functions, its requirements, and its response to various factors.
MORPHOLOGY AND ANATOMY

The morphology of sugarcane has been investigated in considerable detail by Barber (84, 85, 86, 87, 88, 89), Jeswiet (320, 329, 330), Artschwager (65, 66, 68, 69, 70, 71, 72), and many others. Excellent descriptions of the anatomy of the cane plant have been presented by Artschwager (65, 66) and various other investigators. The results obtained by these authors have been freely drawn upon in the following chapters.

The attention of research workers who are engaged in preparing taxonomic descriptions of sugarcane clones is particularly drawn to an illustrated outline designed for this purpose by Artschwager (67).

CHAPTER 1
THE STEM
MORPHOLOGY

The stem as a whole.—Sugarcane is propagated asexually by cuttings (sets, seed cane), each containing one or more buds. Each bud may develop into a primary stem, this in turn may form secondary stems, etc. (fig. 1).

Fig. 1.—The underground portion of a cane stool showing primary, secondary and tertiary stalks. After Martin (448).
The stems are composed of joints which, at the very base of the stem, start very short, then gradually increase in length until a maximum is reached, after which a decrease sets in (fig. 2, 3 and 4). Thus the top and base sections of a stem are characterized by the presence of many short joints, which fact has a practical bearing of some importance. For, since each joint is provided with a bud, the presence of many buds on the basal section of the stem enables the formation of many tillers. Sometimes the very basal part of the stem exhibits the form of a pencil. This pencil, which may be 5 to 10 cm long, indicates that at the time of germination and shortly afterwards, growing conditions have been inadequate (poor drainage!).

The top of the stem is poor in sucrose and rich in melassigenic substances; consequently
it is of little value to the factory. The fact, however, that it contains relatively many buds and an ample supply of nutrients renders it especially valuable for planting purposes. This applies to the uppermost foot of the hard stem. Beyond this, the soft top section is to be found, made up of joints which are either in a state of differentiation or elongation; hence their tender texture.

The arrangement of the joints along the stem is generally aligned, although some varieties exhibit a more or less staggered (zigzag) arrangement (fig. 5). Occasionally zigzag arrangements of internodes and nodes occur as monstrosities (440, 448).

Each joint constitutes a separate unit the length of which is governed by internal and external factors. The normal trend of the length of the joints of a stem is associated with the grand period of growth, which implies that the rate of elongation is small during the earliest stage of development. With increasing age this rate increases till a maximum is reached, after which a decline sets in. When conditions during the elongation of a joint are adverse, its length may become restricted. This is, for instance, the case during periods of drought or low temperature (fig. 6). Under these conditions the normal trend of the length of the joints may be disturbed. The same occurs when the active leaves are damaged.
Fig. 6.—Variation in the length of the joints of a stalk caused by the seasons of the year. This type of variation is very common in countries with alternating warm and cool seasons. After Das (193).

to such an extent that the supply of assimilates to the growing joint is severely affected (leaf diseases or mechanical injury of the leaves). The location of dwarf internodes on the stem permits of estimating the time at which the adverse conditions were active.

In addition to external factors, internal factors may be responsible for the occurrence of dwarf internodes. Several varieties are known in which dwarf internodes alternate with normal internodes in an apparently irregular way and without any relationship to external conditions (448).

The diameter of the joints of a stalk also reveals a certain trend. Fig. 7 shows an example where the thickness of the joints is greatest in the underground part of the stalk with a gradual decrease in upward direction until a more or less constant value is attained. This continues along a great part of the stalk, with only a slight increase in the top section. Fig. 8 on the other hand shows a stalk with a maximum girth at some distance above the soil surface. The trend of the diameter along a cane stalk may be of considerable practical importance, especially as far as the danger of lodging is concerned. It would seem that
a type like that presented in fig. 7 is less liable to lodging since the gradually increasing
thickness in the basal section indicates an increasing resistance toward lodging in this
part of the stalk. The closer the maximum moves toward the top, the more the danger
of lodging becomes apparent.

The trend of both length and diameter of successive joints varies widely with different
varieties and under different conditions. The most detailed data on this subject have
been collected by Barber (85) in India, and by Arendsen Hein (63) and Houtman (313)
in Java.

The cross section of a cane stem is rarely circular, but more or less oval. This is as-
sociated with the dorsiventral structure of the cane stem in general.

The weight of the millable part of a cane stem varies widely. In Java, where the crop
is harvested at an average age of 14 months, two kilograms constitute a fair average weight.
In stand-over cane considerably higher values may be obtained. Similarly, great variations
occur in the length of the stalks.

Occasionally bifurcated stems have been observed in several varieties (86, 373, 440, 461)
(fig. 9). This phenomenon is often associated with twin buds in the internodes below the
bifurcation. Forked stems are considered monstrosities.

Another anomaly is expressed in a spiral arrangement of the nodes and in this case
the buds and leaves are arranged accordingly, a most interesting phenomenon from a
phylogenetic point of view.

Buds are sometimes absent in the top section and, less frequently, in the basal part of
otherwise normal stalks. Thus Barber (86) found canes the joints of which were altogether
devoid of buds, and one variety (Kaghze) was marked in the Coimbatore collection as
especially subject to this deformity. A budless cane seedling has also been reported
from the Philippines (461).

As soon as the growing point of a normal stem ceases its vegetative development in

![Girth of Joints](image)
order to produce an inflorescence, the formation of joints without buds is a normal feature. Moreover, the joints constituting the main axis of the panicle are much longer than normal joints.

A most interesting situation arises when a stalk starts changing from the vegetative to the reproductive stage and after a certain time resumes vegetative growth. This results in the formation of budless cane sections. Since these sections are unable to germinate, this phenomenon may cause some economic distress. It was reported from Hawaii that in the case of H 109 the quantity of “blind” seed cane amounted to from 10 to 20 per cent and constituted a problem of commercial importance. Sections of “blind” seed occurred only in stalks that had not tasseled. Moreover, a comparison of the latter with tasseled stalks showed that the “blind” section had originated at a time when tasseling in the other
stalks had just started. Apparently the stalks under consideration had started to change from the vegetative to the flowering stage, thus giving rise to the formation of budless joints as is normally the case in flowering stalks. For an unknown reason, however, these stalks reverted to the vegetative stage, and resumed the formation of joints with normal buds, leaving as the only trace of their effort a “blind” section.

In two-year-old cane where flowering had occurred twice, non-flowering stalks with two “blind” sections were found. Here, apparently, the stalks had made two starts to flower, neither one of which persisted (585).

This explanation of the phenomenon of “blind” sections is supported by the fact that in later years it has been proved that a temporary change from the vegetative to the generative stage is not rare in sugarcane. The growing point starts developing a flower primordium and subsequently reverts to the vegetative stage (240).

The joint.—The units of which a stem is composed are the joints. Each joint consists of an internode and a node, the latter being the place where the leaf is inserted. After the leaf has dropped, a leaf scar remains (fig. 10).

The joints may exhibit various forms (fig. 11): cylindrical, tumescent, bobbin-shaped, conoidal, obconoidal, curved, etc.

Color.—The color of the internodes depends on variety and on external conditions of which the latter are often dominant. Exposure of the internodes to sun may result in a complete change of color. The same variety, when grown at different altitudes or in different climates, may exhibit different colors. Jesweit (320) reports, as an example of the great variation of color within one variety, that in one field of POJ 100, yellow, green, brown-red and red stems may be present.

All colors of the stem of sugarcane can be traced back to two basic pigments: the red

Fig. 11.—Internode patterns: A, cylindrical; B, tumescent; C, bobbin-shaped; D, conoidal; E, obconoidal; F, curved. After Artschwager (68).
color of anthocyanin present in the epidermis and the subepidermal cells, and the chlorophyll present in the deeper tissues. These two pigments may be present in varying concentrations, especially as far as anthocyanin is concerned, and this accounts for the gamut of tints which is so characteristic of sugarcane. When, for instance, much anthocyanin and little chlorophyll is present, the color will be red. A normal chlorophyll content and very little anthocyanin will result in a greenish color. Much chlorophyll and much anthocyanin gives a purple-red. When both colors are practically absent, the color of the mature stem will be yellow.

The color of the internodes is generally solid, but striped or variegated forms, the so-called ribbon canes, are characteristic of many varieties. They are vegetative mutations sprung up from the solid colored forms. In many cases back mutations giving rise to the original solid color canes, have been observed. The stripes result from the fact that one or both of the basic colors occur in longitudinal bands. In this way many combinations are possible. When anthocyanin is practically absent and chlorophyll is present in bands, green and yellow stripes will result. When chlorophyll occurs in stripes and anthocyanin is only present in the chlorophyll-free zones, alternating green and red stripes will result. Purple-red and red stripes are associated with an even distribution of anthocyanin while chlorophyll is present in bands. A uniform distribution of chlorophyll in combination with anthocyanin in bands will give rise to green and purple-red ribbons (211). Other combinations of the two basic colors may result in other striped patterns.
THE STEM

WAX.—The surface of the internode, with the exception of the growth ring, is more or less covered by a coating of wax. Several attempts have been made to extract this wax on a commercial scale. Mutants of some varieties are known where the wax coating is almost lacking. In Java, a waxless sport of POJ 2878 has been propagated for some time, with a view of avoiding the difficulties resulting from the presence of wax in the factory. The amount of wax on the internode varies greatly in different varieties, and wax may even occur in the form of stripes. Generally it is most conspicuous in the upper section of the internode, where it forms a wax ring (fig. 10). The wax coating consists of densely crowded tiny threads (fig. 12). When the internode is exposed to the air, moulds usually develop on the wax, turning its white color into a dirty black.

CRACKS.—The surface of the internode is generally glabrous. Cracks, however, may occur. They are of two kinds: small corky cracks, which are restricted to the epidermis, and deeper ones, growth cracks, which may extend to the center of the stalk (fig. 10).

The corky cracks, or ivory markings, are small longitudinal slits in which cork formation takes place. They are mostly found in the wax ring and immediately below, and may coalesce into corky patches. Corky cracks are regarded as harmless to the plant.

Growth cracks are not only deeper but also longer, often running along almost the whole length of the internode into the root band. They are fairly characteristic of the varieties but growing conditions also seem to play a role. They develop mostly under the combined effects of vigorous growth (high soil fertility and adequate irrigation), and high transpiration rate (dry air, wind). The name “wind cracks”, as given to them in some regions of Java, is, therefore, not without significance. Growth cracks are harmful since they increase the rate of transpiration. Moreover, the tissue exposed by the cracks is subject to deterioration.

In addition to the longitudinal growth cracks, Barber (86), Lyon (425), Martin (440, 448) and others have described the occurrence of horizontal cracks, the so called “knife cuts”. These are rather deep horizontal cracks generally located in the bud-groove and apparently are not the result of insect attack. They are often found on the youngest internodes and the name “knife cut” is characteristic of their appearance. The cause of this deformity is still unknown.

INTERIOR.—Fresh cross sections of the internodes may exhibit differences in color between different varieties. Some canes show a brownish shade; in others, this color is limited to the rind. *Saccharum robustum f. sanguineum* is characterized by a blood-red color which is most intensive near the rind and grades off to almost a white in the center of the pith. This color is also evident externally in a dark red rind, deep red buds, dewlaps, and growth rings of this clone (274). Jeswiet (320) considers the brown color of the rind an excellent characteristic since it is highly constant.

In addition to varieties with a more or less solid color of the interior, occasionally mutants occur in which colored parts of the interior alternate with uncolored sections.

When a stem is split longitudinally, the interior part generally exhibits a rapid discoloration in the meristematic regions of the apical growing point and of the lateral buds. According to Zerban (617) two kinds of discoloration are involved:
1. A brown discoloration due to the action of oxidases;
2. A green discoloration resulting from the effect of iron on both the oxidases and the polyphenols that have escaped from the action of oxidases.

In mature cane, both types of discoloration are also very pronounced in the nodes, especially in the root bands and in the vicinity of the lateral buds (fig. 13).

Normally the interior of an internode is solid, except for a central cavity which may have the diameter of a pencil. The main axis of the inflorescence, however, is usually pithy, and this pithiness may extend into a smaller or greater part of the upper half of the stalk. Pith development in the interior of non-flowering stalks is considered an undesirable character, either inherent in the variety or resulting from adverse growing conditions.

Experience in Java has shown that the type of soil has a great influence on the size of pith and cavity, and a similar relationship has been reported from India (16). In ratoon crops the central cavity is generally larger than in plant cane.

Sometimes the cut surface of a longitudinal section shows glassy, water-soaked bands due to the fact that the intercellular spaces are partly filled with water. This is a common phenomenon in deteriorating cane.

**ROOT BAND.**—The root band (root ring) is the basal region of the internode where the root primordia (root initials) are located. It is limited at its upper and lower sides by the growth ring and the leaf scar respectively. Its width usually increases toward the bud and is smallest at the opposite side. The number of rows of root primordia varies from one to several, depending on variety. In the individual stalk, the number of rows decreases toward the base to only one row (fig. 2).

The most common shapes of the root band are cylindrical, conoidal or obconoidal. The root primordia may be arranged in rows or they may be distributed more or less irregularly. The largest ones are located at the base of the root band, the smallest at its top. The lower primordia develop more readily than the upper ones.

Each individual root primordium exhibits a dark colored center, the root cap, and a light colored zone or “halo”. The root band has always a distinct coating of wax.

**GROWTH RING.**—The growth ring is a narrow band characterized by the fact that it is able, under certain circumstances, to resume growth. Thus in lodged cane and in stem cuttings planted horizontally, a unilateral elongation of the growth ring may take place, which causes the cane to curve upward. The growth ring lacks the coating of wax. It may be narrow (as is the case in many cultivated varieties), or quite broad (as is often the case in wild canes). In some varieties it is horizontal and consequently passes behind the bud; in others, it is bent and forms a curve on top of the bud (fig. 14).
ANATOMY

A cross section of an internode (fig. 15) shows in consecutive order, from the outside to the center, the following tissues:

- Epidermis
- A narrow cortex or rind
- Vascular bundles embedded in ground tissue

The epidermis.—The stem epidermis exhibits an interesting pattern which differs greatly in different varieties, as was first noted by Wieler (597). De Calvino (149) investigated the epidermis of various Cuban canes but the most thorough study in this field has been performed by Artschwager (66, 68). The latter found that mature internodes, which are no longer covered by leaf sheaths, are best suited for study and that the middle section of the internode shows the greatest uniformity in epidermal pattern. In order to remove
the epidermis from the underlying tissue, he uses SCHULZE's maceration fluid in the following way:

A piece of epidermis with adhering cortical and fibrous tissue is cut from the central part of an internode and placed in a test tube containing several crystals of potassium chlorate and a few cubic centimeters of concentrated nitric acid to which a few drops of water have been added. The mixture is carefully brought to a boil, and after a few seconds, as soon as the epidermis separates off in the form of a thin pellicle, water is added and the contents of the test tube are emptied into a Petri dish partly filled with water. The epidermis is then mounted on a slide and stained with chloroiodide of zinc. If the maceration process is interrupted at the right point, the epidermis stains a bright blue; but if the maceration is not successful, the stain will not take at all or the differentiation will not be satisfactory (66).

In the stem epidermis generally two types of cells alternate with one another: elongated, rectangular cells, the so called long cells, and short cells. The long cells constitute the greater part of the epidermal pattern. The short cells are of two types: cork cells and silica cells (fig. 16).

Fig. 15.—Cross section through the outer part of an internode. 1, Epidermis; 2, thick-walled cells forming the rind; 3, 4, vascular bundles of different sizes; 5, sclerenchyma; 6, ground tissue. After LEWTON-BRAIN from MARTIN (448).
Fig. 16.—Surface view of stem epidermis illustrating four of the six patterns distinguished by Arischwager. A, pattern 1; B, pattern 2; C, pattern 4; D, pattern 6. After Arischwager (63).
The cork cells are suberized and relatively thin-walled; they exhibit a wide variety of forms and are often long or short pointed. They may appear singly or in groups of two or three. Generally, however, a cork cell is combined with a silica cell, forming a typical short group (fig. 16D).

The silica cells are more uniform and usually biscuit-shaped. They rarely occur alone but are generally associated with cork cells. Stomates are comparatively few or entirely lacking, but their distribution sometimes offers a valuable diagnostic character.

ARTSCHWAGER distinguishes between the following six epidermal patterns, four of which are reproduced in fig. 16.

Type 1.—Cork and silica cells in single pairs alternating with long cells. The latter have usually straight-running, undulate vertical walls and straight or somewhat sloping end walls (fig. 16D).

Type 2.—Silica cells wanting or very scarce. Cork cells solitary or in groups; squarish, rhomboid, or, in some varieties, greatly pointed and interspersed with the narrow elongate-rectangular type (fig. 16c).
Type 3.—About 50 percent of the short-cell groups lack silica cells; the shape and distribution of the different cell forms show much variation otherwise.

Type 4.—Practically all cork cells are pointed. The vertical walls of the long cells are often curved and their end walls pointed. There is much difference in the width of the long cells. The number of short-cell groups lacking silica cells may show considerable variation. If this number is approximately 50 percent, the pattern formula would be expressed as $4 + 3$ (fig. 16B).

Type 5.—All cells are rather narrow and there is a predominance of the elongate-rectangular type of cork cell, occurring singly or in short connected rows.

Fig. 18.—Cross section through stem bundle with large sclerenchyma cap. A, Outer bundle parenchyma; B, sclerenchyma cap; C, sieve tube; D, companion cell; E, large pitted vessel; F, bundle sheath; G, protoxylem; H, sclerenchyma cap of xylem pole of bundle; it is poorly developed compared to the cap on the phloem pole. After ARTSCHWAGER (65).
Type 6.—The short-cell groups are very numerous and always occur in multiple pairs (fig. 16A). The cork cells are usually somewhat elongate, squarish, or rhomboid.

Types 1, 2, and 4 are the most frequent. The epidermal pattern may render excellent services as an auxiliary method in classifying varieties.

The rind.—The cortex or rind consists of several layers of cells, many of them being sclerenchymatous. Fig. 17 presents a longitudinal section through the periphery of an
internode. Next to the epidermis, two rows of thick-walled and lignified cells occur which give strength to the stalk. In red-colored stalks, besides the epidermis it is these cells that contain the red pigment. Next to these cells there are one or more rows of thin-walled parenchymatous cells which contain chlorophyll. Then follow one or more layers of sclerenchymatous tissue, which border the outer vascular bundles. The cortex varies in width and composition in the different regions of the stem.

The fibrovascular bundles.—The fibrovascular bundles are rather widely spaced in the central part of the stalk but toward the periphery their number increases while their size decreases (fig. 15). The bundles at the periphery often lie so close together as to form practically one solid ring.

A transverse section of a bundle in the stem center is shown in fig. 18 and 19. The bundle is made up of a sclerenchymatous sheath which encloses the xylem and phloem. The sclerenchymatous sheath is most strongly developed on the inside and the outside of the bundle, thus forming two typical caps. The part adjoining the phloem consists of thicker-walled cells than the part adjoining the xylem.

An interesting phenomenon was reported by CORNELISON and COOPER who found that with increase in age there is more and more a deposition of lignin-like compounds in and around fibrovascular tissue, resulting in what might be called a hardening of the fibers up to the time of tasseling. After tasseling, however, there is a sudden change in the activity of these cell groups from deposition to that of removal. Much of the lignin is lost from the fibrovascular tissue, causing the bundles to become more flaccid than formerly. The rind becomes softer and is more easily penetrated because the tissue remaining, after the decrease in lignin due to tasseling, is mainly cellulosic in character. How the plant is able to move lignin is a wide open question (179).

The xylem consists mainly of the protoxylem with adjacent lysigenous cavity (lacuna or air tube) and two large vessels surrounded by flattened parenchyma cells. The protoxylem is composed of annular and spiral elements; between the two large vessels parenchyma and narrow vessels are to be found. The phloem is made up of sieve tubes and companion cells.

The peripheral bundles are somewhat different; they are smaller but appear larger as a result of the well-developed sclerenchyma sheath (fig. 15).

In the growth ring, the vascular bundles remain practically un lignified for a long time and the sclerenchyma is here replaced by collenchyma. Consequently elongation is not excluded here. Fig. 20 gives an idea of the huge collenchyma sheath surrounding the small peripheral vascular bundles of the growth ring.

While in the internode the bundles run nearly parallel to each other, in the node many of them branch or bend to the leaves, to the buds or to the root primordia (fig. 21). Since, moreover, the ground tissue is often lignified here, the nodes are much harder than the internodes.

The ground tissue or matrix of an internode is composed of parenchyma cells in which the vascular bundles are imbedded. This parenchyma consists of thin-walled cells separated by small intercellular spaces. The size of these cells increases gradually toward the center
Fig. 20.—Cross section through the peripheral region of the intercalary meristem of an internode showing the huge collenchyma jackets surrounding the relatively small bundles. After ARTSWAGER (65)
of the internode (fig. 15). The difference in the refraction of light in the cells and in the intercellular spaces accounts for the fact that a longitudinal section of the stalk appears whitish. If, as a result of disease or deterioration, the intercellular spaces are filled with liquid, the cut surface assumes a glassy appearance.

The extreme top of a stalk consists of the growing point enclosed by the youngest

Fig. 21.—System of vascular bundles surrounding the basis of a root initial. The white oval patch indicates the base of the root primordium; at the upper right side another root primordium is present. Before entering the root initials, the bundles show many anastomoses. After Breukamp (142).
leaves (fig. 22). The growing point is made up of a thin-walled meristem, the cells of which are in a state of active division (fig. 23). The youngest ten internodes are so small that they do not measure more than one centimeter altogether.

Fig. 22.—Left, the stem near the growing point tapers rapidly and the joints become shorter. After ARTSCHWAGER from MARTIN (448).
Right, longitudinal section of the growing point of a cane stem; 1, 2, 3, the three youngest leaves; P, growing point. After LYON from MARTIN (448).
Fig. 23.—Longitudinal section through the growing point of a cane stem. After ARTSCHEWAGER (65).

RIND HARDNESS

The hardness of the cane stalk is a property of considerable concern both in the factory and in the field. Hard canes like Uba and POJ 2878 have been responsible for many difficulties in the mills. Thus the rapid extension of POJ 2878 in Java has resulted in a sudden increase in the breakage of mill rolls. In the field, rind hardness is closely associated with resistance to attacks by animals (stalk borers, rats, pigs, jackals, mongooses, etc.). It is interesting to see how in field experiments, where different varieties are grown in alternating plots, the animals select the soft varieties for their attacks.

This has resulted in a search for harder varieties and in this connection...
was felt for a simple device for measuring the rind hardness of large series of seedlings. The first apparatus of this kind (fig. 24) was designed by Puri and Venkatraman (486, 552). It consists essentially of a plunger (P) to the upper end of which a circular plate (C) is attached to carry weights. The lower end is provided with a piercing bit. This bit has a diameter of 0.7 mm and its free end is flat. The degree of hardness is measured in terms of pounds. Hedley (302) in South Africa, who used a similar apparatus, also devised another type of instrument.

A considerable improvement was achieved by Khanna (349) who developed an instrument for field use. It is constructed on the principle of the "presometer" (fig. 25) and consists of a measuring capacity spring (S) encased in a cylindrical barrel (B). The spring is connected with a rod (R) bearing a needle point (NP). In order to test the rind hardness, the needle is pressed against the cane stalk till it breaks through the rind, when the comparative rind hardness is recorded on a scale (L). Similar instruments have given satisfactory results in Hawaii (fig. 26), in Queensland (147, 468) and in Formosa (547, 612).

The fact should be emphasized that the needle point of these instruments must be of exactly the same diameter throughout the course of an investigation, since otherwise the results are not comparable.

![Fig. 24](image1.png)

**Fig. 24.**—Instrument for testing the rind hardness of sugarcane. P, Plunger working into tube T; L, supporting legs; C, plate to carry weights; OP, operating part fitting into a socket in T; B, piercing point. After Puri and Venkatraman (486, 552).

![Fig. 25](image2.png)

**Fig. 25.**—Instrument for testing the rind hardness of sugarcane in the field. It consists essentially of a spring S encased in a cylindrical barrel B, and a rod R holding a needle point NP. After Khanna (349).
Rind hardness shows a wide range of variation caused by both internal and external factors. Varietal differences have been reported by several investigators (40, 147, 302, 481, 486, 547, 551, 586, 612). Venkatraman (486, 551), who tested many varieties, obtained the following relative values: Keli, the softest tropical cane 2.5, other tropical canes 4 to 6, indigenous Indian canes 7 to 8, hard-rinded Coimbatore seedlings 8 to 9, and Saccharum spontaneum 10 pounds. Hedley obtained the figures presented in Table 1. This author emphasizes the fact that Uba, in addition to its hard rind, is characterized by thin stalks and very short joints. The small diameter implies that the ratio of hard rind to soft pith is unfavorable while the short joints are responsible for an unfavorable proportion of hard nodal tissue to softer internodal tissue.

Rind hardness within one stalk may vary greatly and the fact that the data available in this respect are rather conflicting indicates that many factors are involved. Thus Puri and Venkatraman (486) found a decrease in rind hardness from the bottom to the top of cane stalks and a similar result was reported by Ueno (547). Hedley (302) obtained very little difference between the top and the bottom, although some varieties showed a decrease in rind hardness toward the top. Water shoots (bull shoots) are much softer than normal stalks. According to Buzacott (147), the hardest part of the stalk may be the butt, the middle or the top, although generally the basal two or three joints are somewhat less hard than the other joints of the butt. It is not uncommon to find the uppermost colored internodes to be the hardest of the stalk.

These conflicting data concerning the trend of rind hardness along a cane stalk are suggestive of a dominant effect of external factors.

Fig. 26.—Instrument similar to that of fig. 25 seen from the outside. A, hollow cylinder containing spring attached to plunger B which bears removable needle point C. Pressure of the point against the cane rind compresses the spring and causes the pointer D to slide along the indicator scale and register the number of units of pressure required to force the point into the rind. After Lyon (481).
This opinion is supported by an interesting observation of Hedley (302) who found that within one field all stalks usually show approximately a uniform trend; i.e., either they are all as hard at the base as at the top or they show a gradual decrease in hardness toward the top.

Differences in rind hardness have been found between different sides of a stalk. Puri and Venkatraman (486) found the darker or redder side of a stalk always to be harder than the lighter or greener side. Hedley (302) made the interesting observation that the two sides of the stalk where buds occur are softer than the sides at right angles with these, the relative figures being 7 and 10 respectively. This is in accordance with the dorsiventral structure of the cane stalk mentioned previously. Non-flowering stalks, according to Pemberton (481) are about twice as hard as flowering stalks; the anatomical characteristics responsible for these differences have already been indicated (p. 16).

Differences even occur within individual joints. The softest part is to be found approximately midway between adjacent nodes (147), the growth ring and the root band being considerably harder in mature joints (547). In the youngest joints, however, the rind hardness in the growth ring shows a marked drop.

Among the external factors, irrigation plays an important role, since irrigated crops have been found to be softer than unirrigated cane (table 1). Buzacott (147) states that trash-covered Badila is much softer than uncovered Badila; this seems to warrant the view that artificial trashing tends to increase the rind hardness. The same author obtained evidence that lodging retards hardening of the rind, either due to contact with the ground or as a result of covering by trash.

The relationships between rind hardness and stem anatomy have been studied by Venkatraman (552), Ueno (547), Khanna and Panje (351), van der Weerd (586) and others. Ueno (547) states that rind hardness is associated with the distribution of the vascular bundles, their number and the size of the sclerenchymatous sheath surrounding the bundles. Khanna and Panje (351) found that in addition to these characteristics, the lignification of the intervascular parenchyma cells is associated with rind hardness.

In an extensive study van der Weerd (586) has compared the varieties POJ 3016, 2878 and 2967. The stalks of POJ 3016 are thick, juicy and relatively soft; POJ 2967 is hard and less thick, while POJ 2878 occupies an intermediate position. The anatomy of the stalk exhibits various differences among the three varieties but these differences are insufficient to account for the differences in hardness. The lower section of the stalk of these varieties shows some interesting differences. The tensile strength of this section is 1314, 881 and 945 kg for POJ 2967, 2878 and 3016 respectively; the breaking length (breaking force divided by meter-weight) is 1501, 1103 and 901 respectively. Thus expressed in terms of breaking length, POJ 2967 is considerably stronger than the two other varieties. Within each variety the tensile strength increases with the diameter of the stalks.

In all three varieties investigated, the fibers (fibrovascular bundles) of the rind are heavier (expressed in terms of meter-weight) than the more centrally located fibers. This is explained by the fact that the former contain relatively more sclerenchymatous tissue and less phloem and xylem than the latter. As to varietal differences, the meter-weight
of the fibers in POJ 2967 is higher than in POJ 2878, and the value in the latter is higher
than in POJ 3016. The meter-weight of the fibers in POJ 2878 shows a distinct trend along
the stalk: it increases from the top toward the base. This phenomenon is associated with
an increase of the vascular sclerenchyma sheath in the same direction. The tensile strength
of the individual fibers is greater in POJ 2967 than in POJ 2878.

The degree of rind hardness, as determined by the instruments described before, is in
fairly good accordance with the resistance of canes to animal attack. Consequently, rind
hardness testing has become standard practice in the cane selection work of various
countries (35, 40, 147, 612). Moreover, evidence indicates that wind breakage as a result
of cyclones is at least partly related to rind hardness of the first to fourth internode in
hilled-up soil (610).

CHAPTER 2
THE BUD
MORPHOLOGY

The buds are located in the root band. Normally one bud is present on each node but
sometimes buds are wanting on several or all nodes of the stalk, while in other cases two
or more buds are present on one node (86, 95, 261, 320, 373, 421, 440, 461, 616).

Double buds may occur in the form of twin buds, in which case they are enclosed by
a common bud scale (fig. 27) or they may be entirely separated. Twin buds may occur only
at one side along the stalk while single eyes are present at the other side (461). ZERBAN (616)
found in Peru a stalk with each node bearing two eyes diametrically opposite, which alter-
nated at right angles in successive internodes. Such a decussate arrangement has also been
reported from Hawaii (421, 440).

The occurrence of double buds is not infrequently the prelude to a dichotomous splitting
of the stem (fig. 9). On passing down the stem, such double buds are seen to be preceded
by buds of abnormal width associated with a flattening of the stem. Such cases have been
described by BARBER (86), JESWIET (320) and others.

Fig. 27.—Twin buds enclosed by a common scale. After Jeswiet (320).
Since cane cuttings, containing multiple buds, are capable of producing more primaries than normal cuttings, the question whether the characteristic of multiple buds is inherent has a practical bearing. In the Philippines it was found that the percentage of multiple buds decreased considerably after the first propagation (461). But Jeswiet (320) has reported a clone in which the occurrence of triple buds was very common. After four years of propagation, this characteristic still persisted, indicating that it was inherent in that particular clone.

A quite distinct type of abnormality is the occurrence of adventitious buds. Contrary to multiple buds, which are confined to the node, adventitious buds may originate on any part of the joint. They are usually preceded by the formation of galls, from which they emerge, often in considerable numbers, thus giving rise to so called witches' brooms (fig. 28). One of the first references to this type of malformation was given by Kamerling (332) who in 1900 described and illustrated cases from Java. Additional cases have been reported from most other countries, especially from Hawaii (422, 424, 425, 440, 448). At one time this malgrowth caused some concern in Hawaii as it was suspected of being a new disease, but the investigations of Martin have proved that this is not the case.

Martin started his study by inoculating the extract of galls into healthy stems, but without result (447). He also failed to associate any organism as being directly responsible for stem galls. Suspicion was then drawn to insects feeding on the stalk, since they might incite or stimulate certain cells to form galls. He macerated green leafhoppers and inoculated stems with their extract (447). This resulted in the formation of galls (fig. 29) which subsequently produced adventitious shoots. Similar results were obtained by injecting growth regulating substances, and the same substances applied to cane leaves produced galls and roots on these organs (49).

The interesting fact was observed that the adventitious shoots produced in this artificial way differed from each other as well as from the stalk from which they originated thus constituting new "strains". These "strains" have been propagated in order to test their commercial value in field experiments (45).

When adventitious buds develop at the growing point of a stem, they may give rise to the formation of "bunch top" (fig. 31).

Occasionally unusually large buds and shoots develop from apparently normal stems (fig. 30). This phenomenon is not infrequent in POJ 2878, and the giant buds and shoots of this variety are many times larger than normal ones (261, 422). Cuttings derived from these giant forms give rise to normal stalks only; consequently, this character is not hereditary (422).

A bud is an embryonic shoot consisting of a miniature stem with small leaves, the outer ones having the form of scales. The outermost bud scale has the form of a hood. It is composed of a flat posterior part directed towards the stem and a convex anterior part consisting of two overlapping halves (fig. 32). At the keels, where the anterior and posterior sides meet, the prophyllum is flattened and forms wings (fig. 33). On the latter there may be distinguished the edge of the wing, the juncture of the wing and the corner of the wing.
Fig. 28.—Witches' broom produced by the development of many adventitious buds. After Lyon (424).
Fig. 29.—Stem galls induced by artificial inoculation with an insect extract. After Martin (447).

Fig. 30. An abnormally large stem of POJ 2878 with extremely large buds. After Martin (440).
Fig. 31.—Two cases of bunch top. After Lyon (424).

Fig. 32.—Diagram of a cross section of an outermost bud scale (prophyllum). P, posterior side with two keels flattened out into wings (w). The anterior part is composed of two overlapping sides or halves (oh). After JENIET (320).
Fig. 33.—Anterior side of an outermost bud scale. After Artschwager (67).

Fig. 34.—Different forms of bud patterns. A, Triangular pointed; B, oval; C, obovate; D, pentagonal; E, rhomboid; F, round; G, ovate; H, rectangular; I, beaked. After Artschwager (68).
The overlapping half possesses a membranous margin which at its base often terminates in an appendage. In the uppermost part the halves do not overlap and here the germ pore is to be found. All buds located at one side of the stem overlap in the same direction whereas all buds of the other side overlap in the opposite direction. Most probably the prophyllum has originated from the fusion of two leaves (141, 320).

The form of the buds and the size of the wings vary greatly in different varieties as can be seen from fig. 34. Roundish buds exhibit a more or less central germ pore, oblong buds an apical one. As the direction of the veins points toward the germ pore, the roundish buds exhibit a radiant venation.

The wings may be inserted below the middle, at the middle or above the middle of the bud. Generally the bud is inserted immediately above the leaf scar but occasionally somewhat higher. As regards their position on the stalk, the buds may be flush, depressed or protruding.

**PUBESCENCE**

The great variation in both size and other characteristics of the bud provides a welcome means of distinguishing between the numerous varieties. This applies especially to the hair groups, the taxonomic value of which was first recognized by Jeswiet (320).

This investigator described a series of hair groups which he believed to be fairly constant, occurring on the prophyllum of the bud, on the leaf sheath and on the leaf blade. Those on the prophyllum as represented in fig. 35 are listed by Artschwager (68) in the following way:

Hair groups on anterior side (fig. 35 A):

1. Lateral groups on overlapping halves of prophyllum. Hairs are white, long, and cover the base of the bud to a greater or smaller extent.
2. Basal groups on overlapping halves of prophyllum. These strips of short hairs are often interspersed with groups of longer hairs alternating with the veins and often covering the short hairs.
3. Groups of straight or wavy, very appressed white hairs on one or both sides of the germ pore and usually associated with long buds.
5. A group of long lashes implanted in the germ pore on the inner side of the prophyllum.
6. Groups of long, often wavy, appressed white hairs between the veins, giving the side a silky appearance.
7. Short lashes along the upper half of the membranous margin.
8. Incurved and downward-pointing hairs immediately above the germ pore on the posterior side of the prophyllum.
9. Short, inward-pointing lashes on edge of germ pore.
10. A group of long, white, downward-pointing hairs implanted at the point of insertion of basal appendage.
11. Short brown hairs on the surface of basal appendage.
Fig. 36.—Structure of the leaf. After ARTSCHWAGER (68).

Fig. 37.—Young cane shoot showing the gradual transition from scales (basis) to leaves (top). After JESWIET (330).

Fig. 38.—Scales and leaves of the shoot depicted in fig. 37. a and b, first scale seen from the outside and the inside respectively; c and d, second scale seen from the outside and the inside respectively; e, third scale seen from the inside, with ligule; f and g, fifth scale seen from the outside and inside respectively, with ligule and rudimentary blade; h and i, sixth scale seen from the inside and outside respectively, with ligule and little blade; k and l, seventh scale seen from the inside and outside respectively; m, eighth scale, already leafy. After JESWIET (330).
plants grow older. During the period of maximum development, the number of green leaves per stalk is about ten, depending on variety and growing conditions. Evans (245) in Mauritius found that in plant cane of White Tanna, stalks bearing ten green leaves were the most numerous on the average of the whole growing period.

The leaves are asymmetric in that the half which corresponds to the overlying part of the sheath is narrower than the other half. The midrib at its inner or upper side is more or less white and concave, whereas its outer or lower side is green and convex. The surface area of a well-developed leaf blade may vary considerably, but 0.05 m² constitutes an approximate average. Hence, a stalk with ten green leaves will have a leaf surface of about 0.5 m², or, if both sides of the leaves are taken into account, it will be 1 m². With some 70,000 stalks per hectare, this will result in a total green leaf surface of 70,000 m² or seven times the soil surface, occupied by the crop.

The leaf sheath is tubular in shape; it is broadest at its base and gradually tapers toward the dewlap. At its base the margins overlap, the overlying part being alternately the right and the left margin at the successive nodes. This is especially noticeable at a cross section of the leaf spindle, as there not only the sheaths but the whole leaves overlap (fig. 40).

The outer or lower side of the sheath is green and often hairy, whereas the inner or upper side is whitish and glabrous. The veins are more widely spaced than in the blade and usually there is no midrib. The overlying part of the sheath base may be inserted at a horizontal line (not decurrent) or it may be decurrent (fig. 36). In the latter case, an appendage may or may not be present.
At the base of the sheath the leaf sheath node is to be found, which is characterized by the fact that it is capable of resuming elongation under certain circumstances. Consequently it is comparable to the growth ring of the internode.

**The blade joint.**—The blade joint is the junction of the leaf blade and the leaf sheath (fig. 36). Its inner surface is known as the throat, its outer surface as collar. The latter consists of two more or less wedge-shaped areas called dewlaps or joint triangles. The dewlaps are flexible and this is largely due to the presence of collenchyma, as is the case in the sheath node and in the growth ring. The shape of the dewlaps may change slightly as the leaf ages. Consequently, the dewlaps of mature or almost full-grown leaves are most suitable for the purpose of comparison. Moreover, since leaves in general are more or less asymmetric, only related sides of blade joints should be compared.

The color may vary considerably between varieties, and even along one stalk the color of the dewlaps may change as they mature. The outer side of dewlaps is generally covered with wax, more so than the inside.

The form of the dewlaps in mature or almost full-grown leaves is more or less characteristic of a variety. ARTSCHWAGER (67, 68) recognizes three main types (fig. 41): the

![Diagramatic drawing of a cross section of the leaf sheath. Note that alternately the left and right hand marains of the leaves overlap. After Jesweit (320).](image)
Fig. 41.—Types of dewlaps: A, Very sloping, narrow, triangular-ligulate dewlap, Hawaiian Original 24; B, very sloping, more or less ligulate dewlap, Louisiana Striped; C, tall, triangular dewlap, with convex upper and lower margin, Rayada; D, squarish type of dewlap, Tekcha; E, typical deltoid dewlap, Hatooni; F, triangular dewlap of the type found in varieties of *Saccharum spontaneum*; G, triangular dewlap with horizontal basal margin; H, more or less triangular, sloping dewlap with horizontal upper margin, Striped Mauritius; I, typical ligulate dewlap, very narrow and practically horizontal, 28 NG 251. After ARTSCHWAGER (68).

rectangular or squarish type, the deltoid or triangular type, and the ligular type. In addition, there are many intermediary forms.

The ligule.—The ligule, a membranaceous appendage of the sheath, separates the latter from the leaf blade (fig. 36). It is a conservative organ which is little influenced by external conditions. Consequently, it is of considerable diagnostic value which was first recognized by JESWIER (320) and later corroborated by PANJE (475), ARTSCHWAGER (65, 69, 70, 71) and others.

The ligule is made up of elongated parenchyma cells and contains no vascular bundles. As long as the ligule is young it is translucent and hyaline; with increasing age it dries,
changes in color and becomes more or less torn. The asymmetry of the leaf blade is reflected in an asymmetrical condition of the ligule. One of its sides is usually wider than the other, and a similar asymmetry is often found in the height of its sides. Moreover, the two sides of the ligule may differ in the steepness of their slope. Excellent descriptions of this organ have been given by ARTSCHWAGER (68, 69, 70, 71) and for more details the reader is referred to his publications. According to ARTSCHWAGER (68, 71) four fundamental types are recognized: deltoid, linear, crescent and arcuate (fig. 42). In addition intermediate types occur and an example of the wide variation in the form of the ligule is presented in fig. 43.

The pubescence of the ligule is restricted to the dorsal surface and the free margin. In addition to the hair groups 61 and 66 described by JESWIEI, two others have been found by ARTSCHWAGER (71), viz., group 55A which is in juxtaposition with midrib group 55, and group 65A which is in juxtaposition with group 65.

When preserved in the form of herbarium material, almost all valuable details in the structure of the ligule are destroyed. The increasing attention paid to this organ as a valuable diagnostic character in recent years, both in Java and in Louisiana, has led to a search for more adequate conservation methods. ARTSCHWAGER (71) has described a very handy method. He takes the ligules of the top leaves whose blade joints are just discernible. These ligules are usually most typical of the variety. They are mature and show no retrogressive changes associated with exposure to the outer environment. The ligule is removed and placed between glass slides in a Petri dish with dioxan. After several hours it is taken out, dried between filter paper and mounted with Scotch tape on an index card or glass slide. Ligules may also be mounted without previous dehydration in dioxan, which is of practical importance in field work. Although in the latter case there is a certain amount of shrinkage, such mounts keep well and the general shape of the ligule and its pubescence are well preserved.

The auricles.—The auricles, as their name implies, are ear-shaped appendages; they are located at the upper part of the sheath margin. One or both auricles may be present or they

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Fig. 42.—Types of ligules: A. strap-shaped; B. deltoid; C. crescent-shaped; D. bow-shaped; E. asymmetrical, steeply sloping ligule; F. asymmetrical horizontal ligule. After ARTSCHWAGER (68).
Fig. 43.—Various types of ligules. After Artschwager (71).
Fig. 44.—Types of auricles: 1, 2, 3, Transitional types; 4, deltoid; 5, dentoid; 6, unciform; 7, calcariform; 8, lanceolate; 9, falcate; a, auricle inserted high; b, auricle inserted low. After ARTSCHWAGER (67).

may be wanting, and accordingly JESWIET (320) distinguishes the following possibilities:

a) Two well-developed auricles are present, the inner one being larger than the outer one (S. spontaneum, various indigenous Indian canes);
b) Only the inner auricle is present;
c) Both auricles are little developed or wanting;
d) Both auricles are always wanting.

ARTSCHWAGER (67, 68) described various types which are shown in fig. 44; this figure also shows examples of low and high insertion of the auricles. According to ARTSCHWAGER, the deltoid pattern is the most common, the lanceolate type is very common, whereas the falcate, calcariform and unciform types are less frequent.

Pubescence.—The hair groups on the blade and the sheath of the leaf have originally been described by JESWIET (320). ARTSCHWAGER (68, 69, 70) has contributed valuable additional information about leaf pubescence. The location of the various hair groups is shown in fig. 45 and 46. On the blade the marginal group 53 is always present, while group 67 is relatively rare. The latter is of primary importance. On the sheath it is group 57 which is of great importance. It covers the outer surface of the sheath to a greater or lesser extent. In addition to this dorsal group, two lateral patches occur, known as group 60. At the base of the sheath, a fringe of hair (group 59) is often present, while a series of long or short lashes is located on the upper part of the sheath margin (group 56).

According to ARTSCHWAGER (68), the hair groups on leaf blade and leaf sheath are often more reliable and more easily evaluated than those on the bud.

On the dewlaps, three hair groups can be distinguished, viz.: nos. 51 and 52 on the inner side and no. 58 on the outer surface.

The ligule exhibits four hair groups: nos. 61, 55A, 65A, and 66.

The auricles sometimes have hairs at their free upper edge (hair group 54); in rare cases, the surface of the auricles is covered with hairs (hair groups 70 and 71).
Fig. 45.—Diagram showing the location of hair groups at the outside of the leaf. After Jeswiet (320).
ANATOMY

The leaf sheath.—A cross section at about half way the length of the sheath shows radial rows of fibrovascular bundles (fig. 47). The largest bundles are located at about equal distances both from the outer and inner epidermis; towards the outer epidermis (morphologically the lower surface), the bundles gradually become smaller. The number of bundles in one radial row varies from two to four. The parenchymatous ground tissue, in which the bundles are embedded, shows great cavities alternating with the radial rows of bundles.

The structure of the fibrovascular bundles strongly resembles that of the stem bundles.
Fig. 47.—Cross section through the lower part of the leaf sheath. The fibrovascular bundles are arranged in radial rows and embedded in parenchyma. The cells of the latter are partly broken down thus giving rise to large air cavities which alternate with the radial rows of vascular bundles. After Weller from Martin (448).

Fig. 48.—Cross section of the midrib of a young leaf blade showing the development of a huge mass of parenchyma between the vascular bundles and the upper epidermis. After Van Deventer (211).
Fig. 49.—Cross section through the middle of a leaf sheath about midway between sheath node and blade joint showing a large bundle made up of two single bundles. After ARTSCHWAGER (65).
Several bundles are often united into one large composite bundle (fig. 49). The entire bundle is surrounded by a sclerenchyma jacket which is a continuation of that of the stem bundle. The parenchyma which extends from the radial bundle row towards the inner epidermis abuts on a sclerenchyma group located close to this epidermis.

Toward the blade joint the sheath becomes narrower and thicker, the interstices between the bundles decrease and the air cavities gradually disappear. The fibrovascular bundles move to the center, the outer and inner sclerenchyma caps enlarge, the latter constituting a more or less continuous band.

The basal part of the sheath (sheath node, sheath joint) exhibits a structure which meets the requirement of flexibility, necessary in this part of the leaf. Here the sclerenchyma of the bundle has been replaced by collenchyma and the air cavities have disappeared. The radial arrangement of the bundles has been disturbed and changed into an arrangement of more or less tangential bands. The size of the bundles gradually decreases from the inner band (next to the inner epidermis) to the outer one.

ARTSCHWAGER (65) has called attention to the interesting fact that in young developing leaves cambium-like cells occur between xylem and phloem. They constitute an actively dividing tissue which sometimes takes on the appearance of a typical cambium. This observation is of some interest, since the absence of cambium has been considered generally one of the characteristics of monocotyledonous plants as contrasted to dicotyledonous plants. MORELAND and FLINT (465) have corroborated ARTSCHWAGER'S observation in that they found vestigial cambial activity in the bundles of the leaf sheath of sugarcane. More-

![Fig. 50.—Cross section of a leaf blade showing one large vascular bundle flanked by two small ones. After Martin (448).](image-url)
over, they observed the development of an interfascicular cambium-like meristem which gives rise to cross-connecting veinlets. The development of a secondary meristem and the extension of such cambium from one vertical bundle to another indicates activities within monocotyledonous plants similar to some of those more commonly associated with dicotyledonous plants (465).

The epidermis of the outer side shows a pattern that is very similar to that of the stem epidermis. The cells overlying the veins are long and narrow, the intercostal bands broader. Hairs are sometimes very numerous and strongly developed, especially in varieties with glagah blood (*S. spontaneum* Java). This is true of the newer POJ varieties, some of them being in bad repute for the trouble their hairs cause to laborers, often even producing eczema.

The epidermis of the inner side is quite different. It consists of uniformly large cells, the short cells being absent.

**The leaf blade.**—The vascular bundles of a leaf blade are generally of three sizes: large, medium and small. The large bundles are rhomboid or oval, the medium ones oval and the

Fig. 51.—Diagramatic drawing showing the leaf structure through a large vascular bundle in three dimensions. After Martin (448).
small ones round. The small bundles are situated near the lower epidermis, while the large and medium ones are to be found in the center of the blade. A large bundle is always flanked by two small ones (fig. 50); the small and medium-sized bundles occur between the large bundles and alternate with one another.

In the midrib, a thick layer of parenchyma is to be found between the fibrovascular bundles and the upper epidermis (fig. 48); hence, all bundles in this part of the blade are restricted to the lower side of the leaf, while the upper surface, which contains no bundles, is reinforced by a solid layer of sclerenchyma. ISAAC (318) observed that varieties which are resistant to the top borer, Scirpophaga nivella F., generally are characterized by strong and hard midribs, whereas those which are attacked possess weak midribs. RAO (544), by studying the anatomy of some fifty varieties, was able to confirm the observation of ISAAC. He found a fairly close correlation between the amount of lignification in the midrib (the hardness of the midrib) and the degree of resistance of a variety against top borers.

The fact that the layer of parenchyma, which is interpolated between the vascular bundle and the upper epidermis does not contain chlorophyll accounts for the white color of the upper side of the midrib; its lower side, as a result of the presence of chlorophyll-bearing cells, exhibits a green color.

In the leaf blade each fibrovascular bundle is surrounded by a ring of parenchyma cells.
Fig. 54.—A. Surface view of upper epidermis of leaf blade. bul. Buliform cells; cent., central zone; mar., marginal zone with two-celled hair and short spines; st. stomates. B. Cross section of leaf blade; different types of epidermal cells more or less in juxtaposition with their kind in surface view. C. Surface view of lower epidermis. int., Epidermal tissue overlying intercostal region; v, epidermal tissue overlying veins. After Artschwager (63).
which contain chlorophyll, the so called chlorophyll-bearing bundle sheath (fig. 50 and 51). The bundle itself consists of xylem and phloem, while a cap of fibers is to be found at the phloem side. The cells of the chlorophyll-bearing bundle sheath of the large bundles become smaller on the phloem side and may be even absent here. In the latter case, the phloem fiber cap and the hypodermal fibers will fuse.

The xylem of the large bundles is fully developed and consists of two large vessels in addition to a number of smaller elements. In the smaller bundles the xylem is greatly reduced.

The chlorophyll-bearing bundle sheath is surrounded by palisade cells containing chlorophyll. Chlorophyll-bearing bundle sheath and palisade cells constitute the tissue in which photosynthesis takes place.

Transverse connections between the bundles (anastomoses) occur in the form of branches running in a perpendicular or slanting way; these are the ladder-rung connections, depicted by Brenekamp (fig. 52 and 53).

Starting from the blade joint in an acropetal direction, the number of fibrovascular bundles increases as the blade becomes wider, and later decreases as the blade becomes narrower. The increase results from the interpolation of additional bundles which take their origin from existing ones (fig. 52). In the beginning, these additional bundles are rather small but in the process of running upwards they gradually grow larger and resemble the other bundles more and more.

In the upper half of the leaf blade where the number of bundles decreases, the reverse is observed in that some bundles gradually become smaller and eventually merge into adjacent bundles (fig. 53). Toward the top of the leaf the size of all bundles gradually decreases.

Contrary to the stem epidermis which has a rather uniform pattern, the epidermis of the leaf blade exhibits a great variation of different patterns alternating at regular intervals. As Artschwager (68) points out, this difference between the epidermis of stem and leaf blade is associated with differences in the underlying tissues.

In the upper epidermis, Artschwager distinguishes three types of zones (fig. 54A):

1) A central zone consisting of long cells alternating with short groups, often with one or more of the central rows composed only of short cells (alternating cork and silica cells). A few of the silica cells may be replaced by short or long spines (S. spontaneum).

2) Stomate zones, flanking the central zone, usually composed of one row.

3) Marginal zones, bordering the stomate zone, usually composed of two-celled hairs. These are always present, sometimes spines also, both taking the place of silica cells.

A band made up of one central zone, two adjacent stomate zones and two marginal zones constitutes one wide unit. The wide units are separated from one another by bands of bulliform cells. The width of these bands depends on the relative size of the veins and their spacing. The bulliform cells (Blasenzellen, according to Grob, 275) play an important role in the folding and unfolding of the leaves.

Fig. 55 illustrates the fact that in young leaves there is a great uniformity in the size of
Fig. 55.—Progressive stages in the structure of an unrolling leaf. 1. Before unrolling; 2, partly unrolled; 3, fully unrolled. u.e., Upper epidermis; l.e., lower epidermis. After Cook (176).
the cells and that as the leaf grows, certain cells near the upper epidermis increase in size very rapidly, thus forcing the leaves to unfold, so that they assume their normal position.

The pattern of the lower epidermis of the leaf blade is made up of two kinds of bands: the vein zones or costal zones overlying the fibrovascular bundles, and the intercostal zones overlying the space between two bundles (fig. 54c). De Groot (277) has studied the structure of the lower epidermis in some detail, in order to estimate its value for the description and identification of varieties. The intercostal bands are mainly made up of stomates, short cells (cork cells and sometimes silica cells), and cells of intermediate length. Consequently, the pattern is rather simple. It generally shows two stomate rows separated by one middle row. The former are made up of stomates and fairly long cells, alternating with each other, while the middle row consists merely of fairly long cells.

The costal bands are made up of long cells and cells of intermediate length, together with spine cells and silica cells. The pattern of the costal bands exhibits a greater variation than that of the intercostal bands, and this may be of some importance in the description of varieties. According to De Groot, the great variety in pattern of the costal bands can be traced back to three basic types. Type I, characterized by the lack of spines, occurs very rarely; e.g., in some of the higher glagah nobilizations. The costal bands of type II are characterized by the presence of a central row of spines, while in type III the costal bands are flanked at both sides by a row of spines.

In order to facilitate a quick comparison among different varieties, De Groot condensed the whole pattern of the lower epidermis of each variety into one formula. Differences in the pattern of the lower epidermis permit of distinction among the species of Saccharum as well as between Saccharum and closely related genera. The different groups of indigenous Indian canes (S. barberi) are also characterized by different formulae. Kassoer (first glagah nobilization) shows a certain resemblance to glagah. In the higher glagah nobilizations, the formula approaches that of noble cane more and more, and the fifth glagah nobilization exhibits a formula almost identical with that of noble cane.

Venkatraman and Thomas (560) associated the hairs which protect the stomatal cells against lice with resistance to mosaic but, as Artschwager (68) pointed out, unprotected stomates are found on the upper epidermis. Moreover, Dutt et al (232) were unable, in certain cases at least, to find a correlation between the occurrence of hairs and mosaic resistance.

CHAPTER 4

EVALUATION OF VEGETATIVE CHARACTERS

The identification of cane varieties constitutes no easy task; not only is the number of varieties a considerable one, but the available characters are mostly limited to the vegetative organs of the plant. As long as the collection of cultivated canes was limited to the relatively small group of original varieties, viz., the varieties which date back to the period previous to artificial crossing, identification by such general characters as shape and color of the vegetative organs was sufficient. Along these lines Wakker (579) as
early as 1897, drew up an outline to describe the different varieties grown in Java at that time.

Once the period of artificial crossing had started, the number of new varieties (seedlings) increased at an unprecedented rate and consequently the differences among the varieties became smaller and smaller. Jeswiet (320), aware of the fact that under these circumstances the macroscopic vegetative characters relied upon until that time were no longer adequate, suggested the use of hair groups on bud and leaf for identification purpose. In later years, De Calvino (150) and Artschwager (66) drew the attention to the stem epidermis, while De Groot (277) examined the value of the lower leaf epidermis. Thirty years of experience have shown that the value of hair groups is a relative one and that identification and classification have to be based on several vegetative characters. The present state of this problem has been fully reviewed by Artschwager (68, 70) and De Groot (276, 277).

The value of a character for classification purposes depends largely on its stability. Most characters are more or less subject to modification during the development of the plant, e.g., the internodes which are almost all cylindrical when young, differentiate into various shapes when developing. Another example is the color of the various parts of the plant; this often changes when exposed to light. Stability of vegetative characters is only relative. Structures that are rather stable are the ligule, as shown by Panje (475), the stem epidermis, and the leaf epidermis.

The Jeswiet system of hair groups has not only been used in Java by Jeswiet and his associates (79, 80, 144, 320, 321, 322, 323, 324, 325, 326, 327, 328, 483) but also in Hawaii by Twigg Smith (545, 546), in Argentina by Fawcett (263) and in the U.S.A. by Artschwager (69, 70).

De Calvino (150) in Cuba criticized the method on account of the fact that, in her opinion, the development of the hair groups is dependent upon external conditions; she considered the method as an auxiliary one, which only can be used by technically trained persons.

Artschwager (68), who made a thorough examination of the hair groups, found that some groups overlap (e.g., groups 3 and 13), that others which are numbered separately by Jeswiet are alike and, therefore, should be united (e.g., groups 1 and 2; groups 5 and 17), that group 9 was rarely observed by him and that others do not fit any of the known groups.

In his opinion neither the attitude of Jeswiet nor that of De Calvino appear justifiable: “To be sure, the usefulness of hair groups in the description and classification of sugarcane varieties is limited, but the method may be effectively used if the hair groups, as they occur, are coordinated with each other and with other characters” (68).

He further states that: “The proper evaluation of hair groups from the standpoint of their taxonomic usefulness is at best an unsatisfactory undertaking. A glance through Jeswiet’s and the author’s varietal descriptions shows that only a certain number of hair groups, rarely more than 50 per cent, are constant, and these include the more common groups; the ones most suitable for diagnostic purposes are often absent and their distribution is usually erratic. It is of little comfort to have on the check list such groups as groups 1, 12, 21 and 26, since their occurrence is almost universal on sugarcane buds. Only quantitative and, to a certain extent, qualitative differences within group limits, if constant, give these groups a certain value. Often the mass effect produced by the bud
The pattern of the stem epidermis is more constant, but due to the fact that this epidermis is made up of only few elements, the range of combinations of these elements is limited. Thus De Groot (277) found among 16 Java varieties two in which the pattern of the stem epidermis was identical with that of two varieties patented in the U.S.A.

The pattern of the lower epidermis of the leaf which is also rather constant is a valuable aid in the description of varieties, but it is not suited for identification purposes (277).

CHAPTER 5

THE INFLORESCENCE

When a plant has reached a certain stage of development, its growing point may, under certain conditions, change from the vegetative to the reproductive stage. This means that the growing point ceases forming leaf primordia and starts the production of a flower primordium. The early stages of development of the flower primordium have been studied by Kashibuchi (342), Leung (410), and Engard and Larsen (240).

Excellent descriptions of the sugarcane inflorescence have been given by Wilbrink and Ledeboer (599), Jeswiet (330), and particularly by Artschwager, Brandes and Starrett (72). Their observations may be summarized in the following way:

The inflorescence of sugarcane (tassel or arrow) is an open-branched panicle (fig. 56). Its form, which varies according to the length of the main and lateral axes, the degree of their branching, etc., is typical for each species and even for most of the varieties. The longest main axes are to be found in *S. officinarum*, the shortest in *S. spontaneum* and in *S. barberi*.

The main axis of the inflorescence is round at the base but possesses distinct grooves in its upper part (fig. 57A); in these grooves the lateral branches of the first order rest as long as the inflorescence is still closed.

The main axis carries lateral axes of the first order, and these, in turn, lateral axes of the second order. Sometimes there are lateral axes of the third order. All lateral axes, irrespective of their order, are implanted on cushioned joints. Branching is most profuse at the base of the panicle and decreases acropetally.

The spikelets are arranged in pairs, one spikelet of each pair being sessile and the other
Fig. 56.—Inflorescence of Yellow Caledonia. After Lyon from Martin (448).
Fig. 57.—A, Lateral axes arising from the same cushion joint of upper part of main axis. B, Part of main axis of inflorescence. Each articulation of the axis bears a pair of spikelets of which one is sessile and the other stalked. C, Diagram illustrating the course of the vascular system of the rachis, the pedicel, and the sessile flower; a and b represent the two large bundles of the rachis and c, d, and e, the three peripheral small bundles. After ARTSCHWAGER, BRANDE and STARRETT (72).
Fig. 58.—Diagram of portion of mature raceme of sugarcane inflorescence showing the arrangement of sessile and pedicellate spikelets, and the callus hairs. After ENOARD and LARSEN (240).
THE INFLORESCENCE

Fig. 59.—Diagrams of a longitudinal and a cross section of a spikelet of *S. officinarum*. G₁, Outer glume; G₂, inner glume; G₃, sterile lemma (third glume); Pₐ, fertile palea; L, lodicules. After Rumke (500).

Fig. 60.—Single flower (spikelet) of sugarcane. 1, Ovary, partly hidden by the other parts of the flower; 2, feathery stigmas connected by styles to the ovary; 3, stamens each consisting of a filament and an anther; 4, two lodicules; 5, fertile palea; 6, inner glume; 7, sterile lemma or third glume; 8, outer glume; 9, whorl of bristles surrounding the base of the spikelet, the greater part of them having been removed. After Cons (174).
Fig. 61.—Longitudinal sagittal section of ovule with two-celled embryo and numerous endosperm nuclei. ant, Antipodals; nuc, nucellus; i int, inner integument; per, pericarp; end, endosperm; emb, embryo; p t, pollen tube. After ARTSCHWAGER, BRANDES and STARRETT (72).

Fig. 62.—Sagittal section of a mature seed and embryo. st, Remains of style; o e per, outer epidermis of pericarp; i e p, inner epidermis of pericarp; i l i int, inner layer of inner integument; al, aleuron layer; end, filled endosperm cells; e e end, empty elongated endosperm cells; h o, cells of hilar orifice; s sc, seed scar; ep scut, epithelium of scutellum; scut, scutellum; col, coleoptile; p c, procambium strand; emb l, embryonic leaves; mes, mesocotyl; rad, radicle; r c, root cap; colrh, coleorhiza. After ARTSCHWAGER, BRANDES and STARRETT (72).
stalked (fig. 57B and 58). Each spikelet is surrounded at the base by a ring of long hairs, which give a silky appearance to the whole inflorescence.

The composition of a spikelet is illustrated by the figures 59 and 60. Starting from the periphery, an outer and an inner glume are to be seen, followed by a sterile lemma (third glume) and a floret. A fertile lemma (fourth glume) is not present in *S. officinarum*, but it occurs in *S. spontaneum* and some of its hybrids. Opposite the fertile palea are two lodicules which are capable of swelling by absorbing water, thus pressing the glumes asunder so that the anthers may emerge. The androecium consists of one whorl of three stamens, the filaments of which elongate into long threads at the time the spikelet opens. The gynoecium is made up of one pistil consisting of a branched style, and two feathery stigmas. The ovary contains a single anatropous ovule (fig. 61) which gives rise to an embryo (fig. 62). The latter is fused with the pericarp, thus forming a fruit or caryopsis. Hence, what generally is called a “seed” is, in fact, a caryopsis or fruit.

The “seeds” of cane are extremely small. A sagittal section through a mature caryopsis (fig. 62) shows the integuments, the aleuron layer, the endosperm and the embryo. The latter consists of a plumule (a miniature shoot) and a radicle (a miniature root); they are connected by a mesocotyl. The embryo is separated from the endosperm by the scutellum, an organ which, by secreting diastase, mobilizes the food stored in the endosperm.

The plumule has an apical growing point and some miniature leaves. It is surrounded by a cylindrical organ, the coleoptile, which protects the delicate plumule when it penetrates the soil.

The radicle has a normal root cap; like the plumule, it is enclosed by a protecting organ, the coleorhiza.

## Chapter 6

### The Root

#### Morphology

When a cane cutting is planted, two kinds of roots will develop: first the set roots, later on the shoot roots (fig. 63). The set roots, originating from the root ring of the cutting, are thin and much branched; the shoot roots, which spring up from the lower root rings of the shoots, are thick and fleshy, white and less branched. As the shoot roots emerge from higher root rings, they gradually become thinner.

During the time which elapses between planting and the formation of shoot roots, the germinating cane cutting depends for its intake of water and nutrients entirely on the set roots. The life span of the latter is limited and their function is taken over by shoot roots as soon as these have developed in a sufficient number.

The potential number of set roots is governed by the number of root primordia present in the seed piece. Generally, only part of the total number of root primordia develop into roots; the others are kept in reserve and develop only in case of need (p. 129).
Fig. 63.—Young cane plant showing two kinds of roots: set roots originating from the root primordia of the cutting, and shoot roots originating from the root primordia of the shoots. After Martin (448).

The life of the shoot roots is also limited but as each new shoot will throw out its own roots, the root system of the plant as a whole will be continually renewed, the rate of this process of rejuvenation being governed by the periodicity of tillering. This continuous production of new roots is of great importance, since it enables the plant to adjust itself to changing environmental conditions.

The youngest section of a cane root is white and fleshy (turgescent). As the root grows
older, the cortex gradually loses its turgor, becomes flaccid and assumes a shrivelled appearance; at the same time its color changes to brown. The cortex of the oldest sections is dead and black, but the central part (central cylinder) may be still alive. The usual way, therefore, to examine whether a root is dead or not, is to scratch off the dead cortex, and to see if the central cylinder is still white and turgescent.

The function of the root system is twofold: first, it enables the intake of water and nutrients, second, it serves as anchorage.

As to the latter, it has been proved in India that the force required to pull a cane plant out of the soil may vary considerably for different types of soil and for different varieties. With Co 213, for instance, the required pull strength varied from 7.2 cwt in heavy wet soil to 2.9 cwt in light alluvium. In dry soil, a greater force is required. Varietal differences are shown by the fact that Co 210 requires 5.2 cwt under conditions where Co 303 requires only 1 cwt (16).

Further details about the growth and development of the root system are to be found in the chapter on root growth (p. 123).

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**Fig. 64.—Longitudinal section of a root tip.** cor, Cortex; st, stele or central cylinder; rh, root hairs; v, vascular tissue; m, growing point; rc, root cap. After Cobb (174) from Martin (448).
ANATOMY

A longitudinal section of a root tip is presented in fig. 64. It shows that the root tip consists mainly of four parts: the root cap, the growing point, the region of elongation, and the region of root hairs.

The root cap (calyptra) protects the tender tissues of the growing point against damage from stones and other hard particles which the growing root happens to meet on its way through the soil. Many cells of the outside of the root cap are rubbed off but the loss of these cells is compensated by the addition of new cells from a meristem.

The growing point consists mainly of an apical meristem, where cell division takes place,
resulting in a continuous addition of new cells to the root. In front of the growing point a meristem consisting of a few layers of cells is to be found (calyptrogen) which adds new cells to the root cap.

In the region of elongation, the new cells formed behind the growing point increase in length and diameter till they have reached their ultimate size. It is this process of elongation which provides the force to push the root tip ahead through the soil.

The region of root hairs is characterized by the fact that many epidermis cells, by bulging outward, form out-thrusts in the form of unicellular hairs, thus increasing the absorbing surface considerably (fig. 65 and 124). This enlargement of absorbing surface is of great importance as it is through the root hairs that the plant absorbs most of the water and nutrients required for its growth.

A cross section of a young root (fig. 66 and 67) shows the same tissues that are present in the longitudinal section (fig. 64), viz., the epidermis, the cortex including the endodermis, and the stele or central cylinder. Below and next to the epidermis, the exodermis is to be
found, consisting of a layer of thin-walled parenchyma cells which are larger than the epidermis cells. Adjoining the exodermis a tissue of thick-walled cells is located forming a distinct sclerenchymatous cylinder. The inner layer of the cortex is the endodermis which consists of a continuous ring one cell thick, surrounding the stele or central cylinder. The cells of the endodermis are conspicuous in that their inner tangential walls and part of their radial walls are thickened.

The part of the cortex between the sclerenchymatous tissue and the endodermis is composed of large parenchyma cells which later partly disintegrate, thus giving rise to the formation of large air cavities separated from one another by thin lamellae (fig. 68).

The central cylinder is made up of three parts: the pericycle, the vascular bundles and the ground tissue (fig. 66 and 67). Its outermost layer, the pericycle, consists of one row of thin-walled parenchyma cells. Secondary roots originate always from the pericycle in that some of the cells start dividing, thus forming a meristem.

The vascular bundles show a radial arrangement in which groups of primary xylem and phloem alternate (fig. 66). ARTSCHWAGER (65) in his detailed study of the anatomy of the cane plant states that in young roots there are almost always eight large vessels, while the number is much larger in older and thicker roots. Between the groups of primary xylem and phloem, interstitial parenchyma occurs. The protoxylem and phloem are separated from the large vessels by similar parenchyma cells which also surround the large vessels, thus forming a peripheral sheath around the pith. The cells of this peripheral sheath soon become lignified. This process of lignification starts in the cells adjacent to the pith and proceeds in centrifugal direction. The groups of phloem are small and they rarely contain more than eight elements (fig. 66).

As the roots grow older, considerable changes take place. All the cells of the vascular tissue, with the exception of the phloem, become lignified and thick-walled. The part of the cortex between the sclerenchymatous tissue and the endodermis which is made up of large parenchyma cells partly disintegrates. As a result, large cavities are formed, separated from each other by thin radial strips of tissue which remain attached to the exodermis on the one hand and the sclerotic layer of inner cortical cells on the other (fig. 68). The flaccid, discolored cortex of older roots may be easily stripped off with the fingernails. This provides a simple way of evaluating the condition of roots in the field. When the central part of the root after removal of the cortex is white and turgescent, the root is likely to be alive and active. When the central cylinder is discolored and dry, the root is dead.

Although the time during which the cortex of a cane root functions is rather short, this does not mean that after its disintegration the cortex becomes useless. As BREMEKAMP (143) has pointed out, this tissue continues to protect the inner part of the root and it is particularly effective because it is impregnated with silica, cork, lignin, gum, and other protecting substances.
Fig. 67.—Cross section of a fairly young root. After HAYAKAWA (300 a).
Fig. 68.—Cross section of an older root with partially disintegrated cortex showing radial stripes of tissue which separate the large air cavities from one another. After Hayakawa (300 a).
SECTION II

PHYSIOLOGY

The physiological processes in the sugarcane plant have been studied in various countries of which Hawaii, Java and Mauritius rank among the first. Due to their economic importance, particular attention has been paid to growth, nutrition, sucrose formation and water relationships.

CHAPTER 7

GERMINATION

GERMINATION OF TRUE SEED

For many centuries the belief was held that sugarcane is unable to produce viable seeds. A number of circumstances conspired to sustain this erroneous belief, among them the fact that the sole variety cultivated in the New World for two and one half centuries was indeed male sterile. Furthermore the renowned sugar expert, LEONARD WRAY, had published the results of experiments in 1840, proving to his satisfaction that sugarcane could not be induced to develop viable seeds (604). Thus, A. DE CANDOLLE, when writing about sugarcane in his "Origine des plantes cultivées", stated in 1883: "personne à ma connaissance n'a décrit ou figuré la graine" (no one to my knowledge has described or depicted the seed) (152). He was apparently unaware of the fact that about the middle of the past century germination of cane seed had been noticed in Barbados by PARRIS and OTHUS (480), and some years later in Java by NOTO HAMIT PRODJO (7). No use, however, was made of these observations and they eventually sank into oblivion, as the above statement of DE CANDOLLE proves.

SOLTWEDEL in Java started a systematic study of flowering and seed formation with a view of raising plants from seeds. In 1885 he succeeded in obtaining plants from seeds of glagah (S. spontaneum Java) (522), and soon afterwards HARRISON and BOVELL in Barbados also were able to raise seedlings from cane seed.

The germination of the seed as described by BENECKE (94), BARBER (86), ARTSCHWAGER, BRANDES and STARRETT (72) proceeds as follows:

When moisture and temperature are adequate, the first signs of germination, viz., swelling and change of color, may be visible after 24 hours. One day later, the primary root breaks through the seed coat and the first leaf starts growing. The subsequent stages of development are depicted in fig. 69 and 70.
Germination constitutes a critical period in the life of the cane plant; good germination
means a good start and provides the basis for a safe crop. Germination consists of the
development of organs already present in the cutting. The bud, a miniature stem with its
growing point and primordia of leaves and roots, forms the new shoot. In addition, a
cutting contains in its root band root primordia which develop into set roots and function
as such till the young shoot has produced its own roots.

The transition from the dormant into the active stage constitutes a complex phenomenon
characterized, among others, by changes in the food constituents and by the activity of
enzymes and growth regulating substances (hormones, auxins). Maximum germination
and shoot vigor will result when both internal and external factors are optimal. It is a
happy feature that these factors can be regulated to a considerable degree by adequate cultural methods so that under normal conditions poor germination should be an exception.

**Growth regulating substances.**—Under normal conditions, a bud does not develop as long as it forms part of a living stalk, for the growing point of the stalk exerts an inhibiting effect on the lateral buds, thus keeping the latter in a state of dormancy. This characteristic influence is called top dominance. When the top is removed or when it has ceased its normal activity as a result of injury (frost, top borer, top rot) or flowering, the upper lateral buds will develop into normal shoots. These in their turn exert an inhibiting effect on the lower buds, and the latter will develop fully only after the former have been removed. This is actually what happens when applying the rayungan system of cane propagation (p. 95).

From what is known about other plants, it is assumed that the top of a cane plant produces growth regulating substances which, by flowing down inhibit the development of the lateral buds. This inhibiting effect is even perceptible if cuttings, containing two or more buds, are planted horizontally with the buds to the sides. In this case the youngest or terminal bud generally germinates first and exerts an inhibiting effect on the lower ones, thus retarding or even preventing their development. Consequently, Clements (162) came to the conclusion that to plant cuttings with more than three buds is to waste the extra buds. This is, however, no general rule and under particular conditions the use of cuttings with more than three buds may be preferable (p. 70). The dominant effect of the youngest bud is strongest in cuttings from the top section of the stalk and diminishes in cuttings of the middle and lower sections.

Germination consists of the development of organs which are already present in embryonic form. As with growth phenomena in general, growth regulating substances play an important role in the germination of cane cuttings. This may be easily demonstrated in the following way.

When full-grown cuttings of the upper half of a stem of sugarcane or *Andropogon sorghum*, each containing one bud, are fixed in a vertical position and kept in a humid atmosphere, the buds will develop normally (fig. 71).

When similar cuttings are fixed in a horizontal position, three distinct phenomena will take place. The lower side of the growth ring will elongate, thus forcing the part of the internode situated above the node to curve upward. In addition, roots will develop from the root band, while the development of the bud is inhibited (fig. 71).

Cane elongation (at one side of the growth ring), root development and bud inhibition are characteristic of the presence of growth regulating substances. The same set of phenomena can be induced in vertical cuttings by treating them with synthetic growth regulating substances. To this end, cuttings are severed a little above the growth ring, fixed in a vertical position and a mixture of heteroauxin (beta-indoleacetic acid) and lanolin is applied to the upper cut surface. This results in an elongation of the growth ring and the development of roots, while the lateral buds remain dormant. When heteroauxin is applied only to one half of the cut surface, growth is limited to the corresponding half of the growth ring, resulting in a slight curvature, while also the roots develop only at the treated side (fig. 72).

Thin and medium-thick varieties are more suited for these experiments than thick
Fig. 71.—Difference in behavior between cuttings of *Andropogon sarchium* fixed in horizontal and in vertical position. In the first case the unilateral elongation of the growth ring (resulting in an upward curvature), the development of roots, and the inhibition of the bud are indicative of the activity of growth hormones. In the latter case the bud develops but no curvature nor root development occurs. After V AN DILLEWIJN (215, 220).

Fig. 72.—Effect of applying a mixture of heteroauxins and benilpin to the upper cut surface of cuttings of *Andropogon sarchium*. In the lower right hand pair of cuttings, heteroauxin was only applied to the right hand half of the upper cut surface. After V AN DILLEWIJN (215, 220).

Fig. 72 A.—Gradient of curvature, root development and shoot development in three series of cuttings of *Andropogon sarchium*. Each series is derived from one stem and the arrangement of the cuttings is according to their position occupied on the stem.
Fig. 73.—Varietal differences in the relative development of set roots and buds 5 days after planting. After WELLER (590).
tropical canes since the latter react slowly if at all. The best results were obtained with some strains of grain sorghum.

The phenomena described so far apply to the response during the first week of the experiment, when cuttings are used which have accomplished growth some weeks ago.

The situation during the second week of the experiment is depicted in fig. 72A. It shows three series of one-bud cuttings, each series being derived from one sorghum stem and the arrangement of the cuttings being according to their position occupied on the stem. There is a definite gradient in the phenomena of curvature, shoot development and root development. The youngest joints which had not accomplished growth when the stems were cut, do not exhibit curvatures (No. 1 of series B, and Nos. 1, 2, 3 of series C). The maximum curvatures are found in the joints which had accomplished growth two or three weeks ago, and in the older joints the degree of curvature gradually decreases. Root development is absent in the youngest joints and maximum in the lower joints. The buds show the best development in the youngest full-grown joints.

The phenomena depicted in fig. 71 throw some light on the rather unexpected results which have been obtained in Formosa by storing cane cuttings in different positions previous to planting (611). It appeared that cuttings planted horizontally rooted freely when derived from horizontally stored canes, but hardly at all when derived from canes stored upright. In the light of the experiments mentioned before, these results can be explained in terms of growth regulating substances.

In later years, OVERBEEK et al (44, 51, 473, 474) demonstrated that the auxin concentration in the growth ring of sugarcane actually increases when a cutting is transferred from the vertical to the horizontal position. They failed, however, to obtain any growth response in the growth ring when auxin was applied to vertical cuttings, though root development and bud inhibition occurred as stated above. This may be due to the use of thick cane varieties which are less responsive.

The amount of free auxin present in cane was found to be about three parts per million parts of fresh tissue and at least forty times that amount was found to be held in “storage” and could be released by special methods (44). Thus only a small percentage of the total amount of auxin is present in the free form. The same authors in their efforts to establish the nature of the growth hormone involved found that it behaves exactly like synthetic indoleacetic acid. According to ENGARD and NAKATA (241), at least two different substances are present in sugarcane: first, a growth promoting substance of the acid type and second, an inhibitor. OVERBEEK et al (474) also reported on an inhibitor that can be extracted from boiled sugarcane tissue.

The fact should be stressed that the differences in growth phenomena described above, while being clearly exhibited under laboratory conditions, may become smaller and even disappear when the cuttings are planted under field conditions. In the latter case, other factors (soil moisture, temperature, etc.) apparently are superimposed, and initial differences in development often are smoothed out at later stages.

Food metabolism.— As early as the past century WENT (595) found that in Black Cheribon an increase in the amount of glucose in mature cuttings is perceptible two days after
planting, especially in the neighborhood of the buds. As soon as the first leaflets of the developing bud take on a green color, the amount of glucose in the cutting decreases. Starch, which is absent in cuttings of this variety at planting, appears after two to three days as a starch sheath around the fibrovascular bundles leading to the bud. After ten days the amount of starch decreases, and after twenty days it has disappeared.

Went suggests that the developing bud exerts an influence on the cutting resulting in a conversion of sucrose into glucose, especially in the neighborhood of the bundles. Glucose is partly transported to the bud and partly stored around the bundles of the cutting in the form of starch, in order to be transported later on.

In young top cuttings, which are rich in glucose, no conversion of saccharose seems to be necessary since Went failed to detect any such conversion. An increase of starch, later followed by a decrease, occurs in top cuttings in a similar way as described for stalk cuttings.

As to the changes occurring in the developing bud (fig. 74), it appears that already one to two days after planting, glucose is perceptible in the embryonic stem. It increases gradually and as differentiation into nodes and internodes takes place, glucose concentrates into the latter. As soon as the lower lateral buds of the miniature stem start developing, glucose increases in their neighborhood in the same way as was described for the cutting and its germinating buds.

Glucose in the bud scales first appears in the outer ones; as their growth diminishes, glucose will gradually disappear. The same sequence, i.e., appearance of glucose as growth starts and disappearance as growth slows down, can be observed in all inner scales and leaves.

Starch appears one to two days after planting in the miniature stem and in the outer bud scales. Its amount increases and most of the starch is accumulated in the growing point. The starch content of the outer bud scales eventually will diminish, whereas in the inner scales it will increase.

The same sequence of increase and decrease occurs in the young leaves of the bud, the occurrence of starch always being in advance of that of glucose. In other words, starch predominates in the younger organs, and where glucose appears, starch is generally decreasing (fig. 74).

Tannin shows an increase some five to eight days after planting, when it accumulates gradually in the growing point. As soon as the joints become visible to the naked eye, they no longer contain tannin.

Albumin in the dormant bud occurs both in the little stem and in the leaflets. As the bud develops, the occurrence of albumin is largely limited to the growing point, the youngest leaflets and the lateral buds. Albumin, therefore, is to be found in that part of the stem where no glucose is present (fig. 74).

In summarizing his results, Went states that in the organs where cell division takes place, protein and much starch but no glucose are present; where cell elongation (growth) occurs, no albumin, little starch and much glucose are to be found, the more so as growth is more pronounced. Presumably sugars (whether glucose alone or also sucrose) flow
Fig. 74.—Distribution of glucose, starch, tannin and albumin in a developing bud and in a root tip 15 days after planting. After WENT (595) from AOSSE (1).
from the cutting to the developing bud; part of them are stored in the form of starch around the canals in which they move. Glucose is partly accumulated in the elongating parts and is absent in the growing point, the reason for the latter being that glucose is used for the formation of cell walls and organic nitrogenous compounds. Part of the sugars are deposited in the form of starch in the vegetation point.

It is surprising that during the 50 years which have elapsed since Went published the results of his fundamental research, apparently no serious efforts have been made to deepen and widen our knowledge of food metabolism in germinating cuttings. This is the more amazing since this process largely governs the start of a new crop. An attack at this problem with the aid of modern methods might give an explanation as to the favorable results obtained from different kinds of preplanting treatment of cuttings.

In Mauritius, a negative correlation of $0.62 \pm 0.097$ was found between the reducing sugar content and the number of days required for germination, indicating that a high content of reducing sugars hastens germination (22). This supports the concept of Went, mentioned previously. In India, Rege and Wagle (491) observed a positive correlation between the amount of soluble nitrogenous compounds in the cutting and the rate of germination, while Dutt and Narasimhan (233) found that the presence of starch in the cutting promotes germination.

Factors influencing germination.—Germination is influenced by many factors, both internal and external. Their effect has been studied in some detail but in judging the results obtained, the following points should be kept in mind. First of all, several of the experiments concerned have been performed under more or less artificial conditions, e.g., in greenhouses, in laboratories, or in wooden cases. Under the less uniform environmental conditions out in the field, results may be different, although the basic physiological responses to given conditions remain the same. Second, some of the results are only of a temporary character and will level down in course of time. Finally, results obtained under the growing conditions of one country will not, of necessity, be valid under the conditions of other countries (437).

Variety.—Great differences occur in the germination of different varieties. In some of them roots develop prior to shoots; in others the situation is the reverse, and in between these two extremes a series of intermediate types are to be found. Moreover, varieties differ in the initial rate of germination (117, 534, 590, 611) (fig. 73). In general, there is no strict correlation between the initial rate of germination and the ultimate accomplishment of cane varieties.

Geographic origin.—During many years the idea has prevailed that cuttings derived from certain soils give higher yields than cuttings from other sources. Thus in Java it was believed that cuttings derived from heavy soils and planted in light soils yielded better results than those derived from light soils and planted in heavier soils. Extensive field experiments in Java, however, have shown that provided the cuttings originated from fields which had received adequate water and nutrition, no after effect of the soil type is perceptible (207). The only effect associated with the origin of plant material seems to be related to the occurrence of diseases. Thus, in the period prior to the introduction of
POJ 2878, when sereh was still a serious disease in Java, the planting material for the lowland was partly derived from mountain nurseries where sereh was absent. Recent experiments in Formosa have shown that upland cuttings produce better crops in the lowland than do lowland cuttings. In this case, too, a disease factor seems to be involved, since the occurrence of mosaic in the mountains of Formosa is less common than in the lowlands.

**Nutrition State.**—Since any healthy bud is potentially capable of producing a normal plant, it was often a common practice in former years to assign badly grown cane fields for propagating purposes. Later experience, however, has proved that it is a sounder policy to use only well developed and well nourished cane as planting material. Thus, in Java, fields which are assigned to serve propagating purposes, used to receive an extra fertilizer application of nitrogen, previous to harvesting. Arceneaux (60, 61) reports from Louisiana that heavy applications of nitrogen fertilizer on cane, to be used for seed purposes, increases the rate of germination by approximately 25 per cent and significantly reduces the time required for emergence. Yields of cane and sugar from cuttings treated in this way are also significantly increased. In India, cuttings from crops, grown on high nitrogen and high water level, did not only give a better germination but also a higher sugar yield than cuttings derived from crops grown on low nitrogen and low water level (452). Similar results have been reported from Cuba by Beauchamp and Lazo (91, 92). The beneficial effect of the presence of glucose, starch and soluble nitrogenous compounds in the cutting has already been mentioned.

The importance of an ample supply of available nutrients in the sets has been demonstrated by Evans, who, by placing commercial fertilizers inside the cuttings, obtained a better development of the young plants (38, 39). Since the nutrients are largely stored in the cutting, it follows that the larger the cutting attached to a bud, the better the germination will be (fig. 75 and 76).

**Germination Gradient.**—The position of the bud on the stalk corresponds to its age, the age increasing from the top toward the base. A germination gradient is found along the stalk; cuttings from the top section generally germinate more rapidly than those from the lower sections. By dividing stalks in 22 one-bud cuttings and planting these with the buds to the side, Clements (162) obtained the following shoot lengths, in centimeters, after 44 days: 44.0 (top) - 48.8 - 50.0 - 49.6 - 44.7 - 41.3 - 36.6 - 39.6 - 39.6 - 35.3 - 35.7 - 36.5 - 29.9 - 34.9 - 27.7 - 25.7 - 25.9 - 29.1 - 28.1 - 26.8 - 27.3 - 31.7 - 27.9 (lowest bud), while the corresponding times for emergence in days were: 13.4 - 12.3 - 10.9 - 11.7 - 12.2 - 12.3 - 12.9 - 13.9 - 14.3 - 15.7 - 15.5 - 19.3 - 20.8 - 23.7 - 23.3 - 24.5 - 27.7 - 27.7 - 23.6 - 25.0 - 25.3 - 30.0. Thus the best germination was found in the third internode from the top. Since the very uppermost internodes are too soft to be used as planting material on a commercial scale, one can safely state that for practical purposes, germination decreases from the top to the base of a stalk.

The internal factors governing germination are mainly water, nutrients and growth regulating substances, and it may be worth while to look whether the gradient in germination is associated with the trend of one or more of these factors. As far as the stem
is concerned, it is known that moisture (170), glucose (595) and nitrogen (173) show a
distinct decrease from the top toward the base, while the reverse obtains for sucrose. As
to the buds, it has been shown by Bonazzi (102) that their moisture content decreases
toward the base of the stem and that, moreover, this moisture becomes more and more
bound as the buds are located lower down on the stem. The glucose content of the buds
decreases in basal direction, whereas the content of minerals in the sap of the buds shows
an increase in the same direction. Thus germinability of the buds seems to be positively
correlated with moisture and glucose content of the bud tissue, while it bears an inverse
relationship to their mineral content.

The difference in moisture content may be partly due to the fact that the younger buds
have been less exposed to drying. It is a common experience that buds which have been
protected by leaf sheaths germinate more readily than those of the same age which have
had no sheath protection. Likewise, the very oldest buds which have been protected against
drying by the soil, germinate more readily than the buds which are situated just above
soil surface.

No figures are as yet available on the distribution of growth regulating substances along
the stalk and in the successive buds, and no explanation has as yet been found for the
curious fact that the germination gradient often shows an increase toward the lowest
buds which are located near the soil surface (102, 138) (fig. 79).

Position of the Bud at Planting.—It makes some difference in the time of emergence
whether one-bud cuttings are planted with the bud on the upper side, on the lower side or
to the side. Generally the “up” buds emerge first, while the “down” buds require about
twice the time, according to the greater distance their shoots have to cover in order to
reach the surface of the soil (162). The shoots of the “down” buds, however, are as strong,
if not stronger, than those of the “up” buds.

Experiments have shown that “up” buds of one-node cuttings, planted horizontally,
develop shoots which tiller more readily than “side” buds, whereas for the development of
roots, the reverse is true (44, 51, 162). Most of these results have been obtained with
cuttings covered by only one inch of soil. At greater planting depth, the differences in
germination become smoothed down or even imperceptible, since other factors (moisture,
temperature) enter into the picture.

Length of Cuttings.—The minimum volume of cutting required for germination is
amazingly small. When increasing portions of a cutting are removed prior to planting,
the development of the plant is impaired but germination will occur as long as the bud is
connected with one root primordium and the rind carrying it (fig. 75).

The beneficial effect of long internodes connected with the bud has been demonstrated
by various investigators (55, 83, 102, 354, 463, 549) and fig. 76 illustrates this relationship
in a striking way. This figure not only shows that the early development of the young
plant depends on the amount of internode material available but also that the young
plants are fed more readily by the internode below the bud.

When cuttings carrying more than one bud are planted, an additional factor in the form
of top dominance is involved. For, as stated previously, top dominance is not only active
in entire stalks but in any section of the stalk carrying more than one bud. This is particularly conspicuous when cuttings are planted horizontally with the buds to the sides. In this case, the terminal (youngest) bud will germinate rapidly and at the same time retard or even inhibit the development of the lower buds, with the result that the average germination percentage will be less than when shorter cuttings are used.

When the precaution of planting the cuttings with buds to the side is ignored, as is the case in most cane-growing countries, the situation becomes worse. For in this case the question of the bud position ("up" or "down"), causes an additional complication.

If a two-bud cutting is planted horizontally with the terminal (youngest) bud "up", the oldest bud which is automatically "down", will be adversely affected in two ways. First, its development will be retarded or inhibited by the top dominance of the youngest bud, and second, its downward position forces it to cover an additional distance in reaching the soil surface, thus resulting in a decrease of the average germination percentage (fig. 77). OVERBEEK et al. (51) and BRANDES and OVERBEEK (138, 139), however, have shown that the "down" bud develops shoot roots more readily than the "up" bud, which may compensate, at least partly, for the adverse effect mentioned.

If the basal (oldest) bud is "up", the terminal bud which is automatically "down", will be retarded somewhat in its development, though to a less degree. Analogous effects result when cuttings with three or more buds are planted (fig. 77). CLEMENTS (162), who studied these interesting phenomena, arrived at the conclusion that under the conditions of his experiments, the longer the seed piece, the lower the germination percentage and average shoot vigor; that to use pieces with more than three buds is to waste the extra buds; and that, furthermore, to plant seed pieces with buds in any position, is also to waste nearly all of the buds in the "down" position.

The minimum length of cuttings is largely dictated by the quality of the seed cane, the growing conditions and the care given to the young plants. In Java, where these factors are favorable, cuttings containing two or even one developed bud (rayungans) are mostly used. In regions with less favorable conditions, on the other hand, the length of the
cuttings has to be increased accordingly. This is, for instance, the case with autumn planting in temperate regions where conditions during germination are rather poor. Thus Arceneaux (61), as the result of a series of experiments, found that in Louisiana 5-bud cuttings give the best yields in autumn planting. These findings are in harmony with results obtained by Chow (159) in Formosa, who found that in cases of severe growing conditions 4-bud and 6-bud cuttings are preferable to shorter ones.

Delay between Cutting and Planting.—General experience in Java has shown long since that the germination of top cuttings improves if, prior to planting, they are allowed to lose part of their moisture by drying. This experience has been corroborated by experiments in Formosa (611) which proved that storage of top cuttings during six days at low humidity and high temperature (32 and 36°C) resulted in a maximum germination, whereas storage at high humidity and high temperature gave a minimum germination. The stimulating effect of drying may be obtained in practice by exposure to the sun for a few days. A similar beneficial effect of a delay between cutting and planting of top seeds has been reported by Calma (148) in the Philippines.

In addition to the beneficial effect on germination, it has been found in Java that drying of cuttings for some days increases their resistance to a subsequent hot water treatment (30 minutes at 52°C). In view of the growing importance of hot water treatment as a control measure against chlorotic streak, this result is of particular interest.

In contrast with the beneficial effect of temporary drying on top cuttings, the same treatment appears to be harmful for stalk cuttings. According to experiments in Hawaii, stalk cuttings should not be exposed to the sun any longer than necessary (463).

Little is known about the way in which temporary drying promotes germination of top cuttings. In this connection it is interesting to note that Lauritzen et al found that drying increases the inversion of sucrose into simple sugars (388, 389, 390). Moreover, Sartoris observed that the rate at which moisture is lost is greatest in the top third, less in the middle, and least in the bottom of the stem (507). Apparently a relationship exists between the rate at which water is lost and the beneficial effect of temporary drying on germination.

Presence of Sheath (Trash).—As long as stalks are growing in the field, the leaf sheaths exert a favorable influence on the buds, since they protect the latter from drying out. When, however, cuttings which are still covered by their sheaths are planted, the latter may, under certain circumstances, exert an unfavorable influence, as has been demonstrated in several experiments (21, 162, 181); for the sheaths, besides preventing the cuttings from getting in direct contact with the soil moisture, impede the development of buds in a purely mechanical way. This is more especially the case with varieties possessing very tight trash.

In Natal, the removal of trash has been a matter of some controversy. There it was found that, while without doubt its removal gives rise to a quicker germination, subsequent tillering is greater where the trash is left on, even to the extent of giving a heavier weight of cane at harvest (437, 438).

Temperature.—Of the external factors governing the germination process, temperature
Fig. 76.—Effect of size of internodes on the development of young plants (55).

Fig. 77.—Left, two-bud stalk cutting planted with terminal bud up, showing complete suppression of the basal bud.

Right, three-bud stalk cutting planted with terminal bud up. Due to the dominance exerted by the terminal bud, the development of the basal bud is retarded. The growth of the middle bud is affected in two ways: by its "down" position and by the dominance of the terminal bud. After Clements (162).
Fig. 78.—Influence of soil temperature on rapidity of germination and growth. After Rands and Dopp (487).
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is one of the most important. This is illustrated by fig. 78 which shows that a temperature around 70°F is marginal. VERRET (565) in Hawaii found that 68°F is too cold and 111°F too warm for good germination. The best temperature seemed to be between 93 and 100°F.

According to MATHUR (453), there is a critical range, somewhere about 66°F, for soil temperature, below which germination is adversely affected, while REGE and WAGLE (491) state that any temperature below 50°F is definitely injurious. RYKER and EDGERTON (501) found the minimum temperature for growth of roots and shoots to be 54°F though SARTORIS (506) observed some sprouting of roots and buds at as low as 42.8°F.

Fig. 78 also shows varietal differences in response to temperature. At the lower two temperatures, for instance, POJ 234 exhibits a better development of shoots and roots than POJ 213, which is in harmony with the general experience of cane growers in Louisiana. The optimum temperature in fig. 78 is about 86°F as compared with 93 to 100°F observed in Hawaii. This difference is most likely due to the use of subtropical and tropical varieties respectively. Similar varietal differences have been reported from Formosa where YAMASAKI and TAKESHITA (611) found that the subtropical variety F 108 requires lower temperature for good germination than POJ 2878, a tropical cane. Generally peaking, it can be stated that at temperatures below 70°F germination is very slow and that above 70°F germination increases progressively to an optimum between 80 and 90°F.

COLD TREATMENT.—CALVINO and MASTIO (151) claim to have obtained beneficial results by exposing cuttings to low temperature in a box surrounded by a refrigerating mixture. Although the effect was rather variable, the best germination was observed in cuttings that had been cooled during 3, 6 and 8 hours at 0°C. FAWCETT (262), however, observed only fatal effects in cuttings subjected to temperatures claimed as favorable by CALVINO and MASTIO. The discrepancy may be due to the use of cuttings of different age or of different varieties since FAWCETT found older buds to be more resistant to cold treatment than younger ones. He also observed that different varieties responded differently to cold treatment.

A renewed study of this subject under strictly controlled conditions might yield some interesting results, since there is ample evidence that low temperature may induce chemical changes in the cutting and thus influence the rate of germination.

Apart from its effect on germination, other effects of cold treatment are not excluded. This applies particularly to the phenomenon known as vernalization, which is associated with the change from the vegetative into the reproductive stage of plants. Results recently published by BRANDES (135) may be explained in this way.

SOIL MOISTURE.—Soil moisture is a factor of great importance in germination, especially when the cuttings have not been soaked prior to planting. In India (16), the optimum moisture content for the top six inches of soil was found to be 15 per cent, while CALMA (148) in the Philippines and SHEE (514) in Formosa found the optimum to be 25 per cent. These results are, however, somewhat difficult to interpret in view of the modern conceptions about distribution of moisture in soil (p. 276).
SOIL AERATION.—The process of germination is characterized by a considerable increase in respiration and consequently soil aeration is a factor of importance. Soil moisture and aeration are interdependent and on heavy soils, for instance, where moisture is abundant, aeration may become deficient. Consequently, germination is greatly influenced by the type of soil. BORDEN, for instance, found germination to be better in a soil with a more porous open structure, giving it a better aeration (117).

DEPTH OF SOIL COVERING.—The more a cutting is covered with soil, the greater the distance which the young shoot has to travel in order to reach the soil surface. As long as the shoot has not reached the soil surface, it lives at the expense of the cutting, and it is obvious that with increasing depth of soil covering, the number of shoots that fail to reach the soil surface will gradually increase. Thus, other conditions being favorable, a light soil covering gives the best germination.

In Hawaii, BORDEN (117) found in pot experiments that covering the cuttings with 1, 3 and 5 inches of soil resulted in germination percentages of 96, 93 and 51 respectively. In Java cuttings are pressed horizontally in the muddy soil in such a way that the upper side remains visible after planting. In all cases of shallow planting, care must be taken to keep the soil moist by frequent but light irrigations.

When planting has to be done under adverse conditions (drought, low temperature) a thicker soil covering is required. This is, for instance, the case with cane planted during the fall in temperate zones (60, 61).

Preplanting treatment of cuttings.—The quantity of cuttings required for planting one hectare varies widely. While in extreme cases one quarter of a hectare of standing cane is required, in other countries only one twentieth of a hectare or even less is needed. Since the purpose of cane growing is to deliver as much cane as possible to the mill, the question arises whether it is necessary to sacrifice so much cane to planting purposes. This is largely a matter of quality of the cuttings, and there is increasing evidence that by improving the quality of the seed cane a considerable part of the cane now used for planting purposes could be saved and sent to the mill for the manufacture of sugar.

Improvement of the quality of the planting material has to start several months ahead of the planting season, when the cane from which the cuttings are to be derived is still growing in the field. As stated before, this cane should be amply supplied with water and nutrients in order to assure an adequate quality and an ample reservoir of nutrients in the cuttings. Moreover, the percentage of germination can be raised considerably by permitting the buds to swell or to shoot while still attached to the living stalk (p. 95).

There is ample evidence that when cuttings of good quality are used and when the growing conditions of the germinating plant are adequate, considerable saving of planting material is possible and that a good stand of cane will be obtained. Under such conditions, no additional measures are necessary. When, however, the quality of the cuttings or the external germinating conditions are inadequate, one of the following treatments is indicated. For the matter of convenience, the vast literature existing on this subject is arranged under four headings:
GERMINATION

- Soaking in water;
- Soaking in aqueous solutions of chemical compounds;
- Treatment with fungicides and insecticides;
- Treatment with growth regulating substances.

SOAKING IN WATER.—The first experiments on soaking of cuttings in water and in aqueous solutions of chemical compounds, date back to the eighties of the past century when the sereh disease struck Java and consequently a series of treatments were tested in search for an efficient method of control (355, 358).

Soaking in cold running water during 12 to 24 hours was a common practice in Java by the end of the past century (333). Even soaking during such a short period as half an hour proved to stimulate the germination rate as shown by the experiments of Kamering (333). In the latter case, the beneficial effect, however, is only temporary; it is at its maximum about 18 days after planting and then gradually smooths down and disappears at about the thirtieth day. This result is representative of many treatments of cuttings giving only a temporary effect in contrast to others which ultimately result in higher yields of cane and sugar.

In Hawaii, soaking cane seeds in cold water from 24 to 48 hours seems to be an old practice, which has been used successfully for many years (450). Moir (463) strongly recommended soaking of hard body and butt seed during 48 to 72 hours, changing the water daily. Soaking of top seed, though also beneficial, seemed to be less necessary.

In Formosa, Shee (516) obtained the best results by soaking cuttings in cold water for 1 or 2 days; when soaked longer, the results became less significant. These experiments were, however, discontinued 14 days after planting.

Quite unexpected results have been obtained by soaking cuttings which, prior to soaking, were already fully saturated with moisture. King (353) found that soaking in cold water of succulent cuttings, harvested after rainy weather and planted in wet soil, showed a better germination than comparable unsoaked cuttings harvested and planted under the same conditions.

Hot water treatment has been tried as early as in the past century, in an attempt to control sereh disease in Java (358, 370) but its stimulating influence on germination, in addition to the effect of controlling chlorotic streak disease, was recognized in the early twenties by Brandes and Klapphaak (136). These authors found that immersion of cuttings in water during 20 minutes at about 52°C, results in a rapid development of all buds and a precocious growth of the young cane stools. The stimulating effect is striking, the rate of growth during the first 6 weeks being tripled. There is, however, a very narrow range of critical temperatures and durations of treatment that are effective and safe for practical use (133). The effect is a lasting one, resulting in increased yields of cane up to 5 tons per acre (133, 238).

The effect of hot water treatment on decapitated stalks is illustrated in fig. 79. In untreated stalks, only the uppermost lateral buds germinate and these prevent the lower buds, with the exception of some of the lowest, from developing. When, prior to planting, the
stalk has been subjected to hot water treatment, most of the other buds along the stalk also
develop, indicating that their dormancy has been broken by the treatment. Cuttings are
affected in the same way (fig. 80). Hot water treatment lowers the level of growth regulating
substances by about one half, which explains the disappearance or at least the weakening
of top dominance (138).

The stimulating effect of hot water treatment on germination has been corroborated
by Martin and Conant (450) in Hawaii and an apparatus for treating cuttings in large
quantities has been devised in Java by Nielsen (472).

Soaking in aqueous solutions of chemical compounds.—Lime and inorganic salts
have given lasting beneficial results in Mauritius. Evans (17, 20, 22, 246) reports that both
plant cane and first ratoon give significant increases in yield when the cuttings have been
soaked for 8 to 12 hours in a cold saturated solution of lime, with or without 1 pound
of magnesium sulphate per 50 gallons, the difference between the two treatments being not
significant. Soaking in saturated lime water for 18 to 24 hours has become standard
practice in Mauritius (260).

Similar beneficial results with lime water have been reported by May (460), Calma (148),
Roxas and Grecia (496), Lee and Quizon (406), Burke (146), Ru et al (498, 499), Sun
et al (533, 534) and others. All these results provide evidence that the lime water treatment
is successful at least under certain conditions. Striking effects have been obtained in some
experiments where the yield, as a result of this treatment, was increased by 50 per cent and
more (8, 533).

Other chemical compounds have also been tested. Evans (17) obtained good results by
soaking cuttings in a complete nutrient solution (Knopf's solution three times normal
strength) and Clements (162) found soaking in a one per cent solution of calcium nitrate
to exert a beneficial influence. Clements and Akamine obtained striking results with ethyl
alcohol (10 %) while ammonium phosphate (1 %) also proved to be effective (166). Ac­
cording to Bantug (83, 354) soaking in 0.06 molar solutions of ferric, manganous,
stannic, and stannous chlorides, potassium permanganate and in solutions of 60 parts per
million of iodine in potassium iodide, for 12 hours retards germination while ferrous
chloride has a stimulating effect. Shee (515) found that soaking in diluted solutions (about
0.1 %) of magnesium sulphate or manganese sulphate stimulates germination.

The factors involved in the stimulating effect of cold water and aqueous solutions of
chemicals on germination are only partly understood. This is mainly due to lack of basic
knowledge of the process of germination. Only tentative explanations are possible
and they are presented here to aid in the planning of future research on this important
problem.

In the first place the intake of water seems to be a necessary preliminary for germination.
Thus in South Africa where soaking in water or lime water did not produce a beneficial
effect, it was found that the cuttings had not absorbed water during immersion (435, 436).

The beneficial effect of soaking in a Knopf's solution is most likely due to the intake of
nutrients. It might be compared to the beneficial effect obtained by introducing fertilizers
directly into the cutting in order to raise the nutrition status of the latter.
Fig. 79.—Stems of CP 29/103 planted horizontally with their top to the right. Upper stem, untreated; lower stem, subjected to hot water treatment. Photograph taken 32 days after planting. After BRANDES and OVERBECK (138).

Fig. 80.—Shoots grown from two-bud cuttings of entire stems of CP 29/116 that had been subjected to hot water treatment (upper figure) and from comparable untreated cuttings (lower figure). After BRANDES and OVERBECK (138).
The stimulating effect resulting from soaking in lime water is to be explained in a different way since it is unlikely that calcium would be deficient in all the experiments reported. Moreover EVANS and WIEHE (22, 260) found that no appreciable quantity of this element is absorbed from the lime solution. The effect of lime is an indirect one since it stimulates the intake of water. EVANS and WIEHE (22, 260) report from Mauritius that soaking in a saturated solution of lime results in an absorption of 50 per cent more moisture than soaking in pure water. This phenomenon may be analogous to the salt hydration effect described by PHILLIPS and MASON (482): discs of cotton leaves floated on calcium chloride solutions took up large quantities of water and this was accompanied by considerable swelling of the discs.

There is evidence that a high water content of the cutting promotes the conversion of carbohydrates into reducing sugars, and that the beneficial effect of soaking is, at least partly, due to a higher concentration of reducing sugars. EVANS (22), as a result of his soaking experiments, found a positive relationship between the rate of germination and the content of reducing sugars in the cutting. Similar results have been reported by SINGH et al (520). Certain observations made in Hawaii point into the same direction. Here mature cane stalks which had been standing in a solution of sulphurous acid for six days showed a stimulated germination. This beneficial effect was tentatively ascribed to hydrolysis of carbohydrates present in the stalks. Similar results could be induced in immature stalks by adding carbohydrates to the solution of sulphurous acid (446). All these experiments indicate that treatments promoting the conversion of carbohydrates into reducing sugars are likely to stimulate germination.

Most intriguing is the case in which cuttings, although fully saturated with moisture, respond favorably to soaking in water. Here the intake of water as a possible explanation is excluded. It is more likely that the beneficial effect is associated with the removal of noxious substances from the germinating cutting. This would be in harmony with the general experience in various cane growing countries that soaking of cuttings has to take place in running water, although this might partly be explained by a greater concentration of oxygen in running water. Moreover, BANTUG (83, 354) has proved that during the process of soaking considerable quantities of substances diffuse from the cutting into the soaking water. As to the nature of the harmful substances which probably are removed by the running water, two possibilities are indicated: toxic substances originating at the cut surface as a result of fermentation (436, 438), and inhibiting substances produced inside the plant as a result of the germination process. Evidence of the presence of the latter has been found with fruits and seeds of various plant species by FROESCHEL (267, 268), Voss (571) and others. Soaking of such seeds in running water promotes germination, while germination is inhibited when seeds are kept in water already used for the soaking of seeds of the same species.

It is, however, necessary to stress the fact that all explanations presented above are tentative and that, as long as a thorough knowledge of the basic principles underlying the process of germination is lacking, all efforts to explain the phenomena observed are bound to be mere guesswork.
TREATMENT WITH FUNGICIDES AND INSECTICIDES.—The stimulating effect of fungicides on germination was observed in South Africa. McMARTIN (435, 436) found that some brands of fungicide, apart altogether from disease control, promote the germination of cuttings. Even with healthy cuttings, the treatment with organo-mercurial disinfectants resulted in an earlier and more vigorous root and shoot development. The fungicides concerned thus appear to have a stimulating effect, although McMARTIN uses the term with some reserve. For, in preliminary experiments he obtained indications that the products of fermentation, which occur on the cut surface, may seriously affect the development of buds and roots, and that treatment with fungicides probably delays fermentation long enough to allow a vigorous development of the young organs (436).

The stimulating effect of organo-mercurial compounds on germination has recently been corroborated by EVANS and WIEHE (260) in Mauritius and by CHI (158) in Formosa. BOURNE (130) reports on the stimulating effect of insecticides. Benzene hexachloride and especially chlordane, when mixed with the fertilizers and placed in the planting furrows, were found to exert a beneficial effect on the rate of germination apart from pest control. This indicates a possibility of combining pest control and stimulation of germination in one treatment.

TREATMENT WITH GROWTH REGULATING SUBSTANCES.—The influence of growth regulating substances has already been mentioned before, where it was stated that these substances may exert a double effect, viz. root development and bud inhibition. This result has been corroborated by YAMASAKI and TAKESHITA (611), OVERBEEK et al (44), YAMASAKI and NAKAMURA (608, 609) and LOH et al (417).

Finally, mention must be made of a group of unsaturated compounds which are known to lower the auxin content in plants and therefore break the dormancy of lateral buds. OVERBEEK et al (44) found in preliminary experiments that by treating cuttings with chlorohydrin and acetylene, germination was accelerated.

There is increasing evidence that seed soaking yields the best results when conditions for subsequent germination are below the optimum. This applies, for instance, to cuttings of increasing ages. CLEMENTS and AKAMINE (162, 166), and SUN and LIN (534) found that cuttings of the middle and the lower part of the stem respond more readily to soaking than top cuttings. It applies equally when germination has to take place under dry conditions. Thus in South Africa it was found that soaking stimulates germination when the cuttings themselves are dry, e.g., during droughty seasons (437). In the Philippines and in Barbados soaking proved to be of no advantage when the cuttings were planted in soils with adequate soil moisture. Beneficial results, however, were obtained when planting had to be done under dry conditions (18, 148). Low temperature of the soil is another factor in this connection. CLEMENTS (162) subjected cuttings to various soaking treatments and planted them partly in cool and partly in warm soil. In the former case considerably better responses were observed than in the latter. Similarly, RU et al (498) state that in Formosa soaking yields striking effects during the cool planting season, while during the hot season the results are insignificant.

These results have a practical bearing in that they indicate that seed treatment with the
purpose of stimulating germination is essentially an emergency measure, which should be restricted to cases where the quality of the planting material or the conditions of germination are suboptimal. As to the former, it is a wiser policy to improve the quality by applying adequate cultural methods while the cane intended for propagating purposes is still growing in the field rather than to subject cuttings of bad quality to treatment.

CHAPTER 8
TILLERING

IN SEEDLINGS

The general course of stooling or tillering in cane seedlings resembles that of other grasses (86). The first-formed joints are extremely short, being in the form of narrow, superimposed discs and, consequently, the leaves borne by them are very close together. Moreover, the lower joints are extremely thin and, since their diameter increases upward, the general form of the basal part of the stem is obconical. As each of the joints is provided with a bud, this short-jointed basal part of the stem provides many buds, compactly situated, for the initiation of tillering.

The degree of tillering in cane seedlings is governed largely by internal and structural factors: thick, tropical canes show a low capacity of tillering, whereas the thin wild cane, Saccharum spontaneum, tillers profusely. Besides internal factors, external factors like climate, soil type, etc., play an important role.

IN CUTTINGS

Good germination is considered the basis of a good crop, but tillering is the next step, for it provides the plants with the appropriate number of stalks required for a good yield. Subsequent stages are stalk elongation (growth) which determines the cane yield, and sugar formation (ripening) which fixes the sucrose content. Tillering, or underground branching, thus constitutes a beneficial characteristic of a variety.

Underground branching or tillering,—Tillering is a general characteristic of grasses and according to their mode of growth they are usually divided into two groups: tufted grasses and sod formers. In the latter, underground branching assumes an intense form and the soil is permeated with a mass of underground branches and roots so as to form a coherent mat (lawns, permanent pastures). In the former, after a limited period of underground branching, a number of erect shoots are formed, which proceed to the formation of flowers. In this case, the individual plants are easily separable.

Sugarcane obviously belongs to the tufted grasses, although some forms of Saccharum spontaneum which form an interlacing mass of roots and runners are a near approach to sod formers (86). This applies even more to S. robustum, which, in its natural habitat, forms long runners (stolons) up to 60 feet, which grow out over the mud flats of rivers (140).

The tillers may grow erectly or they may be sprawling in their early stages of development
and bend upward afterward. The sprawling habit is generally a varietal characteristic, but it may also be induced, or at least accentuated, by external conditions. The tillers of cuttings planted shallowly under conditions of bright sunlight, high temperature and low air humidity tend to sprawl, even in varieties which do not do so otherwise. Cases of varieties with oblique tillers, or even with tillers lying flat on the ground, have been depicted by Barber (84). The most curious in this respect are the varieties with tillers dipping below the horizontal before bending upward (84, 352, 555).

MODE OF TILLERING; DIAGRAMS; FORMULAE.—Soon after planting, the buds of a cutting start developing shoots. These are the so called mother shoots or primaries. The little
stem of these primaries consists of many short internodes, each of which carries a lateral bud. These buds give rise to the development of secondary shoots which in their turn may produce tertiary shoots, etc. Thus the mode of tillering may become rather intricate, and its study requires a careful digging up and dissecting of the underground parts of the plant. **Barber** (84, 85, 86, 89) was the first to make an extensive study of this subject, and it is curious to note that no serious efforts have been made since to continue this important line of research.

The simplest mode of tillering is found in the group of thick tropical canes belonging to the species *S. officinarum*. An example is represented in fig. 81A, showing a plant with one primary (a), three secondaries (b) and three tertiaries (c). Its formula runs as follows:  

\[ a + 3b + 3c. \]

Next to this comes the group of thin indigenous Indian canes (*S. barberi*), an example of which is presented in fig. 81B. Here the mode of tillering is somewhat more extensive, the formula being:  

\[ a + 9b + 7c. \]

The most intricate mode of tillering is encountered in the wild cane *S. spontaneum*, as is demonstrated by the diagram in fig. 81C and the long formula:  

\[ a + 8b + 23c + 31d + 3e. \]

**Barber** dissected hundreds of cane stools and the average results obtained with various species and varieties are summarized in table 2. It shows that the formula, consisting of only a few terms in the thick tropical canes, gradually increases in length when passing through the various groups of indigenous Indian canes until in the wild cane the formula becomes very long and the intricacy of tillering reaches a maximum.

The negative relationship between thickness and tillering is by no means a strict rule. **Barber** (89) found in one case that the average number of stalks per plant in the various groups of indigenous canes was: Mungo group, 15.10; Nargori, 15.10; Brown Saretha, 14.00; Sunnabile, 12.55; Pansahi, 11.00; Green Saretha, 9.50. Mungo and Pansahi, however, are among the thickest, and Nargori and Brown Saretha among the thinnest. But within each group the tillering capacity varies more or less inversely with the thickness as shown in table 3 though even then the inverse relationship is not proportional.

**Trend of Tillering.**—Varieties differ greatly in their trend of tillering and in their ultimate number of tillers at harvest. Most of the grasses exhibit two marked phases of development, first, a phase of stooling and subsequently one of stem elongation. During the former, the development of the plant is limited to the formation of tillers which remain low until the second phase starts which is characterized by elongation of the tillers. In seedlings and cuttings of sugarcane, a similar marked division into two periods of development does not seem to exist, at least not as an inherent character.

When a cane cutting is given ample space to develop freely, each shoot will grow steadily upward as soon as it is formed. Moreover, tillering seems to be a more or less continuous process which may result in the formation of stools with several hundreds of stalks. Exceptions are rare and result mostly from abnormal conditions. In severe cases of sereh disease, for instance, the cane plants often remain in the tillering stage without appreciable stalk elongation, thus giving the impression of grass. **Barber** (86) reports that...
Table 2.—Average formulae of tillering. After Barber (86)

<table>
<thead>
<tr>
<th>Variety</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
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<tr>
<td>Thick tropical canes</td>
<td>1</td>
<td>2</td>
<td>1</td>
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<tr>
<td>Indian canes</td>
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<tr>
<td>Sunnabile group</td>
<td>1</td>
<td>3</td>
<td>2</td>
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<tr>
<td>Nargori group</td>
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<td>3</td>
<td>3</td>
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<tr>
<td>Saretha group</td>
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<td>3</td>
<td>3</td>
<td>1</td>
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<tr>
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<tr>
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<td>1</td>
<td>3</td>
<td>4</td>
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<tr>
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<td>4</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 3.—Relationship between stalk thickness and tillering capacity. After Barber (86, 89)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Stalks per plant</th>
<th>Thickness in cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saretha group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chin</td>
<td>29</td>
<td>1.5</td>
</tr>
<tr>
<td>Saretha (green)</td>
<td>28</td>
<td>1.7</td>
</tr>
<tr>
<td>Khari</td>
<td>24</td>
<td>1.8</td>
</tr>
<tr>
<td>Huli Kabhu</td>
<td>22</td>
<td>1.9</td>
</tr>
<tr>
<td>Ganda Cheni (pon)</td>
<td>10</td>
<td>2.0</td>
</tr>
<tr>
<td>Average</td>
<td>24</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Brackish water may exert a similar influence in that the tillering period of the cane plants is prolonged, giving them the appearance of Guinea grass. Another abnormal condition resulting in excessive tillering is the planting of cane in latitudes deviating from their original geographic center of origin. Brandes (134, 135) in an experiment involving the planting of many cane varieties at a series of different latitudes, found that *Saccharum spontaneum* Turkestan planted near the equator tillers profusely, makes no stems (or appreciable ones) and looks like a bunch of grass. This is possibly a day-length effect and contains an important lesson for cane breeders: in selecting a wild cane for nobilization, it is well to use a specimen from about the same latitude as that of the area for which the cane improvement program is undertaken (134).

Under field conditions a distinction between a tillering and an elongating period may be simulated as a result of particular growing conditions. As already mentioned, superficial planting in combination with hot and dry weather is likely to promote profuse early tillering. As soon as the rows close in, the tillers as a result of plant competition, are forced to push ahead, thus dividing the development of cane into two more or less distinct periods, one in which tillering prevails and another which is mainly characterized by stalk elongation. Hence, a distinction between two phases, although not inherent as in other grasses, may
occur in sugarcane when grown in commercial fields, and this distinction is of considerable importance in the practice of cane growing.

The trend of tiller formation is influenced by both internal and external factors. POJ 2878, for instance, tillers very early with rapid subsequent reduction, whereas BH 10 (12) is slow at the commencement, but increases gradually. The first extensive observations on the trend of tillering were made by Müller von Czernicki (467) in the beginning of this century and in later years others followed (218, 221, 224, 225).

Fig. 82 represents the results of an experiment in which the history of 180 cuttings of POJ 2878, each carrying one developed shoot, was recorded. Being planted in July, the number of these primary shoots showed a slight decrease during the subsequent months. In August, many tillers appeared, their initial number being about twice that of the primaries. Since the percentage of mortality in these tillers was about the same as in the mother shoots, the number of the surviving August stalks was also about twice that of the surviving primaries. The September tillers started at a considerably higher level, but their mortality was so great that only some 20 per cent survived. The combined trend of all

![Diagram](https://via.placeholder.com/150)

Fig. 82.—Trend of tillering in 180 single rayungans (one-node cuttings each containing a developed shoot). After Van Dillewijn, Leigh and Wesselingh (218, 224).
Fig. 83.—Integration of the results presented in fig. 82. After Van Dillewijn, Leigh and Wesselingh (218, 224).
Fig. 84.—Trend and causes of mortality in the shoots of fig. 83. After Van Dillewijn, Leigh and Wesselingh (218, 224).
Fig. 85.—Per cent composition of the stalk population at harvest. After Van Dillewijn, Leigh and Wesselingh (218, 224).
TILLERING 83

Tiller classes as presented in fig. 83 shows a flush of tiller formation in August and September, followed by a steep decrease, while a few water shoots appear toward the end of the growing period. Only some 50 per cent of all shoots survived. The mortality was largely due to plant competition. As long as the shoots are young, there is room for many of them. With the full development of leaves, however, light becomes a limiting factor, resulting in the suppression and ultimate death of the weaker tillers which are mostly September shoots (the “lagging” shoots in fig. 84). At harvest, the composition of the stalk population was approximately: 25 % primaries, 50 % August stalks, and 25 % September stalks (fig. 85).

Late suckers constitute a problem in various countries. They appear when the other tillers are already more or less full-grown. They often consist of thick, succulent shoots

Fig. 86.—Dissected cane stool showing stalks of consecutive order. a, Mother stalk; b, secondary stalk, etc. Note the gradual increase in diameter and length of the internodes in the stalks of higher order. Drawn after BARBER (85).
(water shoots, bull shoots), and are most numerous in those parts of a field where for one reason or another light is allowed to enter freely (mortality of stalks; lodging of cane; field edges). In one-year crops, time does not allow them to develop into millable cane; hence they have to be discarded or, where harvest methods do not permit discarding, they will reach the mill and exert a harmful effect on juice quality. Besides, evidence indicates that the rapid development of water shoots takes place, at least partly, at the expense of the older stalks which constitutes another source of juice deterioration.

In stand-over cane, late tillers produced during the first year may make up for development during the second year, but here another problem is sometimes encountered in the form of second-year suckers, which constitute a problem similar to the late tillers in one-year crops. POJ 2878 has been particularly ill-famed for this characteristic in Hawaii. CORNELISON and COOPER (180) even found in one of their field experiments that at 24 months of age POJ 2878 had not a single first-year stalk left alive; the entire stand was composed of second-year tillers. When harvest is delayed for a sufficient time, second-year tillers may attain full maturity.

DIFFERENCES BETWEEN TILLER CLASSES.—The tillers of different order show striking differences in weight, total length and maturity, as well as in length and thickness of the individual joints. An example of this variation is presented in fig. 86 which shows the individual stalks of one stool, arranged according to their order of tillering. The first thing which strikes one is the large number of short joints in the basal section of the mother stalk. It indicates that the early growth of the mother stalk has been slower, obviously due to lack of a well developed root system at the time of its origination. In general, there is a tendency in the shoots of higher order to become thicker, to have longer joints and to exhibit a greater curvature at their base, in order to place them in a favorable position before growing upward. At the extreme end of this series, not represented in the figure, come the well known water shoots, which are characterized by vigorous growth and by long thick joints. Although the trend as described here is the most common one, exceptions may occur as a result of differences in external growing conditions.

There has been considerable controversy about which stalks are the most valuable at harvest time as far as weight and juice quality are concerned. In Louisiana, STUBBS (530) claimed that the mother stalks on an average have the greatest weight and the richest juice, and that the tillers of higher order show a gradual decrease in both properties. STUBBS' results have been fully corroborated by RODRIGUES (493) also working in Louisiana. ARCENEAUX (58) found that the primary stalks were less in weight than the early tillers. As to the sugar content the differences were very slight between the primary stalks and the suckers, with the exception of the latest tillers which showed a sharply significant drop. The smaller differences found by ARCENEAUX may be due to the fact that he studied fall planted cane.

In India, BARBER (84, 86) found that the earlier formed stalks were invariably richer in their juice than the later ones, and the same was reported by KRISHAN (371). Observations in Java (413) indicate that if the cane is allowed to mature, the differences in juice quality between the various stalks of a stool become negligible (fig. 87), though sometimes the
early tillers show a richer juice than both the mother stalks and the later tillers (218, 224). A similar superiority in juice quality of the early tillers over mother stalks and later tillers has been reported from Formosa (157).

With regard to the length, the thickness and the weight of the successive tillers, there exists a similar great variation in results obtained. Contrary to Stubb's (530) who found the mother stalks to be the heaviest, observations in Java (218, 224) and Formosa (157) indicate that the early tillers are heavier than the primaries and the late tillers. This is clearly demonstrated in table 4 for F 108 in Formosa, which shows that a similar trend, consisting of an initial increase followed by a decrease, applies to the weight, the length, the diameter and the juice quality. As for the diameter, Barber (86) found as an average of many varieties a similar trend, the relative figures being:

\[
\begin{align*}
\text{a} - & \text{ (mother stalks)} \quad 177 \text{ cm} \\
\text{b} - & \text{ (second order stalks)} \quad 187 \text{ cm} \\
\text{c} - & \text{ (third order stalks)} \quad 207 \text{ cm} \\
\text{d} - & \text{ (fourth order stalks)} \quad 228 \text{ cm} \\
\text{e} - & \text{ (fifth order stalks)} \quad 219 \text{ cm}
\end{align*}
\]
Table 4.—Average weight, length and diameter of different tiller classes. After Cheng and Chao (157)

<table>
<thead>
<tr>
<th>Time of origin</th>
<th>Weight kg</th>
<th>Length cm</th>
<th>Diameter cm</th>
<th>Available sugar in juice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mother stalks</td>
<td>0.80</td>
<td>197</td>
<td>2.6</td>
<td>17.3</td>
</tr>
<tr>
<td>Prior to May 1</td>
<td>1.08</td>
<td>218</td>
<td>2.9</td>
<td>18.8</td>
</tr>
<tr>
<td>Between May 1 and 15</td>
<td>1.08</td>
<td>212</td>
<td>2.8</td>
<td>18.7</td>
</tr>
<tr>
<td>Between May 16 and 31</td>
<td>0.93</td>
<td>211</td>
<td>2.8</td>
<td>19.3</td>
</tr>
<tr>
<td>Between June 1 and 15</td>
<td>0.85</td>
<td>190</td>
<td>2.5</td>
<td>17.3</td>
</tr>
<tr>
<td>Between June 16 and July 15</td>
<td>0.50</td>
<td>143</td>
<td>2.3</td>
<td>17.6</td>
</tr>
</tbody>
</table>

At first glance these divergent results appear rather confusing, but a second look teaches that this is exactly what was to be expected. Take, for instance, the juice quality. Ripening is mainly a matter of time. As tillers originate at a later date, they will initially lag behind the earlier shoots as far as maturity is concerned. If they are given enough time, however, they will gradually recover the difference; this is the case in Java, as indicated above. In Hawaii it has been observed that even second-season suckers are capable of catching up with first-season stalks, thus making as much sucrose or more than the latter (193). In areas with a short vegetation period where the cane is not allowed to attain full maturity, initial differences may persist until harvest. This may explain the results obtained by Stubbs in Louisiana, where the mother stalks had the best juice and the subsequent tillers showed a gradual decrease in order of their date of origin. The other extreme occurs when harvesting is delayed so long that the primary stalks start deteriorating while the early tillers are still in a state of maximum maturity. In this case, it will be found that many of the tillers show a better juice quality than the mother stalks. Besides this age effect, other factors may be involved.

As to the length of the different stalks, similar considerations apply. Due to their vigorous growth, the early tillers catch up with the mother stalks or even overtake them provided the growing time is sufficiently long. If the latter is not the case, the mother stalks will still be leading at harvest time. Departures from this general scheme resulting from particular external conditions are, however, not rare.

Factors influencing tillering—Before discussing the effect exerted by internal and external factors it is necessary to make some general remarks as to the evaluation of the results obtained by various workers. Much confusion can be avoided by a clear distinction between the influence exerted on initial tillering and on final stalk number. Moreover, it must be borne in mind that various factors may interact. Thus a factor may exert a beneficial influence on the ultimate number of tillers in a widely spaced field, whereas the same factor may be without effect in a field where, as a result of narrow spacing, the number of stalks is already adequate.

Light.—Among the external factors influencing tillering, light is perhaps the most important. Light may exert its effect in two ways, viz., by its intensity and by its duration (day-length, photoperiodism).
Fig. 88.—The upper cane plant, 120 days old, was grown under the light conditions of a greenhouse. Note the profuse tillering. The lower plants, 120 days old, were grown under two layers of muslin. The primaries are long and slender due to partial etiolation; tillers are lacking. After Martin and Eckart (451).

Fig. 89.—Effect of temperature on early tillering. After Randus and Dopp (487).
The effect of light intensity is known by every planter who has noticed the lack of tillers in cloudy regions or in the shade of trees. This effect was first studied by Kamerling (337) in the beginning of this century. He planted six one-bud cuttings in each of two boxes, one of which was covered with green gauze. Two months later, the plants in the covered box had developed no tillers, while their number in the open box averaged three. A similar experiment in pots gave an average of one tiller in the covered and of 4.5 tillers in the open pots.

In later years, similar results were obtained in Hawaii (fig. 88) by growing cane in pots which were covered with muslin of various thickness (567) or with various layers of muslin (451). Though the number of tillers in these experiments decreased gradually as the intensity of the light diminished, it comes somewhat as a surprise that even at four per cent of the normal daylight intensity some tillering took place.

It is a well known fact that in young cane fields the period of initial profuse tillering is followed by a wave of mortality as soon as the rows close in. Plant competition in this stage is supposed to center around two main factors, drain of food and lack of light. It is, however, an easy matter to prove that lack of light is the dominant factor, for after severing the shoots surrounding a lagging shoot, the latter soon recovers and develops normally even in cases where its top leaves have already started drying up (218, 223).

The changes occurring in a field by the time of closing in have been nicely imitated in pot experiments in Hawaii (451). Cane plants raised under the light conditions of a greenhouse were transferred to reduced light conditions when 56 days old. Practically all tillers died, which is exactly what happens when a field closes in. Another group of plants was raised under reduced light conditions and consequently failed to produce tillers. At an age of 56 days, these plants were transferred to the light conditions of the greenhouse where they promptly started tillering.

According to what is known of plants in general, the effect of light intensity is associated with the activity of growth regulating substances. These substances are produced in the top of the plant, and flow downward in a continuous stream. Their effect is a dual one: they promote stem elongation and at the same time prevent the lateral buds from developing. Under the effect of high light intensity, the downward stream of growth regulating substances diminishes. Accordingly, the elongation rate of the stem slows down and the degree of bud inhibition diminishes, resulting in the production of tillers.

When light intensity is reduced, the reverse takes place. The downward stream of growth regulating substances increases, resulting in an accelerated elongation of the stem and an increased bud inhibition, preventing the production of tillers.

Besides light intensity, daily light duration (day-length, photoperiodism) plays an important role in tillering. Experiments in Hawaii (567) and Formosa (409) have shown that shortening the duration of daily exposure to light results in decreased tiller formation. This fact is of particular importance in subtropical countries, which are characterized by long days in summer, shorter days in fall and spring, and very short days in winter.

Temperature.—Next to light, temperature is the most important climatic factor in tiller
With increasing temperature, tillering gradually increases until a maximum is reached somewhere around 30°C (fig. 89). This factor is of particular importance in subtropical and temperate zones, where it may be the limiting factor during the cool season. Shallow planting and a light covering of earth are some of the measures applied in order to improve tillering under these conditions.

Fertilizers.—Increasing applications of nitrogen increase the number of tillers permanently, until an optimum is reached beyond which additional nitrogen dressings remain without effect.

Application of phosphate has a similar permanent effect on soils deficient in this nutrient. On soils adequately supplied with phosphate, the effect is only temporary. But in the latter case, it is often so striking that it may be misleading, since it may simulate phosphate deficiency of the soil.

Moisture.—The beneficial effect of moisture has already been demonstrated in the past century by Arendsen Hein (64) who found that, even without manuring, the number of stalks per hectare at harvest was increased by ample irrigation. Kamerling (337), Matsubayashi (455), and others have corroborated the beneficial effect of soil moisture on tillering.

Spacing.—Spacing in and between the rows affects both the trend of tillering and the ultimate number of millable stalks (86, 161, 205, 222, 225, 467, 529A, 530). With closer spacing, the ultimate number of millable stalks generally increases. Numerous field experiments in Java have proved that there is an optimum for inter-row spacing for each variety at which it will produce its maximum yield of cane and sugar. One is inclined to expect that poorly tillering varieties would require closer spacing than varieties which tiller profusely. In this connection, it is interesting to examine table 5, in which the results obtained with different varieties in Java are summarized. Besides the spacing optimum, the ultimate number of stalks associated with this optimum are listed in this table. It appears that there is no relationship between tillering capacity and spacing optimum. The profusely tillering variety POJ 100, for instance, requires the same spacing as the poorly tillering variety EK 28. This indicates that other factors are involved. One of them may be the position of the active leaves. For POJ 2878 which requires closer spacing than all the other varieties examined is characterized by a more erect position of its active leaves (205).

Table 5.—Optima for row spacing in Java. After Demandt (205)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Optimum of inter-row spacing in cm</th>
<th>Number of millable stalks per hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>POJ 100</td>
<td>119</td>
<td>78,300</td>
</tr>
<tr>
<td>247 B</td>
<td>122</td>
<td>78,100</td>
</tr>
<tr>
<td>DI 52</td>
<td>122</td>
<td>64,300</td>
</tr>
<tr>
<td>POJ 2878</td>
<td>113</td>
<td>63,600</td>
</tr>
<tr>
<td>EK 28</td>
<td>120</td>
<td>49,100</td>
</tr>
</tbody>
</table>
Spacing in the row depends on the amount of cuttings per row and on the number of buds per cutting. An example of the effect of varying numbers of cuttings per row on the trend of tillering is presented in fig. 90. This figure relates to an experiment in which ten rows four feet apart and ten meters long were planted with varying numbers of two-bud cuttings of 247 B. It appears that with increasing numbers of cuttings the initial number of shoots per row increases but that the differences gradually level down as the crop grows older.

Similar results have been obtained by planting cuttings containing different numbers of buds. In a series of experiments, ten rows, three and one-half feet apart and ten meters long, were planted with 18 single rayungans (cuttings containing one developed shoot) of POJ 2878 per row. Ten adjacent rows were planted with a similar number of top cuttings each containing an average of two and one-half bud per cutting. The rows were examined.
Fig. 91.—Trend of shoots originating in successive months from single rayungans and from top cuttings. Note the high initial number of September tillers in the rayungans and their high rate of mortality. After Van Dillewijn, Leigh and Wesselingh (222, 223).
Fig. 92.—Integration of the results presented in fig. 91. Although the rayungans start at a lower level due to the smaller number of buds planted, the maximum of both graphs (about 1300) and the ultimate number of surviving stalks is approximately the same for the two kinds of planting material. After Van Dillewein, Leigh and Wesselingh (222, 225).

Fig. 93.—Percent composition of stalk population at harvest. The rayungans (A) produced relatively fewer primaries but more late tillers than did the top cuttings (B). Consequently the average age of the stalks is higher in the crop grown from top cuttings. After Van Dillewein, Leigh and Wesselingh (222, 225).
at monthly intervals, the newly developed shoots were labeled, and a complete life history of each shoot was kept. The results of one of these experiments are presented in fig. 91, 92 and 93.

Fig. 91 shows that the 180 primaries of the rayungans present when planted in June gradually diminished to some 100 during the subsequent months. In July about 200 tillers originated, part of which died afterwards. The August stalks started at a somewhat higher level, and in September a flush of tillers originated but due to the fact that the rows had closed in, less than 30 per cent of the September stalks survived.

The figure representing the results with top cuttings, shows that due to the greater number of buds planted, the primaries started at a level about two and one-half times that of the rayungans. The July, August and September tillers started at lower levels than the primaries and showed increasing rates of mortality.

An integration of all results is given in fig. 92, showing the total trend of the combined stalk classes for both kinds of planting material. Though the diagrams start at different levels owing to the initial difference in the number of primaries, the maximum and the final number of the totals differ only slightly. Moreover, the yield of cane and sugar was practically the same in both cases. The differences in final composition of the stalk population, however, are striking (fig. 93): the crop from top cuttings contains considerably more primaries but less September stalks. Consequently, the average age of the stalks grown from top cuttings is higher than in the case of rayungans.

These results contain some practical lessons:

1. The ultimate number of millable stalks which a cane crop is able to carry under a given set of conditions is fixed within rather narrow limits;
2. Any effort to surpass these limits by planting excessive amounts of buds is abortive, and constitutes a waste of planting material;
3. Planting increasing numbers of buds per row permanently affects the composition of stalk population;
4. The fact that the final yields of cane and sugar remain practically the same indicates that a cane crop is able to build up its final yield in quite different ways as far as composition of stalk population is concerned.

EARTHING UP.—Early tillering may be promoted by covering the cuttings with as little soil as possible. For that reason sets in Java are slightly pressed into the moist soil in such a way that the upper part remains visible after planting. Under these conditions, the young primaries become fully exposed to light and heat, and tiller profusely.

Subsequent tillering is governed by the time and the degree of soil applications. Light and delayed earthings up promote tillering, whereas early and heavy soil dressings exert an inhibiting effect. In the latter case, only the vigorous shoots are capable of pushing their way through the soil, whereas the development of weak tillers is largely suppressed. Thus both the number and the quality of tillers are affected, and for this reason the policy of earthing up constitutes an important tool in the hands of the cane grower.

It is generally recognized that ideal stooling should start with an early flush of tiller
formation. This provides the crop with an adequate number of shoots of approximately the same age. Moreover, it promotes early closing of the rows, thus suppressing weed growth.

Excessive tiller formation during the subsequent months should be avoided since the ultimate number of stalks which a crop is able to produce is limited. A certain margin of reserve shoots, however, should be allowed for in order to make up for losses resulting from diseases, pests, etc. Under normal conditions this margin should not exceed 100 per cent. Thus if a row of 10 meter is capable of producing some 70 millable stalks, the maximum of the tillering curve should not surpass 140 shoots.

An example of the effect of timing the first soil dressing on the trend of tillering is presented in fig. 94. This figure relates to rows seven meters long in which the first soil was applied at various dates after planting. The time of subsequent soil dressings was the same in all plots. An examination of the graphs indicates that the earlier the first earthing up is applied, the greater its depressing effect on the maximum of the tillering curve. As the crop grows older, the differences tend to diminish, and the final number of millable stalks is practically the same for all treatments (529 A, 467). Thus the main effect of early earthing up consists in the suppression of superfluous tillers which, since they are bound to die, would constitute needless drain of food.

Lodging.—It is a well known fact that lodged cane plants tend to develop suckers. The mechanism of this phenomenon is little understood. It is often held that changes in light and temperature conditions which occur in lodged parts of a cane field are responsible.
for suckering. But suckering may also occur in pot experiments where differences in light and temperature are minimal (115). This would indicate that a horizontal position of the stalk is responsible for the formation of suckers, probably through a weakening of the top dominance.

DISEASES AND PESTS.—Both stem borers and top borers may cause considerable losses in grown-up cane. In contrast to older cane where the damage is irreparable, the harm in young cane may be more or less counterbalanced by the fact that borer infestation stimulates the initiation of tillers.

When the primary shoot of a young plant is killed by diseases or pests, and consequently ceases to exert its inhibiting influence on the development of lateral buds, tillering will be promoted. Borers may destroy mother shoots to such an extent that the plants appear to grow shorter. But as Barber (86) put it, the cane grower views the matter with equanimity, because he knows that this pest merely causes the lateral buds to be developed in large numbers, and he asserts that he gets a better stand of cane when there is an attack of top borers.

THINNING.—Encouraged by this beneficial influence, various efforts have been made to imitate the effect of borers by cutting out the mother shoots of young plants. This treatment has yielded some striking results in Formosa where in one experiment topping increased the number of millable stalks and the cane tonnage by 11.3 and 25.9 per cent respectively (418). The date of topping plays an important role. In one experiment in which this treatment was applied 35, 50, 65, 80 and 95 days after planting, the relative yields of cane were 367, 412, 450, 463, and 462 kg respectively. Thus the best effect was obtained when topping was performed 80 to 95 days after planting (517).

Experience in Java has also proved that early tillering is promoted by severing the primary shoots, but since the same result can be attained by simple cultural methods (adequate amount of planting material, light and delayed earthings up), thinning has never become standard practice on this island. Evidence so far available seems to indicate that the economic importance of thinning is limited to regions where cultural methods fail, e.g. under cool and cloudy conditions.

PLANTING TIME.—The trend of the tillering process as well as the final number of millable stalks are influenced by the planting time. Since initial tillering is greatly affected by heat and light, the influence of planting time will be most marked in regions with distinct seasonal variations. In Formosa, for instance, cane planted in autumn attains its maximum of tillering about March, while spring planting reaches its maximum about May. Moreover, the final number of stalks per plant in spring planting is less than in autumn planting (532). A similar beneficial influence of planting in summer has been observed in field experiments in South Turkey and may apply to subtropical regions in general.

COMPENSATION.—A cane field has an amazing capacity of making up for the losses resulting from dying stalks. Compensatory growth is greatest in young cane where many surplus shoots are ready to take the place of dying ones. Under these conditions, compensation amounts to 100 per cent. As a crop grows older, its compensating ability diminishes gradually, but even then it remains appreciable. This has been proved in a
series of field experiments with POJ 2878 in Java in which 5, 10 and 20 per cent of the stalks were severed at an age of approximately seven months. The stalks selected for elimination were uniformly distributed over the field. Thus in the case of 10 per cent elimination, the first, the eleventh, the twenty-first stalks, etc. were cut out. At harvest, which took place at an average age of 12 months, the actual losses in sugar yield were 2.2, 4.8 and 11.4 per cent respectively. This indicates that about 50 per cent compensatory growth had been made. Further analysis showed that this compensation resulted partly from the development of new tillers, partly from the survival of stalks which otherwise would have died, and partly from an increase in the average weight of the stalks (203). The fact should be stressed that this high rate of compensation was obtained under the conditions of uniform distribution of the stalks eliminated.

When groups of stalks are missing as is the case in gaps, the picture becomes different as has been shown by field experiments in Louisiana (59). Under such conditions, compensation in short gaps is greater than in long ones, and in ratoons it is considerably greater than in plant crops. Moreover, remarkable differences were found between different varieties, CO 290 showing the greatest compensatory growth and POJ 234 the least, of the varieties examined.

Rapid propagation methods.—The fact that the rate of tillering can be easily influenced by external factors has been utilized in devising methods for the rapid propagation of planting material of new varieties (3, 131, 132, 155, 156, 186, 187, 216, 227, 305, 331, 495, 537, 538). These methods are partly based on tillering and partly on aerial branching.

The underlying principles of these methods are twofold. First, the fact that every bud or shoot is capable of producing a complete plant, and second, that by rendering conditions for tillering and growth optimal (fertilizing, irrigation), the cane plant can be forced to produce a maximum of new buds and shoots.

The seblang or sprouting method gives the highest rate of propagation. Plants are grown in light and fertile soil and the utmost care is given in order to promote profuse tillering and growth (wide spacing, shallow planting, frequent watering and ample fertilization). As soon as tillers have developed their own roots they are severed from the mother shoot and carefully planted separately. Under favorable conditions, the latter will soon form their own tillers which are in their turn separated and planted. In the meantime, the original plants have continued tiller formation and these tillers are treated in the same way. The success of this method depends largely on the care given and on the regenerative power of the plants, which is different for different varieties. The method appears to be an old one, since there are indications that it has already been applied in the past century by REYNOSO in Cuba. The method has long since been in use in cane breeding work in Java. Excellent descriptions of its use have been given by various authors (131, 132, 216, 331).

In the single-eye method, shoots are allowed to develop four or more aerial internodes before they are severed at ground surface. These cut stems are segmented into one-eye cuttings and the cut surfaces of the latter are dipped in hot paraffin. The cuttings are carefully germinated in special containers and the young plants are hardened before being planted in the field. This method has successfully been applied in Mauritius (305), Cuba (227) and Louisiana (537, 538).

The rayungan method is also based on the principle of using single-eye cuttings, but it differs from the method just mentioned in that the development of the buds into shoots takes place on the
stems while standing in the field (216, 217). To this end the stalks are decapitated when 6 to 8 months old, in order to eliminate top dominance. Two to four weeks later, the shoots originated from the upper lateral buds have sufficiently developed in order to be harvested. Each shoot, together with the node to which it is attached and part of the adjoining internodes, is severed and planted. This planting material is called rayungan in Javanese. The removal of the upper rayungans stimulates the development of the next lower lateral buds and thus, by subsequently removing the full-grown rayungans, ultimately all lateral buds will develop. This method has the advantage that during germination, at least during the development of the shoot, the cutting forms a part of the mother plant. Thus no special precautions are required and the percentage of non-germinating buds is reduced to a minimum. However, ample irrigation and fertilization are necessary in order to ensure the full development of rayungans along the stalk. This method is so easy to handle that in pre-war time more than half the acreage of commercially grown cane in Java was planted with rayungans.

The production of rayungans constitutes a considerable stress on the supply of energy and nutrients on the part of the cane plant. Thus it may occur that in long stalks the lower buds do not develop into shoots as a result of exhaustion of the plant. In this case the tjiiblok method has proved to be useful. It consists in decapitating the stalk and subsequently severing the upper half of the stem. This upper part, called tjiiblok, is planted vertically in such a way that at least one node is buried in the soil in order to induce root development. Both the tjiibloks and the remaining stumps are amply supplied with water and fertilizers. The upper buds of tjiibloks and stumps soon start developing into shoots and the subsequent treatment is similar to that described for the rayungan method (213a, 216, 217).

As stated before, the sebjang method gives the highest rate of propagation; since, however, the continuous mutilation of the plants puts a heavy stress on their regenerative power, it is not advisable to continue it for too long a time. Some 6 to 8 months after planting, they should be given a rest period, and the shoots which then develop into stalks should be subjected to the rayungan method. Such a combination of the two methods permits of speeding up the propagation rate to several hundred times in the course of one year.

Aerial branching.—The aerial lateral buds generally do not develop in normal healthy stalks since the terminal bud exerts a top dominance which keeps the lateral buds in a state of dormancy. There are, however, some varieties in which the lateral buds may develop in apparently normal stalks, B 208 being one of them (86). Besides, aerial branching may be induced by extreme wetness of soil or atmosphere, and it is reported from India (86) that in places where there is a marked difference in the humidity and temperature during the different monsoons, this difference is often permanently marked on the different sections of the stalk. According to BARBER (86), in North Bengal it is easy, at crop time, to determine which joints have been formed during the hot, dry summer months and at what stages the rains attained their maximum. The development of aerial buds under wet conditions results from the collection of rain water at the base of the leaf sheaths, and stripping away of the older leaves (trashing) is recommended as a control measure (86, 88). Aerial branching is rather common in lodged cane, as here the contact with the moist soil favors the development of aerial buds.

In erectly growing cane, aerial branching is mostly caused by diseases such as sereh (581) and leaf scald, by insect injury, resulting in the formation of adventitious buds (p. 25), or by the fact that the growing point ceases its normal function. In the latter case, the top no
longer exerts an inhibiting influence on the lateral buds and they can develop freely. The normal function of the terminal growing point may be disturbed in various ways: by flowering, by insects (top borers), by diseases (top rot), or by mechanical damage (wind breakage).

CHAPTER 9

GROWTH

GENERAL; GRAND PERIOD; GROWTH FORMULAE

Growth is often thought of in terms of elongation, but in its broadest sense it includes increase in dry matter as well as increase in size and weight. These phenomena do not, of necessity, run parallel. During a period of drought, for instance, elongation of the cane stem may come to a standstill while assimilation continues, resulting in an increase of dry matter. The reverse is to be found during the initial stage of germination when the development of the shoot and roots takes place at the expense of the nutrients stored in the cuttings. In this case increase in size is associated with decrease in total dry matter.

Since the cane stem does not exhibit the phenomenon of secondary thickening, its increase in length is more or less proportional to its increase in volume. There are, however, a few exceptions. As has been pointed out previously, the diameter of the internodes along the stem is not uniform. This applies especially to the bottom section and the top of the stem where the internodes are generally thinner. In addition, the diameter of other sections of the stem may be affected as a result of abnormal growing conditions. Apart from these exceptions, however, the correlation between increments in length and in volume is sufficiently high in sugarcane to justify the substitution of simple length measurement for the laborious determination of volume.

Three processes are involved in the formation of new organs: cell division, cell differentiation and cell elongation. Cell division which results in a continuous formation of new cells, takes place in the meristem of the growing point. The newly formed cells gradually differentiate, thus forming different kinds of cells, and elongation takes place in a subsequent stage. The result is depicted in fig. 22 which shows how minute joints, each carrying one leaf, originate in the top of the stem and how these units gradually increase in size.

The growth of the cane plant as well as of its constituent parts does not proceed at a uniform rate. Development starts very slowly in the germinating bud and it increases gradually till a maximum is reached which is followed by a gradual decrease. According to Sachs, this trend of development is called the grand period of growth (fig. 99B, 100, 101).

It is explained by the fact that in the early stage of germination the assimilating apparatus (leaves) as well as the absorbing apparatus (roots) are very small. Consequently, the rate at which organic matter is produced is limited. With each increment of dry matter, both the assimilating and absorbing apparatus increase in volume, and thus production of dry matter augments at a rate expressed by the law of compound interest (97, 98). This
law, however, is only partly valid since a certain fraction of the dry substance is consumed in the process of respiration and does not contribute to the production of new substance. Moreover, as mentioned before, the initial phase of germination during which the productive organs are formed is characterized by a loss of dry matter (respiration) rather than by an increase. The greatest divergence, however, is caused by the fact that as the plant grows older the proportion of tissue that does no longer contribute to the production of organic substance gradually increases. This applies particularly to the stem, to the dead leaves and to that part of the root system that is no longer actively engaged in absorption. In full-grown cane the dry matter contained in these non-productive tissues may even surpass 80 per cent of the total dry substance. Not only are these organs no longer active in the production process, but some of them actually consume organic matter through respiration.

This gradual decrease in the ratio of producing to consuming tissues explains the general form of the grand period. Once the young plant has been established, the ratio is favorable and this is expressed by a steep increase of the curve representing the growth rate. When the ratio becomes increasingly less favorable, the curve approaches a horizontal trend and reaches a maximum. This is followed by a decrease till a point next to or at zero is reached, indicating that production and consumption are in equilibrium. When instead of the monthly increment the accumulated growth is presented in graphic form, a sigmoid curve will result. Examples of both types of curves are to be found in fig. 99. Although this figure relates to length increment, the figures for increment in weight are fundamentally the same.

The formula of compound interest introduced by BLACKMAN (97, 98) to express the growth of plants, runs as follows:

$$\log e \frac{W_1}{W_0} = rt$$

where $W_0$ is the initial dry weight of the plant, $W_1$ the dry weight at the end of the time $t$ while $r$ is the rate of interest or increase. As pointed out before, the best agreement between actual growth and growth calculated from this formula is to be found during the ascending branch of the grand period. Many formulae have been presented in an attempt to express plant growth, but with the exception of BLACKMAN’s formula they have not been applied to sugarcane.

**GROWTH OF COMPLETE STOOLS**

Under normal conditions, the monthly increments of fresh and dry substances of complete stools exhibit the form of a symmetric grand period. This is, for instance, the case in Java, where the growing period of cane is about 14 months, and where external conditions are fairly constant. In countries with seasonal fluctuations in temperature or rainfall, the grand period may be altered. This is the case in most countries where the growing period exceeds one year. Under these conditions, the growth curve becomes bimodal, the two maxima being separated by a minimum corresponding to the season of adverse growing conditions.

EVANS (245) has emphasized the fact that not all organs of a cane plant grow at the same
GROWTH

rate. For cases of differential growth rates HUXLEY (317) has suggested the term “hetero-
gonic growth”. A characteristic example of differential growth rates in sugarcane is to
be found during early germination when leaf development is far ahead of stem growth.
As the plant grows older, this discrepancy gradually disappears, since the unfolding of
each leaf is associated with the completion of one joint.

GROWTH OF AERIAL PARTS

Growth of leaves.—In contrast with the stem, the assimilating apparatus consisting
mainly of the green leaf blades is continuously renewed; mature leaves die and young
ones are added.

The area of the individual blades along a cane stalk is smallest at the base and gradually
increases toward the top till a maximum is reached, which is followed by a decrease.
When a favorable period of growth is followed by an adverse period, the surface of the
newly produced blades may become smaller. A subsequent improvement of growing
conditions may result in newly formed leaves with an increased surface. Thus the normal
trend of the surface of the blades along the stalk may be disturbed by external conditions
in the same way as has been pointed out for the length of the internodes (fig. 95).

The longevity of a leaf differs according to variety and external conditions. Observa-
tions in Hawaii (199) indicate that under the conditions prevailing on that island a blade
remains green for about 60 to 75 days from the time it expands fully. In F 108 grown in
Formosa (416) it was found that the lowest two leaves of the stalk live only for 30 to 40
days, that the fifth up to the sixteenth blade live for 60 up to 150 days, and that the leaves
above the twentieth usually function for 60 to 90 days.

Another factor of importance is the rate at which the leaves are produced. The time
which elapses between the formation of successive joints and their leaves is indicated as
plastochron (73). Since the young joints are hidden within the leaf spindle, direct obser-
vations as to their development are not possible but the rhythm of the plastochron can be
estimated by observing the time which elapses between the unfolding of successive leaves.

Fig. 95.—Area in cm² of the individual leaves of a stalk of F 108 from the base (left) to the top (right) of the stalk. Abscissa,
nos. of the internodes. Ordinate, leaf blade surface in cm². Drawn after figures from LOH and CHIN (416).
Here again varietal and seasonal differences play a role. Kuiper (380) found that under Java conditions the average plastochron during the entire growing period ranged from 5.0 to 7.2 days for different varieties. Observations in Formosa (416) indicate that the plastochron is shorter in early maturing than in late maturing varieties; in other words, the former produce leaves at a quicker rate than the latter. Moreover, it was found that under favorable conditions the plastochron was of only one week's duration, while it was two and more weeks under adverse conditions (416). For the sake of comparison, it may be interesting to note that the plastochron of Selaginella is one-third of a day, that of sunflower 5.6 days, that of agave 16 days and that of the fern Pteris aquilina about one year (508, 509).

The number of green leaves present on a stalk is governed by two factors: the rate at which the leaves are produced and the longevity of the individual leaves. Since the plastochron is more affected by varying conditions than is the longevity, it will be evident that the number of green leaves follows closely the fluctuations in plastochron. Thus during periods of favorable growing conditions, the number of green leaves per stalk is greater than during periods of adverse growing conditions. Early varieties are generally characterized by a greater number of green leaves than later varieties.

One of the most important characteristics of leaves with regard to their function is their total area. The latter depends on two factors: number of leaves and average surface per leaf. Some examples are presented in fig. 96 and 97. A comparison of the two figures shows that the total leaf surface of the early variety F 108 is greater than that of the later maturing variety POJ 2883. The effect of external conditions is demonstrated by the fact
Growth of stems.—When one-year cane is grown under normal conditions, its elongation exhibits a normal grand period with one maximum. An example is presented in fig. 99 that the maximum leaf surface attained per stalk is greater when planting is done in spring than in autumn. Another example demonstrating the effect of climate is presented in fig. 98. It shows that the total green leaf area in the sunny climate of Waipio is considerably larger than in the more cloudy climate of Kailua.
which is characteristic of POJ 2878 grown in West Java. It shows one maximum, and the
grand period has a symmetrical form. In the same figure, the trend of the total length is
reproduced which has a regular sigmoid form.

External factors may affect the form of the grand period. Interesting examples are
shown in fig. 100 and 101. They relate to a collection of different species and varieties
grown by BRANDES (135) at different latitudes. The average grand period of the whole
collection shows a symmetrical form in Canal Point (Florida) while the form in Summit
(Panama Canal Zone) is asymmetric. There are many factors which may cause deviations
from the normal shape of the grand period; in this particular case, BRANDES has emphasized
the difference in day length as the stimulus. Similar asymmetric curves have been reported
from British Guiana (177).

The greatest disturbances in the shape of the grand period are caused by seasonal
differences in climate. They are rather common in countries with biennial cane and

![Fig. 100. Grand period of growth of different cane species grown at Canal Point (Florida). Ordinate, monthly increment in
length expressed in per cent of ultimate length. Abscissa, months.
--- Average of varieties of S. robustum
--- Average of varieties of S. officinarum
--- Average of varieties of S. bahberi
--- Average of varieties of S. spontaneum
Calculated from data of BRANDES (135).](image1)

![Fig. 101. Grand period of growth of different cane species grown at Summit (Panama Canal Zone). For explanation see
fig. 100. Calculated from data of BRANDES (135).](image2)
alternating hot summers and cool winters. The example given in fig. 102 shows how the interference of the cool winter results in a growth curve with two maxima. Bimodal curves have been reported from Mauritius (245), Peru (420), Hawaii (173, 178, 180, 191, 199, 524) and many other countries.

**Growth distribution.**—The distribution of growth constitutes one of the most fascinating phenomena in the physiology of the cane plant. This applies particularly to the leaf spindle where many leaves are firmly packed together. Here the growth of the individual organs must be extremely well balanced, otherwise deformations will result in the form of tangle tops.

The study of growth distribution is rendered rather difficult by the fact that the growing organs are well hidden within the leaf spindle. It is a curious fact that this aspect of growth distribution has mainly been studied by Java workers (215, 222a, 223, 339, 375).

Before discussing the details of growth distribution, it is necessary to agree on a clear nomenclature for the organs of which a cane plant is composed. Much confusion has resulted from such vague indications as “the first leaf from the top”, etc. What is the first leaf? Is it the outer leaf of the spindle or the upper unfolded leaf? The situation is even more confused where the joints are concerned. The designation “upper joint” leaves to the reader a choice among at least four internodes.

Fortunately, KUIJPER (375) has introduced a system which is simple and which leaves no doubt about the organ which is meant. Moreover, this system, as will be explained below, gives a good deal of information as to the physiological stage of each of the organs. This system starts with the highest visible dewlap, which is designated as +1. The leaf to which this dewlap belongs is leaf +1 and the joint on which the leaf is implanted carries the same number. Leaf +1 represents the highest of the unfolded leaves. Fig. 103 gives a picture of the constituent parts of the upper section of a cane stalk and their relative position. It shows that the leaf with the uppermost visible dewlap is leaf +1. The older leaves are consecutively numbered +2, +3, etc. Each joint has the same number as the leaf it carries. In this way, it is possible to designate any organ of a cane plant by a specific number.

As new leaves emerge, the designation is adjusted accordingly. Thus in fig. 103, leaf zero is about to overtake leaf +1 and actually there may be some doubt which of them
represent leaf +1. Within a few days the leaf now designated as +1 will have become +2 and by that time the present leaf 0 will carry the number +1.

In order to avoid future confusion, the general application of this system of nomenclature is strongly recommended to all students of sugarcane physiology.

The first attempt to study the growth distribution in sugarcane was made by KAMERLING (339). Since the growing regions are surrounded by the older leaves, he tried to remove the latter. The growing regions thus exposed were protected from drying by glass tubes. But even so the method proved to be too injurious.

The best method so far available is that introduced by KUIJPER (375). It consists of piercing small holes with a thin needle in the leaves and the underlying organs. The holes are made at a uniform distance of 10 or 20 mm starting at dewlap +1 and they are numbered consecutively. The plants treated in this way are severed after some days and the leaves unravelled as shown in fig. 103, in order to measure the distance between the holes. The increase in distance between successive holes indicates the growth made. The results are drawn to scale as shown in fig. 104a.

This figure represents, in form of a diagram, a longitudinal section of the upper part of a sorghum stalk. Horizontal lines represent the nodes; between the nodes the internodes (+2, +3, +4, etc.) are to be found. The length of the internodes decreases toward the top and the youngest internodes are so small that they are not indicated in the figure. The leaf sheaths originating from the nodes are indicated by thick vertical lines, the blades by thin lines. Each leaf carries the number of the internode immediately below its point of attachment. The figure represents only the left half of the plant and is stretched out in horizontal direction for the matter of clarity. The rate of growth is plotted in the form of dotted curves, using the vertical lines as abscissa. A similar diagram of a sugarcane stem is presented in fig. 104b.

The growth distribution shows various interesting aspects. The youngest leaves (-1 and younger) exhibit a symmetrical growth curve and it is interesting to note that as far as growth is concerned, there is no discrimination between the blades and the sheaths. Moreover, the growth curve is uniform for all these leaves, stretching over a zone about 8 cm long. Thus these leaves behave as one single organ and push ahead synchronously. This fact is of fundamental importance, for since these leaves are packed together very tightly, any difference in growth between adjacent leaves would of necessity result in distortion, crimping and folding of the tender leaves. This is actually what happens when the uniform growth is occasionally disturbed by external conditions; e.g., in the case of top rot or under conditions of extreme drought. Thus the causal organism of Fusarium pokkahboeng (Fusarium moniliforme) is known to penetrate into the leaf spindle and to infect the growing zone of the leaves. Consequently, growth is deranged and the ultimate result appears in the form of malformed leaves which are so characteristic of this disease (100, 222a, 223, 448). Prolonged drought also may result in characteristic malformations known as mechanical pokkahboeng and tangle top (375, 448). The exact mechanism of the latter disorder is not clearly understood but WADSWORTH (572) has provided evidence that drought does not affect all growing zones of a cane plant to the same extent. The growth of the older organs appears to be more affected than that of the younger ones,
Fig. 103.—The upper part of a cane stalk separated into its constituent parts. After Clements, Martin and Morisuch (172). The numbers of the leaves have been changed according to the system of Kuiper.

Fig. 104a.—Diagrammatic drawing of a sagittal section of the upper left hand half of a stalk of Andropogon sorghum showing the internodes -1, 0, +1, +2, +3, +4, +5, and the leaves -5 to +5. The leaf sheaths are indicated by heavy lines, the leaf blades by thin ones. The dotted curves represent the growth rates using the vertical lines as abscissa. After Van Dillewijn (215).
Fig. 104b.—Diagrammatic drawing of a sagittal section of the upper left hand half of a stem of POJ 2878 examined two days after puncturing. The punctures were made at distances of 20 mm and their position after two days is indicated by numbers.
indicating that the latter occupy a preferential position as far as moisture is concerned (575). Thus differential rates of growth within the leaf spindle may result and disturb the synchronous behavior of the young leaves.

Leaf 0 generally differs from the younger leaves in that its growth maximum has moved downward. Leaf +1 is characterized by the fact that it has accomplished growth. This explains why leaf +1 is so well suited for growth measurements. Since it no longer grows, upward displacement of its dewlap is exclusively the result of stem elongation.

The growth of the youngest internodes (+1 and younger) is extremely small. It is interesting to note that internode 0 shows a perceptible growth. This proves that, at least during a certain period, growth in the leaf and in its underlying internode proceeds simultaneously. As in the case of the leaf, the initial growth curve of the young internode is symmetrical, but as the internode grows older the maximum gradually moves downward and growth becomes more and more limited to the lower part of the internode. Ultimately growth is only found in the growth ring. Under normal conditions, internode +5 is characterized by the fact that it has almost accomplished growth.

Both KAMERLING (339) and KUIJPER (375) state that the leaf blade completes its growth first, that then the leaf sheath follows, and that only after the leaf sheath is full-grown does the internode start growing. The results presented in fig. 104, which are in accordance with many others obtained with sugarcane, indicate that the view held by the former workers is not correct, at least not in all cases. It is, however, true that growth in each organ proceeds in basipetal direction and that consequently accomplishment of growth proceeds in the order: leaf blade, leaf sheath, internode.

The organs which under normal conditions are growing simultaneously are: the internodes +4 and younger, and the leaves 0 and younger. It is the great advantage of KUIJPER's system of nomenclature that apart from denoting the various organs in an unmistakable manner, it also provides basic information about their stage of development.

Growth measurement.—The standard procedure for estimating the rate of cane elongation in the field consists of measuring at periodic intervals the distance of dewlap +1 to the soil surface or to another fixed point. As stated before, this method is based on the fact that leaf +1 is normally full-grown and that consequently any displacement of its dewlap is exclusively due to elongation of the stem. It is tacitly understood that the length of the successive sheaths along the stalks is uniform. This is generally the case in most of the cultivated varieties (87, 339) with only a few exceptions. Consequently, this standard method is correct during most of the growing period of a crop, but the results are unreliable during the beginning and toward the end of the grand period.

KAMERLING (339) already distinguished between apparent growth as estimated from the displacement of dewlap +1 and actual growth of the stem. As long as the length of successive sheaths along the stalk is uniform, apparent growth equals actual growth. During the early stages of germination, however, the length of the successive sheaths increases rapidly; consequently, apparent growth = actual growth + increase in sheath length; or, in other words, the actual growth is less than the apparent growth. The discrepancy is considerable since the apparent growth in this stage of development may
amount to several centimeters per day while the actual growth of the little stem does not exceed a few millimeters.

The reverse applies when the sheaths become shorter, which is often the case toward the end of the grand period. In that case, apparent growth = actual growth – decrease in sheath length, which means that the actual growth is greater than the growth indicated by the displacement of dewlap +1. KAMERLING (339) has even described a case of a diseased plant which showed a negative apparent growth. The growth of the stem was actually 28 mm, but since the length of the successive sheaths decreased in the meantime by 44 mm, a negative apparent growth of 16 mm resulted. Discrepancies may also occur when the length of the leaf sheaths is temporarily affected by such factors as a cool season or a period of drought. Moreover, this method is unsuited for various indigenous Indian varieties, since BARBER (89) found up to 2.5 cm difference in length between successive sheaths in some of these canes.

An optical device which permits of precise growth measurements under laboratory conditions has been described by WADSWORTH (572). This apparatus enabled WADSWORTH to show that during a period of drought the elongation of the stem as measured by the displacement of dewlap +1 is greatly diminished even to the extent that during the afternoon shrinkage may take place. The leaf spindle, on the other hand, continues to grow for some time although at a much reduced rate (fig. 203). This interesting result seems to indicate that the leaves of the latter draw upon reserves of moisture of older organs (575).

The cane plant has its own automatic device for recording daily growth in the form of “growth stripes”. These are marks impressed in the wax coating on the outer (lower) side of the sheath. During day time, the blade joint (dewlap) exerts a pressure on the underlying leaf sheath so that the wax film of the latter is locally pushed away. During the night the blade joint loosens to such an extent that the enclosed sheath is allowed to push ahead without its wax coating being disturbed by the surrounding blade joint. The next day a new mark is impressed and the distance between two successive marks gives a fairly good idea of the differential growth of the stem sections involved.

Factors influencing the growth of aerial parts.—Cane growth is governed by a complex of internal and external factors. Its study meets with considerable difficulties, since it is not always easy to isolate the effect of single factors. This applies especially to climatological factors; rainfall and high air humidity, for instance, are closely interrelated. A good review of the influence of weather on cane growth has been presented by LEAKE (395).

The importance of various factors varies according to the climatic conditions of the different countries. In insular tropical regions, such as Java, where fluctuations in temperature and day length are small, but which are characterized by the occurrence of alternating dry and wet seasons, growth of cane is largely governed by the amount and the distribution of rainfall (p. 112).

In subtropical countries, the situation is more complicated, since cool winter seasons alternate with warm summer seasons. Under these conditions it is possible that in one season rain is the limiting factor and in another temperature or day length.

VARIETY.—Varieties may differ in growth rate as well as in vegetation time. Early
maturing varieties are characterized by the fact that they accomplish their grand period within a short time. Some varieties are particularly suited for one-year cropping, while others can be grown as biennial crops. Most of the POJ varieties, for instance, are typical one-year canes. When they are kept growing for another year, a considerable number of the first-year stalks will die and many suckers will be produced during the second year. Consequently, the ultimate crop will be greatly made up of second-year suckers (p. 210).

Age.—The effect of age is reflected in the grand period of growth, which, as stated before, is largely associated with the fact that with increasing age the ratio of productive to consuming organs gradually decreases.

The effect of age is also expressed in a striking decrease of the plant’s ability to respond to external factors. Thus the response of the cane plant to fertilizers, to irrigation, etc., is greater during the first half of its grand period than during the latter half. The same applies to the plant’s ability to respond to meteorological factors such as temperature and sunlight.

Some typical examples have been reported by BORDEN (122) who found that under Hawaiian conditions the highest total green weights per unit of energy, hours of sunshine or day degrees, were found when the crop was 3 to 6 months old, between August and November. These weights were four times corresponding gains in the subsequent August to November period, when the crop was 15 to 18 months old. The dry weights per unit of all three weather measurements were greatest at 6 to 9 months, in November to February, and they were seven times those secured in the following November to February period, when the crop was 18 to 21 months old. Sunlight and temperature had their greatest effect on the millable cane yield between 3 and 9 months (August to February).

In another experiment (127) even more striking interactions between weather factors and crop age were found. Expressed in millable cane produced per unit of weather, the efficiency at 6 to 9 months (May 10 to August 8) was thirty times that of the same period one year later (18 to 21 months).

The mechanism of these interactions is only partly understood. One factor involved is the total area of green leaves which constitutes the assimilating apparatus of the plant. As stated previously, the total area of green leaves, after having reached a maximum, may gradually decrease toward the end of the growing period. This explains, however, only a very small part of the interactions. A factor of more importance may be found in the fact that the proportion of productive to consuming tissues decreases considerably with age. Even when the productive capacity (absorbing system and assimilating apparatus) and its ability to respond to external factors were to remain unchanged, the share of the assimilates available for building purposes would gradually decrease, since the portion utilized in respiration and other consuming processes increases gradually with age.

The fact that the plant’s ability to respond to external factors decreases with age contains some practical lessons. It indicates that as far as the factors concerned are within human control (fertilization, irrigation, etc.) they should be adequately applied during the period when their efficiency is maximal, namely, before and during the period of maximum growth. Hence the endeavor to apply the major portion of nitrogen as early as possible.

The same applies to climatological factors. It is true that these are beyond human
control, but by proper adjustment of the planting time a situation can be created in which the maxima of the climatological factors coincide with the period of the plant's maximum responsive ability. This is the fundamental principle upon which the long established systems employed in most cane growing countries, with their characteristic optimum times of planting and harvesting, are based. Some tropical countries where seasonal differences are negligible are characterized by the fact that they do not have a particular optimum planting time. Planting and harvesting in such countries may continue the whole year through.

**Diurnal Variation.**—Generally, the rate of cane elongation during night is considerably greater than during day time. An example is presented in fig. 105, which shows the diurnal fluctuation of growth in the main axis of an inflorescence. Since the rate of elongation in this organ is extremely great, the difference between day and night growth is quite marked. In the much slower elongating stem, the differences are correspondingly less striking (left quarter of fig. 106). Among the factors which are responsible for the diurnal variation in growth, moisture plays a dominant role.
MOISTURE (RAIN, IRRIGATION, SOIL MOISTURE).—Since growth is largely a process of cell elongation associated with the intake of water, a close relationship may be expected to exist between the water content of the cane plant and its rate of elongations. Actually, CLEMENTS and KUBOTA (170) found a correlation of + 0.756 between the moisture content of the elongating cane and meristem, and the rate of elongation. A high positive correlation between rate of stalk elongation and rainfall has been reported from Formosa by SUN and CHOW (532).

An interesting relationship exists between soil moisture and cane elongation. Contrary to expectation, the stem grows at a uniform rate as long as the moisture content of the soil is above the wilting percentage. At the wilting percentage growth ceases. It does not make any difference whether the soil is more or less moist; as long as its moisture content is above the wilting point, the growth rate is uniform provided, of course, other factors are not limiting (p. 279).

According to KUIJPER (380), the influence of rainfall on cane elongation is dual: it levels down the difference between day and night growth, and it alters the shape of the grand period. This effect is demonstrated in fig. 106, which represents the growth response of a cane stem to rainfall after a period of drought. The diurnal variation disappears and the general rate of elongation increases from about 5 to nearly 20 mm per day.

In view of the dominant effect of moisture on cane elongation, it is not surprising that many efforts have been made to find correlations between rainfall and ultimate yield, in order to enable the forecasting of yields.

Fig. 107.—Actual sugar yield (solid line) and sugar yield calculated from rainfall in October-November and planting time (broken line) for the years 1912 to 1923 inclusive. After TENGWALL and VAN DER ZIIL (542).
The first attempt seems to date back to 1874 when Rawson (489) in Barbados found that 25 mm of rain during the calendar year preceding the year of harvest resulted in 800 hogsheads of sugar.

The most comprehensive study in this respect has been made by Tengwall and Van der Zuil (542), who used the Java figures of the years 1903 to 1922, inclusive. In Java the monsoons consist of alternating dry and wet seasons, the latter lasting approximately from October to April, inclusive. Planting generally takes place during the first three months of the dry season, and consequently the young cane has to be irrigated. The available quantity of irrigation water, however, gradually decreases, and since at the same time the water requirement of the developing crop increases, the end of the dry monsoon constitutes a critical period. When the rains start early (September, October), the growth rate of the cane will hardly be affected. If, however, rains are delayed till November or even December, the growth will be checked considerably and the crop will suffer accordingly.

The starting point for the study of Tengwall and Van der Zuil was the quantity of rainfall during this critical period. In addition, the planting time was taken into account. A high positive correlation appeared to exist between sugar yield and rainfall in October-November of the year of planting. A similar high positive correlation was found between the rendement (commercial sugar per cent cane) and the rainfall during the same critical months, while the correlation in the case of cane yield was less significant.

The combined correlation coefficient between sugar yield, rainfall in October-November and planting time for Java as a whole was $+0.88$ and proved to be valuable for forecasting purposes (fig. 107). The combined correlation coefficient between rendement, rainfall in October-November and planting time was even higher ($+0.95$) and gave excellent results in forecasting (fig. 108). Thus it became possible to predict at the
end of November the average sugar yield and rendement of Java to be harvested 6 to 10 months later.

Since growing conditions, varieties and cultivation methods differ in various regions of Java, it was to be expected that the same method applied to small, more or less uniform, units would give better results. This has actually been the case. Smit Sibinga (521) found for his plantation a combined correlation coefficient of +0.994 between sugar yield, rainfall in October-November and planting time, but the number of years on which this correlation coefficient is based is rather small.

The effect of rainfall on cane yield in Formosa has been studied by Sun and Chow (531). Formosa is characterized by summer rains and it appears that in the case of summer planting, any additional rainfall of 10 mm per month above the average is more or less harmful during the early months of growth (September to January); it is beneficial during the period of February to June, and again harmful after July. The effect on cane planted in December and January is quite different.

It will be noted that in the studies mentioned so far, the distribution of rainfall has been disregarded. This was permissible in the case of Barbados, since the distribution of rainfall on that island is extremely uniform. It was also permissible in the case of Java, since the amount and distribution of rainfall during the critical period is such that most of the moisture is absorbed by the soil.

With the exceptions of these and a few other cases, the distribution of rainfall is a factor of great importance and the search for correlations between rainfall and ultimate yield has largely centered around the question as to what part of the rainfall is actually effective.

The first attempt to answer this question has been made by Walter (582) in Mauritius who calculated the effective rainfall by multiplying the average daily rainfall per month by the number of wet days. The “degree of wetness” of any month was expressed by the formula

$$\frac{R \cdot t'}{t}$$

where R is the total rainfall during the month, t the number of days of that month, and t’ the number of rainy days. In this way the total rainfall R is given a weight corresponding to the number of days during which it fell. For, if a rainfall of 5 inches occurs on one day in any month, and in another is distributed more or less evenly over twenty days, the latter is a wetter month, from an agricultural point of view at least, than the former, and the relative degree of wetness for the two months would be

$$\frac{5 \cdot 30}{30} = 0.167$$

and $$(5 \div 30) \times 20 = 3.333$$ respectively.

Moreover, Walter wrote off a portion of the rainfall during periods of excessive wetness. He also gave formulae to express rainfall in terms of soil moisture (583).

A disadvantage of this and other methods is that they tacitly assume that the effect of rainfall is restricted to a certain period; e.g., a month. This is incorrect, for it is obvious that a heavy rain, falling at the end of a month, exerts its major influence during the
succeeding month. Or, in other words, the effect of rainfall is not discontinuous but continuous. Fisher (264a) and Leake (393, 394, 395, 396) have developed formulae which take this factor into account. The latter presented the formula

\[ E_n = r_n + k r_{n-1} + k^2 r_{n-1} + \ldots + k^{n-1} r \]

where \( r_n \) is the actual rainfall measured on the morning of the \( n \)th day and \( k \) is a constant, always less than 1 and here nineteen-twentieths. This formula expresses the fact that not only the actual rainfall of the day concerned is effective but that fractions of the rainfall of the previous days are also effective on the day under consideration. A heavy rainfall of 10 inches in one day, as may occur in the tropics, is thus effective after 60 days to an extent equalling 0.47 of an inch. The above formula may also be written

\[ E_n = r_n + k E_{n-1} \]

The factor \( k \) which is a measure of that fraction of the rainfall which becomes available for plant growth is not universally constant but depends on soil type and climatic factors. The advantage of the method lies in the fact that a continuous evaluation of the rainfall effectiveness is obtained, and that it permits of adopting any division of arbitrary periods of time without break of continuity.

The formula has the advantage that it indicates that \( k \), though a constant for any particular set of determinations, may possess different values. Actually the method aims at evaluating the soil moisture from rainfall. The adapted value of \( k \) applies to the tropical conditions of the northern Indian monsoon season, and is considered to be approximately correct for tropical conditions generally (395).

Leake has applied this method to the data of certain sugar estates in Barbados, and was able to estimate, at the end of December, before harvest commenced, the probable yield with an even chance of being within 3 tons of the actual yield. He has also applied the method to Rawson’s data and found it to give a more accurate estimate of production.

The effect of light showers on soil moisture is generally negligible. Observations in Mauritius have shown that a rainfall less than 3 mm hardly reaches the soil of cane fields when the soil is covered by dead cane leaves, while of rains of 5 to 7 mm only three-fifths will penetrate into the soil. During the summer, a precipitation of 5 mm does not seem to increase the moisture reserve of the soil, since this quantity equals the amount lost in one day by transpiration (523).

Light showers, and even heavy dewfall may, however, influence cane growth since the cane plant seems to have an amazing capacity to absorb moisture through its aerial parts (p. 272). In addition, light showers which are too small to be registered by ordinary rain gauges may affect the growth in an indirect way; partly because the leaves are washed and cleaned, and partly because light showers are generally associated with high air humidity, which reduces transpiration and moderates the effect of excessive heat.

Concerning the effect of air humidity, only few data are available, and these are not quite conclusive. Its study is rendered difficult by the fact that, except in controlled laboratory experiments, changes in air humidity are generally associated with changes in other
GROWTH

Fig. 109.—Relationship between temperature (solid line), cane elongation (broken line) and increase in volume (dotted line) of cane per month in Hawaii. After Stender (524).

factors. Hill and Evans (306) found a significant negative correlation between growth and relative dryness of the air (measured by atmometer readings) which means that growth decreases as air humidity decreases.

Fertilizers.—Cane growth is markedly affected by the rate at which fertilizers are applied. Examples of this influence will be presented in the chapter on nutrition.

Temperature.—Since the processes involved in growth are mainly of a chemical nature, the relationship between growth and temperature approximates closely the Van 't Hoff coefficient, which says that with each increase of 10°C the rate of a chemical process is approximately doubled (245, 306). This relationship is actually non-linear, but over the range of temperature prevailing under field conditions, the straight line gives substantially the same value as the curve (191).

Under insular tropical conditions, where the fluctuations in temperature are rather small, temperature is rarely a limiting factor. In subtropical countries, however, temperature is responsible for considerable fluctuations in growth. An example is presented in fig. 109 which shows the relationship between temperature, increase in length, and increase in
volume of sugarcane in Hawaii. All three curves exhibit a minimum during winter and a maximum during summer. The seasonal effect on cane formation is, moreover, demonstrated in fig. 111, which shows the sections of cane produced during each month. The differences between the portions formed in January and in the summer months are striking. Not only the length but also the diameter of the joints appears to be affected by seasonal differences. Fig. 110 represents the diameter of the cane sections formed in successive months and shows that the thinnest section has been formed during fall and the thickest during spring.

At temperatures below 60°F very little growth takes place (530, 566). The minimum temperature for cane growth, according to Ryker and Edgerton (501) is about

![Graph showing diameter of cane sections](image_url)

Fig. 110.—Diameter of the sections of a cane stalk formed in successive months. The two curves represent measurements at different ages, 18 months (solid line) and 24 months (broken line). After Stender (524).
Fig. 111. - Sections of a cane stalk produced in successive months in Hawaii. Note the minimum in January and the maximum during the summer months. After Siroky (1924).
Fig. 112.—Influence of climate on cane growth in Hawaii.
1. Grown in lowland soil in lowland climate (extreme left hand pot);
2. Grown in lowland soil in upland climate;
3. Grown in upland soil in lowland climate;
After BORDEN (114).
54°F, although sprouting of buds may take place at temperatures as low as 43°F (506).

As in the case of rainfall, all considerations of the relationship between temperature and growth ultimately center in the problem of a correct evaluation. Often the mean daily temperature (half the sum of the daily maximum and minimum) is used and although this figure may be useful under insular tropical climates, where variations in temperature are negligible, it is certainly not correct under subtropical conditions where cane growth is largely controlled by maximum and minimum temperatures. There is, for instance, little use in taking into consideration temperatures below the minimum temperature. Since growth below this minimum is checked, all temperatures below this limit should be evaluated as zero, as far as cane growth is concerned.

The first to depart from the method of mean daily temperatures was Walter (582). He considered 70°F as the temperature below which no appreciable growth takes place, and counted only the number of degrees Fahrenheit by which the daily mean temperature exceeded 70°F.

Following a similar line of thought, Hawaiian workers (2, 191, 192, 194) have introduced the concept of day degrees into sugarcane agriculture. They assume that measurable cane elongation does not take place when the daily maximum temperature drops below 70°F. Hence, when the maximum temperature on a given day has been below 70°F, its influence on cane elongation is estimated as nil. A day having 71°F of maximum temperature counts for one day degree. If there are thirty such days in one month, the total effective warmth will be 30 day degrees. A day with a maximum of 85°F counts for 15 day degrees.

One of the advantages of the introduction of day degrees is that in this way warmth, like rainfall, can be accumulated per month or per vegetation period, and that it can be compared for various years. By way of example, the calculation of the effective warmth for the summer months July, August and September, on a plantation, is given below (192).

<table>
<thead>
<tr>
<th>Area in cane:</th>
<th>July</th>
<th>2,000 acres</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>August</td>
<td>2,600</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>3,200</td>
</tr>
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<table>
<thead>
<tr>
<th>Temperature mean maximum:</th>
<th>July</th>
<th>85°F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>August</td>
<td>86°F</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>87°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day degrees:</th>
<th>July</th>
<th>(85–70) × 31 = 465</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>August</td>
<td>(86–70) × 31 = 496</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>(87–70) × 30 = 510</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acre day degrees:</th>
<th>July</th>
<th>2,000 × 465 = 930,000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>August</td>
<td>2,600 × 496 = 1,289,600</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>3,200 × 510 = 1,632,000</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Total for three months.</th>
<th>...</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3,851,000</td>
<td></td>
</tr>
</tbody>
</table>
The application of the principle of day degrees in Hawaii has given a series of interesting results (2, 194) and several plantations have adopted the method. Some experiments have indicated that, although there is a definite gross correlation between growth and day degrees, the relationship is far from precise (513). This was to be expected since temperature is only one of the many factors influencing cane growth, other important factors being light intensity and day length. That, nevertheless, such a high correlation seems to exist between cane growth and temperature, suggests that temperature is also more or less indicative of other factors, viz., light intensity and light duration (day length). This is understandable, since the seasonal fluctuations of these three factors often run parallel.

In Mauritius HALAIS (279) has obtained satisfactory results with a modified method. Starting from a basic temperature of $15^\circ C$ ($59^\circ F$) he takes the number of degrees Celsius which the daily maximum is in excess of $15^\circ C$, and counts the degrees above $21^\circ C$ double. Thus, a day with a maximum temperature of $20^\circ C$ represents 5 day degrees; a day with a maximum temperature of $25^\circ C$ represents 14 day degrees (6 plus 8). A correction for the age of the cane is made by writing off half of the number of day degrees from the moment that flowering starts till harvest.

A second correction is made for soil moisture. It is assumed that under the conditions prevailing in Mauritius, the soil moisture content below which no growth takes place is 20 per cent, and that the maximum soil moisture is 40 per cent. Between these limits a linear interpolation is applied. Thus at a soil moisture of 30 per cent, the growth rate will

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Fig. 113.—Rate of cane elongation and effective day degrees in a first ratoon crop of POI 2878 in Mauritius. After HALAIS (279) from DAS (197).
be \((30-20) \div 20 = 0.5\) of the normal; at a soil moisture of 25 per cent, it will be 0.25 of the normal, etc. Once the mean maximum temperature and the mean soil moisture of a certain month are known, it is possible to calculate the number of effective day degrees. The assumed relationship between soil moisture is open to question, since it deviates from the prevailing concept (p. 279).

By applying the above corrections, the relationship between growth and temperature was found to be very satisfactory, the correlation coefficients in the three sets of data studied being +0.954, +0.961, and +0.951. The close relationship is also demonstrated in fig. 113.

In Formosa, Sun and Chow (532) found significant positive correlation coefficients between stalk elongation and both monthly mean minimum temperature and monthly mean maximum temperature. The first and second orders of partial correlation coefficients between the rate of cane elongation and monthly mean minimum temperature are much larger than those between the rate of cane elongation and monthly mean maximum temperature. Hence it is concluded that the mean minimum temperature is the major factor controlling cane elongation (fig. 114). The same authors presented a regression equation which permits of predicting the ultimate yield from the mean minimum temperature for crops planted in summer and grown on irrigated lands (531).

These authors also found a negative correlation between sugar content and monthly mean minimum temperature, which is in harmony with the well established fact that low temperatures promote sugar storage.

The effect of night temperature on growth is very striking, according to the results of an exploratory experiment performed in Hawaii. Six-months-old plants were used to test the effectiveness of cool and warm nights. During the day the plants were kept under identical conditions, but during the night one group was cooled to 57°F, and the other warmed to 73°F. The growth of the former was reduced to approximately half that of the latter, and so were the weight of leaf blades and the overnight translocation of sucrose from the leaves to the stem (55). Thus night temperature appears to be a factor of considerable importance.
There is ample evidence that sugarcane is a sun loving plant par excellence. In a previous chapter the effect of sunlight on tillering has been mentioned; in one of the following chapters, it will be pointed out that sugarcane responds to differences in light intensity which are so small that they are not registered by ordinary sunshine recording apparatus.

The influence of light intensity on cane growth has been studied in pot experiments (451, 567) which proved that light intensity affects the entire complex of cane growth. In full sunlight the stalks are thicker but shorter, the leaves are broader and greener, while tillering is promoted (fig. 88). Plants grown under conditions of deficient light intensity have long and slender stalks, thinner and narrower leaves and the latter show a distinct yellow color. Moreover, the percentage of dry matter is decreased, which renders the plants more succulent.

In addition to light intensity, day length plays an important role. Plants grown in full sunlight produce more dry matter and have a lower moisture content than plants which receive direct sunlight only from sunrise to noon or from noon to sunset (table 63).

Apart from its direct effect, day length exerts an indirect influence on cane growth, for day length is largely responsible for flowering, which checks the vegetative growth of the stem. Moreover, a considerable portion of the assimilates is utilized in the flowering process which otherwise would have increased the cane and sugar yield. Recent experiments in Hawaii have proved that flowering in commercial cane fields can be prevented by interrupting the night period for two hours by illumination with light intensities from 10 to 100 foot candles (52). Subsequent experiments have shown that an illumination of 10 minutes and even 1 minute, depending on light intensity, may be sufficient for complete suppression of flowering (54, 55). In view of the losses associated with tasseling, these preliminary results are very promising.

Yields of cane and sugar may differ considerably, even in localities which are only a few miles apart. For a long time these differences have been largely attributed to differences in soil. Research in Hawaii, however, has changed this concept since it has proved that differences in climate, and particularly in light intensity, may be far more important.

Das (195) was the first to study the effect of climate on yield by growing cane in pots at different localities. The pots were filled with the same soil; the same varieties were used and care was taken to keep the other factors (fertilization, irrigation, etc.) identical. The two climates involved were the lowland climate at Makiki station, 40 feet above sea level, and the upland climate at Manoa station, at 650 feet above sea level. The climate at the former station is characterized by bright sunny weather with relatively few rainy days; at the latter there are many rainy days and the sunlight received is less than 50 per cent that at the former station. Maximum temperatures at Makiki are about 4°F higher than at Manoa, but there is not much difference in minimum temperatures (114).

The results of the first experiment were striking; both varieties, POJ 36 and POJ 2878, produced nearly three times as much cane at Makiki as at Manoa.

This interesting experiment has been repeated and extended by Borden (107, 114) who grew cane in pots filled with both soil types (Makiki soil and Manoa soil) at both stations.
This offered the possibility of separating the soil effect from the climate effect. The results are depicted in fig. 112 which shows the dominant effect of climate over soil. Additional data are presented in table 6 which gives the average results obtained from one plant crop and four successive ratoon crops at both stations. Under the conditions of the climate of Makiki, the cane yield is almost three times that obtained at Manoa; the rendement is also higher and the sugar yield is more than three times as high.

Table 6.—Effect of climate on cane. After Borden (114)

<table>
<thead>
<tr>
<th></th>
<th>Makiki climate</th>
<th>Manoa climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pounds of cane</td>
<td>69</td>
<td>24</td>
</tr>
<tr>
<td>Rendement (yield % cane)</td>
<td>11.1</td>
<td>8.7</td>
</tr>
<tr>
<td>Pounds of sugar</td>
<td>7.8</td>
<td>2.1</td>
</tr>
<tr>
<td>% P₂O₅ in juice</td>
<td>0.065</td>
<td>0.069</td>
</tr>
<tr>
<td>% K₂O in juice</td>
<td>0.10</td>
<td>0.16</td>
</tr>
</tbody>
</table>

These results contain some lessons of practical importance. First, since it has been proved that sugar yields at Manoa can only be one-third to one-fourth of the yields which can be obtained at Makiki, one need not waste much time attempting to increase them beyond this proportion, for the climatic factors at Manoa are not favorable for greater sugar yields, even when adequate food and water are supplied. Second, efforts to secure an improved physical condition of soils in regions where heavy cane tonnages can be grown should take precedence over similar soil improvement operations in regions where yields will be lower, for returns from the former would be considerably higher. Third, there is little to be gained from increased fertilization under low sunlight conditions, such as are found at Manoa; i.e., piling on the fertilizer will not give increases in sugar under such climatic conditions (114).

A similar experiment has been conducted by Clements (163) who grew cane in two localities only a few miles apart; viz., Waipio with very bright days, and Kailua with many cloudy days. The differences in temperature between the two localities are insignificant, but differences in light intensity are quite large. Despite comparable fertilization and moisture conditions, the Waipio crop was more than twice that obtained at Kailua, due, mainly, to differences in light intensity. Clements expresses the latter in terms of "light degrees" and has developed a formula which permits the calculation of growth at Kailua from that at Waipio:

\[ G_k = \frac{G_w \times A \times L}{D} \]

where \( G_k \) and \( G_w \) are the growth increments at Kailua and Waipio respectively, \( A \) is the ratio of leaf areas at the two stations (Kailua—Waipio), \( L \) the corresponding ratio of light intensities and \( D \) the corresponding ratio of stalk densities. The calculated value was very close to the observed growth. The trend of the average leaf area at both stations is presented.
in fig. 98 which shows that in the sunny climate of Waipio the leaf area is considerably larger during the period of maximum growth.

The effect of light intensity on cane growth is greatly influenced by temperature as has been proved by Brandes and Lauritzen (137) and Lauritzen, Brandes and Matz (391), who grew sugarcane and Erianthus in different combinations of light intensity and temperature. It was found that, in general, the health of the plants improved and growth increased with an increase in light intensity at each of the temperatures. But for each temperature there was a minimum light intensity for survival, health and growth; the higher the temperature, the higher that minimum. Hence, at given temperatures, there are definite light requirements, the light needs being greater at higher temperatures and less at lower temperatures. Fortunately, in nature, temperature, light intensity and day length run closely parallel. This is of particular importance in temperate regions, where a favorable combination of these three factors during summer results in rapid cane elongation.

WIND.—The effect of wind may be dual: direct, inasmuch as the plant is damaged in a mechanical way, and indirect, through changes in transpiration, soil moisture, air humidity, etc.

The direct effect of wind may be considerable if the latter reaches the intensity of cyclones, as is sometimes the case in Mauritius, Formosa, Louisiana and other localities. Walter (582) in Mauritius, and Arceneaux and Hebert (62) in Louisiana have developed special formulae for calculating this damage.

The indirect effect of wind on cane growth has been studied by Verret and McLennan (568) who exposed cane plants to the artificial wind of a fan. When soil moisture was kept optimal, the loss in weight resulting from wind was 14 per cent. When, however, normal water supply for still air was maintained, the losses amounted to 35 per cent by weight and 20 per cent by length, while tillering was increased.

LODGING.—It is generally recognized that lodging exerts a harmful effect on sugar yield, but exact figures as to the losses involved are scarce. Borden (115) has reported the results of a pot experiment. Half the number of pots were laid on their sides with the stalks horizontal when the plants were 8 months old. When harvested 5 months later, it appeared that lodging had resulted in an average loss of almost 25 per cent sugar and, curious to relate, the loss was greatly restricted to the lower portion of the stalk which was already mature when lodging occurred. The average loss of 25 per cent was primarily due to poorer juice quality. According to Honig (unpublished data) lodging is associated with starch formation in the concave side of the stem.

PHYSICAL CONDITION OF THE SOIL.—No exact figures are available as to the effect of the physical condition of the soil on cane growth. The following observations, however, indicate that this effect may be of considerable importance.

In certain field experiments, all shoots of various running rows were counted and measured at weekly intervals in order to record the life history of each individual shoot. These frequent observations entailed considerable walking along these rows, and toward the end of the growing period, the stalks of these rows proved to be markedly shorter. When passing the field, these rows were recognizable as distinct depressions in the “roof”
of the cane resembling furrows, one to two feet deep. In several other experiments on the control of pests and diseases, a similar effect has been observed. The growth of the cane in the plots which were treated at weekly or half-weekly intervals was often affected to such an extent as to counterbalance the beneficial effect of the control measures.

These observations indicate a weak point in field experiments in which treatments requiring frequent walking are applied. The adverse effect of walking on soil structure might be partly counteracted by repeated light soil cultivation. These observations, moreover, give an indication of the serious damage which may result from the increasing use of heavy machinery in cane fields. The physical condition of the soil of large areas may have been spoiled in this way.

Leaf surface.—Any change in the total area of the active leaves may affect the rate of assimilation and consequently influence growth. Went (594) found that defoliation of young cane plants resulted in decreased length and diameter of those internodes which had not yet completed their growth at the time of the treatment. With the formation of new leaves, the subsequent internodes gradually attained a normal size.

Muir and Van Zwaluwenberg (466) pruned the leaves of cane plants three and a half months old, leaving only the two uppermost leaves. Pruning was repeated at intervals averaging about twelve days. Plants thus treated remained considerably shorter than untreated plants and their joints were shorter and thinner.

The most extensive study in this field has been made by Yamasaki and Arikado (605) who defoliated various sections of the cane stem at different ages of the plant. They found that removal of the leaves of the top section not only reduced the length and diameter of the defoliated joints, but also of all higher internodes formed subsequently. Defoliation of the middle and lower sections of the stem had no marked effect on the size of the joints. In addition, leaf pruning had a striking effect on the storage of sugar in the stem (p. 331). The effect of defoliation depends largely on the age of the plants at the time treatment is applied. These investigations indicate that considerable losses may result from leaf damage by diseases, pests or mechanical injury (wind).

Growth of Roots

The study of root development has long been neglected in favor of that of aerial parts. This was largely due to the particular difficulties associated with this kind of research. First, the root system is hidden in an opaque mass (the soil), which requires careful excavation. Second, the medium in which root growth takes place, contrary to that of the aerial parts, is often characterized by heterogeneity (stones, hardpan, differences in soil moisture, in soil structure and in chemical composition), thus giving rise to great variations in root development. Finally, these heterogeneous and ever-changing growth conditions render the interpretation of the results of root studies rather difficult, and this accounts for the many controversies which exist in matters concerning root development.

The particular difficulties associated with root studies make it necessary to use special
techniques, and since the value of the results obtained depends largely on the methods used, a review of the various techniques will be given first.

Methods of investigation.—The direct method of root examination introduced by Weaver (584) consists in excavating a trench 8 to 12 inches from the plants to be examined. The trench should be long enough to include several stools and it should be about 2.5 feet wide and 5 to 7 feet deep. Evans (244) digs the trench in the first instance to a depth of about 4 feet and lays roots bare, starting from the stool outward. The position and course taken by every root in the various soil layers is mapped, and in following the roots downward, the trench is deepened. A chart showing the root system in section is thus obtained, but it may be advisable to take a section in two directions at right angles, since the root system is not always symmetrical. The direct examination method has been applied by Jensen (319), Kulescha (384) and Evans (243, 244).

The block method developed by the East Malling Research Station (England) and adapted to the study of cane roots by Evans (243, 244) enables the determination of the position in space of every root, as well as the subsequent reconstruction of the root system in a specially made frame. The method consists of digging a square trench enclosing an area sufficiently large to cover the complete root system of a plant. This area is divided into four quarters A, B, C and D, and each quarter is subsequently divided into smaller squares with one foot sides. In each of these small squares, the roots are laid bare to a depth of 6 inches and their direction and position are marked to scale on a chart so that their course in space is accurately known. The next 6 inches are dealt with in the same way, and similarly the following layers, until the whole root system has been excavated and charted. Then the root system is reconstructed in a large frame of about 8 by 8 by 6 feet, with cross wires at intervals of 6 inches, each root being placed in its correct position, so that it can be studied and photographed.

A later modification allows of dealing with areas larger than one square foot at a time, these areas being narrow sectors reaching to the stool. Evans considers this to be probably the best method that is likely to be worked out for the detailed investigation of sugarcane roots. The method is, however, laborious and requires adequate funds and labor. For young root systems and for those which are very superficial, the method does not take so long and has advantages over all other methods (244).

The successive section method is, according to Evans (243, 244) intermediate between the two methods mentioned previously. Fig. 115 shows how a trench to a depth of 1 foot, at a distance of about 8 feet from the stool, has first to be dug, this trench being sufficiently long to cover about four stools. Then the side of the trench nearest the stool is worked toward the stool for a few inches with hand-picks, and all the roots entering into the trench are marked to scale on graph paper. The trench is then widened to 2 feet and deepened to 2 feet, and so on till in the final stage, a section is obtained equivalent to that of the direct method of root examination.

This method thus amounts to the examination of one-half of the complete root system, and it tends to have a quantitative value in that the number of roots at varying distances from the stool and at varying depths is obtained. Although this method is not as detailed
as the block method, it gives considerably more information than the direct method of root examination.

Venkatraman and Thomas (557) have described a method by which it is possible to keep the roots in their natural position while removing the soil. To this end, these investigators dug vertical trenches on opposite sides of the plant and encased the two sides of the earth column in wire mesh, while thin iron rods were driven from one side to the other to keep the roots in place. Then the earth was washed away by a jet of water.

For ratoon crops where only the roots in the first 8 inches of soil are markedly affected by manuring and cultivating, Evans (243, 244) has suggested a simpler method. Pegs are placed in the ground to hold the roots in their position, and the soil is removed by means of a water jet. Then the roots in the inter-line and between the stools in the row are plotted to scale on graph paper.

If an exact knowledge of the course of the roots in space is not required, the method used by Atherton Lee (397, 398, 399, 401, 403) can be applied. This method consists mainly of removing the soil in measured layers, separating the roots from the soil by means of a wire screen, and weighing the roots contained in each layer. The method is purely quantitative and does not give information about the course of the individual roots.

Hardy (281) has applied a simplified modification of this method in that he takes soil cores around the plant by means of an edge-sharpened iron tube of 3 inches internal diameter. Cores are taken 2 or 3 feet deep and divided in lengths of 6 inches. Thus this method is essentially a sampling method, since only part of the root system is obtained. The method has been severely criticized by Evans who pointed out that the soil core method is entirely inadequate for the study of the root system of sugarcane. Since cane may have a superficial spread up to 15 feet and penetrate the soil up to 20 feet, thus exploring a volume of 4,000 cubic feet, it will be evident that cores taken along radii at distances of 4, 11 and 18 inches, and to a depth of 3 feet, cannot give much information (243).

The methods described so far have the advantage of studying root distribution under natural field conditions and in undisturbed soil which is not the case with the methods to be described below.

Venkatraman and Thomas developed a method which consists of making a large
excavation prior to planting, and placing horizontal wire nettings at suitable heights in this excavation. Then the latter is refilled with the soil removed, taking particular care to place the layers of soil in the same positions in which they were removed. In the plots thus prepared, cane plants are grown. In order to examine the roots, the soil is washed out so that the roots are left more or less in their original position, since they are caught in the mesh of the interposed wire netting (557).

An interesting modification of this method has been introduced by the same authors (558). It consists of digging trenches and placing therein columns composed of earthenware rings, each 1 foot 6 inches in diameter and 6 inches high. Iron netting is fixed between the rings. The columns are filled with soil and a cutting is planted in each column. In order to examine the root system, the columns are removed from the trench and the soil in each column is washed out while the roots are kept in position by the iron netting.

After the soil has been washed away, each column is placed in the center of a bamboo or wooden frame 4 by 4 by 4 feet, and the edges of the netting are fastened to the frame as tightly as possible. Finally the rings are removed, resulting in the full exposure of the whole root system, the roots being caught up in their original position or very near thereto.

The root boxes used in Hawaii (400, 401) are based on the same principle. Instead of earthenware columns, 30-inch cube wooden boxes with removable sides are used in which wire netting is inserted at different levels. At the end of the experiment, the sides of the box are removed and the soil is washed out, leaving the root system entangled and held in place by the wire (fig. 116).

The foregoing methods, insofar as the soil is first dug out and then filled in, have been criticized for the fact that the natural physical structure of the soil is disturbed. Moreover, the space available for the development of roots both in horizontal and in vertical direction is limited in the earthenware columns and in the wooden boxes.

If one wants to know at what depth in the soil the root system is most active, a technique introduced by Venkatraman (553) may be useful. A vertical trench is dug at one side of the cane plant and filled with sand. By keeping the sand moist, root development is stimulated and after removal of the sand, the region of maximum root activity is easily visible. A modification of this method consists of placing a layer of thick, soft cloth vertically in the trench and filling the trench with sand as described before. After a lapse of time, the active roots will be found enmeshed in the interstices of the cloth.

For a continuous observation of the development of individual roots, Evans (243, 244) used boxes 3 by 3 by 3 feet. One side was made of glass placed at an angle of about 30° to the vertical and marked in square centimeters. The roots grew against the glass and were marked daily to scale on graph paper. Growth took place in complete darkness except during the daily examination. In this way growth rates up to 8 cm in 24 hours have been recorded.

Similar observations under field conditions are possible by fixing glass plates on the side of trenches dug at a distance of 2 feet from the stool (243, 244).

When it is desirable to observe continuously the development of the entire root system, the plants have to be grown in culture solutions. Venkatraman and Thomas (558) used
Fig. 116.—Root study boxes showing the horizontally placed wire netting stretched at different levels from a wooden frame. After Atherton Lee (400).
Fig. 117.—Arrangement for studying set roots and shoot roots in sugarcane. 1, Sugarcane plant growing on set roots alone: 2 and 3, arrangement for the artificial production of shoot roots; 4, arrangement for detailed study of set roots. In the latter case the set is raised from the pot on two supports, and the set roots are allowed to develop into a vertically placed paper cylinder. The ends of the set are wrapped and kept moist to prevent their drying up. After Thomas (543).

Fig. 118.—The upper pair of cuttings had been allowed to develop normal set roots and shoot roots. The lower pair of cuttings had been forced to live on set roots only. After Verret (563).
for this purpose earthenware pots, since these provide a free exchange of gasses so that little aeration is required.

It is also possible to grow different roots of one cane plant in different solutions by detouring the individual roots to various flasks containing different nutrient solutions (153, 154).

Finally, advantage has been taken of the fact that a germinating cutting develops two different types of roots, to introduce some interesting techniques.

One of these methods permits of growing cane on set roots alone (fig. 117, no 1). A cutting with all buds removed except the topmost one is planted vertically in a pot, and care is taken to bury only the bottom node in the soil. This node will develop set roots, while the topmost bud will produce a shoot. Since the shoot is too far removed from the soil to develop shoot roots, the entire plant will be fed by set roots.

Another method permits of growing the entire plant on shoot roots (fig. 117, no 2 and 3). A cutting is prepared as described above and planted in a vertical position. As soon as the topmost bud has produced a shoot and the set roots of the bottom node have developed, a paper cylinder filled with soil is leaned against the cutting in such a way that its top touches the base of the shoot. Watering the tube from above will create favorable conditions for the development of roots from the shoot. These roots traverse the paper cylinder and when they reach the soil, the set roots of the buried node are carefully removed. From this moment on the plant will be fed entirely through the artificially induced shoot roots. These methods offer some interesting possibilities. Individual roots may, for instance, be conducted into pots filled with different types of soil in order to study their development (fig. 138).

Set roots and shoot roots. The early development of roots and their distinction as set roots and shoot roots has already been mentioned briefly in the chapter on germination. Set roots function only for a limited time and once the shoot roots have taken over their task, the former die and decay. Venkatraman and Thomas (561) have drawn attention to the morphological differences between these two kinds of roots. Shoot roots are much thicker than set roots (fig. 63). They possess larger and stronger root caps which, together with their greater thickness and vigor, render them particularly fit to pierce the soil. In addition, shoot roots are lighter and less fibrous than set roots, and they grow faster. Evans (243) has corroborated these observations for the greater part, although he disagrees with some of the corollaries drawn from them.

Both types of roots are fundamentally identical. Both originate from root primordia; the set roots from primordia located on the cutting (a section of a more or less full-grown stem), the shoot roots from primordia of the shoot (a young stem). Since the root initials of the cutting are older than those of the shoot, the difference between the two kinds is essentially a matter of age.

Similar differences occur between the roots originating from the successive nodes of the young shoot. While the roots developing from the lower nodes of the shoot are thick and vigorous, the roots from the higher nodes tend to become thinner, thus resembling more and more set roots.
Each cutting exhibits a marked polarity; the roots develop first at the basal internodes, while shoot development starts at the upper internodes. As stated previously, this phenomenon is caused by top dominance and is associated with the presence of growth regulating substances. It is not directly related to gravity, since cuttings placed in an inverted position exhibit the same phenomena.

It has been claimed by Venkatraman (549, 561) that the presence of set roots is essential for proper germination, and that a bud, however carefully tended, will not develop into a shoot until at least one root primordium is allowed to germinate. Bonazzi (102), however, has shown that a bud is able to sprout when all root primordia have been removed, although its full development is impeded by the operation. Bonazzi concluded from his experiments that the developing root primordia produce some correlating substance which promotes bud development, a conclusion which is very interesting in the light of modern concepts of growth regulating substances (calines).

Root development is governed by many internal and external factors, among which growth regulating substances play a dominant role. Martin (49) has even succeeded in inducing root development on cane leaves by applying synthetic growth regulating substances to these organs.

Among the external factors, moisture plays an important role in root formation. Under the conditions of a humid climate, the aerial nodes of plants growing in the field may produce roots, especially at the nodes which are still surrounded by sheaths. The development of aerial roots is considered an unfavorable characteristic. Some indigenous Indian canes have the habit of rather regularly developing aerial roots up to two-thirds or three-fourths of the length of the stem (603).

Sometimes the development of aerial roots is required for special investigations. In such cases pot layering or marcottage adapted to use with sugar cane by Venkatraman and Thomas (559) may give satisfactory results. It consists of surrounding a node with moist soil. This induces the root primordia to develop and permits of subsequently severing the stalk below these roots and planting it in a pot. This rooting method has rendered excellent services in cane breeding work, since it permits of isolating stalks which are about to flower from the original plant, and growing and handling them at any place desired.

This technique offers various other possibilities and might be used with advantage in physiological experiments. Nutrients applied to the soil may, under certain conditions become unavailable to the cane roots in that these nutrients are converted into an insoluble form or in that they are fixed by the soil particles. Thus plants may be lacking a certain element, e.g., manganese, and yet fail to respond to manganese applications to the soil. In such cases the nutrient involved might be fed to aerial roots in order to eliminate interference of the soil complex.

Development of roots on the above-ground part of the stem is a common feature in flooded cane. Sartoris and Belcher (507a) found in Florida that the development of stem roots in cane flooded two to three months varies among the different varieties and even more markedly among the different species of sugarcane. S. spontaneum, S. barberi, S. sinense, S. robustum and most hybrids of S. officinarum with S. spontaneum or S. barberi
developed an abundance of stem roots. The roots enveloped the stem forming a matrix, often a foot in diameter and extending from the surface of the water to the base of the stem. Root development on the stems in the varieties of *S. officinarum* varied from none or a very few short roots to large masses of roots.

The number of set roots produced during the early stages of development of a cutting varies widely in different varieties. Venkatraman and Thomas (561) found that the number of set roots produced within 10 days after planting is large in tropical canes and less in Indian and wild canes, the average figures per node being: tropical canes 28, Indian canes 10, Coimbatore seedlings 11, POJ seedlings 24, and *S. spontaneum* 2.3. These differences can be traced back to two factors: first, the number of root primordia present at a node, and second, the percentage of these root primordia that actually develop into roots.

An example of the wide variation of the number of root primordia per node has been given by Weller (590):  

<table>
<thead>
<tr>
<th>Variety</th>
<th>Number of Root Primordia per Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>D 1135</td>
<td>123</td>
</tr>
<tr>
<td>H 109</td>
<td>117</td>
</tr>
<tr>
<td>Yellow Caledonia</td>
<td>114</td>
</tr>
<tr>
<td>Lahaina</td>
<td>94</td>
</tr>
<tr>
<td>POJ 213</td>
<td>45</td>
</tr>
<tr>
<td>Uba</td>
<td>38</td>
</tr>
<tr>
<td>POJ 36</td>
<td>30</td>
</tr>
</tbody>
</table>

Moreover, the number of root primordia per node varies within a variety and even along one stalk. The former variation is caused by external factors, the latter by differences in age.

As to the second factor, the percentage of germination, Venkatraman and Thomas (561) have drawn attention to the interesting fact that not all root primordia take part in the early formation of set roots, but that a certain percentage remains dormant and is kept in reserve. This is considered a valuable provision against possible adverse conditions. As these authors put it, the plant seems reluctant to place all its eggs in one basket.

This phenomenon has been studied later in more detail by Weller (590). In one series cuttings were allowed to grow without any disturbance for 50 days, while in another series the set roots were cut off at periodic intervals. In the latter series, more set roots developed in the course of 50 days than in the former. Thus, pruning of the set roots appears to stimulate the germination of root primordia which, under normal conditions would not have developed. Apparently under normal conditions a certain number of root primordia is held in reserve and develop only in case of emergency. This phenomenon is of considerable importance in regions where cane is exposed to root injury either by insects, by diseases or by cultivating implements (off-barring, subsoiling, etc.).

Dutt (230) also found that in both *S. officinarum* and *S. spontaneum* part of the root primordia remain dormant during the early stages of germination and that they can be forced to develop by scissoring off the set roots already formed. He even made the interesting observation that in certain cases the total number of set roots produced, including
those cut off, exceeded the number of root primordia originally present at the node. This indicates that formation of adventitious set roots has taken place.

Longevity of set roots differs according to variety. It is greatest in *S. spontaneum* and some of its hybrids (561). The gradual substitution of shoot roots for set roots has been studied by Venkatraman and Thomas (561) in India and by Lee and Weller (408) in Hawaii. The former found in one experiment that at the ages of 37, 58, 81 and 104 days, the dry weight in grams of the set roots was 0.8, 0.7, 0.4, 0.1 respectively, and that of the shoot roots 3, 12, 20, 27 respectively. The latter observed that during the first month after planting, the germinating plant functions almost entirely by the set roots. Fig. 119 shows how the set roots alone furnish the nutrients for the first month. After the first month and to the end of the second month, there is a transition period during which the burden of supply shifts from the set roots to the shoot roots. At the end of the third month and thereafter, the burden of supplying nutrients rests almost entirely on the shoot roots (408).

What is it that causes the set roots to die prematurely? As stated before, set roots and shoot roots are fundamentally identical, which implies that their potential longevity is the same. That the set roots are able to live for a long time has been proved by experiments in which cuttings were forced to grow on set roots alone. Thus Kamerling (341) reported results of experiments in which cuttings, after removal of the basal buds, were planted in vertical position so that they could only produce set roots. These plants kept on growing for 6 months. Cuttings from which the upper buds had been removed and which were subsequently planted in an inverted vertical position, showed a similar good final development. Venkatraman and Thomas (561) grew plants on set roots alone in experiments similar to the first mentioned of Kamerling, and although the vigor of the plants thus grown suffered markedly when compared with that of plants grown on both types of roots, the former kept on living for at least 5 months.

Verrett (563) planted cuttings in a normal horizontal position and systematically removed the shoot roots as they appeared, in order to force the plants to live on set roots alone. Another series of cuttings planted in the same way was allowed to grow normally and to produce shoot roots as well as set roots. At the end of the experiment, when the plants were 7 months old, the former series was still in good health, proving once more that cane plants are able to live on set roots alone, and that set roots may remain alive and active for many months. That they do not do so under normal conditions is apparently due to competition of the shoot roots. The latter occupy a preferential position, since they are connected directly with the young shoot. This implies that shoot roots can pass water and nutrients directly to the shoot, while the set roots are forced to do this via the cutting. The experiment just mentioned has thrown an interesting side light on the factors involved in the decay of cuttings after planting. It appeared that no decay took place in the sets which were grown on set roots alone (fig. 118). This is explained by the fact that under these conditions all water and nutrients absorbed by the set roots had to pass through the cutting, thus rendering the latter an essential and living part of the plant.
THE PERCENTAGES OF SEED-PIECE ROOTS
AS COMPARED TO AERIAL-SHOOT OR STALK ROOTS
AT DIFFERENT AGES IN THE CANE GROWTH

Fig. 119.—Ratio of set roots to shoot roots in a germinating cutting. After Lee and Weller (408).
Root development.—Under the conditions prevailing in Mauritius, Evans (17, 243, 244) distinguished among three types of roots: superficial absorbing roots, buttress roots and rope systems (fig. 120).

The root primordia at the very base of the young shoot are much larger than those born later. These large root initials give rise to thick white roots, the buttress roots, which will be described later on, while the nodes higher up the shoot produce thinner roots, the superficial absorbing roots which are located, for their entire length, in the surface soil.

The latter first grow away vigorously from the stool and very seldom branch during their early stage of development. Prolific branching occurs when the growth in length is completed. Branches of the first and second order occur, those of the third order being rare. The branch-rootlets are covered very densely with root hairs, the superficial roots thus exposing a much increased area for absorption. The main roots turn dark with age, and the old superficial roots often become ribbed, assuming the appearance of the
shoots of switch plants. Under moist conditions, the main superficial system supplies the stool with large quantities of water and with most of its mineral substances, but under conditions of drought, absorption by the superficial roots is rendered almost impossible, and in order to survive, the stool has to rely upon the deeper roots. The average breaking stress of the main superficial roots is about 1.5 kg.

The buttress roots, as stated before, originate from the basal nodes of the young shoot. They are white and succulent, and they pass outward and downward at an angle of 45 to 60 degrees, thus resembling underground stilts (fig. 120). They are often considerably distorted and flattened in various planes (fig. 121) apparently adjusting their growth in this

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Fig. 121.—Buttress roots. Left, young unbranched root; right, older branched root showing distortions. After EVANS (244).

Fig. 122.—Part of rope system of sugarcane. After EVANS (244).
way in passing through a dry subsoil. From the direction of growth, the nature of their branching, and their localization in the subsoil, which is poor in mineral nutrients, EVANS concludes that, in the main, they are anchoring roots, though they undoubtedly absorb to some degree. Their average breaking stress is about 3 kg, a value which is double that of the main superficial roots.

The rope system and other deep roots are characterized by the fact that they grow more or less vertically downward and that they form strands which may contain 15 to 20 roots (fig. 122). The rope systems are much more strongly developed in canes having wild blood than in noble tropical canes (*S. officinarum*). EVANS found in some varieties, particularly *Uba* (*S. sinense*) and seedlings of the cross POJ 2878 × *Uba Marot*, that these roots descend to depths of 15 to 20 feet. Rope systems can withstand stresses from 2.5 to 12 kg and they are capable of very vigorous absorption, particularly because they descend to depths of soil which are moist even in times of extreme drought.

The fact should be stressed that the differences among the three classes of roots are often less distinct or wanting in other countries (492, 525, 526) where growing conditions differ from those in Mauritius. Buttress roots have been observed by JENSEN (319) in Cuba, though he did not distinguish them as a separate class. But Barbados investigators were unable to find rope systems even in those varieties in which they had been observed in Mauritius. These investigators stress the fact that all roots are fundamentally of one type and that differentiation is subsequent and due to the conditions under which the cane grows (525, 526). Proof of the dominant influence of soil conditions on root differentiation has also been provided by EVANS himself (250) who observed that subsoiling affected the nature of buttress roots in a striking way; they were so modified as to appear almost identical with superficial roots. This indicates that the typical morphological characteristics of buttress roots are not inherent, but are caused by the nature of the subsoil in which they develop.

In the course of their development, the shoot roots exhibit various characteristics which have been described by JENSEN (319) and EVANS (243). The roots tend to grow along lines of least resistance, often following old cane roots, tree roots, and in particular, canals formed by insects. They show increased branching when coming against rock or other hard objects. After meeting the hard object, the root tip may first flatten out and then veer off in another direction, or rootlets may become appressed to the rocky surface, and in some cases penetrate the soft crust of the rock. When roots have grown into a rock cavity and further penetration is impossible, the root tip often becomes blunt and stubby.

The buttress roots generally show a larger diameter toward the tip than at their point of attachment to the stool. Roots growing into rocks, cracks, or between pebbles are often flattened out. This has also been observed by KULESCHA (384). The growth of roots is slower in passing through hard subsoil as compared to their initial progress. Breaking up the subsoil results in quicker growth and deeper penetration.

Malformations of roots and root hairs are a common feature in soils which are in poor physical condition, as has been shown by KAMERLING (336). In such a soil the root tip is often damaged, resulting in the formation of lateral roots. When the tips of the latter
also become damaged, they too will start branching, and so forth. Thus, the roots in a compact soil remain relatively short and much-branched, as compared to the long and little-branched roots in a physically good soil (fig. 123). This is of great importance since, in the former case, the soil volume penetrated by the roots is much smaller than in the latter case, and this may affect the absorption of water and nutrients.

Examples of well grown and malformed root hairs are presented in fig. 124. The latter are short, distorted, often branched, and they show an abnormally thick wall. Moreover, the surface of these root hairs is completely covered with very small soil particles, which stick to the root hairs or which may even partly penetrate into them. Between these types of malformed and normal root hairs, many transitional stages occur, some of which resemble, in a striking manner, the well known phenomenon of interlacing of root hairs and soil particles. The latter phenomenon was first described by Sachs and has found its way into most text books on botany.

Kamerling stresses the fact that this phenomenon is not as common as the text books might suggest, for in physically good soils he rarely observed it in sugarcane. It is characteristic of roots grown in physically bad soils. Hence he suggests that such interlacing is a pathological condition; viz., a malformation of the root hairs caused by mechanical resistance of soil particles. Normal root hairs do not interlace with soil particles; at best, they may, as a result of the production of mucilage, stick to the latter.

Shoot roots, like set roots, die after a time, their place being taken by new roots. Thus there appears to exist an almost continuous change of roots. Venkatraman and Thomas (561) realized this aspect of root activity for the first time when they grew cane in water culture and the root development thus became clear for continuous observation. The almost continuous production of fresh roots enables the cane plant to quickly adjust itself to changing environmental conditions. When, for instance, the soil water table drops during a dry season, an initially shallow root system will change into a much deeper one. In the case of a plant with a more permanent root system, this adjustment would be made by the development of new lateral roots. In sugarcane, however, the fresh roots which are constantly formed grow immediately toward the points of advantage in the soil (561).

The new roots partly originate from root primordia which have remained dormant during the early stages of germination, but the great bulk is produced by new tillers, each of which develops its own root system. Thus the trend of root production closely follows the trend of tiller formation (525). As long as young tillers are present, root formation will proceed.

This fact has a special bearing on the initial development of ratoon crops insofar as the presence of late tillers is indicative of a vigorous root system. Consequently, a field which at harvest shows a certain percentage of late tillers is more likely to germinate readily than a field consisting entirely of old stalks (525).

An interesting habit of cane roots has been reported by Weller (587) who observed that the majority of the roots grow in the direction in which the bud points. This is most markedly demonstrated when cuttings containing one bud are planted in a horizontal position with the buds to the side. In this case, the majority of the roots will spread in the soil in the direction in which the bud faces.
The growth of the root system as a whole exhibits a grand period. It is slow in the early stages when the set roots function and then decay, it increases gradually as the plant becomes established, and then gradually decreases. At the age of 2 to 3 months, the soil between the rows is already very closely penetrated with roots; consequently, intercultivation at and after that age may cause damage to the root system (23).

**Root distribution.**—The earliest studies on the quantitative distribution of the root system of sugarcane in successive layers of the soil were started in Hawaii. They were begun in boxes and repeated under field conditions by the screen method, the latter mainly consisting of excavating soil layers of 8 inches each, passing the soil through a wire screen and collecting the roots (p. 125). Thus the weight of the roots in various layers could be estimated.
LEE et al (397, 399, 401, 403) found that in irrigated cane generally more than 50 per cent of the roots occur in the topmost 8 inches of the soil, and that this percentage decreases markedly in the deeper layers. An example depicting one of the plants studied is given in fig. 125. From the fact that more than 50 per cent of the root weight is present in the upper 8 inches and more than 85 per cent above the 24-inch level, various conclusions are drawn with relation to irrigation, fertilization and soil cultivation. Calculations indicate that the amount of organic matter left by a cane crop in the soil is about 1 to 1.85 tons of dry root weight per acre (397).

Fig. 124.—Nos. 8 and 9 represent root hairs grown in soil with a good physical structure. The other root hairs have developed in soil with a poor physical structure. After KAMERLING (336).
The vertical distribution of roots changes with the age of the plant. Quantitative data about this change have been collected by Lee and Weller (407, 408) which show that the percentage of roots present in the upper 8 inches of soil gradually decreases, while in the lower layers an increase takes place. Fig. 126, for instance, shows a case in which the percentage of roots present in the topmost 8 inches of soil decreases from about 85 per cent at the end of the first month to 60 per cent at the end of the fourth month. At the same time the percentage of roots in the lower strata increases accordingly. From these observations it is concluded that water and nutrients, to reach the greatest proportion of roots, should be placed in the uppermost 18 inches of soil, as more than 75 per cent of the roots are usually present here. Moreover, it is suggested that cultivation between the rows may damage the surface roots to such an extent that it more than offsets whatever benefits might result from cultivation (407, 408). Experiments conducted in the Philippines by Roxas and Villano (497) yielded similar results.

The methods used in these investigations are subject to serious criticism, and thus the results obtained by these techniques and the conclusions drawn therefrom should be questioned carefully. The condition of a soil placed in a box is different from that of a

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**Fig. 125.—Diagrammatic drawing of the root distribution of a H 109 cane plant 21 months old grown in a furrow in irrigated soil. After Lee (397).**
natural soil occurring in the field; moreover, the space available for root development is limited in both horizontal and vertical directions. The main drawback of the screen method is that only the weight of the roots in the various layers is estimated. Since the main roots originate from the set and from the shoot, and since these roots are thickest at their upper part, it is not very surprising that the topmost 8-inch layer contains the highest percentage, according to weight. It is, however, very questionable whether any relationship exists between root weight and root activity.
The distribution of cane roots in Barbados has been investigated by Stevenson and McIntosh (525, 526). Root systems were studied by direct examination in profile and by quantitative and qualitative examination of plunger samples. Several varieties were studied during four examinations, at approximately 4-month intervals. These investigations yielded a great deal of information on varietal differences and on the influence of external factors, many of which will be dealt with later on.

In Cuba, Jensen (319) carried out a comprehensive study of sugarcane roots using the direct examination method of Weaver. Nine different varieties, growing on two soil types, were included in this study. Jensen found that in all cases examined more than 50 per cent of the roots of mature plants, on dry weight basis, are present in the topmost 8 inches of soil. This is most probably associated with the better growing conditions occurring in this layer: better physical condition of the soil, presence of decaying vegetable matter, better aeration, etc. His observations on varietal differences and on the influence of external factors on root distribution will be reviewed later.

The most comprehensive study of cane roots ever carried out in Java has been performed by Kulescha (384). The method adopted was the Weaver-Kwarazechelia direct examination method, according to which all roots are carefully freed from the soil without using water. From the distribution of roots, plans of the root system drawn to scale were

<table>
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<tr>
<th>Date of excavation</th>
<th>6/21</th>
<th>7/6</th>
<th>8/7</th>
<th>9/9</th>
<th>1/11</th>
</tr>
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<tbody>
<tr>
<td>Age in days</td>
<td>14</td>
<td>30</td>
<td>61</td>
<td>98</td>
<td>218</td>
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<table>
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<tr>
<th>% of total roots</th>
<th>0-8 inches</th>
<th>8-16</th>
<th>16-24</th>
<th>24-32</th>
<th>32-40</th>
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<td></td>
<td>100</td>
<td>14</td>
<td>16</td>
<td>3</td>
<td>1.6</td>
<td>0.4</td>
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<table>
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<tr>
<th>No. of set roots</th>
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<th>55</th>
<th>38</th>
<th>34</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of shoot roots</td>
<td>23</td>
<td>6</td>
<td>40</td>
<td>207</td>
<td>1090</td>
</tr>
<tr>
<td>Total number of roots</td>
<td>26</td>
<td>61</td>
<td>78</td>
<td>241</td>
<td>1106</td>
</tr>
<tr>
<td>Length of set roots in m</td>
<td>1</td>
<td>21</td>
<td>11</td>
<td>30</td>
<td>*</td>
</tr>
<tr>
<td>Length of shoot roots in m</td>
<td>3</td>
<td>5</td>
<td>31</td>
<td>100</td>
<td>*</td>
</tr>
<tr>
<td>Total length in m</td>
<td>4</td>
<td>26</td>
<td>42</td>
<td>130</td>
<td>426</td>
</tr>
<tr>
<td>Dry weight of roots in g</td>
<td>0.15</td>
<td>1.90</td>
<td>6.11</td>
<td>23.00</td>
<td>110.10</td>
</tr>
<tr>
<td>Dry weight of shoots in g</td>
<td>0.31</td>
<td>3.04</td>
<td>31.27</td>
<td>88.54</td>
<td>1603.95</td>
</tr>
<tr>
<td>Dry weight ratio shoots/roots</td>
<td>8.73</td>
<td>1.60</td>
<td>5.12</td>
<td>3.85</td>
<td>14.57</td>
</tr>
</tbody>
</table>

* Not estimated separately.
constructed. Moreover, the length, the number and the weight of the individual roots was estimated. The cane plants were grown from one-bud rayungs of POJ 2878, and 4 to 7 excavations were made during the growing period on each of six representative soil types. The results obtained on a brown lateritic clay are given in table 7.

Kulescha found that in all cases of cane plants of approximately seven months of age, at least 82 per cent of the total number of roots were present in the upper 16 inches of soil.

In Mauritius a most comprehensive study of the root system was conducted by Evans (243, 244, 249, 250) using proper methods and including a series of varieties. Some of the results obtained have already been mentioned, others will be referred to later.

Table 8.—Total length of roots in cm of a stool of POJ 2878

<table>
<thead>
<tr>
<th>Lateral distance from stool</th>
<th>Total</th>
<th>Grand total per ft</th>
<th>Class of root</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1 ft</td>
<td></td>
<td></td>
<td></td>
<td>0-1 ft</td>
</tr>
<tr>
<td>1,795</td>
<td>44,708</td>
<td>12,858</td>
<td>62,858</td>
<td>Cl. I</td>
</tr>
<tr>
<td>5,228</td>
<td>4,445</td>
<td>1,278</td>
<td>7,578</td>
<td>Cl. II</td>
</tr>
<tr>
<td>495</td>
<td>4,918</td>
<td>1,431</td>
<td>7,973</td>
<td>Cl. III</td>
</tr>
<tr>
<td>3,085</td>
<td>2,963</td>
<td>831</td>
<td>5,810</td>
<td>Cl. IV</td>
</tr>
<tr>
<td>nil</td>
<td>1,890</td>
<td>565</td>
<td>2,575</td>
<td>1-2 ft</td>
</tr>
<tr>
<td>1,358</td>
<td>468</td>
<td>133</td>
<td>500</td>
<td>2-3 ft</td>
</tr>
<tr>
<td>nil</td>
<td>1,583</td>
<td>455</td>
<td>500</td>
<td>3-4 ft</td>
</tr>
<tr>
<td>1,358</td>
<td>432</td>
<td>130</td>
<td>400</td>
<td>4-5 ft</td>
</tr>
<tr>
<td>nil</td>
<td>1,702</td>
<td>500</td>
<td>300</td>
<td>5-6 ft</td>
</tr>
<tr>
<td>3,210</td>
<td>3,170</td>
<td>1,059</td>
<td>7,655</td>
<td>Cl. I</td>
</tr>
<tr>
<td>950</td>
<td>1,702</td>
<td>599</td>
<td>7,775</td>
<td>Cl. II</td>
</tr>
<tr>
<td>35</td>
<td>700</td>
<td>185</td>
<td>540</td>
<td>Cl. III</td>
</tr>
<tr>
<td>nil</td>
<td>928</td>
<td>245</td>
<td>5,225</td>
<td>Cl. IV</td>
</tr>
</tbody>
</table>

Grand total for all classes of roots = 810,911 cm
All studies mentioned so far have been restricted to the growth and development of the roots without taking into account their physiological activity. Since the latter is associated with the actual absorbing surface of the roots, it is obvious that an estimate of the absorbing surface is required. Absorption is restricted to the root hairs and, to a smaller extent, to part of the surface of the roots. The technical difficulties involved in the measurement of the surfaces of these tiny organs explains sufficiently why these measurements have been so long delayed.

Evans (253, 255) has filled this gap by a brilliant study in which the distribution of roots in three varieties (POJ 2878, BH 10 (12) and White Tanna) was investigated. The length and the surface of the individual roots was measured in each foot of soil. Moreover, the roots were divided into four classes, according to their diameter, and the length and surface was determined for each of these classes, while the surface of the root hairs was measured separately. It is impossible to do full justice to this study, but the tables 8 and 9 may give an idea of the fundamental importance of this investigation.

Class I consists of fibrous roots; the classes II to IV refer to roots under 1 mm in diameter, roots 1 to 2.5 mm in diameter, and roots over 2.5 mm in diameter respectively. It appears that the vast majority of fibrous roots (which are most actively engaged in absorption) is present in the uppermost foot of soil. They are most numerous between 3 and 4 feet away from the plant, while within the 1-foot circle surrounding the plant only one-eighth to one-ninth of their total length occurs. The number of white and actively growing roots at the time of examination was estimated to be not more than 3 to 5 per cent of the total.

The total surface of root hairs is given in table 9, which shows that roughly 70 per cent of the total root hair surface is concentrated in the first foot of soil and of these nearly 90 per cent is distributed at a distance greater than one foot from the center of the stool. From a comparison of the tables 8 and 9, the density of root hair surface per unit volume of soil can be calculated, which shows that the concentration of root hair surface is greatest in close proximity to the stool. Other results obtained from these investigations will be presented in a subsequent chapter.

Shoot root ratio.—There has been some controversy as to the question whether the ratio between the weight of shoots and roots is constant or not. A careful analysis of the available data shows that to put the question in this general form is out of place. There is growing evidence that plants in general show a certain relationship between the development of aerial parts and roots, since the development of the former depends on that of the latter and vice versa. Evans (243, 245, 248), in his extensive study of the development of a plant crop of White Tanna, harvested 25 stools each month and found a very good positive correlation between the weight of cane and the weight of roots for each harvest independently. The correlation coefficients for the months of March 1933 to October 1934 inclusive were: 0.85, 0.84, 0.87, 0.81, 0.70, 0.77, 0.83, 0.87, 0.77, 0.74, 0.70, 0.82, 0.71 and 0.75 respectively, while the correlation coefficient of all harvests was 0.85. It should be stressed that these marked correlations were obtained with plants of the same variety, the same age and grown in the same field.
Table 9. — Total surface of root hairs in cm² of a stool of POJ 2878

After Evans (255)

<table>
<thead>
<tr>
<th>Lateral distance from stool</th>
<th>Total</th>
<th>Grand total per ft</th>
<th>Class of root</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1 ft</td>
<td></td>
<td></td>
<td></td>
<td>0-1 ft</td>
</tr>
<tr>
<td>7,160</td>
<td>7,160</td>
<td></td>
<td>Cl. I</td>
<td></td>
</tr>
<tr>
<td>1,063</td>
<td>1,063</td>
<td></td>
<td>Cl. II</td>
<td></td>
</tr>
<tr>
<td>4,775</td>
<td>4,775</td>
<td></td>
<td>Cl. III</td>
<td></td>
</tr>
<tr>
<td>1,925</td>
<td>1,925</td>
<td></td>
<td>Cl. IV</td>
<td></td>
</tr>
<tr>
<td>813</td>
<td>813</td>
<td></td>
<td>Cl. I</td>
<td></td>
</tr>
<tr>
<td>345</td>
<td>345</td>
<td></td>
<td>Cl. II</td>
<td></td>
</tr>
<tr>
<td>958</td>
<td>958</td>
<td></td>
<td>Cl. III</td>
<td></td>
</tr>
<tr>
<td>118</td>
<td>118</td>
<td></td>
<td>Cl. IV</td>
<td></td>
</tr>
<tr>
<td>543</td>
<td>543</td>
<td></td>
<td>Cl. I</td>
<td></td>
</tr>
<tr>
<td>133</td>
<td>133</td>
<td></td>
<td>Cl. II</td>
<td></td>
</tr>
<tr>
<td>565</td>
<td>565</td>
<td></td>
<td>Cl. III</td>
<td></td>
</tr>
<tr>
<td>nil</td>
<td>nil</td>
<td></td>
<td>Cl. IV</td>
<td></td>
</tr>
<tr>
<td>85</td>
<td>85</td>
<td></td>
<td>Cl. I</td>
<td></td>
</tr>
<tr>
<td>113</td>
<td>113</td>
<td></td>
<td>Cl. II</td>
<td></td>
</tr>
<tr>
<td>248</td>
<td>248</td>
<td></td>
<td>Cl. III</td>
<td></td>
</tr>
<tr>
<td>nil</td>
<td>nil</td>
<td></td>
<td>Cl. IV</td>
<td></td>
</tr>
<tr>
<td>588</td>
<td>588</td>
<td></td>
<td>Cl. I</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>72</td>
<td></td>
<td>Cl. II</td>
<td></td>
</tr>
<tr>
<td>174</td>
<td>174</td>
<td></td>
<td>Cl. III</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td></td>
<td>Cl. IV</td>
<td></td>
</tr>
<tr>
<td>312</td>
<td>312</td>
<td></td>
<td>Cl. I</td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>49</td>
<td></td>
<td>Cl. II</td>
<td></td>
</tr>
<tr>
<td>170</td>
<td>170</td>
<td></td>
<td>Cl. III</td>
<td></td>
</tr>
<tr>
<td>nil</td>
<td>nil</td>
<td></td>
<td>Cl. IV</td>
<td></td>
</tr>
</tbody>
</table>

Grand total area of root hair surface = 124,511 cm²

Kamerling (341) was, perhaps, the first to present an explanation for this relationship. He experimented with one-bud cuttings. In one series, he prevented the buds from developing by a gypsum cast and found that in this case the development of the root primordia was considerably delayed. In another series in which the development of the root primordia was prevented by the same technique, the development of the buds was seriously affected. These were the first crude experiments with sugarcane, which provided evidence of the existence of growth correlations between shoot and root.

The constancy of the shoot root ratio ceases as soon as differences between the plants involved occur. Thus the ratio changes with the age of a plant as has been proved by...
Evans (245) who, in Mauritius, obtained the result expressed in fig. 127. The general trend of the curve shows an increase in the shoot root ratio as the plants grow older. The irregularities are caused by variations in growing conditions characteristic of the climate in Mauritius. Thus the depression in the value of the ratio about July is associated with the roots having a greater relative growth. The increase in the value during the dry months of October and November is caused by almost complete cessation of root growth during these months. The sudden drop in February is due to the rapid root growth following the heavy rains of January, and the steady increase after this period is caused by active stem formation, with very little root growth (245).

A similar increase in the shoot root ratio has been observed by Chu, Shih and Chao (160) in Formosa, while Roxas and Villano (497) in the Philippines found a decrease up to five months when the observations were discontinued.

Kulescha (384) in his extensive study also found in most cases an initial decrease in shoot root ratio which, however, in a later stage of development, was followed by an increase. The initial decrease in shoot root ratio was due to the fact that rayungans (sets with well developed shoots but without roots) were used as planting material, which gave the shoots an initial advantage. As an example, the following series of ratios is given with the age of the plants in days between parentheses: 11.00 (16), 7.21 (24), 4.71 (40), 6.86 (56), 7.86 (90), 6.66 (120), 20.67 (219). Another example has been presented in table 7.

There is no necessary correlation between shoot root ratio and yielding capacity of
different varieties as has been shown by Evans (39, 243) in Mauritius, by Chu, Shih and Chao (160) in Formosa, and by Stevenson and McIntosh (526) in Barbados. Thus, high yielding varieties are not, of necessity, those with an extensive root system. Some varieties produce high yields with a mediocre root system, while others with a more extensive root system give the same yield or even less (245). It is evident that apart from the quantity of roots, their efficiency (absorbing capacity) plays an important role.

The shoot root ratio is greatly influenced by external factors. It seems that generally under favorable growing conditions, this ratio is higher than under unfavorable conditions. Or, in other words, the production of a certain quantity of aerial parts requires a smaller quantity of roots under favorable growing conditions than under unfavorable conditions.

Thus, Matsubayashi (455) reports that within certain limits the shoot root ratio increases as the moisture content of the soil increases, indicating that with an adequate supply of moisture, a relatively smaller quantity of roots is required for the production of aerial parts than when soil moisture is inadequate.

Likewise, the application of fertilizers increases the shoot root ratio in soils deficient in nutrients (309, 344, 403, 492, 497, 503, 588). In fertile soils, a relatively smaller quantity of roots is required to provide the nutrients needed for the production of the aerial parts.

From an integration of the effects of the separate soil factors, it may be postulated that the shoot root ratio increases as soil conditions become more favorable, and this is in harmony with the results obtained by Kulescha, as shown in table 10. In this table the soils are arranged according to their productivity, expressed in terms of dry weight of shoots. It appears that as the productivity of the soil increases, the shoot root ratio also increases.

In reviewing the facts available so far, it can be said that, according to our present knowledge, a positive correlation between shoot and root in sugarcane has been found only in plants of the same variety, of the same age, and growing under the same conditions. Changes in one or more of these factors result in changes of the shoot root ratio. It generally increases with increasing age of the plant and it is generally higher, the more favorable the growing conditions.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Total no. of roots</th>
<th>Total length of roots</th>
<th>Dry weight of roots</th>
<th>Dry weight of shoots</th>
<th>Maximum depth of roots</th>
<th>Shoot root ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium heavy clay</td>
<td>1147</td>
<td>335</td>
<td>93</td>
<td>1916</td>
<td>2.20</td>
<td>20</td>
</tr>
<tr>
<td>Light sandy clay with stones</td>
<td>708</td>
<td>400</td>
<td>97</td>
<td>1706</td>
<td>1.65</td>
<td>18</td>
</tr>
<tr>
<td>Medium heavy mountain clay</td>
<td>1106</td>
<td>426</td>
<td>110</td>
<td>1604</td>
<td>1.20</td>
<td>15</td>
</tr>
<tr>
<td>Medium heavy clay on gravel</td>
<td>2008</td>
<td>510</td>
<td>162</td>
<td>1587</td>
<td>1.10</td>
<td>10</td>
</tr>
<tr>
<td>Light to medium heavy clay on sandstone</td>
<td>582</td>
<td>220</td>
<td>57</td>
<td>956</td>
<td>1.05</td>
<td>17</td>
</tr>
<tr>
<td>Heavy old black clay</td>
<td>659</td>
<td>95</td>
<td>51</td>
<td>249</td>
<td>0.90</td>
<td>5</td>
</tr>
</tbody>
</table>
Factors influencing the growth of roots.—Root development is influenced by a series of internal and external factors. The study of the effect of these factors on root growth has revealed many interesting facts which have a practical bearing on cane breeding as well as on cultivation, irrigation and fertilization.

Variety.—Various investigators have conducted comparative studies of the root development in different varieties: Venkatraman et al (552, 556, 557, 561, 562); Jensen (319); Hardy (281); Lee (398, 399); Evans (243, 249, 250, 255, 257, 258); Stevenson et al (525, 526).

As to the importance of cane root studies in general, it should be made clear at the very outset that the nature and extent of the root system by itself has very little relationship to the yielding capacity of a variety. A great many of the varieties with large root systems are low yielders, e.g. thin canes, or varieties of wild ancestry such as Uba (247). The importance of root study is to be sought in other directions. First, a relationship often exists between the nature of the root system and its suitability to particular growing conditions (dry soil, wet soil, incidence of root pests). Second, an exact knowledge of root distribution permits the making of certain suggestions concerning the placement of fertilizers and the appli-

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**Fig. 128.**—Influence of the male parent on the root system of the progeny. Left, offspring of three POJ varieties pollinated by a shallowly rooted tropical cane (B 6388); right, offspring of the same POJ varieties pollinated by the deeper rooted Co 205. After Venkatraman (552).
Fig. 129.—Varietal differences in root system between a tropical shallowly rooted noble variety (top), a deeply rooted wild cane (bottom), and an intermediate type (center) showing both superficial and deep roots in the latter. After Venkatraman and Thomas (561) from Das (190).

cation of irrigation, and cultivation. Third, root studies may be helpful in the breeding of special purpose varieties when it comes to transmittal of certain desirable characteristics from the parents to the progeny, e.g., a deep root system when breeding for drought resistance.

Venkatraman et al (550, 552, 557) have proved the possibility of introducing a desired
type of root system in the progeny by choosing suitable parents. Fig. 128 shows the progeny of three POJ varieties, in one case pollinated by a shallow-rooted tropical cane (B 6388), and in another case by the deeper-rooted Co 205. The influence of the male parent on the root system of the seedlings is evident. Co 205 is a hybrid of a noble cane (S. officinarum) and a wild cane (S. spontaneum), and it is assumed that it has inherited its deep root system from the wild parent. Likewise it is known from cane breeding work in Java that the strong root system of glagah, the Java form of S. spontaneum, is handed down when crossed with tropical canes. This explains the strong root system of POI 2878 and related varieties.

Varietal differences in India have been studied by Venkatraman et al., and an example of these differences is shown in fig. 129.

Atheron Lee (398, 399) in Hawaii compared the root systems of the three noble varieties, H 109, Laihana and D 1135, without finding marked differences.

In Cuba, Jensen (319) compared the root systems of nine varieties on different soil types: POJ 2883, POJ 2878, POJ 2727, POJ 2725, POJ 2722, POJ 2714, BH (10)12, SC 12 (14) and Cristallina, and observed many interesting varietal differences.

Stevenson and McIntosh (525, 526) made a thorough study of the root system of several varieties in Barbados. Moreover, they made an attempt to analyze the components which are involved in building up a root system. Each shoot produces its own root system, the so called root unit. Differences in root systems are due to differences in the number of tillers per plant and to differences in the number of roots per tiller. Since these two features tend to neutralize one another, the authors find that differences among varieties in actual number of roots per plant are relatively small (525). Moreover, they stress the importance of the time factor. The number of roots present and the time of their production are closely related to the tillering periodicity. The roots of varieties containing wild blood are characterized by an early and profuse production of fibrous roots, while those of noble Barbados canes (S. officinarum) are definitely inferior in this respect. At later stages of development the latter, however, gradually make up for the difference and eventually even become superior. The authors conclude that roots of the Barbados varieties show a longer growth period than those of the other varieties studied.

The fact that varietal differences in root development are not constant throughout the growing season implies that varietal comparisons of root development made at one time have only a limited value (525). This is illustrated by fig. 130 which represents the comparative root development of Katha, a rather primitive Indian variety, and Co 205. It shows that at the end of seven weeks the root system of Co 205 is inferior to that of Katha but that at the end of 15 weeks Co 205 has made up for the difference and that it becomes superior during the subsequent weeks (352).

The most extensive study of varietal differences in root development has been conducted by Evans in Mauritius (243, 249, 250, 255, 257, 258). This author stresses the fact that, although the three classes of roots distinguished by him (p. 132) are represented in most sugarcane varieties in Mauritius, their relative proportions vary greatly, thus giving rise to considerable varietal differences in the mature root systems (249). His many drawings,
Fig. 130.—Showing that varietal differences in root development are not constant throughout the growing period. The root development of Co 205, although lagging behind that of Katha during the first seven weeks, gradually makes up for the difference and eventually becomes superior. After KHANNA and VENKATRAMAN (352).
Fig. 131. — Root system of ordinary Uba. After Evans (249).

some of which are reproduced here, fully corroborate this concept. Fig. 131 shows the root system of ordinary Uba, which has the most extensive root system of all varieties examined by Evans. Superficial roots, buttress roots and rope systems are present in great numbers and attain a considerable length. The longest superficial roots are 12 feet or more in length and rope systems go down to a depth of 18 feet. The root systems of POJ 2727 (fig. 132) and POJ 2878 resemble each other to some extent. The superficial system in both is fairly extensive. The buttress roots in POJ 2878 generally descend to a depth of 4 to 5 feet but immediately beneath the stool they are better developed and often reach a depth of 7 feet. This variety has very few rope systems. In POJ 2727 there is a stronger development of buttress roots and some rope systems are present which descend to more than 10 feet. Considered as a whole, the root system of POJ 2878, though vigorous, is not outstandingly so. There is little doubt, however, that POJ 2727 has a superior root system to POJ 2878, though in distribution the root systems of the two varieties show great similarity (249).

A typical example of the Barbados type of root system is that of BH 10 (12) (fig. 133) which resembles greatly that of three other important West Indian varieties; viz., SC 12(4),
D 1135 and RP 8. The characteristic feature of this root system is that it is located much nearer to the stool than in most other varieties. EVANS has drawn attention to the interesting fact that a relationship exists between root distribution and orientation of the leaves in sugarcane. In varieties with more or less erect leaves, the water dripping from the leaves will reach the soil nearer to the stool than in varieties with recumbent leaves. Consequently the absorbing region of the roots of the former varieties will be nearer to the stool than in varieties with recumbent leaves. Since the Barbados varieties mentioned before are characterized by a more or less upright orientation of the leaves, this would explain the concentration of superficial roots near the stool.

In BH 10(12) the extent of the superficial system is comparatively restricted; most of its roots are only 2 feet long, though a few reach 4 to 5 feet. Buttress roots are very numerous, descending to 6 or 7 feet. Rope systems are well represented, growing down to about 10 feet. The general distribution of roots is thus very satisfactory.

An example of the root system of the older noble varieties bred in Mauritius is presented in fig. 134. It is a comparatively shallow system, with 60 per cent or more of the roots present in the first foot of soil, and the number of roots reaching below 4 feet being negligible. The superficial system is rather extensive, but the buttress roots are not outstanding in their development.

The quantitative examination of the root system by EVANS already mentioned previously has revealed equally varietal differences. There are distinct differences in the rate of growth of the root system, the order of merit in the three varieties investigated being: White Tanna,
BH 10(12) and POJ 2878. At 6 months of age, the root system of White Tanna had almost completed its development, whereas the two other varieties had still much progress to make in order to reach the mature stage. This proves that there are marked varietal differences in the rate of development of the root system. In all three varieties, about 70 per cent of the total root hair surface was located in the first foot of soil. In BH 10(12), root development is active in the early stages, and thereafter in the absence of new shoot development, very few roots are formed. In POJ 2878, on the other hand, root growth is very slow in the early stages and the development of the root system is more gradual. Consequently, at 12 months of age or later, POJ 2878 shows a greater proportion of young roots than BH 10(12), resulting in a higher density of root hairs in the former. POJ 2878 shows a few white roots at almost all times during the year, whereas after the first flush of growth BH 10(12) has very few new roots for a considerable period. This explains, at least partly, the fact that the roots of mature BH 10(12) are older in appearance and darker in color than those of POJ 2878 (255). The total length of the roots and the total surface of the root hairs are presented in table 75, which shows that though POJ 2878 has the smallest total length (8 km), its total root hair surface in the largest (12 m²) of the three varieties investigated.
RATTOON.—The root system of a ratoon crop is more shallow than that of a plant crop, at least as far as the absorbing system is concerned (243, 281). This is associated with the fact that the shoots of a ratoon plant originate at a higher level than those of a first year plant (fig. 135). EVANS (243) who examined the surface root system of a ratoon field one week after the previous crop had been harvested, found that the space between the rows was completely ramified by roots from the adjoining shoots (fig. 136). The branching was even so profuse that generally only the main roots could be plotted. The amount of branching was greater in the interlines than close to the stools. At a depth of 6 inches or more, the surface roots were quite black in color and bore no root hairs. In the upper 6 inches, the fibrous root branches bore a dense covering of root hairs. The number of new white roots was comparatively small.

The roots of the plant cane remain active for a considerable period after the crop is harvested and EVANS (243) found that the roots which explore the interlines very closely, still bear a few root hairs, even after an interval of three months. One might expect that the developing ratoon crop would take advantage of the root system inherited from the plant crop by forming new rootlets on the main framework already in existence. This, however, occurs only to a limited extent; the old root system gradually ceases to function and decays while a completely new root system is formed by the developing shoots of the ratoon crop. It is a process of gradual replacement, the older roots inherited from the previous crop functioning side by side with the new system formed from the ratoon shoots for
a time. Then the former gradually cease to function, until finally the entire root system is a product of the ratoon shoots. There is some evidence that the deeper roots of the plant crop continue functioning for a longer period than the superficial ones (243).

TEMPERATURE.—Comparatively little is known about the influence of temperature on root growth. Ryker and Edgerton (501) found the minimum temperature for root growth to be about 54°F, but Sartorie (506) found development of roots to take place even at 43°F. In the experiment of Rands and Dopp (487) in which plants were grown at different soil temperatures, the best root development was observed at about 86°F, with marked differences between the two varieties used (fig. 78).

LIGHT.—A very marked indirect effect of light intensity on root development was found by Martin and Eckart (451) in an experiment already mentioned previously. Plants grown under the light conditions of a greenhouse showed the pots to be wholly filled up with roots. The roots of plants which had been grown under one layer of unbleached muslin occupied only one-half of the space of the pots, while the roots of plants grown under two thicknesses of muslin were so meager that they were barely able to support the plants. Apart from light intensity, day length (photoperiodism) influences root development.

AERATION.—Cane roots like other organs require oxygen for respiration. They are positively aerotropic; in other words, when oxygen is lacking they direct their growth

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![Fig. 136.—Distribution of roots in the interline (between two rows) of White Tanna ratoon one week after cutting the previous crop. Plan of roots to a depth of 6 inches. After Evans (243).](image-url)
Fig. 137.—Varietal differences in aerotropism of cane roots. After Venkatraman and Thomas
toward a region containing more oxygen. This can be clearly demonstrated by growing cane in water culture. Venkatraman and Thomas found interesting varietal differences in this respect as shown in fig. 137. The set roots of Katha, for instance, are less aerotropic than those of Striped Cheribon, which is in accord with the experience that Katha is more tolerant of water-logging than Striped Cheribon. The red sport of Striped Mauritius in the same figure shows the roots growing out of the wet soil, a phenomenon often observed in water-logged fields.

SOIL MOISTURE.—The wide range of soil moisture in which sugarcane is able to thrive is remarkable. Some varieties can withstand extreme drought, others are confined to flooded areas like the Indian cane Hathooni. Sewari and Co 205 have been found growing in 4 feet of water (16). Das (189) has published a picture of Co 205 growing in India in a field which had been under water for 5 months. This cane had a brix of 18° at harvest. The remarkable fact about Co 205 is its ability to withstand both drought and water-logging. Noel Deerr (202) has published a most curious picture showing cane and rice culture combined with fishing in India. The cane in this case was Hathooni.

Almost nothing is known about the factors which enable cane to grow in flooded areas. A clue may be found in investigations by Kamerling (336) performed some 50 years ago. This author found that cane roots continue to respire intensively, even when the soil atmosphere surrounding them contains but little oxygen. He assumed that under these conditions the oxygen required for respiration of the roots is provided by the aerial parts of the plant and that this gas reaches the roots through the intercellular spaces of the stem and the roots. In view of the great importance of this problem on heavy, impermeable soils where cane growing encounters great difficulties, it is surprising that since Kamerling no efforts have been made to study this problem in more detail.

Irrigation has a distinct influence on the development of the root system in that it results in a concentration of the roots in the surface layers of the soil. The same variety, when grown without irrigation, develops a more extensive and deeper root system in order to secure the necessary water (557). The quality of the irrigation water also plays a role (372), saline water exerting a harmful effect on root development (561).

The vertical distribution is largely controlled by fluctuations of the ground water level (281, 319, 561). It is a common phenomenon in Java and other regions with monsoon systems that during the dry season root development proceeds to a considerable depth and that with rising ground water level during the wet season, the deeper roots die and decay. During the wet season the newly-developing roots do not pass beneath the ground water level. Such root systems, dissected toward the end of the wet season, show a very sharp horizontal demarcation line between the black, dead roots and the newly-developed fresh roots, the line of separation coinciding with the ground water level during the wet season.

The distribution of roots is clearly affected by weather conditions; low soil moisture encourages deep rooting, and adequate soil moisture promotes surface rooting (492, 525, 526). Under dry conditions, the primary roots show a tendency to descend vertically or slightly obliquely, while adequate soil moisture induces a more horizontal direction (526).
Hence it would appear that between seasons the rate of root differentiation is influenced by soil moisture conditions (525).

A common fault made during periods when irrigation water is amply available is to use up the water. This causes the plants to develop a shallow root system which will prove to be inadequate during a subsequent dry period. Hence, under conditions of alternating wet and dry seasons, it is a good policy not to spoil the plants with water during the wet season, but rather to wean them more or less, in order to promote a deeper root development. In this way the crop is gradually prepared to withstand a subsequent dry period.

In addition to the roots, the root hairs are also influenced by variations in soil moisture. Evans (258) states that it is a common feature for the cane to produce an absorbing surface three to four times greater in the dry localities than that produced in the wet localities. Since the absorbing surface is largely restricted to the root hairs this implies a marked effect of soil moisture on the development of these organs. The influence of soil moisture on root growth in Formosa has been investigated by Matsubayashi (455).

Soil type.—The influence of the type of soil on root development has been studied in various countries. The evaluation of the results obtained, is, however, rendered somewhat difficult as apart from the soil per se, often other factors are involved. This is especially the case when the root system is compared in different soils, situated in different localities, for in this case, differences in climatic conditions may also be involved.

This difficulty has been surmounted by Venkatraman (190, 550, 554) by the use of a special technique which consists mainly in conducting equal numbers of roots of the same plant into separate pots containing different types of soils. Fig. 138 shows that the varieties 247 B and Hemja have a preference for the sandy loam soil, whereas the wild cane S. spontaneum seems to be equally at home in both the stiff clay and the sandy loam.

Other examples of the influence of the type of soil are shown in fig. 139 which once more demonstrates the inhibitory effect of a stiff soil as compared with a free, open soil.

In Hawaii it has been found that differences in soil are associated with differences in both the total weight and the vertical distribution of root weight (398, 400, 401, 601).

Hardy (281) in Trinidad reports that he failed to find a marked effect of soil texture on the root system of sugarcane, though its weight in heavy soils tends to be greater than in light soils. His results, however, have been severely criticized, both on the ground that they differ from the results obtained by other workers (105) and that the method used by Hardy is entirely inadequate (243).

The most extensive investigation using a flawless technique has been undertaken by Kulescha (384) in Java with POJ 2878, grown on different types of soil. This worker found great differences in different kinds of soil, as regards maximum depth of the root system, number, weight and total length of the roots, etc. (table 10). The differences were so striking that they permitted ascertainment of the soil in which the plants had been grown. On the other hand, plants which had been raised at a great distance from each other but on the same soil type, showed striking similarities in their root systems.

In looking over the data on the influence of soil type on root development so far available, it appears that this influence is of a rather intricate nature. There is, however, evidence
Fig. 138.—Method of examining the development of roots of one cane plant in different types of soils. After Venkataraman (530).
Effect of environment on root development in Sugarcanes.

Fig. 139.—Influence of type of soil on the root system of different varieties. After Venkatraman and Thomas (557).

that at least three factors play a major role: fertility, aeration and moisture content, the latter two being interrelated. As will be mentioned later, the presence of fertilizers causes roots to branch profusely and this is exactly what happens when roots pass from an infertile layer of soil into a fertile soil layer. As to the two other factors, aeration and moisture content, an interesting observation has been reported by Alexander (4). In a very heavy and compact adobe soil, five plants growing over the main line of a tile drain were excavated as well as five other plants about 300 feet away, where there was no influence from the drainage system. The former had grown normally and had produced a good crop, while the growth of the latter was poor. The differences in root development were striking. The plants had been grown in furrows, and the adjacent ridges, together with the upper inches of soil, contained 97 per cent of the roots in the poorly drained area, as compared with 75 per cent above the tile. The depth of penetration of roots and their total weight above the tile was quite remarkable; drainage had increased the total root weight by more than 50 per cent. The percentage of roots found in the layers 24 to 40 inches below the surface over the tile drain system, was comparable to that often obtained in a sandy loam.

Fortunately, the three factors mentioned above are, at least to a certain extent, within the reach of human control. This is not so much the case with a fourth factor, which is of
a purely mechanical character. As already pointed out, root development is often inhibited when the soil particles are packed tightly together, as is the case in stiff, compact soils. It is especially the most active parts of the root system, the hairs, which are affected by this condition (fig. 123, 124).

**Acidity.**—According to Khan (350), the roots of cane grow normally within a range of pH 6.1 to 7.7. Soil pH values on the acid side are distinctly more harmful than on the alkaline side of neutrality. Martin (445) reports that roots growing in a solution having a pH value of 2.0 become flaccid and badly distorted, while at a pH value of 3.0 the majority of the roots are flaccid and discolored. According to this author, the pH value of the nutrient solution should be approximately 5.0 to 5.2, in order to maintain the iron in a form which is available to the cane plant.

**Fertilizers.**—Cane roots, according to Weller (588), do not show a chemotropic response to fertilizers; viz., he found no instance of a root changing the direction of its growth toward the place where the fertilizers were buried. When, however, a root happens to be growing in the direction of the buried fertilizer, it shows greater branching when coming into the region of the fertilizer. In Java, where the nitrogenous fertilizer is applied to a small hole in the soil, it has often been observed that cane roots have branched so profusely in the wall of the fertilizer hole that they form a nest-like structure which can be lifted from the soil, and which is locally known as “fertilizer nest”.

Upon placing fertilizer contained in a small bag in one-half of a root study box, Weller (588) found no significant difference between the proportion of roots on the same side of the box as the fertilizer, and on the opposite side. Fertilizer applied to one part of the root system resulted in a stimulation of the entire root system, as well as in a local stimulation. Weller furthermore found that application of each of the nutrients, nitrogen, phosphorus and potassium, resulted in an increase in the actual total weight of shoot roots and a decrease in the actual total weight of set roots.

The influence of nitrogen, phosphorus, potassium and other elements on root growth has been investigated by various workers (153, 154, 309, 344, 359, 429, 445, 492, 497, 503, 588, 602). The results obtained generally indicate an increase in total dry weight of roots when fertilizers are added to culture solutions or soils deficient in nutrients. The increase in dry weight of the aerial parts, however, is greater than that of the roots, resulting in an increased shoot root ratio. Van den Honert (309) found that when the content of nitrogen, of phosphorus, or of potassium of the nutrient solutions in which cane plants were grown was increased, the weight of the stems showed the greatest increase, followed by the leaves, while the weight of the roots showed the smallest increase. Apparently a relatively smaller quantity of roots is required to support a plant growing in a medium adequately supplied with nutrients than in a poor substratum. In the latter, a greater volume of soil has to be explored by the roots in order to provide the plant adequately with nutrients, and this requires a more extensive root system.

Interesting results concerning the influence of different culture solutions on root development have been reported by Carpenter (153, 154). Young cane plants were grown during six weeks in a complete culture solution. Then all but ten roots of each plant were
excised. Nine of the remaining roots were diverted into nine flasks, each containing a
different culture solution, and the tenth root was diverted into a flask containing distilled
water. In addition, one plant was retained as control and grown continuously in a complete
nutrient solution. The development of the roots showed a great dissimilarity in the different
solutions. The results of these experiments are difficult to interpret, since factors other
than the chemical compounds present in each solution are involved; e.g., acidity. But
these experiments certainly prove the great influence of environmental conditions on root
development. The same author found that cane plants growing in sterilized soils or in
water cultures showed a heavy mass of superfine roots, while plants growing in raw soil
showed none (14).

Cultivation.—Evans (250, 255) has shown that cultivation of the subsoil and topsoil
exerts a marked effect. The root system produced as a result of subsoiling is superior in
depth, spread, and number of roots, to that of untreated plants. This may be of considerable
benefit to the plant under conditions of drought, or high winds, or heavy root pest infestation.
The remarkable fact that the nature of the buttress roots is fundamentally affected
by subsoiling has already been mentioned (p. 134). Actually, they are so modified that the
main differences between buttress roots and superficial roots disappear, the former
assuming the features of the latter.

The effect of cultivation of the surface soil is not so marked. Breaking up the subsoil
has a greater effect, in that it promotes deep root growth which is probably an aeration
effect (243).

Wind.—Cane plants exposed to wind, for instance on the windward side of fields, often
show a stunted growth and an increase in root development. Rege and Wagle (492)
found for exposed and sheltered plants the following oven dry weights in grams for shoots
and roots respectively: exposed 409 and 37.2; protected 487 and 25.4. They also found
differences in the vertical root distribution as shown in table 11.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Exposed to wind</th>
<th>Sheltered</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–12 inch</td>
<td>58.3%</td>
<td>37.4%</td>
</tr>
<tr>
<td>12–24 &quot;</td>
<td>34.0%</td>
<td>31.6%</td>
</tr>
<tr>
<td>24–36 &quot;</td>
<td>7.7%</td>
<td>31.0%</td>
</tr>
</tbody>
</table>

In this respect the influence of root development on uprooting deserves mention. In
India, the pulling strain was determined, viz., the force (in cwt) required to pull out a cane
stump. Tests with Co 213 varied from 7.2 cwt in heavy wet soil to 2.9 cwt in light alluvium.
In dry soil a larger force was required. Differences between varieties occurred, Co 210
requiring 5.2 cwt under conditions in which Co 303 required only 1 cwt (16).
CHAPTER 10

VEGETATIVE COMPOSITION

The term vegetative composition denotes the share of the individual organs (stem, leaves, roots) in the total dry weight of the cane plant.

The above-ground portion of a cane plant consists of the millable cane, the leafy top (including the non-millable part of the stem, and the leaves attached to it) and the other leaves. The below-ground part consists of the stubble and the roots. In countries where the below-ground portion of the stem is harvested, the stubble is included in the millable cane.

The millable cane which is removed from the field constitutes only a part of the total dry matter of a crop, although this part is considerable (50 to 60 per cent). The roots, and in most cases the stubble, are left behind in the soil. The tops remain on the field or they are fed to cattle, either directly or in the form of ensilage. The trash may be left on the field or it may be used for building purposes (roofs of native houses) or as fuel in the factory.

The dry matter of the organs of a cane plant consists of more than 90 per cent of organic matter and since the enrichment of the soil with organic matter is a problem of great concern, some knowledge of the quantities of organic matter returned to the soil is of importance.

Moreover, the cane plant contains mineral substances the amount of which differs in different organs. An estimate of the quantities of these nutrients returned to the soil requires knowledge of both the chemical and vegetative composition of the cane plant.

In Java, KOBUS and VAN HOUWELINGEN started an extensive series of experiments on

Fig. 140.—Trend of vegetative composition of cane plants grown in Java. Abscissa, age of plants in weeks. Ordinate, weight of dry matter in grams. St, Stem; GT, green top; R, roots. Drawn after data from KOBUS (361).
this subject toward the end of the past century (314, 315, 359, 360, 361, 363, 365, 366). Details regarding these and other experiments will be provided in the following chapter. The results of these experiments proved that the vegetative composition of a cane plant is not uniform, but that it varies according to age, fertilization, variety, etc. The effect of age is dominant as is demonstrated by the diagram in fig. 140, representing the results of one of Kobus' experiments. The same data, on a percentage basis, are presented in fig. 141. At the time of planting, the plant consists only of a cutting. The initial growth is largely restricted to the development of leaves and roots which constitute the production apparatus of the plant. Stem formation does not start, or at least is negligible, as long as the assimilating and absorbing organs have not developed to a certain extent. But once this stage has been reached, stem formation starts at a rate which soon becomes considerably higher than that of any other organ.

An example relating to conditions in Mauritius is presented in fig. 142. In this case only the above-ground parts have been taken into consideration. The figure indicates, again, that first of all the development of the assimilating apparatus (the green top) is accomplished, and that subsequently the formation of millable cane starts. This figure, moreover, shows that the dry weight contained in the green top, apart from minor seasonal fluctuations, remains fairly constant during most of the growing period of the plant, while that in millable cane and in trash gradually increases. The increase in millable cane is largely due to the increase of fiber and sucrose, the share of other constituents remaining more or less constant.
The vegetative composition of sugarcane has been studied in many other countries and references to these investigations will be presented in the next chapter. The two examples given may suffice to demonstrate in a general way the changes occurring in a growing cane plant. They may be summarized as follows:

1. The development of an adequate production apparatus in the form of leaves and roots is a necessary requisite for the formation of millable cane. This implies that during the early stages of its development, a cane plant consists largely of leaves and roots, the amount of millable cane being practically nil.

2. The dry weight of the green top remains more or less constant during the entire growing period of the plant, while that of the root system increases gradually but slightly. The growth of the latter as compared with that of the whole plant is even so small that in many cases it may be disregarded.

3. Once the production apparatus has developed to a certain extent, the formation of millable cane starts. It soon reaches a considerable rate which, with the exception of seasonal fluctuations, is maintained throughout a great part of the growing period.

4. The formation of trash is closely correlated with cane formation, since the production of each joint is associated with the formation of a leaf.

5. Reduced to its most simple form, the cane plant might be considered to consists of a root system and a leafy top between which an increasing series of joints, each carrying

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Fig. 142.—Trend of vegetative composition of a ratoon crop grown in Mauritius. Ordinate, tons of dry matter per arpent (0.42 ha); abscissa, age in months. GT, entire green tops; Tr, trash; SNS, soluble non-sugars; F, fiber; RD, reducing sugars; S, sucrose (33).
VEGETATIVE COMPOSITION

Table 12.—Vegetative composition of sugarcane in two different years in Mauritius (53, 56)

<table>
<thead>
<tr>
<th>Part of plant</th>
<th>Share of total dry matter in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millable cane</td>
<td>60.2</td>
</tr>
<tr>
<td>Green tops</td>
<td>16.5</td>
</tr>
<tr>
<td>Trash</td>
<td>23.3</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table 13.—Vegetative composition of three Hawaiian varieties (expressed in per cent of total dry matter)

After BORDEN (123)

<table>
<thead>
<tr>
<th>Part of plant</th>
<th>H 109</th>
<th>32-8560</th>
<th>35-1515</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millable cane</td>
<td>54</td>
<td>58</td>
<td>51</td>
</tr>
<tr>
<td>Tops and trash</td>
<td>37</td>
<td>31</td>
<td>36</td>
</tr>
<tr>
<td>Roots and stubble</td>
<td>9</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 14.—Effect of nitrogen fertilization on vegetative composition (expressed in per cent of total dry matter)

After BORDEN (123)

<table>
<thead>
<tr>
<th>Part of plant</th>
<th>Very low</th>
<th>Low</th>
<th>Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millable cane</td>
<td>57</td>
<td>55</td>
<td>54</td>
<td>53</td>
</tr>
<tr>
<td>Tops and trash</td>
<td>32</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Roots and stubble</td>
<td>11</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

a leaf, are interpolated. The dry weight of the two former is more or less constant, while the dry weights of millable cane and trash increase gradually. Thus the higher the yield of millable cane, the lower the relative share of the roots and the leafy top. Or in other words, growing heavy crops is preferable from an economic point of view, since relatively less of the available nutrients and solar energy are locked up in the non-millable portion of the crop.

Many data on the vegetative composition of the ultimate crop, as far as the aerial parts are concerned, have been reported from Mauritius. The average results obtained in two different years are presented in table 12, which shows that, in round figures, 60 per cent of the total dry matter is contained in the millable cane, 15 per cent in the leafy tops and 25 per cent in the trash.
Fig. 143.—Vegetative composition of a 12-month old crop in Hawaii (54).

A rather detailed example from Hawaii, including the below-ground parts, is given in fig. 143. It relates to a crop of 12 months of age.

Varietal differences may occur as shown in table 13, which relates to cane harvested at an age of 12 months in Hawaii. The differences are small, but they may be larger when the varieties involved are botanically less related.

Another factor affecting vegetative composition is fertilization, an example of which is presented in table 14.

The data presented in the foregoing diagrams and tables permit the making of some
VEGETATIVE COMPOSITION

interesting estimates. Fig. 143, for example, indicates that for each 100 tons of millable cane (equivalent to 30 tons of dry matter) harvested, a total crop of approximately 61 tons of dry matter is associated. This crop of dry matter would be made up of 5.5 tons from cane tops and 30 tons from the stalks. Trash would amount to 15 tons, stubble to 2.75 tons and roots to 7.75 tons. The large amounts of roots and stubble, roughly equivalent to 20 tons of green weight, are responsible, at least partly, for the maintenance of soil fertility (54).

In several of the examples given so far, the vegetative composition has been studied in relation to age. Age, however, is a rather arbitrary indicator of the development of a plant. Plants of the same age but grown under different conditions may exhibit considerable differences in growth and development. For this reason, BORDEN (119) has studied the relationship between vegetative composition of cane plants and the actual stage of development. As a criterion for the stage of development, he chose the number of leaves produced. Plants were grown in carefully controlled pot experiments and the proportion of belowground to above-ground dry weight was as presented in the second column of table 23. The figures show that at the time when the 6th leaf had developed (at an age of approximately 8 weeks) the below-ground part represented nearly twice as much dry weight as the above-ground part, the actual ratio being 1.91 to 1.00. Toward the end of the experiment (52 weeks) the ratio gradually decreased to 0.18, indicating that at that time the quantity of dry matter contained in the below-ground part was less than one-fifth that of the above-ground portion. The segregation of total dry weight in the aerial parts is shown in table 15 and in fig. 144. In the latter, the age in weeks has been substituted for the leaf-stage in order to enable a comparison with fig. 141. The resemblance between the two figures is satisfactory, although they relate to different varieties, grown under quite different climatic conditions, with a difference in time of nearly half a century. This suggests once more that although differences may occur, an inherent trend in the ratios, characteristic of sugarcane in general, seems to exist. This is of importance, since it permits of an approximate estimate of the dry weight contained in different portions of a cane crop, when the dry weight of one of them, e.g., the millable cane, is known. Moreover, once the dry matter contained in the different portions has been estimated, it is possible to calculate, on the basis of the moisture content, the fresh weight of these portions. This implies that since the cane

<table>
<thead>
<tr>
<th>Leaf stage</th>
<th>Approximate per cent of total dry weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As cane</td>
</tr>
<tr>
<td>6th</td>
<td>-</td>
</tr>
<tr>
<td>12th</td>
<td>-</td>
</tr>
<tr>
<td>18th</td>
<td>28</td>
</tr>
<tr>
<td>24th</td>
<td>42</td>
</tr>
<tr>
<td>30th</td>
<td>52</td>
</tr>
<tr>
<td>36th</td>
<td>55</td>
</tr>
<tr>
<td>45-48th</td>
<td>58</td>
</tr>
</tbody>
</table>
tonnage of each crop is known, it is possible to roughly estimate the fresh and dry weight of the below-ground and the above-ground parts, as well as the fresh and the dry weight of the tops and the trash associated with the millable cane.

CHAPTER 11
CHEMICAL COMPOSITION

GENERAL

The millable cane is largely made up of three elements: hydrogen, oxygen and carbon, which together constitute more than 99 per cent of its fresh weight. The remainder, containing all other elements, is obtained from the soil, and ordinarily has to be supplied
partly in the form of fertilizers. Although the latter part does not surpass a few tenths of one per cent of the fresh weight, it constitutes a major problem in cane culture, since the application of fertilizers is a matter of cost and labor.

This is one of the reasons why much research has been devoted to the study of the chemical composition of the cane plant. The original idea was that a knowledge of the chemical composition of the cane plant would enable the estimation of the quantity of nutrients removed by a crop and thus provide an indication of the amounts of fertilizers required to make up for the loss in soil fertility. This line of research has, however, not yielded practical results, since it was found that the soil is able to restore, at least partly, its fertility.

In later years a more promising approach has been attempted which is based on the premise that the nutritional status of a plant is more or less reflected by its chemical composition. According to this concept, cane growing in soil deficient in one or more elements would contain a lower concentration of these elements than plants growing in soil adequately supplied with these elements. This line of research requires a thorough knowledge of the chemical composition of the cane plant and its constituent parts, and consequently has greatly promoted chemical analyses of cane grown under very different conditions.

Another factor which proves the importance of a knowledge of the chemical composition of the cane plant is the fact that some diseases, the cause of which was not understood for many years, have turned out to be the result of nutritional deficiencies.

Studies of the chemical composition of the cane plant have largely centered in two periods. The first started at the end of the past century in Java, where KOBUS (359, 360, 361, 363, 365) and VAN HOUWELINGEN (314, 315) conducted a series of remarkable experiments, covering some ten years and including many varieties, different kinds of fertilization, and different kinds of watering. Since the plants were harvested at periodic intervals, the trend of the chemical composition as well as the trend of the uptake of nutrients could be ascertained. During the same period, MAXWELL (457, 458, 459) and ECKART (236, 237) in Hawaii published detailed analyses of more or less mature cane plants.

The second period of activity in this field of research started some thirty years later in Hawaii, with studies by STEWART and VERRET (527, 528). These were continued by Ayres (74, 75, 76, 77, 78), BORDEN (112, 113, 114, 116, 119, 126) and others. Java is represented in the latter period by HONIG (311), Mauritius by EVANS (245), India by PRAMANIK et al (484), and the Philippines by DEOMANO (210).

In addition, various other countries have made valuable contributions in this field of research and the amount of data concerning the chemical composition of cane juices is particularly large.

Part of the information so far available will be dealt with in the present chapter, while another part is included in the subsequent chapter on nutrition. All data on the percentage of ash, its distribution in the various parts of the plant and its changes in the course of time are discussed in the present chapter. The same applies to the ash constituents and nitrogen as far as they are considered collectively. Thus the total analyses of the cane plant and its constituent parts will be dealt with in the present chapter. The distribution of each individual element, however, as well as its trend in the growing plant, will be discussed in the subsequent chapter.
In comparing the results obtained by different workers, the fact should be borne in mind that the material and the methods used are often different. In some cases, complete plants (including roots and sets) have been examined, while in other cases only the above-ground portions or parts thereof have been investigated. Moreover, attention should be drawn to the fact that although the results of most investigations are presented in terms of the oxides of the elements ($P_2O_5$, $K_2O$, etc.), in some instances the concentrations are expressed in terms of the elements (P, K, etc.). The latter is always the case with nitrogen.

For a correct evaluation of the results obtained by the different workers, it is necessary to know how the plants were raised and what parts were analyzed. In order to avoid repetition at various places, details of the more important investigations will be summarized here.

In his first experiment, Kobus (359) grew cane plants in bamboo baskets each containing 150 kg of soil. One series was not fertilized, while three other series were supplied with increasing amounts of ammonium sulphate. One thousand baskets were involved in this experiment. The plants were harvested at periodic intervals and the sets, the roots, the millable cane, the green leaves (including the whole top), and the dead leaves were weighed and analyzed separately. Besides the fresh and dry weight, the concentrations of ash, nitrogen, phosphorus and potassium were estimated, and from the data thus obtained the amount of nutrients removed by the whole crop was calculated.

For his second study, Kobus (361) grew the plants in the same way but this time all cane received excessive quantities of nitrogen. Harvesting took place at periodic intervals, and the sets, the roots, the millable stalks, the green leaves and the dry leaves, were weighed and analyzed separately. The components estimated were the same as in the first experiment. In addition, the concentration of calcium was determined, and in some cases the amounts of fiber and protein were also determined. The rate of absorption of the different nutrients and the total amount removed from the soil were calculated.

In the third study with cane grown in baskets (365), seven different varieties were compared. Harvest took place at three different dates; viz., when the plants were 110, 187 and 310 days old, respectively. The roots, the millable cane, the green leaves and the dry leaves were weighed and analyzed separately. The components determined were the same as in the preceding experiment, and the trend of absorption of the various nutrients, as well as the amounts removed from the soil were calculated.

A similar experiment was performed by Van Houwelingen (315).

In addition to these experiments in bamboo baskets, other series of experiments were conducted in large cement containers sunk into the soil. The bottom surface of each was $2\ m^2$, its depth 1.5 m, and 60 of these containers were involved in each experiment.

In the first experiment of this kind, Kobus (360) compared the effect of different amounts of three nitrogen fertilizers; viz., ammonium sulphate, Chile saltpeter and oil-cake. The plants were harvested at an age of 10 months and the millable cane and the leaves were weighed and analyzed separately. The components determined were: fresh and dry weight, nitrogen, phosphorus, potassium and protein.

The second experiment in large containers (361) consisted of plants grown in a soil which was deficient in nitrogen. Harvest took place at an age of 41 weeks. Roots, millable cane and leaves were weighed and analyzed separately. Besides fresh and dry weights, the concentrations of nitrogen, phosphorus, potassium, and calcium were determined.

The third study of this kind (363) aimed at determining the influence of various ratios of nitrogen, phosphorus, potassium and lime fertilizers on the chemical composition of the cane plant. Harvest took place at the age of 8 months. The weight and the chemical composition of
CHEMICAL COMPOSITION 171

the roots, the millable cane and the leaves was determined separately. The analyses included
determinations of fresh and dry weight, nitrogen, phosphorus, potassium, calcium, chlorine and
sulphur. The total amounts of nutrients removed by the plants were calculated.

This experiment was repeated in the subsequent years (363). The plants were harvested at an age
of 33 weeks and the millable cane, the green leaves and the dry leaves were weighed and analyzed
separately. The analyses were for the same components as in the previous experiment.

A fifth experiment in large containers conducted by VAN HOUWELINGEN (314) was a repetition
of the third. The cane plants harvested were handled and analyzed as described before, and the
amounts of nutrients removed from the soil per 1000 pikols (61,800 kg) of millable cane were
calculated.

In the sixth study (314) of this type, the plan of the experiment was slightly altered in that
the lime treatments were replaced by irrigation treatments (much versus little water), while instead
of one variety, three varieties were included. For the rest, this experiment resembled largely the
former.

The seventh experiment (314) was an exact duplication of the sixth.

In Hawaii research on the uptake of nutrients was started by STEWART (527) who harvested
at periodic intervals cane plants grown in field plots. The plots had received different applications
of fertilizers and the plants harvested were divided into stems, tops (including all green leaves)
and trash. The analyses of each of these parts included the determination of fresh and dry weight,
ash, nitrogen, phosphorus, potassium, calcium, magnesium and silicon. From the results obtained,
the rates at which the various nutrients were accumulated in the different parts of the plants were
calculated on an acre basis.

A second experiment conducted along this line (74, 528) was harvested at intervals of three
months. The same properties were analyzed as in the preceding study. The removal of the various
nutrients from the soil in the course of the development of the plants was calculated separately
for millable cane, tops plus green leaves, and trash.

In a third experiment conducted by Ayres (75), samples were taken at monthly intervals.
The plants were separated into the green leaf blades, the green leaf sheaths, the upper 6-inch top
of the stems, while the remaining portion of the stems was divided into 3-foot sections. Analyses
were made for ash, nitrogen, phosphorus, potassium, calcium, magnesium and silicon.

The ratoon crop was also sampled at monthly intervals (16, 78). In this case, however, the
green and dry leaves were collected and analyzed separately, while the stems were divided in the
same way as in the preceding experiment. The analyses included determinations of nitrogen,
phosphorus, potassium, calcium and magnesium. The quantities of nutrients were expressed in
terms of the elements and not of the oxides of the elements, as done in the experiments mentioned
so far. The amounts of the nutrients removed from the soil in the course of the development of
the crop were calculated.

BORDEN (119), in an effort to secure data on the total uptake of nitrogen, phosphorus and
potassium, conducted a series of controlled pot experiments. Complete plants, including roots,
stubble and abscised leaves were harvested at periodic intervals and analysed for nitrogen, phos­
phorus and potassium. From the data thus collected, the rate of intake of the three elements was
calculated, both for the below-ground and the above-ground portions of the cane plant.

HONIG (311) sampled fields of POJ 2818 grown at seven plantations in Java at monthly intervals
during the second half of their growing period. The plants were segregated into millable cane and
leaves (including tops, green leaves and adhering trash). Since it is the practice in Java to remove
the lower dry leaves at the time the final hilling up is performed, the trash was not completely
represented in the samples. The cane was crushed in a sample mill and the juice, the bagasse and
the leaves were analyzed separately. The components determined included fresh and dry weight,
ash, phosphorus, silicon, potassium, calcium, magnesium, iron, aluminum and sulphur. From
the data thus obtained, the rate at which the nutrients were accumulated in the various parts of
the plants were calculated per hectare.
DEOMANO (210) in the Philippines sampled four varieties grown in the field, at ages of 9, 10, 12 and 14 months, separated the leaves from the millable stalks and divided the latter into five equal sections. The analyses comprised determinations of moisture, ash, phosphorus, potassium, calcium, magnesium, silicon, sodium, iron and sulphur.

EVANS (245) in Mauritius, sampled cane plants grown in the field at monthly intervals during the first year and at longer intervals during an additional period of eight months. All dead leaves and roots were collected very carefully. The stalks were severed at soil level. The green leaves, the roots, the stems, as well as the remaining parts (stubble plus trash) were sampled and analyzed separately. The analyses included determinations of moisture, ash, nitrogen, phosphorus, potassium and calcium.

Before entering into a detailed examination of the chemical composition some general data will be presented about the distribution of moisture, organic matter and mineral matter in the cane plant.

Table 16 shows that the moisture content of fresh millable cane stalks varies from 70.5 to 75.6 per cent, with an average of 73.0 per cent. The organic matter ranges from about 23.5 to 29 per cent with an average of 26.1 per cent. This organic matter consists of fiber, sugars and other organic material. The fiber content of fresh cane may vary from 9 to 16 per cent with an average around 12 per cent. The ash content in Table 16 ranges from 0.65 to 1.00 per cent, with an average around 0.9 per cent. Thus millable cane consists of nearly three-quarters water, approximately one-quarter organic matter (half of which is fiber) and less than one per cent mineral matter. These figures refer to noble varieties (S. officinarum). The chemical composition of other cane species may differ considerably.

Table 17 gives an idea of the share of organic and mineral matter in the dry weight of millable cane. It shows that nearly 97 per cent of dry weight consists of organic matter.

Table 16.—Percentage composition of fresh cane stalks
After MAXWELL (459)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Water</th>
<th>Organic</th>
<th>Mineral</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lahaina</td>
<td>71.34</td>
<td>27.89</td>
<td>0.77</td>
<td>100.00</td>
</tr>
<tr>
<td>Rose Bamboo</td>
<td>73.13</td>
<td>25.96</td>
<td>0.91</td>
<td>100.00</td>
</tr>
<tr>
<td>Yellow Caledonia</td>
<td>73.47</td>
<td>25.66</td>
<td>0.87</td>
<td>100.00</td>
</tr>
<tr>
<td>Yellow Bamboo</td>
<td>70.91</td>
<td>28.07</td>
<td>1.02</td>
<td>100.00</td>
</tr>
<tr>
<td>Moore's Purple</td>
<td>73.78</td>
<td>25.22</td>
<td>1.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Demerara, No. 117</td>
<td>73.41</td>
<td>25.67</td>
<td>0.92</td>
<td>100.00</td>
</tr>
<tr>
<td>Demerara, No. 95</td>
<td>70.50</td>
<td>28.85</td>
<td>0.65</td>
<td>100.00</td>
</tr>
<tr>
<td>Demerara, No. 124</td>
<td>75.58</td>
<td>23.51</td>
<td>0.91</td>
<td>100.00</td>
</tr>
<tr>
<td>Louisiana, Tibboo Mird</td>
<td>74.43</td>
<td>24.56</td>
<td>1.01</td>
<td>100.00</td>
</tr>
<tr>
<td>Louisiana, Striped</td>
<td>73.40</td>
<td>25.79</td>
<td>0.81</td>
<td>100.00</td>
</tr>
<tr>
<td>Louisiana, Purple</td>
<td>74.02</td>
<td>25.17</td>
<td>0.81</td>
<td>100.00</td>
</tr>
<tr>
<td>Striped Singapore</td>
<td>72.76</td>
<td>26.48</td>
<td>0.89</td>
<td>100.00</td>
</tr>
<tr>
<td>Big Ribbon</td>
<td>72.76</td>
<td>26.35</td>
<td>0.89</td>
<td>100.00</td>
</tr>
</tbody>
</table>
CHEMICAL COMPOSITION

Table 17.—Segregation of organic and mineral matter in per cent of dry weight

After Maxwell (459)

<table>
<thead>
<tr>
<th>Variety</th>
<th>In stems</th>
<th></th>
<th>In leaves, tops and dead canes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Organic</td>
<td>Mineral</td>
<td>Organic</td>
<td>Mineral</td>
</tr>
<tr>
<td></td>
<td>matter</td>
<td>matter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lahaina</td>
<td>97.30</td>
<td>2.70</td>
<td>91.56</td>
<td>8.44</td>
</tr>
<tr>
<td>Rose Bamboo</td>
<td>96.60</td>
<td>3.40</td>
<td>91.05</td>
<td>8.95</td>
</tr>
<tr>
<td>Yellow Caledonia</td>
<td>96.71</td>
<td>3.29</td>
<td>91.08</td>
<td>8.92</td>
</tr>
<tr>
<td>Yellow Bamboo</td>
<td>96.48</td>
<td>3.52</td>
<td>91.90</td>
<td>8.10</td>
</tr>
<tr>
<td>Moore’s Purple</td>
<td>96.17</td>
<td>3.83</td>
<td>90.22</td>
<td>9.78</td>
</tr>
<tr>
<td>Demarara, No. 117</td>
<td>96.52</td>
<td>3.48</td>
<td>89.54</td>
<td>10.46</td>
</tr>
<tr>
<td>Demarara, No. 95</td>
<td>97.79</td>
<td>2.21</td>
<td>90.01</td>
<td>9.81</td>
</tr>
<tr>
<td>Demarara, No. 124</td>
<td>96.26</td>
<td>3.74</td>
<td>87.94</td>
<td>12.06</td>
</tr>
<tr>
<td>Louisiana, Tiboo Mird</td>
<td>96.04</td>
<td>3.96</td>
<td>91.34</td>
<td>8.66</td>
</tr>
<tr>
<td>Louisiana, Striped</td>
<td>96.95</td>
<td>3.05</td>
<td>90.05</td>
<td>9.95</td>
</tr>
<tr>
<td>Louisiana, Purple</td>
<td>96.85</td>
<td>3.15</td>
<td>90.07</td>
<td>9.93</td>
</tr>
<tr>
<td>Striped Singapore</td>
<td>97.19</td>
<td>2.81</td>
<td>91.58</td>
<td>8.42</td>
</tr>
<tr>
<td>Bib Ribbon</td>
<td>96.73</td>
<td>3.27</td>
<td>91.06</td>
<td>8.94</td>
</tr>
</tbody>
</table>

Since organic matter is largely built up from elements derived from the air (carbon, oxygen and hydrogen), this means that nearly 97 per cent of the dry matter contained in millable cane is derived from the air and only some 3 per cent from the soil. The part of the crop which is more or less wasted consists of green leaves (including tops), trash and dead stalks. The dry matter of this part consists of more than 90 per cent organic matter, largely derived from the air, while less than 10 per cent consists of mineral matter absorbed from the soil.

DISTRIBUTION OF NUTRIENTS

The highest concentration of mineral nutrients is to be found in the most active tissues of the cane plant, viz., in the top section of the stem, in the leaves and in the roots, while the concentration in the older parts of the stem decreases as they mature. This is illustrated by fig. 145 which represents the ash content expressed in per cent of dry matter in different parts of the cane plant. It shows that the ash content is highest in the upper section of the stem, where it runs up to 12.5 per cent (stalk A). When passing from the top of the stem to its lower sections (stalk B to E), the mineral content gradually diminishes till it reaches a value of approximately one per cent in the bottom portion of the stem. The ash content of leaf blades and sheaths is rather high and, apart from seasonal fluctuations, it remains fairly constant.

The trend of the ash content in the developing cane plant has been studied by several investigators (74, 210, 245, 311, 315, 359, 365, 527). Although the ash concentration is greatly influenced by differences in growing conditions, the general trend appears to be the same under most circumstances: a gradual decrease in the maturing internodes and a relatively high and constant level in the tops and the trash.
HONIG (311) found the ash content of tops plus trash to vary greatly for different fields scattered over Java, the level of the ash content being fairly characteristic of each field. The same applied more or less to the ash content of the raw juice and of the bagasse.

In the stem.—The general trend of the separate elements in the stem largely resembles that of the total ash, viz., a gradual decrease as the internodes grow older. An example is presented in fig. 146 which shows that the percentages of all elements except silicon are highest in the young cane which at that time consists merely of a top section. As the plant grows older, the percentages of all elements except silicon decrease. This decrease is very rapid at first, and then reaches a slower rate. The percentage of silicon, on the other hand, starts at a low level, increases during the early stages of development and subsequently decreases.

From the foregoing, it is apparent that the mineral composition of the stalk is a function of the age or development of the plant. It illustrates the danger of an indiscriminate utilization of data pertaining to the mineral composition of the stalk as a guide to fertilization (76, 77, 78).

Periodic analyses of cane stems have been made by various investigators and the results obtained are in general harmony with the example mentioned before (75, 210, 245, 311, 315, 359, 460, 361, 365, 527).

Evidence has been obtained that a translocation of some elements occurs within the stem from the maturing internodes toward the younger ones. In fig. 147 the quantity of various nutrients in successive 3-foot sections of the stem at the age of 14 months is represented. The quantities of magnesium, phosphorus and silicon per unit of length of stem increase as the base of the stalk is approached. Potassium, on the other hand, shows a decrease in this direction. This suggests that as the tissues of the stalk mature they lose
potassium through the upward migration of this element. (The same is generally true of nitrogen, although this is not the case in this particular experiment).

In fig. 148 the nutrients are expressed as per cent of total ash. The ash in the top section consists of nearly 50 per cent of potash but toward the bottom of the stalk the proportion of this nutrient decreases to some 25 per cent. Proportions of phosphorus and silicon, on the other hand, increase in the same direction. The movement of potassium in the cane stalk has also been reported by Boname (101).

Honig (311) made extensive ash analyses of the juice, of the bagasse and of the tops (including green and dry leaves). He found that in the juice potassium (as K₂O) is the most important element, constituting from 6 to 50 per cent of the ash of the juice. In cane grown on soils adequately supplied with this nutrient, the potassium content ranges from 35 to 50 per cent; on soils deficient in potassium, this figure is 5 to 25 per cent; an average would be 30 to 40 per cent.

Silicon (as SiO₂) ranges from 3 to 25 per cent of the total ash in juice. It appears to be particularly high in stalks with a low potassium content.

The percentage of CaO and MgO combined varies from 1 to 20. The extremely high values are found in juices which are poor in potassium. Averages for calcium as well as for magnesium appear to range from 3 to 7 per cent.

The phosphorus (P₂O₅) content in the ash of the juice fluctuates from 2 to 12 per cent with averages between 5 and 8 per cent.

Sulphate (SO₄²⁻) which constitutes the major part of the acid radicals (PO₄³⁻, SO₄²⁻,

![Graph](image-url)
Fig. 147.—Quantity of nutrients contained in successive three-foot sections of the cane stem at the age of 14 months. Note that potassium decreases as the base of the stem is approached, whereas most of the other elements tend to increase. After Ayres (76, 78).

Fig. 148.—Proportion of potassium, phosphorus and silicon in the ash of different sections of the cane stem indicating a migration of potassium from the maturing to the youngest parts. For an explanation of the symbols on the abscissa, compare fig. 147. After Ayres (75).
CHEMICAL COMPOSITION

Fig. 149.—Trend of chemical composition of the green leaves of a developing cane plant. After Ayres (76, 78).

Cl', organic acids) is present in percentages ordinarily ranging from 10 to 30 with averages commonly between 15 and 20.

The percentage composition of the ash in bagasse shows a rather uniform picture. Silicon constitutes the major part, varying from 60 to 90 per cent SiO₂. The next important element is potassium with values of 5 to 10 per cent K₂O on average fertile soils, while on soils deficient in this nutrient, the value may decrease to below 1 per cent. The percentage of CaO and MgO combined averages 1 to 2 per cent, while values of 4 per cent for either CaO or MgO are extremely high. The content of iron averages between 2 and 4 per cent of Fe₂O₃; high values run up to 5 per cent and more. Phosphorus is relatively low, averaging 1.5 to 2.0 per cent of P₂O₅; values of 1 per cent and less are considered low, while values exceeding 2 per cent are relatively high. All these figures of Honig relate to POJ 2878 grown in Java.

In addition to the elements discussed so far, others occur which are generally of minor importance. In table 18 the ash composition of two varieties is presented including figures on the occurrence of titanic oxide, manganese oxide, chlorine and soda. Additional data regarding minor elements will be found at the end of the next chapter.

In the tops and leaves.—Honig (311) found that the major ash constituent in the tops plus leaves is silicon (SiO₂), since it represents 35 to 70 per cent of the total ash, with averages from 50 to 60 per cent. Potassium (K₂O) varies from 8 to 28, with average values of 15 to 20 per cent. The proportion of CaO and MgO in the tops is somewhat lower than in cane juice, their combined quantities varying from 3 to 5 per cent. Phosphorus (P₂O₅) in the ash of the tops ranges from 1.5 to 4 per cent with average values of 2 to 2.5. The proportion of sulphate (SO₄'') is considerably lower than in cane juice, since it amounts only to 2.5 to 5 per cent of the ash in the tops.
Contrary to the marked changes in chemical composition of the stem in relation to age, the variations in tops and leaves are of minor importance. An example is presented in fig. 149. The concentrations of potassium, silicon, nitrogen and phosphorus show a marked decrease during the first three to four months of growth. But apart from this, and making allowance for seasonal fluctuations, all nutrients with the possible exception of potassium and silicon decrease slightly as the cane plant grows older. These changes in chemical composition of the green leaves are of importance when leaves have to be sampled for estimating the nutritional requirements of a crop. In doing so, it would appear advisable to confine sampling to periods during which the effect of age is least pronounced. This would exclude the sampling of the very young cane plant for such purposes (76).

Superimposed on this age effect of the plant as a whole, is the age effect of the individual leaves. This is apparent from fig. 150, which illustrates the changes in chemical composition occurring in a leaf when growing old and becoming inactive. It appears that with increasing age the concentrations of some elements increase, while those of others decrease. It is interesting to note the apparent migration of potassium and nitrogen back into the stem and the striking accumulation of silicon in the maturing leaf. Calcium and magnesium also accumulate in the maturing leaf while the behavior of phosphorus in this connection is indefinite (78). It is thus obvious that not only the composition of the leafy top as a whole changes as the plant grows older, but that the composition of each individual leaf is also altered as it matures.

This age effect on the individual leaves is also of importance when leaves are sampled in order to ascertain the nutritional status of the plant, and it is advisable to restrict sampling for such purposes to leaves of a definite age (77).

Additional periodic analyses of both green and dry leaves of the developing cane plant
have been published by various investigators (77, 210, 311, 315, 359, 360, 361, 365, 527), and it is generally agreed that the age effect on the chemical composition of the total green top is relatively small as compared with that of the stalk.

The gradual changes occurring in the individual leaves suggest that the composition of green leaves and trash would differ considerably. This is what actually has been found some fifty years ago (314, 315, 359, 361, 363, 365), and which has been corroborated by subsequent investigations (78, 527). A comparison of the composition of the dry matter of green and dead leaves shows that the former contain much higher percentages of potassium and nitrogen and sometimes greater percentages of phosphorus, than the latter. These figures suggest that large proportions of nitrogen and potassium contained in the green leaves have migrated back to the stalk before the leaves became physiologically inactive (78). Other workers have arrived at similar conclusions (101, 286, 314). Thus VAN HOUWELINGEN (314) concluded from his experiments that approximately two thirds of the nitrogen contained in green leaves move back into the stem before the leaves die; similar though less substantial migrations from the maturing leaves into the stem were
found for phosphorus and potassium. The differences in chemical composition of green and dead leaves, however, may be due partly to leaching since the same investigator found that by subjecting trash and green leaves to leaching during 24 hours, the losses were as listed in table 19.

As to the percentage composition of the leaves, some data obtained by Honig have already been presented. In addition table 20 gives the percentage ash composition of leaves as reported by Maxwell in Hawaii.

Finally, the distribution of some minor and trace elements is given in table 21. The meaning of the symbols is as follows:

- GL: Green leaves (blades)
- DL: Dead leaves (blades)
- GP: Non-millable top (growing point and several inches below)
- GC: Green-leaf cane
- DC: Dead-leaf cane

The elements were estimated by means of a spectograph. The symbol for the part of the plant containing the largest amount of the particular element is listed first, followed by the others in the order of decreasing amounts. Symbols enclosed in parentheses indicate approximately equal amounts present in those parts, and a dash indicates a large difference in amount between the parts whose symbols it separates. The estimated amounts of the various trace metallic elements present in the ash of the dry leaf section of the stem are given in the last column. These, too, are expressed on the dry weight basis. They may be in error by as much as a factor of 5 or 10 (82).

Proportion in below-ground and above-ground parts.—So far only the composition of the aerial parts of the cane plant has been discussed. The composition of the below-ground parts, however, is also of considerable importance, more particularly when attempts are made to estimate the amount of nutrients left behind in the soil by a crop.

Borden (119) has studied this problem by means of pot experiments, taking care that all parts of the plants, including absised leaves, roots and stubble, were carefully collected. The results are presented in table 22, together with the leaf stages which are more characteristic of the rate of development of the plant than the age. The last plants were harvested

<table>
<thead>
<tr>
<th>Table 19.—Losses from leaching during 24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>After Van Houwelingen (314)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>From trash</td>
</tr>
<tr>
<td>Dry matter</td>
</tr>
<tr>
<td>Nitrogen</td>
</tr>
<tr>
<td>Lime</td>
</tr>
<tr>
<td>Phosphorus</td>
</tr>
<tr>
<td>Potassium</td>
</tr>
</tbody>
</table>
CHEMICAL COMPOSITION

Table 20.—Ash composition in leaves. After MAXWELL (458)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Rose Bamboo</th>
<th>Lahaina</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td>58.50</td>
<td>58.44</td>
</tr>
<tr>
<td>Titanic oxide</td>
<td>1.12</td>
<td>1.38</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>1.32</td>
<td>1.26</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>5.85</td>
<td>5.54</td>
</tr>
<tr>
<td>Carbonic acid</td>
<td>0.10</td>
<td>0.12</td>
</tr>
<tr>
<td>Chlorine</td>
<td>2.73</td>
<td>2.64</td>
</tr>
<tr>
<td>Iron oxide</td>
<td>4.40</td>
<td>3.58</td>
</tr>
<tr>
<td>Alumina</td>
<td>0.75</td>
<td>1.84</td>
</tr>
<tr>
<td>Manganese oxide</td>
<td>1.29</td>
<td>1.26</td>
</tr>
<tr>
<td>Lime</td>
<td>4.84</td>
<td>4.79</td>
</tr>
<tr>
<td>Magnesia</td>
<td>3.33</td>
<td>3.30</td>
</tr>
<tr>
<td>Soda</td>
<td>1.78</td>
<td>1.33</td>
</tr>
<tr>
<td>Potash</td>
<td>14.19</td>
<td>14.74</td>
</tr>
<tr>
<td></td>
<td>100.20</td>
<td>100.22</td>
</tr>
</tbody>
</table>

Table 21.—Distribution of minor and trace elements and estimated absolute percentages (dry-weight basis) for dry-leaf cane. After BALLARD (82)

<table>
<thead>
<tr>
<th>Element</th>
<th>Order of abundance</th>
<th>Estimated per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>(GP GC DC) GL DL</td>
<td>0.001</td>
</tr>
<tr>
<td>Manganese</td>
<td>DC-(GP GC)-GL</td>
<td>0.01</td>
</tr>
<tr>
<td>Boron</td>
<td>(all equal)</td>
<td>0.01</td>
</tr>
<tr>
<td>Copper</td>
<td>(all equal)</td>
<td>0.001</td>
</tr>
<tr>
<td>Aluminum</td>
<td>(GP GC DC)</td>
<td>0.001</td>
</tr>
<tr>
<td>Sodium</td>
<td>GL-DC (GP DL) GC</td>
<td>0.01</td>
</tr>
<tr>
<td>Strontium</td>
<td>DC-(GP GL)</td>
<td>0.0005</td>
</tr>
<tr>
<td>Barium</td>
<td>DC-GP</td>
<td>0.0005</td>
</tr>
<tr>
<td>Lead</td>
<td>GL</td>
<td>-</td>
</tr>
</tbody>
</table>

at the 45th to 48th leaf stage, corresponding to 52 weeks of age. The table shows that the percentage concentration of all nutrients decreases as the crop grows older. But this decrease is considerably larger in the above-ground parts of the crop than in the roots plus stubble. A comparison of the above-ground and below-ground parts shows that during the early stages of development the concentration of nitrogen in the above-ground portion is higher than that in the parts below ground. But shortly after the 24th leaf is formed, this relationship is reversed and thereafter the percentage of nitrogen present in the parts below ground is slightly the higher. A similar reversal, however, is not found in the percentage of potassium or phosphorus.
Estimating the nutrients left behind in the soil by a cane crop usually constitutes a laborious task, since it involves the digging up and careful cleaning of roots and stubble. BORDEN has introduced a simplified method. He computed the proportion of below-ground to above-ground parts of cane plants at periodic intervals. Thus, by estimating the chemical composition of the aerial portion, which is a relatively easy matter, those of the below-ground parts, difficult of access, can be determined. The proportional figures are given in table 23.

The figures of the second column have already been discussed. The figures relating to the concentrations of N, P₂O₅ and K₂O are derived from table 22. According to this table the N concentrations at the 12th leaf stage e.g., are 0.81 and 1.55 in the below-ground and aerial portions respectively, which is indicated by the ratio 0.52 (0.81 ÷ 1.55) in table 23.

The use of the latter table in estimating the amounts of nutrients in roots and stubble from measurements in the aerial portion is illustrated by BORDEN (119) in the following way:

At the 36th leaf stage, the amounts of dry matter in roots, stubble and seed pieces of a crop, according to table 23 are 0.19 of the amount of dry matter produced above ground.

---

**Table 22.**—Concentration of nutrients in per cent of dry matter. After Borden (119)

<table>
<thead>
<tr>
<th></th>
<th>6th</th>
<th>12th</th>
<th>18th</th>
<th>24th</th>
<th>30th</th>
<th>36th</th>
<th>42nd</th>
<th>45–48th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ab. ground</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>N</td>
<td>1.81</td>
<td>1.55</td>
<td>.93</td>
<td>.70</td>
<td>.59</td>
<td>.49</td>
<td>.45</td>
<td>.34</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>.76</td>
<td>.63</td>
<td>.52</td>
<td>.46</td>
<td>.35</td>
<td>.30</td>
<td>.27</td>
<td>.25</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.08</td>
<td>2.69</td>
<td>2.16</td>
<td>1.52</td>
<td>.98</td>
<td>.61</td>
<td>.59</td>
<td>.34</td>
</tr>
<tr>
<td>Bel. ground</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>.74</td>
<td>.81</td>
<td>.68</td>
<td>.65</td>
<td>.66</td>
<td>.65</td>
<td>.56</td>
<td>.59</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>.52</td>
<td>.41</td>
<td>.32</td>
<td>.29</td>
<td>.29</td>
<td>.28</td>
<td>.26</td>
<td>.26</td>
</tr>
<tr>
<td>K₂O</td>
<td>1.39</td>
<td>1.24</td>
<td>.94</td>
<td>.55</td>
<td>.32</td>
<td>.27</td>
<td>.32</td>
<td>.23</td>
</tr>
</tbody>
</table>

**Table 23.**—Proportion of below-ground to above-ground parts of a cane plant at successive intervals. After BORDEN (119)

<table>
<thead>
<tr>
<th>Leaf stage</th>
<th>In total dry weight</th>
<th>In concentration of nutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P₂O₅</td>
</tr>
<tr>
<td>6th</td>
<td>1.91</td>
<td>.41</td>
</tr>
<tr>
<td>12th</td>
<td>.40</td>
<td>.52</td>
</tr>
<tr>
<td>18th</td>
<td>.32</td>
<td>.74</td>
</tr>
<tr>
<td>24th</td>
<td>.23</td>
<td>.93</td>
</tr>
<tr>
<td>30th</td>
<td>.20</td>
<td>1.15</td>
</tr>
<tr>
<td>36th</td>
<td>.19</td>
<td>1.32</td>
</tr>
<tr>
<td>45–48th</td>
<td>.18</td>
<td>1.72</td>
</tr>
</tbody>
</table>
Suppose that it were known that the above-ground crop yields 15 tons per acre of total dry weight (which would be equivalent to approximately 60 tons of green weight, made up of about 46 tons of stalks and 14 tons of tops and trash), then it could be assumed that 0.19 of 15 tons or 2.85 tons of dry matter would be left in the soil. If an analysis of samples of the dry weight of the aerial parts were to show 0.49 per cent N, their corresponding below-ground parts would average about 1.32 times 0.49 per cent or 0.65 per cent N. Thus this 2.85 tons of dry matter at 0.65 per cent N would leave something in the order of 37 pounds of nitrogen behind in the soil at harvest, whereas the remainder, some 12.15 tons of stalks and leaves at 0.49 per cent N, would mean that about 119 pounds of nitrogen would leave the field as the crop was removed and no residue left behind.

In a similar way, the approximate amounts of P₂O₅ and K₂O which would be left behind in the soil would be estimated from an analysis of the above-ground parts harvested. Thus if these showed 0.30 per cent P₂O₅ and 0.61 per cent K₂O, it would be estimated that these 2.85 tons of dry weight below ground averaged 0.94 times 0.30 per cent or 0.28 per cent P₂O₅, and 0.44 times 0.61 per cent or 0.27 per cent K₂O, and so would leave behind some 16 pounds of phosphate and 15 pounds of potash, while some 73 pounds of phosphate and 148 pounds of potash were being taken away (119).

**Trend of uptake.**—The rate at which the different nutrients are absorbed differs greatly. Fig. 151 gives an example of the amounts removed by complete cane plants (including trash and roots) in experiments conducted by KOBUS (361) in Java. It shows that during the early stages, absorption is slow but as soon as shoots and roots have developed to a certain extent, the rate of absorption increases markedly. This is particularly the case with potassium and nitrogen which are taken up at a maximum rate between 3 and 6 months after planting; thereafter absorption of these two elements slows down somewhat, but still remains considerable till harvest. This figure clearly demonstrates the tremendous demand made upon the soil for potassium.

An example from Hawaii relating to the aerial parts of cane plants only is presented in fig. 152 and 153. Both cover a growing period of 30 months. It is interesting to note that although fig. 152 relates to plants which were grown under quite different conditions from those in Java, the first part of this figure, viz., up to 9 months, resembles greatly fig. 151. In both cases absorption is most active between 3 and 6 months and also the ratio of the three nutrients absorbed during this period shows a great resemblance.

Fig. 152 shows the interesting fact the uptake of nitrogen ceases practically after 12 months, while that of potash and phosphate continues at a more or less constant rate.

The uptake of some other elements in addition to those already mentioned is shown in fig. 153. The demand made upon the soil for nitrogen, phosphate, lime and magnesia appears quite moderate when compared with that for silica and potash.

An example from Mauritius representing the uptake by complete cane stools (including roots and stubble) is presented in fig. 154. In contrast with the figures relating to Java and Hawaii, the uptake of nitrogen in this figure proceeds at a fairly constant rate up to 22 months.

The rate at which the different nutrients accumulate in the cane plant and in its con-
Fig. 151.—Grams of nutrients removed by a complete cane stool. Abscissa, age of the plant in weeks. Ordinate, grams removed. Drawn after data from Koru (361).

Fig. 152.—Pounds of nutrients per acre accumulated in the above-ground part of a cane crop. After Ayres (74).
Fig. 153.—Pounds of nutrients per acre accumulated in the above-ground part of a cane crop. After Ayres (74).

Fig. 154.—Grams of nutrients removed by a complete cane stool. Abscissa, age in months; ordinate, grams removed. Drawn after data of Evans (245).
Fig. 155.—Trend of nutrients contained in millable cane (St), green tops (GT), and trash (Tr) of a cane crop in Mauritius (53). Abscissa, months. Ordinate, kilograms per arpent (0.42 ha).

The minerals accumulated in the cane plant represent the quantity of nutrients removed from the soil by a cane crop. Although detailed figures on the quantities removed in this way will be presented in the chapter on nutrition, some general considerations will be given here.

The amount of nutrients contained in the millable cane will generally increase with
increasing cane tonnage. So will the amount of nutrients contained in the total trash since one leaf is associated with each internode.

The situation in the non-millable top section of the stalk is different. Although the quantity of nutrients contained in this section and in the leaves associated with it, may change as the plant grows older, this change is so small when compared with that in the millable cane that it is almost negligible. This is nicely demonstrated in fig. 155 which shows that while the quantity of nitrogen, phosphate and potash contained in stem and trash increases at a constant rate, the amounts of the same nutrients present in the green tops remain practically uniform. As stated previously, this fact is of practical importance, since it indicates the advantage of growing heavy cane crops, for the higher the yield of millable cane, the lower the relative amount of nutrients removed by the tops.

There has been some controversy regarding the value of the juice composition as an indicator of the general nutritional status of the cane plant. Investigations in Barbados (11, 502) have shown that under the conditions of that island approximately 42 per cent of the total ash, 40 per cent of the nitrogen, 54 per cent of the phosphate, and 62 per cent of the potash present in the millable cane, are expressed in the juice. These results were obtained with different varieties and in different years, as shown in table 24. Nevertheless, the proportional distribution of the nutrients in juice and bagasse was fairly uniform.

In order to assess how far juice analyses are representative of the whole millable cane, the correlations between the analyses of juice and cane have been calculated. The correlation coefficients were high and positive, viz., +0.81, +0.81, +0.96 and +0.92 for ash, nitrogen, phosphate and potash respectively. This shows that in this experiment juice analyses, in view of the determinations made, were a good comparative indication of the millable cane as a whole (502).

In Java this subject has been studied by Honig (311) who estimated the proportion in which various nutrients are present in the tops (including green and adherent dead leaves), in raw juice and in bagasse. The results are summarized in table 25. It would appear from these results that since most of the phosphate is present in the juice, a juice analysis may give a fair indication of the phosphate content of the plant as a whole. As far as potash is concerned, the juice is less representative, and this is even more true of lime and magnesia.

The proportion of nutrients contained in below-ground and above-ground parts of a cane crop has already been mentioned. In addition to the studies discussed so far, several other investigators have examined the proportional uptake of nutrients in the various portions of the cane plant (74, 76, 119, 245, 314, 315, 359, 360, 361, 363, 365, 527, 528).

Factors influencing the chemical composition.—The chemical composition of the cane plant is greatly influenced by internal and external factors. A thorough knowledge of these effects is of importance to both the cane grower and the factory man. There is a growing tendency for the former to use the cane plant as its own indicator, as to its nutritional requirement. A correct evaluation of the data relating to the chemical composition of the cane plant is, however, only possible if the effects of internal and external conditions are taken into account.
Table 24.—Proportion of nutrients present in juice and in bagasse
After SAINT (502)

<table>
<thead>
<tr>
<th>Year and variety</th>
<th>Proportion present in juice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ash</td>
</tr>
<tr>
<td>1929 Ba 11569</td>
<td>39</td>
</tr>
<tr>
<td>B 381</td>
<td>42</td>
</tr>
<tr>
<td>B 417</td>
<td>46</td>
</tr>
<tr>
<td>1930 Ba 11569</td>
<td>39</td>
</tr>
<tr>
<td>B 381</td>
<td>42</td>
</tr>
<tr>
<td>B 417</td>
<td>43</td>
</tr>
</tbody>
</table>

Table 25.—Percentage of the total quantity of nutrients of the aerial parts of the cane plant present in juice. After HONIG (311)

<table>
<thead>
<tr>
<th>Plantation</th>
<th>P$_2$O$_5$</th>
<th>K$_2$O</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wringinanam</td>
<td>70-85</td>
<td>60-70</td>
<td>40-50</td>
<td>50-65</td>
</tr>
<tr>
<td>Semboro</td>
<td>55-75</td>
<td>70-80</td>
<td>30-50</td>
<td>50-60</td>
</tr>
<tr>
<td>Winongan</td>
<td>70-85</td>
<td>70-80</td>
<td>35-40</td>
<td>40-65</td>
</tr>
<tr>
<td>Meritian</td>
<td>40-80</td>
<td>35-65</td>
<td>30-50</td>
<td>50-60</td>
</tr>
<tr>
<td>Modjo</td>
<td>40-50</td>
<td>50-60</td>
<td>40-50</td>
<td>55-65</td>
</tr>
<tr>
<td>Klampok</td>
<td>50-65</td>
<td>40-65</td>
<td>40-50</td>
<td>45-65</td>
</tr>
<tr>
<td>Kalimati</td>
<td>50-65</td>
<td>30-40</td>
<td>35-45</td>
<td>60-70</td>
</tr>
</tbody>
</table>

The factory man is particularly interested in the chemical composition of the cane juice, since this may effect the factory results. Some varieties, e.g., Co 290, cause more difficulties in the factory than others, and the same applies to cane grown under particular conditions.

VARIETY.—Since varieties differ widely in other respects, it is only natural to expect differences also in their chemical composition. KOBUS (364) in one of his studies on this matter compared the chemical composition of thirty varieties and the results presented in table 26 show that the maximum values are 50 to 100 per cent higher than the minimum values. Consequently, the amount of nutrients removed from the soil differs considerably for different varieties. Considerable differences were also found by comparing other varieties including two indigenous Indian canes, Puri and Chunnee. The latter two had a higher ash content than the noble varieties (S. officinarum), and the same was true for a cross (No. 33 A) between noble and Indian cane (table 27). The percentages of phosphate and potash in the stem of the Indian canes were higher than in that of the noble varieties, while the reverse was true in the case of nitrogen.

In another investigation including seven different varieties, KOBUS (365) studied the
Table 26.—Varietal differences in chemical composition (as per cent of dry weight). After KOBUS (364)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Ash</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>CaO</th>
<th>Crude fiber C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C*</td>
<td>L*</td>
<td>C</td>
<td>L</td>
<td>C</td>
<td>L</td>
</tr>
<tr>
<td>35</td>
<td>3.1</td>
<td>9.4</td>
<td>.16</td>
<td>.75</td>
<td>.27</td>
<td>.36</td>
</tr>
<tr>
<td>36</td>
<td>2.6</td>
<td>9.8</td>
<td>.15</td>
<td>.62</td>
<td>.21</td>
<td>.27</td>
</tr>
<tr>
<td>POJ 36</td>
<td>3.0</td>
<td>11.7</td>
<td>.16</td>
<td>.64</td>
<td>.17</td>
<td>.32</td>
</tr>
<tr>
<td>46</td>
<td>3.5</td>
<td>11.1</td>
<td>.17</td>
<td>.82</td>
<td>.19</td>
<td>.35</td>
</tr>
<tr>
<td>POJ 49</td>
<td>3.8</td>
<td>11.6</td>
<td>.18</td>
<td>.70</td>
<td>.23</td>
<td>.32</td>
</tr>
<tr>
<td>51</td>
<td>2.7</td>
<td>10.1</td>
<td>.14</td>
<td>.64</td>
<td>.16</td>
<td>.32</td>
</tr>
<tr>
<td>66</td>
<td>2.8</td>
<td>10.3</td>
<td>.15</td>
<td>.70</td>
<td>.18</td>
<td>.34</td>
</tr>
<tr>
<td>72</td>
<td>3.4</td>
<td>14.4</td>
<td>.19</td>
<td>.78</td>
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<td>.32</td>
</tr>
<tr>
<td>96</td>
<td>3.8</td>
<td>13.2</td>
<td>.14</td>
<td>.68</td>
<td>.17</td>
<td>.36</td>
</tr>
<tr>
<td>100</td>
<td>4.0</td>
<td>10.0</td>
<td>.16</td>
<td>.62</td>
<td>.21</td>
<td>.48</td>
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<td>9.5</td>
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<td>.86</td>
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<td>.35</td>
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<tr>
<td>137</td>
<td>3.5</td>
<td>12.4</td>
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<td>.75</td>
<td>.20</td>
<td>.32</td>
</tr>
<tr>
<td>155</td>
<td>2.6</td>
<td>9.7</td>
<td>.16</td>
<td>.72</td>
<td>.19</td>
<td>.35</td>
</tr>
<tr>
<td>182</td>
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<td>9.3</td>
<td>.15</td>
<td>.71</td>
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<td>.34</td>
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<td>.17</td>
<td>.83</td>
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<td>.32</td>
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<tr>
<td>Yellow</td>
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<td>9.9</td>
<td>.17</td>
<td>.72</td>
<td>.23</td>
<td>.32</td>
</tr>
<tr>
<td>Red</td>
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<td>11.1</td>
<td>.17</td>
<td>.82</td>
<td>.24</td>
<td>.33</td>
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<tr>
<td>229</td>
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<td>10.4</td>
<td>.15</td>
<td>.79</td>
<td>.22</td>
<td>.33</td>
</tr>
<tr>
<td>234</td>
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<td>10.0</td>
<td>.16</td>
<td>.75</td>
<td>.18</td>
<td>.40</td>
</tr>
<tr>
<td>237</td>
<td>2.8</td>
<td>10.8</td>
<td>.17</td>
<td>.76</td>
<td>.19</td>
<td>.39</td>
</tr>
<tr>
<td>239</td>
<td>3.9</td>
<td>14.7</td>
<td>.19</td>
<td>.76</td>
<td>.22</td>
<td>.32</td>
</tr>
<tr>
<td>247</td>
<td>2.5</td>
<td>9.7</td>
<td>.15</td>
<td>.71</td>
<td>.17</td>
<td>.29</td>
</tr>
<tr>
<td>313</td>
<td>3.7</td>
<td>11.3</td>
<td>.19</td>
<td>.85</td>
<td>.22</td>
<td>.41</td>
</tr>
<tr>
<td>315</td>
<td>2.7</td>
<td>11.8</td>
<td>.15</td>
<td>.79</td>
<td>.21</td>
<td>.38</td>
</tr>
<tr>
<td>324</td>
<td>3.8</td>
<td>13.1</td>
<td>.17</td>
<td>.75</td>
<td>.21</td>
<td>.34</td>
</tr>
<tr>
<td>Cheribon</td>
<td>3.8</td>
<td>11.3</td>
<td>.19</td>
<td>.85</td>
<td>.20</td>
<td>.40</td>
</tr>
<tr>
<td>D 1</td>
<td>3.2</td>
<td>11.8</td>
<td>.20</td>
<td>.93</td>
<td>.13</td>
<td>.37</td>
</tr>
<tr>
<td>E 12</td>
<td>4.0</td>
<td>12.3</td>
<td>.16</td>
<td>.76</td>
<td>.21</td>
<td>.39</td>
</tr>
<tr>
<td>311/100</td>
<td>3.0</td>
<td>9.8</td>
<td>.17</td>
<td>.66</td>
<td>.22</td>
<td>.43</td>
</tr>
<tr>
<td>344/50</td>
<td>3.9</td>
<td>17.3</td>
<td>.16</td>
<td>.66</td>
<td>.21</td>
<td>.42</td>
</tr>
</tbody>
</table>

* C, cane; L, leaves.

rate at which the nutrients are absorbed. It appeared that varietal differences in this respect were small during the early three months, but that they increased to more than 100 per cent for each nutrient during the subsequent three months, while during the last months the differences were still greater. These varietal differences in the rate of uptake appeared to be associated with differences in the chemical composition of the plants.

KOBUS (362) and VAN HOUWELINGEN (314, 315) found that among the noble canes, the weak variety Black Cheribon absorbed the least mineral matter, the least phosphate and lime, but the largest amount of N per ton of cane, as compared with POJ 100, POJ 36 and Djamprok.
About the same time, Maxwell (458) described varietal differences in chemical composition of Hawaiian canes (table 18 and 20). In later years these studies have been continued in Hawaii by Moir (464), Ayres (77) and others. Some of the results reported by Ayres, as listed in table 28, show a wide variation.

In South Africa, Dymond (234) found that 12-months-old plant cane of Uba, Co 281 and especially Co 290, showed a very considerable ash increase at this age, but not POJ 2725. The ash content of Co 290 juice proved to be almost double that of POJ 2725, grown under the same conditions. Moreover, a high chlorine content was found to be associated with high potash.

Beater and Du Toit (90) did not find significant differences in the mineral constituents of the ash of Co 290, Co 281 and Co 301, except that Co 301 was noticeably lower in calcium in the stalks.

Table 27.—Varietal differences in chemical composition (in per cent of dry matter). After Konus (362)

<table>
<thead>
<tr>
<th></th>
<th>Fiji</th>
<th>Puri</th>
<th>Chunnee</th>
<th>No. 33 A</th>
<th>Cheribon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cane</td>
<td>Leaves</td>
<td>Cane</td>
<td>Leaves</td>
<td>Cane</td>
</tr>
<tr>
<td>Ash</td>
<td>2.1</td>
<td>9.1</td>
<td>3.2</td>
<td>9.8</td>
<td>3.1</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>.14</td>
<td>.60</td>
<td>.09</td>
<td>.59</td>
<td>.09</td>
</tr>
<tr>
<td>Phosphate</td>
<td>.16</td>
<td>.27</td>
<td>.23</td>
<td>.24</td>
<td>.21</td>
</tr>
<tr>
<td>Potash</td>
<td>.75</td>
<td>1.96</td>
<td>.97</td>
<td>1.73</td>
<td>.93</td>
</tr>
<tr>
<td>Lime</td>
<td>.10</td>
<td>.31</td>
<td>.09</td>
<td>.34</td>
<td>.09</td>
</tr>
</tbody>
</table>

Table 28.—Varietal differences in mineral composition (expressed in per cent of dry matter). After Ayres (77)

<table>
<thead>
<tr>
<th></th>
<th>POJ 2878</th>
<th>Badila</th>
<th>H 109</th>
<th>D 1135</th>
<th>Yellow Caledonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>Stalks</td>
<td>3.54</td>
<td>2.98</td>
<td>2.38</td>
<td>3.01</td>
</tr>
<tr>
<td></td>
<td>Tops</td>
<td>9.43</td>
<td>7.58</td>
<td>8.83</td>
<td>8.83</td>
</tr>
<tr>
<td>N</td>
<td>Stalks</td>
<td>.10</td>
<td>.17</td>
<td>.13</td>
<td>.06</td>
</tr>
<tr>
<td></td>
<td>Tops</td>
<td>.81</td>
<td>.83</td>
<td>.96</td>
<td>.62</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>Stalks</td>
<td>.26</td>
<td>.35</td>
<td>.30</td>
<td>.32</td>
</tr>
<tr>
<td></td>
<td>Tops</td>
<td>.41</td>
<td>.45</td>
<td>.54</td>
<td>.48</td>
</tr>
<tr>
<td>K₂O</td>
<td>Stalks</td>
<td>1.74</td>
<td>1.16</td>
<td>1.06</td>
<td>1.45</td>
</tr>
<tr>
<td></td>
<td>Tops</td>
<td>3.19</td>
<td>2.95</td>
<td>2.98</td>
<td>2.81</td>
</tr>
<tr>
<td>CaO</td>
<td>Stalks</td>
<td>.04</td>
<td>.06</td>
<td>.05</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>Tops</td>
<td>.32</td>
<td>.28</td>
<td>.36</td>
<td>.22</td>
</tr>
<tr>
<td>MgO</td>
<td>Stalks</td>
<td>.08</td>
<td>.10</td>
<td>.10</td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td>Tops</td>
<td>.24</td>
<td>.20</td>
<td>.29</td>
<td>.20</td>
</tr>
<tr>
<td>SiO₂</td>
<td>Stalks</td>
<td>.46</td>
<td>.58</td>
<td>.30</td>
<td>.28</td>
</tr>
<tr>
<td></td>
<td>Tops</td>
<td>3.34</td>
<td>1.94</td>
<td>2.68</td>
<td>3.48</td>
</tr>
</tbody>
</table>
In a comparison of Co 281 and Co 290, grown under Louisiana conditions Fort and Holmes (265) found that Co 290 contained more soluble ash and potash but less nitrogen and phosphorus in both the top and the stem than Co 281. The most detailed study on varietal differences in juice composition, including eight varieties, has been published by Fort and McKaig (266) and some of their results are represented in fig. 156. According to this figure, the juices of the varieties POJ 36M, POJ 234, and CP 28/19 are comparatively lower in ash and salts than those of varieties Co 281, Co 290, CP 807 and CP 28/11. From the viewpoint of soil depletion, the following characteristics were found (fig. 157): CP 28/11 and Co 290 utilize large amounts of potash per ton of cane, and the POJ varieties use the least. CP 28/11 and CP 807 contained the most phosphates per ton of cane, and the POJ varieties contained the least. Total nitrogen per ton of cane was highest for the POJ varieties, and lowest for Co 290. CP 28/11 and 28/19 were not tested.

In Barbados, Saint (502) analyzed the juices of different varieties and some of the results obtained by him are summarized in table 29 and 30. No significant differences were found between the potash, phosphoric acid or ash content of the varieties Ba 11569 and BH 10(12) when grown at similar centers and under similar climatic conditions. The varieties B 417 and B 374, however, showed a significantly higher ash content than the varieties Ba 11569 and BH 10(12). Between 30 and 40 per cent of this increase in ash was due to potash. The phosphoric acid contents of these four varieties were not significantly different. Figures obtained in different years showed that the composition of the juice is a varietal characteristic. The variety White Transparent was classified with B 417 and B 374 as having a significantly higher potash and ash content in the juice than the varieties Ba 11569, B 381 and BH 10(12) when grown under similar soil and climatic conditions. As far as nitrogen

![Fig. 156.—Relative amounts of certain non-sucrose substances in the crusher juice of different varieties grown in Louisiana. After Fort and McKaig (266).](image-url)
is concerned, White Transparent had a significantly higher percentage of this nutrient in the juice than the varieties Ba 11569, B 381 and B 417. The interesting fact was noted that the varieties B 417, B 374 and White Transparent absorb from the soil similar quantities of phosphoric acid, but different quantities of potash than the varieties Ba 11569, B 381 and BH 10(12). This possibly explains the fact that varieties may show a differential response to fertilization.

In Mauritius also considerable varietal differences in juice composition have been observed. Craig (182) reports that different cane varieties grown under identical field conditions in plots replicated as many as thirty-six times, showed marked differences in their phosphate content (table 31). The question arises whether White Tanna is a much more efficient absorber of phosphate from the soil than RP 73 or whether the requirements of White Tanna for normal growth are very much higher than those of RP 73.

Deomano (210) in the Philippines also found a wide variation in the inorganic constituents of different varieties.

AGE.—The dominant effect of age or of development of the cane plant on its chemical composition has already been discussed (p. 174–179).

EXTERNAL FACTORS IN GENERAL.—The combined effect of all external factors on the chemical composition of the cane plant becomes apparent in comparing the same variety grown in different countries or even in different fields of one plantation. A large amount of data has been collected on this subject, and in this respect the very detailed investigations of Honig (311) who analyzed one variety (POJ 2878) grown on seven plantations in Java...
CHEMICAL COMPOSITION

Table 29.—Varietal differences in juice composition in 1928. After SAINT (502)

<table>
<thead>
<tr>
<th></th>
<th>Ba 11569</th>
<th>B 417</th>
<th>BH 10 (12)</th>
<th>B 374</th>
</tr>
</thead>
<tbody>
<tr>
<td>% K₂O in juice</td>
<td>0.0747</td>
<td>0.0923</td>
<td>0.0771</td>
<td>0.0985</td>
</tr>
<tr>
<td>% P₂O₅ in juice</td>
<td>0.0384</td>
<td>0.0402</td>
<td>0.0380</td>
<td>0.0454</td>
</tr>
<tr>
<td>% ash in juice</td>
<td>0.2750</td>
<td>0.3280</td>
<td>0.2768</td>
<td>0.3284</td>
</tr>
</tbody>
</table>

Table 30.—Varietal differences in juice composition in 1929. After SAINT (502)

<table>
<thead>
<tr>
<th></th>
<th>Ba 11569</th>
<th>B 381</th>
<th>B 417</th>
<th>Transparent</th>
</tr>
</thead>
<tbody>
<tr>
<td>% K₂O in juice</td>
<td>0.0792</td>
<td>0.0737</td>
<td>0.1061</td>
<td>0.0940</td>
</tr>
<tr>
<td>% P₂O₅ in juice</td>
<td>0.0151</td>
<td>0.0155</td>
<td>0.0159</td>
<td>0.0147</td>
</tr>
<tr>
<td>% ash in juice</td>
<td>0.2571</td>
<td>0.2578</td>
<td>0.3198</td>
<td>0.3052</td>
</tr>
<tr>
<td>% N in juice</td>
<td>0.0363</td>
<td>0.0317</td>
<td>0.0343</td>
<td>0.0433</td>
</tr>
</tbody>
</table>

Table 31.—Amount of P₂O₅ in 100 ml of juice
After CRAIG (182)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Grams P₂O₅ in 100 ml of juice</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Tanna</td>
<td>0.025</td>
</tr>
<tr>
<td>RP 8</td>
<td>0.014</td>
</tr>
<tr>
<td>RP 73</td>
<td>0.006</td>
</tr>
</tbody>
</table>

are of particular interest. This author found that the concentrations of various nutrients in the plant and its constituent parts are fairly characteristic of the conditions under which the cane was grown.

SOIL TYPE.—The effect of soil on chemical composition of cane is generally recognized, but the number of experiments in support of this view is rather limited. Data presented by HONIG (311), CRAIG (182) and others indicate that on an average the amount of nutrients in the plant is lower, the more deficient the soil is in the elements concerned. BORDEN (106) found even a direct relationship between the available phosphate and potash in the soil, and the concentration of these nutrients in the crusher juice.

The same investigator (107, 114) conducted pot experiments with cane plants in which all factors but the soil were kept uniform. The design of these experiments has been described earlier (p. 120). It was found that the Makiki soil had produced cane with considerably greater concentrations of mineral plant nutrients than the Manoa soil and
that also the percentages of phosphate and potash in the crusher juices of the former were greater. AYRES (77) reports that the concentrations of phosphate and potash were from 1.5 to 3 times as great in the plants grown in Makiki soil, as in those grown in Manoa soil.

**Fertilizers.**—A considerable amount of research has been devoted to the effect of fertilizers on the chemical composition of sugarcane, but the results obtained differ widely from place to place. This was to be expected since the effect of fertilizers is greatly influenced by other factors, e.g., climate, fixation of fertilizers by the soil, etc. Generally, the application of increasing amounts of a nutrient results in an increased concentration of this nutrient in the different parts of the cane plant, but exceptions to this rule are not rare. In addition to this effect, the application of one element generally results in changes in the concentrations of other elements. This is particularly striking in plants deficient in one nutrient. In such cases the concentration of other elements is often relatively higher than in plants adequately supplied with nutrients.

There is no need to analyze the results of the many experiments at this time since most of them will be dealt with in the chapter on nutrition. Suffice it to say that the relationships between fertilization and chemical composition of the cane plant have been studied in Java (314, 360, 363), Hawaii (77, 114, 286, 464, 527), Mauritius (56, 57, 182), Barbados (502), Louisiana (316, 433), South Africa (234) and elsewhere.

**Climate and Season.**—The chemical composition of the cane plant may vary from year to year, even if the same variety is grown on the same plantation. An example is given in table 32, which shows considerable differences in phosphate content between the year 1928/29 and the two other years; the differences in the other constituents are relatively small. It is interesting to note that the relative order in which the three varieties stand to one another in respect to the percentages of potash, phosphate, ash and nitrogen in the juice, remains the same from year to year, and is apparently unaffected by climatic changes (10, 502).

The amount of rainfall seems to play an important role, since SAINT (10) found a positive correlation of about 0.50 between the rainfall and the concentration of phosphate in juice. No correlation was found between the rainfall and the percentage of potash in juice.

Seasonal fluctuations in the chemical composition occurring in the course of the development of a crop have been reported from Mauritius by EVANS (245) and from Hawaii by AYRES (74, 75, 76) and others.

The effect of climate has been demonstrated very clearly by growing cane plants in pots located in different climates of Hawaii. Table 33 gives the results obtained during five subsequent crops which show that the plants grown at Manoa have a significantly greater potash concentration in crusher juice than those grown at Makiki. The differences in the phosphate content are not significant. Other examples of the effect of climate on the chemical composition of sugarcane have been reported by BORDEN (107), AYRES (77) and others.

**Water.**—It has been stated earlier that differences in the amounts of irrigation water applied result in differences in root distribution. With inadequate irrigation, the surface
soil tends to lose part of its moisture, and root activity will become more and more restricted to the lower soil layers. Since the quantities of nutrients available in the subsoil may differ greatly from those in the surface soil, an inadequate water supply may indirectly affect the absorption of nutrients and their concentration in the cane plant.

**PESTS AND DISEASES.**—Any injury to the cane plant may affect its chemical composition. Such a case has been reported from Louisiana, where McKAIG and FORT (432) observed that extreme damage by the sugarcane borer and by red rot were associated with marked differences in the concentration of various nutrients in the plant.

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### CHEMICAL COMPOSITION

Table 32. *Effect of season on juice composition. After SAINT (502)*

<table>
<thead>
<tr>
<th>Year</th>
<th>Variety</th>
<th>% K₂O</th>
<th>% P₂O₅</th>
<th>% Ash</th>
<th>% N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1927/28</td>
<td>B 11569</td>
<td>0.0807</td>
<td>0.0382</td>
<td>0.2832</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B 417</td>
<td>0.0965</td>
<td>0.0399</td>
<td>0.3345</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B 281</td>
<td>0.0817</td>
<td>0.0401</td>
<td>0.2795</td>
<td></td>
</tr>
<tr>
<td>1928/29</td>
<td>B 11569</td>
<td>0.0753</td>
<td>0.0154</td>
<td>0.2473</td>
<td>0.0363</td>
</tr>
<tr>
<td></td>
<td>B 417</td>
<td>0.0945</td>
<td>0.0162</td>
<td>0.3003</td>
<td>0.0333</td>
</tr>
<tr>
<td></td>
<td>B 381</td>
<td>0.0709</td>
<td>0.0146</td>
<td>0.2567</td>
<td>0.0309</td>
</tr>
<tr>
<td>1929/30</td>
<td>B 11569</td>
<td>0.0838</td>
<td>0.0398</td>
<td>0.2381</td>
<td>0.0396</td>
</tr>
<tr>
<td></td>
<td>B 417</td>
<td>0.1089</td>
<td>0.0413</td>
<td>0.2944</td>
<td>0.0375</td>
</tr>
<tr>
<td></td>
<td>B 381</td>
<td>0.0876</td>
<td>0.0420</td>
<td>0.2441</td>
<td>0.0322</td>
</tr>
</tbody>
</table>

### Table 33. *Climatic effect on juice composition. After BORDEN (114)*

<table>
<thead>
<tr>
<th>Crop</th>
<th>Year</th>
<th>% P₂O₅ in juice at</th>
<th>% K₂O in juice at</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Makiki</td>
<td>Manoa</td>
</tr>
<tr>
<td>Plant crop</td>
<td>1935</td>
<td>.062</td>
<td>.071</td>
</tr>
<tr>
<td>1st Ratoon</td>
<td>1936</td>
<td>.056</td>
<td>.055</td>
</tr>
<tr>
<td>2nd Ratoon</td>
<td>1938</td>
<td>.064</td>
<td>.064</td>
</tr>
<tr>
<td>3rd Ratoon</td>
<td>1939</td>
<td>.067</td>
<td>.073</td>
</tr>
<tr>
<td>4th Ratoon</td>
<td>1940</td>
<td>.077</td>
<td>.081</td>
</tr>
</tbody>
</table>
CHAPTER 12
NUTRITION

NITROGEN

General.—Although nitrogen constitutes only a fraction of one per cent of the total dry weight of a mature sugarcane plant, it plays a role as important as carbon, hydrogen and oxygen, which, together, form more than 90 per cent of the dry matter. While carbon, hydrogen and oxygen are supplied by nature in the form of air and water, nitrogen has, at least partly, to be provided by man, and thus constitutes a major part of the plantation's fertilizer budget. Since nitrogen fertilization is one of the most important problems, and an item of considerable expense, it is necessary to be familiar with the function of this nutrient in the cane plant, with its effects, and with the interaction between nitrogen and various internal and external factors.

The main natural source of nitrogen is the soil. Irrigation water may also contain considerable quantities of nitrogen, especially when this water is rich in fine silt as is, for instance, the case in Java. Other natural sources of minor importance are the nitrogen compounds present in the air in the form of ammonia, nitrates and nitrites. They originate from the decay of organic matter, and from electrical discharges during thunderstorms; they are brought down to the soil by rainfall. When the natural sources are inadequate, nitrogen has to be supplied in the form of fertilizers.

Nitrogen is present in plants in different forms and the ratio of the latter may vary considerably in different plants. Thus, three types of plants are usually distinguished: nitrate plants, amide plants and ammonia plants, depending upon whether nitrates, amides or ammonia are prevalent respectively. Sugarcane belongs to the amide group (245, 287).

It was observed by Evans (242, 245) that the liquid exuded from cane roots contains nitrates, ammonia and even nitrites, and it is believed that most of the nitrogen is absorbed in the two former forms.

According to Cornelison and Cooper (178, 179) nitrogen in the cell colloids is largely present in the ammoniacal form, and no nitrate or nitrite nitrogen forms have been found by these investigators, either by microchemical or analytical work in normally field-grown canes in Hawaii.

Nitrogen is transported from the roots to the leaves, where the process of nitrogen assimilation takes place. During this process, nitrogen is transformed into protein substances which constitute an important part of the protoplasm. Nitrogen assimilation in the leaves takes place under the influence of light as is the case with carbon assimilation. The role of light in nitrogen assimilation, however, is most likely an indirect one, since it has been shown in various plants that nitrogen assimilation can take place in the dark, even in roots, provided carbohydrates are available in adequate quantity. It seems that not light itself but the carbohydrates produced under its influence are essential for the synthesis of proteins.
The way in which nitrogen is absorbed and translocated has been demonstrated in Hawaii by the administration of heavy nitrogen ($N^{15}$) to sugarcane (54). A one-year old plant of the variety 32-8560, growing in a culture solution, was fed with the tagged nitrogen. All nitrogen was taken up by the fifth day and the plant was harvested at the seventh day. An analysis showed that within seven days the tagged nitrogen had moved to every part of the plant. The nodes were richer than the internodes, the younger cane richer than the older, and the lateral shoot (lala) much richer than the node on which it was growing. The sheath of the lateral shoot appeared to be richest of all parts above ground. Curious to relate, the new nitrogen was even present in the oldest joints. These results indicate that nitrogen absorbed by the roots is mainly transported to the young organs of the plant, but that part of it is directed to older, full-grown portions which, according to present knowledge, are already adequately supplied with nitrogen or are even yielding nitrogen to younger organs.

In another experiment, thorough mixing of the tagged nitrogen throughout the plants was found in four-month-old 37-1933 and 32-8560 seven days after feeding. Even in the oldest green leaves (seven to nine inclusive) the new nitrogen constituted from 8 to 12 per cent of the total. Since these leaves are no longer growing and may be actually losing nitrogen, this is very likely an exchange. In the most rapidly-growing regions, almost one-third of the total nitrogen was derived from the recent feeding. The amide nitrogen fractions were richest, being in some cases as much as two-thirds tagged nitrogen (55).

Distribution in the plant.—Clements et al (163, 172, 173) have studied the distribution of nitrogen in the cane plant and some of their results are presented in table 34 and 35. These records were obtained by cutting the millable cane into sections of three internodes beginning at the bottom of the cane and continuing upward to the point where leaves were still attached. These sections of the stem were numbered acropetally. The bottom leaves on the cane, up to and including leaf no. 7 (counting the emerging spindle leaf as no. 1) were removed and separated into sheaths and blades. The stem, to which these leaves were attached, was cut off below the node of leaf no. 6. This section of the stem is referred to as the green-leaf cane and the corresponding sheaths and blades are the green-leaf sheaths and green-leaf blades, respectively. The stem associated with the leaves 6, 5, 4 and 3 being the region of rapid elongation, was cut off below the node carrying leaf no. 2, and is referred to as the elongating cane. The corresponding sheaths and blades are referred to as the elongating (cane) sheaths and the elongating (cane) blades, respectively. The remaining material, including the meristematic tip of the stem and the leaves nos. 2, 1 and younger, was divided into two parts: a lower one comprising 5 inches of the bottom of this material, referred to as meristematic material, and the remaining portion called spindle cluster. Samples consisting of five selected plants representative of the major stand were used for each monthly analysis.

Waipio (table 34) is characterized by bright days, while at Kailua, a few miles away, light intensity is considerably lower. A study of table 34 and 35 shows in the first place the great differences in nitrogen content which exist within a cane plant. The highest concentration of nitrogen occurs in the meristematic tissues. This is in harmony with the results obtained.
by Went (595) who found that albumin is largely concentrated in the vegetation point of the stalk (fig. 158). As already reported previously (p. 64), protein in the germinating buds is also concentrated in the growing point and the youngest leaves. Table 34 and 35 show that as far as nitrogen concentration is concerned, the elongating cane follows next to the meristematic tissue, thus indicating a close relationship between growth and nitrogen content. Next in order are the elongating blades, the spindle cluster, and the green-leaf blades. It is interesting to note that each tissue has a rather characteristic nitrogen level. This is particularly striking in the case of the leaves where the nitrogen content of the blades is more than double that of the sheaths. The nitrogen content of the internodes of the Waipio cane is highest at the top and gradually decreases toward the base, where it approaches 0.1 per cent. The internodes of the cane grown under the less favorable conditions of Kailua differ in two respects: first, the percentage of nitrogen is considerably higher, and, second, the gradient in the nitrogen content along the stem is less marked than in the Waipio cane. This interesting effect of climate on nitrogen content will be discussed under another heading.

Table 34.—Distribution of nitrogen in plants grown at Waipio (N as % dry weight). After Clements (163)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Meristem</td>
<td>3.70</td>
<td>3.06</td>
<td>3.09</td>
<td>2.79</td>
<td>2.96</td>
<td>2.79</td>
<td>2.57</td>
<td>2.35</td>
<td>3.22</td>
<td>3.04</td>
<td>2.46</td>
<td>2.90</td>
<td>2.06</td>
<td>2.63</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spindle cluster</td>
<td>1.23</td>
<td>1.06</td>
<td>1.14</td>
<td>0.96</td>
<td>1.09</td>
<td>0.99</td>
<td>0.91</td>
<td>0.94</td>
<td>1.02</td>
<td>1.05</td>
<td>0.89</td>
<td>0.91</td>
<td>0.78</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elongating blades</td>
<td>1.24</td>
<td>1.28</td>
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Table 36 provides another example of the distribution of nitrogen in the cane plant. The first column of this table relates to plants grown in complete nutrient solution. The amounts of nitrogen in the top portions of these plants are very similar to those produced under field conditions (table 34 and 35). The nitrogen of the mature internodes is, however, about ten times higher than that of plants grown under field conditions. This indicates that the plants in the complete nutrient solution have absorbed much more nitrogen than they could utilize. In the minus-nitrogen series, the deficiency is shown throughout the plant, although the plant maintains a disproportionate amount of nitrogen in its youngest organs at the expense of the nitrogen in the mature internodes. The interpretation would be that it removes nitrogen from the old tissues and uses it in the young ones (172).

According to CORNELISON and COOPER (180), nitrogen in the stem is stored or lodged in the tissues of the node immediately under axillary buds, root primordia, and to a lesser extent in the protoplasm of the storage cells. With increasing age, the nitrogen material in the node complex diminishes more rapidly than in the internode, which indicates that the node is the place in which the greater portion of the nitrogen in the stems is temporarily

Table 35.—Distribution of nitrogen in plants grown at Kailua (N as % dry weight). After CLEMENTS (163).

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stored. This concept is in general harmony with the results of experiments on the temporary storage and the translocation of heavy nitrogen mentioned before. Evidence indicates that the growing point may be fed from many other locations and according to CORNELISON and COOPER the analytical data all point to the conclusion that the growing point of the stem exercises a preferential demand as far as water and food supply are concerned. Under shortage of water or nutrient materials, the remainder of the stem below the top will supply the lacking material to the extent of its ability (180).

Migration.—That the younger parts of the plant draw upon the nitrogen of the maturing internodes is also indicated by the fact already mentioned that the nitrogen content of the internodes decreases gradually with increasing age. Apparently, the maturing joints release part of their nitrogen and the latter is translocated to younger tissues for reutilization.

The same applies to the aging leaves. VAN HOUWELINGEN (314) reported that dry leaves had lost two-thirds of their nitrogen content compared with green leaves, which is in harmony
Table 36.—Distribution of nitrogen in % of dry matter. After Clements, Martin and Moriguchi (172)

<table>
<thead>
<tr>
<th>Plant part</th>
<th>Compl.</th>
<th>-N</th>
<th>-P</th>
<th>-K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle cluster</td>
<td>.76</td>
<td>.70</td>
<td>.86</td>
<td>1.12</td>
</tr>
<tr>
<td>Green-leaf cane blades</td>
<td>1.02</td>
<td></td>
<td>.92</td>
<td>.94</td>
</tr>
<tr>
<td>Elongating cane blades</td>
<td>.95</td>
<td>.78</td>
<td>.92</td>
<td>1.20</td>
</tr>
<tr>
<td>Green-leaf cane sheaths</td>
<td>.33</td>
<td>.33</td>
<td>.28</td>
<td>.42</td>
</tr>
<tr>
<td>Elongating cane sheaths</td>
<td>.32</td>
<td>.33</td>
<td>.37</td>
<td>.51</td>
</tr>
<tr>
<td>Elongating cane and meristem</td>
<td>1.46</td>
<td>.88</td>
<td>2.10</td>
<td>1.32</td>
</tr>
<tr>
<td>Green-leaf cane</td>
<td>.68</td>
<td></td>
<td>.94</td>
<td>.74</td>
</tr>
<tr>
<td>Top internodes</td>
<td>.91</td>
<td>.87</td>
<td>.63</td>
<td></td>
</tr>
<tr>
<td>3rd 3 internodes</td>
<td>1.15</td>
<td>1.02</td>
<td>.66</td>
<td></td>
</tr>
<tr>
<td>2nd 3 internodes</td>
<td>1.13</td>
<td>.25</td>
<td>1.12</td>
<td>.60</td>
</tr>
<tr>
<td>1st 3 internodes</td>
<td>1.06</td>
<td>.13</td>
<td>1.37</td>
<td>.51</td>
</tr>
</tbody>
</table>

with observations of Clements and Moriguchi (173) who found that a dead leaf still attached to the plant contains about one-third to one-half the nitrogen which it contained when fully active. These large differences may be partly due to leaching (p. 180). There is, however, strong evidence that part of these differences are caused by nitrogen migrating back to the stem before the leaves become physiologically inactive (78, 490). Hartt (286), however, was unable to detect any migration of nitrogen from dying leaves.

Apart from the fact that the nitrogen content of the individual internodes and leaves decreases as these organs mature or die, table 34 indicates also a slight decrease in the meristem and the spindle cluster as the plants age. The latter organs are continually renewed and consequently do not age. But the plant as a whole does. It seems that two processes are involved in the decrease of nitrogen concentration. On the one hand, each organ shows a decrease in nitrogen concentration as it develops from the embryonic state to full maturity or death, and superimposed is a general decrease in nitrogen concentration associated with the aging of the plant as a whole.

Trend of uptake.—The trend of nitrogen uptake in different varieties under various conditions has been studied by many investigators (78, 121, 122, 125, 127, 173, 180, 198, 199, 245, 252, 315, 361, 614). It has been stated previously that potassium is absorbed at a much greater rate than nitrogen (fig. 151, 152, 154, 155). Since the general trend of nitrogen uptake was presented earlier (p. 183), it will suffice to discuss here some particular features associated with nitrogen absorption.

There is, in the first place, the fact that uptake of nitrogen and production of dry substance do not run parallel. Koubus (361) was perhaps the first to observe that during the early stages of development of the cane plant the uptake of nitrogen is ahead of the production of dry substance. This phenomenon has been corroborated by many other investigators (43, 78, 122, 173, 315, 484, 614). A nice illustration of this fact is presented in fig. 159, which relates to cane grown in pots and supplied with a limited amount of nitrogen fertilizer. The upper graph shows that the maximum amount of nitrogen is absorbed,
within a period of 90 days. The lower figure shows that growth during those 90 days yields less than one-half of the ultimate dry weight. While nitrogen uptake is completed at an age of 90 days, growth continues till an age of 161 days. The fact that growth still proceeds long after nitrogen absorption has ceased, indicates that the cane plant is able to store considerable quantities of nitrogen during its early stages of development, a phenomenon which has an important bearing on the practice of nitrogen fertilization. The storage is clearly demonstrated in the lower half of fig. 159 which shows that the concentration of nitrogen in both aerial and below-ground parts reaches a maximum at a time when the plants are only one month old and that thereafter a sharp decline occurs.

In addition to fig. 159, which refers to plants grown under the particular conditions of a pot experiment and of a limited supply of nitrogen fertilization, fig. 160 gives the result of plants grown under field conditions and excessively supplied with nitrogenous fertilizer, namely 216 pounds of nitrogen per acre applied as indicated by the arrows. The uptake is very rapid during the first months and reaches a maximum on November 3, when the plants are approximately 10 months old. Thereafter the amount of nitrogen contained in the plant remains more or less constant. Growth, however, continues after November 3 for almost

![Diagram](image-url)

**Fig. 159.**—Nitrogen absorption, production of dry matter, and nitrogen concentration in cane plants grown in pots with a limited supply of nitrogen fertilizer. Note the storage of nitrogen in the plants during the early 90 days of development. After Yuen and Borden (614).
NUTRITION

1,6.0 tit

Fig. 160.—Growth and nitrogen uptake showing that the uptake of nitrogen (curve C) is ahead of the production of fresh matter (curve B). Curve C represents the pounds of nitrogen per acre contained in the above-ground parts of the crop, and is read off the inside right-hand ordinate. Arrows on curve C represent time of nitrogen applications in amounts indicated per acre. Curve B represents the total tonnage per acre of millable cane and green portions and is read off the outside right-hand ordinate. Curve A when read off the left-hand ordinate represents the accumulating volume of the stem per pilot plant; when read off the outside right-hand ordinate, it represents the accumulating tonnage of millable cane per acre. After CLEMENTS and MORIGUCHI (173).

12 months and the cane tonnage is doubled during this period. Since the total amount of nitrogen contained in the plant remains practically constant, it follows that the concentration of nitrogen gradually decreases.

Under the conditions prevailing in Java, where cane is harvested at an average age of 14 months, it has been shown by KOBUS (361) that nitrogen absorption is most rapid up to 8 months of age, followed by a decrease in uptake. Thousands of carefully controlled field experiments have proved that in Java the total amount of sulphate of ammonia required by the crop, should be applied within two months after planting.

Pot experiments in Hawaii (43) have indicated that cane plants are able to store up within their tissues a sufficient supply of nitrogen, when they are only four months old, to enable them to give yields at 14 months that are fully comparable with plants which received later applications. The correct timing of nitrogen fertilization depends on many factors, e.g., the nitrogen requirement of the crop, the age at which the cane is harvested, etc. Thus BORDEN (122) found in experiments in Hawaii that from a total amount of 100 pounds of nitrogen per acre for the crops harvested at 18 months or younger, the best yields were obtained when the total amount was applied within 4 months, but when the crops were harvested at an age of more than 18 months or more, completion of the nitrogen fertilization at 6 months gave the best results. When, however, 220 pounds of nitrogen were
applied, the best sugar yields after 12 months were obtained when part of this amount was held off until 11 months.

The effect of the concentrations of nutrients on the development of cane plants grown in sand-water culture solutions has been investigated by Van den Honert (309). He found that for the normal development of cane plants, the concentration required for nitrogen is higher than that for potassium and much higher than that for phosphate (fig. 161). When nitrogen is the limiting factor for growth, a cane yield of 50 per cent of the optimum requires about 21 mg N\textsubscript{2}O\textsubscript{5} per liter.

The accumulation of nitrogen in the various organs of a plant is shown in fig. 162 which relates to cane grown under field conditions in Hawaii. The interesting point in this figure is that during the first 6 months the bulk of nitrogen is stored in the green leaves. At the age of 6 months, these parts of the plant have largely completed their development and the total amount of nitrogen contained in these organs does not increase materially. The stalks and the dry leaves continue to accumulate nitrogen at a more or less uniform rate until harvest. An integration of the individual curves results in the absorption curve of the entire plant which is characterized by a rapid absorption during the first 6 months, followed by a lower absorption rate. During the first 6 months, all organs accumulate nitrogen while during the subsequent months nitrogen accumulation in the green top is practically nil. The latter phenomenon is also obvious in fig. 155 relating to Mauritius cane.

Deficiency symptoms.—The symptoms associated with nitrogen deficiency have been described by various investigators (43, 172, 309, 442, 448, 449, 469, 477). The leaves of plants lacking nitrogen exhibit a yellow-green color, later turning yellow and both the tip and the margin of the leaves dry off prematurely. The leaves of nitrogen-deficient plants dry earlier than the leaves of normally fed plants. Moreover, the leaves are very rigid,
which is associated with a lower moisture content. The color of the older leaves turns to reddish purple. The leaves appear to originate from a common point, a phenomenon associated with the fact that the length of the upper internodes is reduced in plants deficient in nitrogen. The growth of the primary shoot and leaves is depressed. The ratio of width to length of the leaves and the ratio of diameter to length of the internodes are smaller than in normal plants, which means that the leaves are narrower and the stems thinner. Tillering is reduced.

The development of roots is generally less affected by nitrogen deficiency and consequently the shoot root ratio is decreased. The chemical composition is markedly affected. Sucrose content increases and the concentration of reducing sugars in the stem becomes lower. The ash content is higher in both leaves and stems, while the nitrogen content is lower.

Effects of nitrogen.—Nitrogen influences the composition and development of the cane plant in many respects, and a thorough knowledge of these effects is of economic importance. The sugar industry owes its present knowledge on this subject largely to the outstanding research performed in Hawaii, with which the names of DAS, BORDEN, CORNELISON, CLEMENTS, KUBOTA, COOPER and others are closely associated. The pioneer work was done by DAS and CORNELISON (198, 199) in an exhaustive study covering all major effects of nitrogen on the cane plant. The knowledge thus obtained was considerably extended by BORDEN (116, 121, 122, 123, 125, 127, 128, 129), who, besides other experiments, grew and examined crops during five years, and collected a unique mass of interesting data. The effect of nitrogenous fertilizers on the yield of cane and sugar of one-year crops has been most intensively studied in Java by means of more than six thousand carefully conducted field experiments, among them more than four thousand with POJ 2878. The results of the Java experiments have been summarized and analyzed in great detail by GEERTS (269, 272), DEMANDT (206, 209) and others.

NITROGEN UPTAKE.—Increasing applications of nitrogen result in an increased uptake of
nitrogen by the cane plant. Recovery of nitrogen in the total dry weight is consequently positively related to the amounts of nitrogen applied (116, 121, 122, 125, 198, 199, 359). An example is given in fig. 163 which relates to the nitrogen present in the stalks and the green leafy tops of a biennial crop in Hawaii. The decline in most of the graphs after 9 months is due to the fact that the nitrogen contained in the trash was not included.

**PER CENT NITROGEN RECOVERY.**—Only part of the nitrogen applied to the soil reaches the cane crop (116, 121, 122, 125, 127, 198, 199). The percentage of nitrogen recovered by a crop from the nitrogen fertilizer applied has been determined in Hawaii by means of field experiments in which no nitrogen, and 40, 100, 160 and 220 lb of nitrogen were applied per acre. By deducting the nitrogen present in the crop of the unfertilized plots from the amounts found in the different nitrogen-fertilized crops, the recoveries of the amounts of nitrogen that were actually applied were estimated. In one experiment, 46, 59 and 52 per cent were recovered from the 100-, 160-, and 220-pound treatments respectively (122). In another experiment (127), the figures were 44, 65, 72 and 70 per cent for the 40-, 100-, 160-, and 220-pound treatments. Since the underground parts of the crop and the trash were not taken into account in these experiments, the per cent recovery in the complete crop should be considerably higher.

**NITROGEN CONTENT.**—An increase in the amounts of nitrogen applied, is immediately reflected in an increase of the nitrogen concentration of all parts of the cane plant and particularly in the foliar tissues and the tissues adjacent thereto (116, 121, 122, 125, 127, 180, 198, 251, 615). An example of this quick response is presented in fig. 164 showing the result of four successive applications of nitrogen on the nitrogen percentage in total dry weight. This figure also shows nicely the gradual decrease of nitrogen content as the plant grows older, viz., from approximately one per cent at three months of age to some two-tenths of one per cent at 27 months of age.

![Fig. 163](image-url)
Another example is represented in fig. 165 which gives the nitrogen content of plants supplied with different amounts of nitrogen. This figure shows that the differences in nitrogen content resulting from the different treatments tend to level down as age of the cane increases.

The effects of increasing nitrogen applications on the concentration of nitrogen in the stem resemble largely those mentioned for the plant as a whole.

The same applies to the active leaves (fig. 166) and the crusher juice (fig. 167). Both...
show the greatest response shortly after nitrogen has been applied, and it is interesting to note that the differences between the different treatments tend to diminish as the plants grow older.

The effect of deficiencies of nitrogen, phosphorus, potassium and other elements on the nitrogen content of the cane plant has also been studied in Hawaii (172) and some of the results obtained are presented in table 36.

The fact that the increases in nitrogen application are so clearly reflected in the nitrogen content of the whole plant, as well as in its separate organs, has induced various investigators to search for one or more index tissues which would give reliable information about the nitrogen status of a growing cane crop. Since the detailed results of these investigations will be dealt with in a subsequent volume, it will suffice here to state that the active leaves or parts of them have given very promising results.
Moisture Content.—Cane which is amply supplied with nitrogen fertilizer is more juicy than cane grown under poor nitrogen conditions. This field observation has been fully corroborated by chemical analyses (108, 116, 121, 122, 125, 127, 171, 179, 180, 198, 199) and an illustration of this effect is presented in fig. 168. The abnormal increase in moisture content of the unfertilized plots after May is due to the development of non-millable suckers. Each application of nitrogen is reflected in an immediate increase in succulence. In this respect, moisture content follows the same pattern as nitrogen content (fig. 164).

An increased moisture content means a dilution of juice and thus one of the various ways in which nitrogen affects the quality of juice is indicated. In the case of fig. 168, the differences in moisture content between the different treatments tend to diminish as the cane grows older, and under favorable conditions they may almost disappear. Under certain conditions, however, the succulence induced by high nitrogen applications is more or less lasting, and the tissues formed under these conditions may be permanently impaired for sugar storage (180).

The close relationship between nitrogen concentration and moisture content in sugar-cane leads to some interesting consequences, as has been pointed out by Clements and Kubota (171). It implies that plants growing under conditions of inadequate nitrogen supply, both from soil nitrogen and fertilizer, are likely to have a low moisture content whatever the moisture conditions of the soil may be. It should even be possible to dry out a crop during wet weather by simply reducing the nitrogen applications. This fact is of importance to cane growers in high-rainfall areas, who might find it advantageous to ripen their cane off by reducing the application of nitrogen (171).

The way in which nitrogen affects the moisture content is only partly understood. For some time it was held that application of nitrogen would promote the intake of salts and that the higher salt concentration in the tissues would account for the higher moisture content. But experiments have proved that increasing applications of nitrogen actually
decrease the intake of salts, with the exception of calcium (179, 180). The increased absorption of calcium is of particular interest since this element has the property of swelling cellulose, which process is associated with the absorption of moisture. Hence, part of the increased water content in cane supplied with nitrogen may be held in this condition (180).

CORNELISON and COOPER (179) obtained evidence that even the water holding capacity of the non-living parts of the cell, viz., the cell wall, may be affected. They found that dead, oven-dried material re-absorbed moisture from the air roughly in the relative proportions that were held by the tissues during life. This may explain, at least partly, the fact that under certain conditions nitrogen applications may increase the water holding capacity of the cells permanently.

Fiber content.—The effect of increasing nitrogen application on fiber content is almost the reverse of that on moisture content. An example of this effect is presented in fig. 169 showing how each application of nitrogen is reflected in a decreased fiber content.

Stalk population.—The effect of additional applications of nitrogen on the trend of the stalk population depends largely on the conditions under which cane is grown.

In Java, where the cane is harvested at an average age of 14 months, increasing applications of nitrogen result in an increased number of millable stalks, till a maximum is reached beyond which additional nitrogen dressings give no further increment in the number of millable stalks.

In biennial crops, the effect is somewhat more intricate as has been proved by Hawaiian workers (121, 122, 125, 127, 180, 198). The rate of mortality during the second year runs so high that at harvest often only a fraction of the first-year stalks are millable. On the other hand, suckers develop profusely, many of them developing into millable stalks and thus making up for the loss of first-season stalks. An example of this partial renewal of the crop during its second year's growth is presented in table 37 and 38, showing a general shift from first-year stalks to second-year suckers. About two-thirds of the primaries in table 37 died in the course of the second year. POJ 2878 is particularly ill-famed in this respect and one case has been reported from Hawaii in which at 24 months of age not a single first-year stalk was left, the entire crop consisting of second-year suckers (180).
Fig. 170.—Effect of increasing rates of nitrogen applications on the stalk population during the second year of a biennial crop in Hawaii. After BORDEN (127).
Table 37.—Changes in stalk population during the second year of growth in a biennial crop. After Borden (122)

<table>
<thead>
<tr>
<th>Age</th>
<th>No. of sound stalks per foot of row</th>
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<tbody>
<tr>
<td></td>
<td>Primaries</td>
</tr>
<tr>
<td>12 months</td>
<td>3.47</td>
</tr>
<tr>
<td>15 ”</td>
<td>3.19</td>
</tr>
<tr>
<td>18 ”</td>
<td>2.71</td>
</tr>
<tr>
<td>21 ”</td>
<td>2.19</td>
</tr>
<tr>
<td>24 ”</td>
<td>1.65</td>
</tr>
<tr>
<td>27 ”</td>
<td>1.09</td>
</tr>
</tbody>
</table>

Table 38.—Changes in stalk population during the second year of growth in a biennial crop. After Borden (127)

<table>
<thead>
<tr>
<th>No. of stalks per foot of row</th>
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</thead>
<tbody>
<tr>
<td>18 mos</td>
</tr>
<tr>
<td>Sound primaries ...</td>
</tr>
<tr>
<td>Dead primaries ...</td>
</tr>
<tr>
<td>Millable suckers ...</td>
</tr>
<tr>
<td>Non-millable suckers</td>
</tr>
<tr>
<td>Dead suckers</td>
</tr>
<tr>
<td>Total ...</td>
</tr>
</tbody>
</table>

The effect of nitrogen on the stalk population in a biennial crop is demonstrated in fig. 170. The upper part of this figure shows that at an age of 12 months, increasing nitrogen applications have resulted in an increased number of living primary stalks consisting of millable cane, and that the effect of the first two dressings was greater than that of the last increment of nitrogen. Thus far, the situation is in harmony with the results obtained in one-year crops in Java. During the second year, however, the differences gradually level down and at an age of 27 months they have practically disappeared. The explanation is given by the next lower set of graphs which shows that increasing the rate of nitrogen dressings results in an increased mortality of primary millable stalks.

The next set of graphs shows that nitrogen exerts a beneficial effect on the development of second-year suckers into millable cane. Thus, summarizing these results, it can be stated that, although nitrogen has a beneficial effect on the number of primary millable stalks during the first year, this effect is offset during the second year by an increased rate of mortality. The ultimate beneficial effect of nitrogen is due to the increased number of second-year millable suckers. It will be evident that the ultimate effect of nitrogen on the millable stalks is practically the same in one-year and in two-year crops, viz., an increase in their number. But the way in which this result is obtained is fundamentally different: in the
case of one-year cane the number of first year millable stalks is increased, whereas in a two-
year crop the beneficial result is wholly derived from an increased number of second-year
millable suckers.

The fact that increasing the rate of nitrogen dressings exerts an adverse effect on juice
quality by diluting the juice, has already been mentioned. Fig. 170 shows that the increasing
number of dead stalks constitutes another adverse factor which is of particular importance
when cane is harvested mechanically, since in that case all dead stalks will reach the mill.

EVANS (251) has reported on the effect of a late heavy application of nitrogen on a first
ratoon crop in Mauritius. The control plants were given the normal estate treatment, \textit{viz.},
a dressing of 60 kg ammonium sulphate, 40 kg potassium nitrate and 75 kg phosphatic
guano per acre soon after the harvesting of the plant crop in September. The treated plants
received an additional application of 500 kg ammonium sulphate per acre in the following
February. At harvest the treated plots had about 20 per cent more millable stalks than the
controls. This increase in millable stalks was attributable partly to the increased production
of new stalks after the extra application of nitrogen and partly to a greater rate of survival
among the shoots thus formed.

SUGARS.—Hawaiian workers (116, 121, 122, 125, 127, 179, 180, 198) have found that
the content of both reducing sugars and sucrose in the cane plant is markedly affected by
the quantity of nitrogen applied. Higher applications result in higher percentages of reducing
sugars in total dry weight of the plant (fig. 171). This effect tends to diminish as the cane
grows older and it may even disappear, as in the case represented in table 39.

<table>
<thead>
<tr>
<th>Lb N per acre</th>
<th>6 mos</th>
<th>9 mos</th>
<th>10 mos</th>
<th>11 mos</th>
<th>12 mos</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>5.68</td>
<td>2.52</td>
<td>2.07</td>
<td>1.78</td>
<td>–</td>
</tr>
<tr>
<td>100</td>
<td>8.39</td>
<td>3.84</td>
<td>2.42</td>
<td>2.44</td>
<td>2.25</td>
</tr>
<tr>
<td>160</td>
<td>10.02</td>
<td>4.53</td>
<td>2.97</td>
<td>2.51</td>
<td>2.11</td>
</tr>
<tr>
<td>220</td>
<td>10.08</td>
<td>6.00</td>
<td>4.04</td>
<td>2.82</td>
<td>2.23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lb N per acre</th>
<th>6 mos</th>
<th>9 mos</th>
<th>12 mos</th>
<th>15 mos</th>
<th>18 mos</th>
<th>21 mos</th>
<th>24 mos</th>
<th>27 mos</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>12.4</td>
<td>30.9</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>100</td>
<td>9.7</td>
<td>28.4</td>
<td>37.4</td>
<td>41.9</td>
<td>40.8</td>
<td>40.4</td>
<td>41.1</td>
<td>44.9</td>
</tr>
<tr>
<td>160</td>
<td>8.5</td>
<td>27.8</td>
<td>37.8</td>
<td>42.3</td>
<td>43.4</td>
<td>41.8</td>
<td>41.7</td>
<td>45.1</td>
</tr>
<tr>
<td>220</td>
<td>7.0</td>
<td>26.1</td>
<td>36.9</td>
<td>42.6</td>
<td>43.3</td>
<td>42.0</td>
<td>42.0</td>
<td>46.3</td>
</tr>
</tbody>
</table>

Table 39.—Effect of increasing nitrogen applications on the per cent reducing sugars in
total dry weight. After Borden (127)

Table 40.—Effect of increasing nitrogen applications on the per cent sucrose in total dry weight
After Borden (127)
The effect of increasing nitrogen application on the concentration of sucrose is quite the opposite from that on the concentration of reducing sugars. Fig. 172 shows that the sucrose content decreases as a result of additional nitrogen applications. This effect becomes less apparent as the plant grows older as is also demonstrated in table 40. This table shows that nitrogen has a depressing effect on the sucrose content when the cane is 6 months old, but that this effect gradually levels down by 15 months of age. In the subsequent months, the nitrogen-fertilized plots show even a slightly increased sucrose content.

The effect of nitrogen on the per cent total sugars results from the combined effects on
reducing sugars and sucrose, and consequently is less marked than in the case of each of the components separately (fig. 173).

It will have been noted that reducing sugars and moisture content respond similarly to nitrogen applications and that the response of sucrose is the opposite. The close correlation between reducing sugars and moisture is apparent throughout the life of the cane plant and so is the negative correlation between these two components and sucrose (fig. 174).

**Cane elongation.**—The rate of cane elongation increases as the rate of nitrogen application is increased until the optimum supply of nitrogen is reached (180, 198, 199, 615). An example is presented in fig. 175 showing that the effect of the first two nitrogen increments is considerable, while the effect of the third one is negligible.

**Rendement.**—The rendement indicates the pounds of commercial sugar recovered from 100 pounds of millable cane; it is also indicated as yield per cent cane (Y% C) or cane quality.

The rendement of healthy cane stalks is adversely affected by increasing applications of nitrogen and this constitutes a major problem in nitrogen fertilization. Fig. 176 gives an example of this effect under Java conditions. It represents the trend of the rendement in a field experiment supplied with 0, 4, 8, 12 and 16 metric quintals of ammonium sulphate per hectare. It is interesting to note that the depressing effect of the highest nitrogen application (16 AS per ha) is greatest in the first samples (4/24) and gradually diminishes towards harvest (7/15) which took place at an age of one year. Whether the difference would continue to diminish and eventually disappear at an age of more than one year is not known under Java conditions, since on that island cane is always harvested at the end of the first year.

Investigations by Hawaiian workers (116, 121, 122, 125, 127, 180) have proved that the

![Graph](image-url)
differences actually continue to level down in biennial cane grown under Hawaiian conditions. These workers found that the adverse effect of nitrogen on the rendement is quite definite during the first year but that it decreases during the second year's growth as is illustrated in Fig. 177. Table 41 presents the results of an experiment in which the differences in rendement disappeared entirely.

So far the effect of nitrogen on rendement of sound millable cane has been discussed. When cane is harvested mechanically, another factor enters into the picture, viz., the presence of dead and dying stalks, and suckers. As already mentioned, the quantity of such stalks is markedly increased by additional nitrogen increments, and thus a large part of the adverse effect of nitrogen on rendement is to be considered as a direct result of its effect on stalk population.

**Total Green and Dry Weight.**—Total green weight, total dry weight and cane yield generally increase with an increase in application of nitrogen. The effect of the initial increments of nitrogen is more marked than that of additional dressings (116, 121, 122, 125, 127, 180, 198, 226, 614). This fact is clearly demonstrated in Fig. 178 which presents the
Fig. 175.—Effect of increasing rates of nitrogen applications on the length of cane. After CORNELISON and COOPER (180).

Fig. 176.—Trend of rendement in an optimum nitrogen experiment supplied with 0, 4, 8, 12, and 16 metric quintals of ammonium sulphate per hectare. Note how the depressive effect of nitrogen fertilization diminishes as the cane grows older. After VAN DILLEWIJN and LEVERT (226).
influence of nitrogen on the total green weight of a biennial cane crop in Hawaii. The effect on cane yield in a one-year crop in Java, as shown in fig. 179, is essentially similar: a marked increase from the initial nitrogen increments, until a maximum is reached beyond which additional nitrogen applications remain without effect.

Sugar Yield.—The yield of commercial sugar is determined by cane tonnage and rendement. Fig. 179 shows that in a one-year crop under Java conditions, the rendement steadily decreases with increasing nitrogen application. The sugar curve first follows more or less

---

**Fig. 177.—Effect of increasing rates of nitrogen applications on the rendemment (cane quality) of a biennial crop in Hawaii. After Borden (116).**

---

**Fig. 178.—Effect of increasing rates of nitrogen applications on the total green weight of a biennial crop. After Borden (116).**
the cane curve till an optimum is reached. Once the cane curve becomes more or less horizontal, the sugar curve follows the rendement curve, and thus gradually declines.

In biennial crops, where the adverse effect of nitrogen on the rendement tends to level off as the crop grows older, the sugar curve follows more closely the cane curve, and the depressing effect of higher nitrogen applications on sugar yield becomes less apparent. Occasionally the relationship between cane tonnage and sugar yield becomes almost linear. (116, 120, 121).

LEAVES. — The leaves constitute the apparatus in which the major part of the assimilation of carbon dioxide and nitrogen takes place. Since it has been shown that the formation of dry substance is greatly promoted by nitrogen, it follows that this element must exert a marked effect on the leaves and their function.

With increasing applications of nitrogen, the color of the leaves becomes darker green to almost blue green. Analyses have shown that the chlorophyll content of the leaves of

Table 41.—Effect of nitrogen on rendement. After Borden (127)

<table>
<thead>
<tr>
<th>Lb N per acre</th>
<th>Rendement at successive harvest months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9</td>
</tr>
<tr>
<td>0</td>
<td>6.7</td>
</tr>
<tr>
<td>40</td>
<td>7.7</td>
</tr>
<tr>
<td>100</td>
<td>6.3</td>
</tr>
<tr>
<td>160</td>
<td>5.4</td>
</tr>
<tr>
<td>220</td>
<td>4.4</td>
</tr>
</tbody>
</table>
plants grown in the field increases with each application of nitrogen (fig. 180). In experiments with plants grown in water cultures lacking nitrogen, the chlorophyll content of the leaves was only half that of normal plants and their photosynthetic uptake of radio carbon was reduced to as little as one-fifth that of controls (54, 55).

Moreover, increasing the rate of nitrogen application results in wider leaves and an increased rate of leaf formation (fig. 181). Consequently, the tonnage of green tops per acre definitely increases with additional nitrogen applications, as has been shown in Hawaii (116, 121, 122, 125, 127). An example of this effect is presented in table 42.

Fig. 180.—Effect of increasing rates of nitrogen applications on the chlorophyll content of green leaf blades. After Borden (116).

Fig. 181.—Effect of nitrogen application on the rate of new leaf formation. After Das (198).
The response of the leaves to nitrogen applications is so marked that workers in Mauritius have based a method on this principle in order to estimate the nitrogen requirement of a standing crop. Details of this method will be given elsewhere.

ASH CONSTITUENTS.—The first determinations of the effect of nitrogen on the ash content were made by measuring the electrical conductivity of cane juice since this method had been accepted by plant physiologists in general as satisfactory. It was found that increasing applications of nitrogen increased the electrical conductivity of expressed juice, and the conclusion was drawn that nitrogen increases the salt content of the juice (198, 199). Subsequent studies have revealed that this opinion had to be corrected since increased applications of nitrogen do not cause an increased concentration of ash, but just the opposite. It appears that the increased conductivity found previously in high-nitrogen cane is due to accumulation of acidic radicles of which no small part is probably organic (179, 180). Only one element, calcium, seems to increase when cane is supplied with additional nitrogen and the possible importance of this element in connection with the succulence of cane has already been mentioned (p. 210). An example of the effect of nitrogen on juice composition is presented in table 43. The data indicate that increasing rates of application of nitrogen exert a depressing effect on the percentages of ash, phosphorus and potassium. The only exception reported so far comes from Mauritius (251) where excessive application of nitrogen did not affect the concentrations of potassium and calcium in the juice, but the concentration of phosphate was significantly lower in the high-nitrogen treatment.

### Table 42.—Effect of nitrogen on green tops. After Borden (127)

<table>
<thead>
<tr>
<th>Lb N per acre</th>
<th>Tons of green tops per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6 mos</td>
</tr>
<tr>
<td>0</td>
<td>11.4</td>
</tr>
<tr>
<td>100</td>
<td>20.4</td>
</tr>
<tr>
<td>160</td>
<td>24.0</td>
</tr>
<tr>
<td>220</td>
<td>21.3</td>
</tr>
</tbody>
</table>

### Table 43.—Effect of fertilizers on the composition of crusher juice

<table>
<thead>
<tr>
<th>Fertilizer N - P₂O₅ - K₂O</th>
<th>Per cent total (brix) solids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total N</td>
</tr>
<tr>
<td>20 - 0 - 0</td>
<td>.17</td>
</tr>
<tr>
<td>12 - 4 - 4</td>
<td>.13</td>
</tr>
<tr>
<td>4 - 8 - 8</td>
<td>.11</td>
</tr>
<tr>
<td>0 -20 - 0</td>
<td>.11</td>
</tr>
<tr>
<td>0 - 0 -20</td>
<td>.10</td>
</tr>
<tr>
<td>none</td>
<td>.11</td>
</tr>
</tbody>
</table>

The response of the leaves to nitrogen applications is so marked that workers in Mauritius have based a method on this principle in order to estimate the nitrogen requirement of a standing crop. Details of this method will be given elsewhere.
Field experiments in Hawaii have shown that nitrogen also lowers the percentage of phosphoric acid and potassium in the total dry weight of the cane crop. The omission of nitrogen results in a higher concentration of both phosphoric acid and potassium. This indicates an inverse relationship between the nitrogen concentration and the concentration of the latter two elements (116, 121, 124, 125).

FLOWERING.—The depressing effect of nitrogen fertilizers on tasseling is so well known that it will be sufficient to give only one example. In a fertilizer experiment in Queensland, it was found that the percentages of arrowed stalks in plots supplied with no, 200 and 400 lb of sulphate of ammonia per acre were 71, 54 and 11 respectively (348).

LODGING.—Nitrogen fertilization promotes lodging. In a country like Java, where only one-year crops are grown, lodging and poor juice quality are considered as the principal adverse effects of excessive nitrogen application. The drawback of lodging is still more obvious when cane has to be harvested mechanically.

Little is known about the processes involved in this phenomenon. It is reasonable to assume that the increased succulence and the lower fiber content mentioned before have something to do with it. Moreover, the development of heavier tops may play a role. Investigations with cereals have provided evidence that lodging is associated with less lignified and sclerenchymatic tissue which might also apply to cane (198).

DISEASES AND PESTS.—The occurrence of various diseases and pests is often promoted by generous applications of nitrogen. POJ 2878 has been largely abandoned in Java on account of its susceptibility to Fusarium toprot (Fusarium moniliforme SHIELD. var. subglutinans WR. et RG.) and it has been proved that increasing nitrogen applications promote the occurrence of the disease (226).

It is reported from Hawaii (444) that the incidence of eye spot disease (Helminthosporium sacchari [Van Breda de Haan] Butler) can be greatly reduced by withholding heavy applications of nitrogen toward the end of the growing period.

An example of the influence of nitrogen on the occurrence of pests is the white top borer (Scirpophaga auriflava ZELL. var. intacta St.). It has been proved in Java that this pest increases with additional nitrogen fertilization and that this increase is associated with a higher moisture content of the leaf spindle. Hazelhoft (301) has shown the close relationship which exists between the moisture content (succulence) of the leaf spindle and the occurrence of the white top borer. The softer the tissue of the leaf spindle, the easier the young larvae can penetrate.

Factors influencing the effect of nitrogen.—The problem of nitrogen fertilization is considerably complicated by the fact that the response of a cane crop to a certain amount of nitrogen is not uniform but depends on many factors, both internal and external. Thus, different varieties may react in different ways and even the response of the same variety differs according to age. In addition to these internal factors, there are external factors which play an important role, among which climate occupies a dominant place.

VARIETY.—Field experiments in Java have provided strong evidence that the optimum rate of nitrogen fertilization is higher with POJ 2878 than that with EK 28. The average difference found in the field experiments of one year amounted to about one metric quintal
Fig. 182.—Development of four different varieties grown in a complete nutrient solution (left) and in a solution lacking nitrogen (right). Note the striking varietal differences in the minus-nitrogen series. After MARTIN (449).
of sulphate of ammonia per hectare (213). The differences between POJ 2878 and the newer varieties appear to be less obvious. There is some evidence that the optimum rate with POJ 3016 is lower and with POJ 2967 higher than in the case of POJ 2878. Moreover, it seems that POJ 3016 and 2967 are less tolerant to sub-optimal nitrogen fertilization than POJ 2878 (96).

Striking differences in tolerance to nitrogen deficiency have been demonstrated in pot experiments in Hawaii (449). An example is presented in fig. 182, which shows the differences in tolerance of four varieties to nitrogen deficiency.

Field experiments on the optimum amount of nitrogen fertilizer in Hawaii have given evidence that the variety 32-8560 requires less nitrogen than H 109. Pot experiments have corroborated this opinion. This would indicate that 32-8560 has a greater nitrogen efficiency or ability to produce more dry weight per unit of available nitrogen than H 109 (123).

Pot and field experiments with 32-8560 and 37-1933 failed to provide evidence of differences in their optimum nitrogen requirement, although the varietal responses to nitrogen differed in many other respects, e.g., in the percentage nitrogen in tops and trash (54, 128).

Similar varietal differences have been demonstrated by feeding these two varieties with heavy nitrogen (N16) which resulted in striking differences in the nitrogen content and its distribution among chemical fractions (55).

**Plant Cane Versus Ratoon.**—Plant crops are more efficient users of the applied nitrogen than ratoon cane, according to field experiments in Hawaii. The plant crops in these experiments needed for their optimum yields less than two pounds of nitrogen per ton of cane; whereas the ratoons required two and a half pounds (120).
AGE.—The ability of the cane plant to respond to external factors depends largely on its physiological age. Examples have been presented previously where it was stated that the growth response of cane to meteorological factors was many times greater during the “boom stage” than when the cane was one year older.

The response to nitrogen during the “boom stage” is also greater than during earlier or later stages of development (fig. 183). This is at least partly associated with the fact that the development of the root system and of the photosynthetic apparatus (green tops) reach their maximum during this stage. During the early development of the plant, a heavy application may even have an adverse effect on the ultimate yield. This is demonstrated in table 44A which gives the results of pot experiments in which the same amount of nitrogen was applied at different intervals.

Nitrogen absorption is very slow during the initial stages of development but increases rapidly as the absorbing surface of the root system increases. The rate of absorption is apparently independent of the immediate needs of the plant and nitrogen absorbed beyond the requirements of the moment may be stored up and used for later growth. Thus it is possible for the cane plant to absorb nitrogen from one application at an early stage of its life and without further uptake continue to grow (614).

An exact timing of nitrogen applications is, however, required for, as stated previously, the permanent conditioning of the storage cell, as far as its general sucrose and water holding capacities are concerned, depends on the nitrogen which is available during the periods of formation and maturation of the tissues concerned. It is possible, therefore, to influence permanently to a certain degree any set of joints in the stem by nitrogen treatment during

**Table 44A.—Effect of time of application of nitrogen. After Borden (110)**

<table>
<thead>
<tr>
<th>Time of application</th>
<th>Lb cane</th>
<th>Rendt. (Y % C)</th>
<th>Lb sugar</th>
<th>Juice purity</th>
<th>N in soil available in p.p. m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All at 1 month</td>
<td>2.99</td>
<td>9.79</td>
<td>.36</td>
<td>76.5</td>
<td>8</td>
</tr>
<tr>
<td>1/2 at 1 mo.; 1/2 at 3 mos.</td>
<td>3.40</td>
<td>10.37</td>
<td>.40</td>
<td>81.8</td>
<td>8</td>
</tr>
<tr>
<td>1/2 at 1 mo.; 1/2 at 5 mos.</td>
<td>4.11</td>
<td>12.64</td>
<td>.52</td>
<td>87.2</td>
<td>7</td>
</tr>
<tr>
<td>1/4 at 1 mo.; 3/4 at 3 mos.</td>
<td>4.60</td>
<td>12.81</td>
<td>.57</td>
<td>87.0</td>
<td>7</td>
</tr>
<tr>
<td>1/4 at 1, at 3, at 5 and at 7 mos.</td>
<td>4.68</td>
<td>12.77</td>
<td>.60</td>
<td>87.3</td>
<td>6</td>
</tr>
<tr>
<td>1/8 at 1 and at 3 mos.; 1/2 at 7 mos.</td>
<td>4.39</td>
<td>12.70</td>
<td>.55</td>
<td>86.4</td>
<td>7</td>
</tr>
</tbody>
</table>

**Table 44B.—Effect of time of nitrogen application on the production of total dry weight. After Borden (127)**

<table>
<thead>
<tr>
<th>Last nitrogen application</th>
<th>Tons per acre of total dry weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At 9 mos</td>
</tr>
<tr>
<td>At 4 months</td>
<td>23.0</td>
</tr>
<tr>
<td>At 6 months</td>
<td>19.9</td>
</tr>
</tbody>
</table>
the time of their development. The joints which are formed at an earlier date will show temporarily the detrimental effects of subsequent nitrogen treatment but these effects, as far as can be determined, are not permanent (179). Cane tissue which is formed under the stimulus of high nitrogen is never able to carry as much sucrose per volume of juice as is cane tissue formed under optimum conditions as to nitrogen supply (180).

These phenomena are of considerable practical importance, since they indicate the necessity of supplying the cane plant with the proper amount of nitrogen at the proper time.

TIME OF APPLICATION.—Evidence that the timing of nitrogen applications affects the cane plant in many of its vital functions has been presented in table 44A. In view of the commercial importance of this phenomenon, some additional figures will be given. These figures relate to a field experiment in Hawaii in which a uniform quantity of nitrogen was applied but distributed over different intervals. The quantity was 220 pounds of nitrogen per acre. In one treatment the whole amount was applied within 4 months; in another treatment the last 60 pounds were given at 6 months. The effect on the total production of dry

![Graph](image-url)

Fig. 184.—Effect of time of nitrogen application on the length of cane. After Cornelison and Cooper (179).
weight by the whole crop is demonstrated in table 44B. The differences are obvious even though there is only a two months’ difference in the time of application.

An example of the effect on cane elongation is presented in fig. 184. The three curves for 250 lb of nitrogen indicate that although the same total amount of nitrogen was applied, the length of the cane was permanently affected by the different times of application.

Table 45 shows the effect on the quantity of green tops expressed in per cent of total green weight. Delayed nitrogen application resulted in an increased percentage of tops at an age of 15 months, but the differences leveled off during the subsequent months.
The effect of time of nitrogen application on the content of moisture and reducing sugars is shown in table 46 and 47 respectively. At the ages of 15 and 18 months, the content of reducing sugars was significantly increased by the late nitrogen applications. It is, however, interesting to note that at 21, 24, and 27 months these effects were reversed.

The rendement (yield per cent cane) is adversely affected by late nitrogen application, but this effect tends to disappear when the crop grows older (table 48).

An example of the effect of time of nitrogen application on commercial sugar yields is presented in table 49. When harvested at an age of 12 months, late nitrogen application had exerted an adverse effect, but at later harvests the differences disappeared. The picture presented in the foregoing tables relates to a high total dressing of 220 lb nitrogen per acre. When the total amounts of nitrogen are lower, the situation becomes different.

It appears that the larger the total amount of nitrogen applied, the later the last nitrogen dressing should be applied. From an economic viewpoint, one or two applications seem ideal for short crops, whereas for long crops more applications may be advisable (179).

The effect of nitrogen on flowering also depends largely on the time of nitrogen application. In a field experiment in Hawaii, it was observed that the earlier the nitrogen was applied, the greater its depressing effect on tasseling (127).

CLIMATE.—The effect of fertilizers on a cane crop is greatly influenced by climatic factors. Generally speaking, the beneficial effect of nitrogen will be more pronounced the better the weather conditions are. Reference has already been made to the ingenious pot experiments in Hawaii in which plants of the same variety were grown in the same soil but under different climatic conditions, viz., the sunny climate of Makiki, and the cloudy climate of Manoa (p. 120). In part of these experiments the plants were grown at two fertilizer levels (including nitrogen, phosphate and potassium), viz., an adequate amount of fertilizer versus one-fourth as much. The results of one experiment are presented in table 50. A glance at this table shows that under the conditions of the Makiki climate, the gains in cane and sugar from the high fertilizer application were much greater than at Manoa. Moreover, the rendement (yield per cent cane) of the cane grown at Makiki was not adversely affected by the heavier fertilization, while the depressing effect at Manoa was obvious (107, 114). These results indicate that cane which is grown under less favorable climatic influences (chiefly reduced sunlight) is unable to utilize liberal applications of fertilizer (108). This is of considerable practical importance, since it proves that there is relatively little to be gained

Table 49.—Effect of time of nitrogen application on the yield of commercial sugar
After BORDEN (127)

<table>
<thead>
<tr>
<th>Time of application</th>
<th>At 12 mos</th>
<th>18 mos</th>
<th>24 mos</th>
</tr>
</thead>
<tbody>
<tr>
<td>All N by 4 mos</td>
<td>9.5</td>
<td>12.0</td>
<td>13.0</td>
</tr>
<tr>
<td>Last N at 6 mos</td>
<td>9.1</td>
<td>12.7</td>
<td>12.2</td>
</tr>
<tr>
<td>Last N at 11 mos</td>
<td>7.9</td>
<td>13.0</td>
<td>13.2</td>
</tr>
</tbody>
</table>
Table 50.—Influence of climate on fertilizer effect. After Borden (114)

<table>
<thead>
<tr>
<th>Climate</th>
<th>Inadequate fertilizer</th>
<th>Adequate fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane (lb)</td>
<td>Makiki 48.0</td>
<td>80.3</td>
</tr>
<tr>
<td>Manoa 21.2</td>
<td></td>
<td>28.4</td>
</tr>
<tr>
<td>Sugar (lb)</td>
<td>Makiki 6.96</td>
<td>10.59</td>
</tr>
<tr>
<td>Manoa 2.64</td>
<td></td>
<td>2.96</td>
</tr>
</tbody>
</table>

Table 51.—Influence of climate on nitrogen effect (52)

<table>
<thead>
<tr>
<th>Climate</th>
<th>Lb cane</th>
<th>Rendt.</th>
<th>Lb sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M¹</td>
<td>H²</td>
<td>M</td>
</tr>
<tr>
<td>Makiki</td>
<td>62.2</td>
<td>75.4</td>
<td>13.5</td>
</tr>
<tr>
<td>Manoa</td>
<td>24.4</td>
<td>25.9</td>
<td>10.2</td>
</tr>
</tbody>
</table>

¹ M, medium nitrogen application; ² H, heavy nitrogen application.

Table 52.—Influence of light on nitrogen effect. After Borden (108)

<table>
<thead>
<tr>
<th>N per acre</th>
<th>Dry yield (grams)</th>
<th>% Moisture in cane harvested</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full¹</td>
<td>A.M.²</td>
</tr>
<tr>
<td>No N</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>150 lb N</td>
<td>82</td>
<td>76</td>
</tr>
<tr>
<td>225 lb N</td>
<td>129</td>
<td>110</td>
</tr>
<tr>
<td>300 lb B</td>
<td>173</td>
<td>134</td>
</tr>
</tbody>
</table>

¹ Full, full day sunlight; ² A.M., morning sun; ³ P.M., afternoon sun.

from increased fertilization under low sunlight conditions, such as prevail in many mountainous regions.

The influence of climate on the effect of nitrogen has been studied by the same experimental technique, and the results clearly show that the nitrogen effect is definitely influenced by climate (52, 54, 55). Table 51, presenting the results of an experiment in Hawaii, indicates that the higher nitrogen application has markedly increased the cane and sugar yields at Makiki, whereas the gains at Manoa are practically nil. Thus the higher nitrogen level was ineffective at Manoa. The major factors involved in the influence of climate on nitrogen are light and temperature.

Light.—The influence of light on the effect of nitrogen has been studied in pot experiments supplied with increasing rates of nitrogen fertilizer. Part of the pots were grown in full sunlight; a second series received direct sunlight from sunrise to midday only, while
a third series was exposed to direct sunlight from midday until sunset. The results of this experiment are summarized in table 52. There are no significant differences between the final results of the morning and afternoon series. An application of 150 lb N per acre gives a gain of 11 times the dry-weight without nitrogen in both the full-sunlight and reduced-sunlight series. A second similar 150 lb increment produces 13 and 10 times the dry-weight without nitrogen respectively for the full-sunlight and reduced-sunlight series, thus indicating that the plants grown in reduced light conditions are not able to utilize the heavier applications of nitrogen as effectively as they might have if more sunlight had been available. It is furthermore interesting to note that the nitrogen series grown in full sunlight are less succulent than either of the series grown under reduced light. This result indicates that a large part of the reason for poor juices in areas that have inferior light conditions is due to the higher moisture content of such cane, and since the moisture content is greater when liberal amounts of nitrogen are furnished, better juices might be secured by not being too liberal with this plant food under such conditions. It would be a fallacy to expect that better results would be secured from lands that are subject to continued periods of overcast or cloudy weather, by boosting the nitrogen applications to compensate for the shortage of sunlight (108).

In another pot experiment, the effects of three different nitrogen applications were studied. From the sixth month on some of the plants were grown in full sunlight and the others in reduced sunlight (shading with a single thickness of burlap). The results of this experiment are listed in table 53, and show once more the dominant influence of light on the effect of extra nitrogen applications. For instance, under full-sunlight conditions, the high nitrogen gave increased cane yields and the rendement was only slightly poorer than from the average nitrogen treatment. With decreased sunlight, however, the high nitrogen applications did not increase the cane yield and the rendement was badly affected. Thus, under decreased-sunlight conditions, each successive nitrogen increment has resulted in less sugar, while with full sunlight the sugar yield was adversely affected only at the excessive nitrogen level. The practical conclusion is that when cane is grown under conditions where sunlight is apt to be deficient, high nitrogen applications must be avoided or maximum sugar yields will not be secured (112).

TEMPERATURE.—Experiments in Hawaii have provided evidence that cane and sugar yields of H 109 respond to differential nitrogen applications only when the average of the day and night temperatures is above 67 °F. Below this minimum, growth does not cease but no large acceleration in elongation due to nitrogen fertilization is obvious. Observations seem to indicate that this threshold temperature will be different for different varieties of cane (179). This average of day and night temperature of 67 °F must not be confused with the 70 °F base of the day degree method of temperature evaluation mentioned earlier (p. 117).

CROPPING SEASON.—A crop planted during the summer season is exposed to a sequence of climatic factors which may differ from that to which a winter-planted crop is exposed. Experiments in Hawaii have indicated that under the conditions of those islands crops started in fall (October, November and December) produce poorer yields and are less efficient in their use of nitrogen than crops started in other seasons (120).
Table 53.—Influence of sunlight intensity on the effect of nitrogen. After Borden (112)

<table>
<thead>
<tr>
<th></th>
<th>Sunlight</th>
<th>Average N</th>
<th>High N</th>
<th>Excessive N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lb cane</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full</td>
<td></td>
<td>4.79</td>
<td>5.26</td>
<td>5.07</td>
</tr>
<tr>
<td>Decreased</td>
<td></td>
<td>3.91</td>
<td>3.91</td>
<td>3.68</td>
</tr>
<tr>
<td>Purity</td>
<td></td>
<td>90.5</td>
<td>89.8</td>
<td>85.8</td>
</tr>
<tr>
<td>Full</td>
<td></td>
<td>87.5</td>
<td>79.4</td>
<td>73.7</td>
</tr>
<tr>
<td>Decreased</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rendement (Y % C)</td>
<td></td>
<td>14.5</td>
<td>14.1</td>
<td>12.1</td>
</tr>
<tr>
<td>Full</td>
<td></td>
<td>12.0</td>
<td>8.6</td>
<td>7.2</td>
</tr>
<tr>
<td>Decreased</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lb sugar</td>
<td></td>
<td>.70</td>
<td>.74</td>
<td>.61</td>
</tr>
<tr>
<td>Full</td>
<td></td>
<td>.47</td>
<td>.34</td>
<td>.27</td>
</tr>
<tr>
<td>Decreased</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% N in juice</td>
<td></td>
<td>.024</td>
<td>.046</td>
<td>.125</td>
</tr>
<tr>
<td>Full</td>
<td></td>
<td>.040</td>
<td>.099</td>
<td>.254</td>
</tr>
<tr>
<td>Decreased</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% K₂O in juice</td>
<td></td>
<td>.195</td>
<td>.181</td>
<td>.175</td>
</tr>
<tr>
<td>Full</td>
<td></td>
<td>.255</td>
<td>.260</td>
<td>.234</td>
</tr>
<tr>
<td>Decreased</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total dry weight (grams)</td>
<td></td>
<td>1074</td>
<td>1155</td>
<td>1147</td>
</tr>
<tr>
<td>Full</td>
<td></td>
<td>829</td>
<td>808</td>
<td>756</td>
</tr>
<tr>
<td>Decreased</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Nitrate versus ammonia.—Early experiments with cane plants grown in culture solutions in which the effect of different forms of nitrogen nutrients were compared, have resulted in poor growth in those cases where nitrogen was applied in ammoniacal form only (13, 428). Under these conditions, ammoniacal nitrogen appeared to exert a toxic effect on root growth, resulting in malformation of the roots which greatly resembled the phenomena known in Java as root rot (13). Since POJ 2878, which is resistant to Java root rot and EK 28, which is highly susceptible to this disease, are both affected in the same way by ammonium salts, there is no evidence that Java root rot is caused by the application of ammonical nitrogen (13).

Cane plants grown in soil show little preference, if any, for nitrates as compared with ammonia, and this was generally explained by assuming that ammonium salts in the soil are converted into nitrates before being absorbed by the cane plant.

Subsequent studies, however, have shown that the concentrations of ammoniacal nitrogen used in the early experiments mentioned before have been too high and that the cane plant is able to absorb ammonium salts directly from nutrient solutions, provided their concentration is sufficiently low. Under these conditions, cane roots often absorb ammonia more rapidly than nitrates (13, 19, 477, 478). Thus a conversion into nitrates is not required in order to make ammonia available to the cane plant.

Nitrogen absorbed in the form of nitrates has to be reduced in the process of building up
the plant's nitrogenous constituents. This is not the case with nitrogen absorbed in the form of ammonia and it has been pointed out that the energy saved in the latter case may be applied for other purposes such as growth (477).

It has been observed by ParDO (477, 478, 479) that cane plants fed with nitrogen exclusively in the form of ammonia salts generally contain very distinctly higher percentages of nitrogen than plants supplied with nitrate nitrogen. Apparently a greater plant weight is produced per gram of nitrogen when absorbed as nitrate than when absorbed as ammonia, thus indicating a greater efficiency of the former (479).

Experiments in water cultures have indicated that ammonia and nitrate are equally good as nitrogen sources for sugarcane if judged by the total plant weight results of these tests (479). The fact should, however, be stressed that these results relate to young cane plants and that the effect may be different in old cane as is the case with rice which prefers ammonia when young and nitrates when older (477).

The results obtained with cane grown in soil are in general agreement with those obtained in nutrient solutions as far as the comparative values of ammonia and nitrate as sources of nitrogen are concerned. But a detailed analysis shows that under field conditions the picture is somewhat more complicated by the interaction of other factors.

Hundreds of field experiments in Java have proved that ammonium sulphate and sodium nitrate, if applied in equivalent amounts, produce the same amount of cane and sugar if the general average of all experiments is considered. There is, however, evidence that certain soil types show a preference for one or the other of the forms of nitrogen (269, 382). This is due to secondary actions, e.g., the fact that nitrates are more subject to leaching in light sandy soils. In addition to this, the fact that the anions and cations of the nitrogen compounds are absorbed by the cane plant at different rates may play a role. Thus, if ammonium sulphate is applied, the plant absorbs the ammonium ion while the sulphurous acid accumulates in the soil. If, on the other hand, sodium nitrate is applied, the nitrate is absorbed and the sodium ions are for the greatest part left behind in the soil. Consequently, salts like ammonium sulphate, which lead to an accumulation of acid in the soil are considered to be physiologically acid, while salts like sodium nitrate, which result in an increased concentration of bases in the soil are referred to as physiologically alkaline.

The comparative values of different forms of nitrogen for sugarcane have been studied in some detail by Borden in pot experiments, to which ammonium sulphate, sodium nitrate and urea were applied in equivalent amounts. Total dry weight, millable cane, rendement and sugar yield were not markedly affected by the form of nitrogen when only the general averages of the experiment were considered. But a more detailed analysis showed distinctly the effect of some interesting factors which may influence the direct effects of the nitrogen fertilizer used. One of these factors is the type of soil. Hence, one should be exceedingly cautious not to generalize with respect to the relative efficiencies of nitrogen from commercial fertilizer sources (111).

The fact that sodium nitrate is more subject to leaching but that ammonium sulphate promotes soil acidity, has always been a topic of discussion among sugarcane technologists. For a long time little was known about the exact extent to which these phenomena occur in
cane fields, and about their exact effect on cane and sugar yields. This induced BORDEN to start pot experiments in which cane supplied with heavy equivalent doses of ammonium sulphate, sodium nitrate and urea respectively was grown continuously. Fertilization was so excessive that at the end of ten years of cropping the quantity of nitrogen applied would have been sufficient to raise 45 crops of sugarcane in the field, fertilized at the rate of 200 pounds of nitrogen per acre.

The results indicated a marked effect of ammonium sulphate on soil acidity. The pH of the pots supplied with ammonium sulphate, sodium nitrate and urea was 4.8, 6.4, and 6.3 after 11 years of cropping as compared with a pH of 5.3 at the time when the experiment was started. No significant differences were found in the yields, even in the fifteenth consecutive crop, indicating that the increased soil acidity had not yet seriously affected its productivity (48, 55, 118, 129). Thus it is apparent that sugar cane, grown under irrigation, can be made to produce very satisfactory crops of cane of good quality, even if the soil is, or becomes, very acid, providing, of course, that it is adequately furnished with plant nutrients (118).

OTHER NUTRIENTS.—The effect of increasing rates of applications of nitrogen on cane and sugar yields depends greatly on the presence of other nutrients. Thus, HOOGLAND (214, 312) has demonstrated in both pot and field experiments with soils poor in phosphate that with additional applications of phosphate the optimum requirement of nitrogen gradually increases. Or, to put it otherwise: in order to render the higher nitrogen applications effective, the phosphate supply has to be increased.

The effects of different ratios of calcium, magnesium, and sodium in connection with different rates of nitrogen supplied to sugarcane have been studied by BORDEN (124) in pot experiments, but due to irregularities in the yields, no clean-cut influences from the different Ca-Mg-Na ratios could be established.

Both potassium and phosphate may accelerate the absorption of nitrogen by the cane roots (614). The interaction between potassium and nitrogen has been studied in pot experiments in Hawaii. In table 54 part of the results obtained in these experiments are presented. It is interesting to note that the deleterious effect of high nitrogen application on juice purity and rendement is reduced by increasing the level of potassium. Consequently, the loss of sugar resulting from high nitrogen at average potassium level is not apparent when this high nitrogen is accompanied by extra potassium (112). Other pot experiments have provided evidence that the highest yields of total dry weight, of millable cane, and of sugar are generally secured from the combination of high nitrogen with high potassium, whereas most of the lower yields come from the combination of high nitrogen with low potassium. The best juice purities and rendements are associated with low nitrogen and high potassium (124).

Many field experiments in Java have yielded the interesting result that potassium counterbalances the adverse effect of both supraoptimal and suboptimal applications of nitrogen and phosphate. This effect is of considerable importance, but it is difficult to explain and requires further study (208).

Some processes underlying the interaction between potassium and nitrogen have been studied by HARTT (283, 287). Both synthesis and translocation of proteins are diminished
by potash starvation, resulting in an accumulation of nitrogen in the blades and the stems. The curtailment in the synthesis of proteins occurs after the formation of amino acids rather than before, indicating that in these plants the reduction of nitrates proceeds as usual. The suggestion is made that the interference with the translocation of proteins is caused by a necrosis of the phloem.

**IRRIGATION.**—It has been proved in India that heavy dressings of nitrogen without heavy irrigation are useless (454). Similar results have been obtained in Hawaii where in one experiment the effects of 150 and 250 pounds of nitrogen per acre were compared at short and long irrigation intervals. With liberal irrigation (short irrigation intervals), the higher amount of nitrogen produced more cane and sugar than the lower amount of nitrogen. When irrigation was reduced (long irrigation intervals), the higher nitrogen level did not increase the yields over the lower one (45).

**Quantity removed by a crop.**—Much study has been devoted to estimating the quantities of nutrients removed by a cane crop from the field. This was one of the first problems tackled by the experiment stations in Java and Hawaii shortly after their establishment at the end of the past century.

The amounts of nitrogen removed by a crop vary so widely that it is impossible to give average figures. The dominant factor for this variation is cane tonnage. It is obvious that in general, the bigger the crop the more nitrogen will be removed. This offers a possibility of rendering the figures somewhat more comparable.

This has been done in table 55 in which a selected series of figures is given representing the pounds of nitrogen associated with each ton of millable cane. Thus, if the cane yield in a particular case was 30 tons per acre, the quantities of nitrogen contained in the stalks, in the green tops, and in the trash have been divided by 30 before entering them in the table. From these figures the amounts of nitrogen removed by a crop of a certain tonnage can be easily calculated.

It appears that the quantity of nitrogen present in one ton of millable cane is rather
characteristic of the producing regions. In Mauritius it is about 1.4 lb and in Hawaii about 1 lb. The difference may be due to differences in age. The high tonnages in Hawaii indicate that the crops were harvested at a high age, and since it is known that the nitrogen concentration in the stem decreases with age, it is obvious that the Hawaiian figures should be lower than those relating to Mauritius.

The figures for nitrogen in the trash also show differences, e.g., 0.9 in Mauritius and 0.5 to 0.9 in Hawaii. This may be due to the fact that in some cases not all the trash has been collected. Moreover, the quantities of nitrogen disappeared by leaching may have been different. As stated elsewhere, there is a certain relationship between cane weight and trash weight since a leaf is associated with each internode. Therefore, if all dry leaves were collected and leaching did not interfere, one might expect that the figures for nitrogen contained in trash associated with each ton of millable cane would not vary greatly.

The situation is different with respect to the green tops, since there is no relationship between the weight of the tops and the age of a crop. Old crops may even have a lower tonnage of tops than younger ones. Thus expressing the figures on the basis of one ton of millable cane which is useful in the case of millable cane and trash, is inappropriate in the case of tops. The older a crop becomes, the more the ratio of top to stem will decrease. This may explain the low figures for nitrogen in the tops found in Hawaii, for judging from the high cane tonnages, the cane in Hawaii was harvested at an advanced age. Another factor which may be involved, is the fact that topping may have been done at different heights.

The amount of nitrogen contained in the whole aerial part per ton of millable cane averages 3.5 lb for Mauritius, 2.0 lb for Hawaii and 2.5 lb for South Africa. But in the latter case only part of the trash was included. The approximate average would seem to range between 2.5 and 3.0 lb.

The effect of age and rate of nitrogen application on the removal of nitrogen by the crop is shown in table 56. The underground portion of the plant and part of the trash are not included in the figures presented. As was to be expected, the quantity of nitrogen contained in the crop associated with each ton of millable cane increases with increasing nitrogen applications. This is particularly apparent at the age of 12 months. As the crop grows older, the differences become smaller and eventually disappear. The effect of age is striking. In some cases the quantity of nitrogen removed by the crop per ton of millable cane decreases by 50 per cent between 12 and 27 months of age.

To summarize: the quantities of nitrogen removed by a crop of sugarcane show wide variations, due to the different conditions under which the crop is grown (soil, climate, fertilization, age, tonnage). The dominant factor responsible for this variation is cane tonnage, and the variation due to this factor can be greatly eliminated by expressing the nitrogen contained in tops, trash, etc., per ton of millable cane. The figures obtained in this way show that the quantity of nitrogen contained in one ton of millable cane ranges approximately from 1.0 to 1.4 lb with an average of about 1.2 lb. It is lower for older crops, since the concentration of nitrogen in the stem decreases as the plant grows older. The nitrogen contained in the trash associated with one ton of millable cane ranges from
0.5 to 0.9 lb, with an average of some 0.7 lb. The variation is partly due to varying proportions of trash collected.

The widest range of variation is found in the nitrogen contained in the tops associated with each ton of millable cane. This is due to the fact that the weight ratio of tops to millable cane decreases with age. While the figures for Mauritius vary around 1.4 lb of nitrogen, those for the heavy crops in Hawaii average only 0.3 lb. The amount of nitrogen contained in the entire above-ground part averages approximately 2.5 to 3.0 lb for each ton of millable cane.

Additional figures on the removal of nitrogen from the soil have been reported from Mauritius (245), Hawaii (74, 119, 120, 237, 458, 459, 527, 528, 614), South Africa (303), Java (314, 315, 359, 360, 361, 362, 363, 364, 365, 366, 419) and Queensland (345, 346).

| Table 55.—Pounds of nitrogen contained in the aerial parts associated with each ton of millable cane |
|----------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| **Country and author** | **Variety** | **Age in months** | **Cane yield tons/acre** | **Part of plant** | **C** | **To** | **Tr** | **CTo** | **CToTr** | **CTo(Tr)** |
| **Mauritius** | | | | | | | | | | |
| ANON. (53) | M134/32 | 15 | 36 | 1.3 | 1.4 | 0.9 | 1.7 | 3.6 |
| ANON. (53) | M134/32 | 23 | 1.3 | 1.4 | 0.9 | 1.7 | 3.6 |
| ANON. (46) | M134/32 | 11 | 33 | 1.6 | 1.5 | 0.9 | 2.1 | 4.0 |
| **Louisiana** | | | | | | | | | | |
| FORT et al (265) | Co 281 | 20 | 0.9 | 1.6 |
| Co 290 | 30 | 0.6 | 1.2 |
| **Hawaii** | | | | | | | | | | |
| Clements et al (173) | 31/1389 | 20 | 81/117 | 1.0–1.8 |
| BORDEN (122) | 32/8560 | 15–24 | 0.9–1.5 |
| BORDEN (121) | 32/8560 | 17 | 150 | 1.5 |
| BORDEN (116) | 32/8560 | 20 | 140 | 1.5–2.0 |
| BORDEN (127) | 32/8560 | 12–27 | 90 | 1.0–1.5 |
| BORDEN (125) | 32/8560 | 20 | 120 | 1.2–1.5 |
| STEWART (9) | H 109 | 76 | 1.0 | 0.4 | 0.9 | 1.4 | 2.3 |
| H 109 | 118 | 1.0 | 0.2 | 0.5 | 1.2 | 1.7 |
| H 109 | 102 | 0.9 | 0.4 | 0.7 | 1.3 | 2.0 |
| **South Africa** | | | | | | | | | | |
| BEATER et al (90) | Co 290 | 15 | 30 | 0.9 | 2.7 |
| Co 281 | 15 | 30 | 0.9 | 2.3 |

1 C Millable cane  
To Green top  
Tr Trash  
CTo Millable cane plus green top  
CToTr Above-ground part of crop  
CTo(Tr) Above-ground part of crop except the trash dropped on the soil
Table 56.—Pounds of nitrogen removed by a cane crop (except underground portion and part of the trash) associated with each ton of millable cane. After BORDEN (127)

<table>
<thead>
<tr>
<th>Lb N applied</th>
<th>At 12 mos</th>
<th>15 mos</th>
<th>18 mos</th>
<th>21 mos</th>
<th>24 mos</th>
<th>27 mos</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1.33</td>
<td>1.29</td>
<td>1.18</td>
<td>.96</td>
<td>.84</td>
<td>.80</td>
</tr>
<tr>
<td>160</td>
<td>1.39</td>
<td>1.33</td>
<td>1.13</td>
<td>.95</td>
<td>.83</td>
<td>.76</td>
</tr>
<tr>
<td>220</td>
<td>1.63</td>
<td>1.46</td>
<td>1.22</td>
<td>1.01</td>
<td>.84</td>
<td>.77</td>
</tr>
</tbody>
</table>

PHOSPHORUS

General.—Phosphorus plays an important role in plant life and is considered as an indispensable element for several vital functions. In its organic compound, lecithin, it is found in practically every living cell. As will be stated below, the distribution of phosphorus in sugarcane coincides with the centers of greatest activity, viz., the centers of growth and of carbon assimilation. Considerable concentrations of this element are present in the meristematic tissues and in the chlorophyll (392).

Distribution in the plant.—The occurrence of phosphorus in the various organs of the sugarcane plant is shown in table 57. The column relating to plants grown in a complete nutrient solution, shows that the highest concentration of phosphorus occurs in the organs of greatest growth activity: the meristem and the elongating cane. Next to these organs comes the leaf spindle. It is interesting to note that, in contrast with nitrogen, the phosphorus content of the internodes increases as they grow older.

The figures of the minus-phosphorus series are much lower than those of the complete series. This is especially the case in the older tissues, while the reduction of the phosphorus content in the most active organs (meristem, elongating cane, leaf spindle) is considerably less. This demonstrates once more the preferential position of the latter organs, as far as nutrients are concerned. Another interesting difference is to be found in the mature internodes. While the plants in the complete solution show an increase of the phosphorus content as the internodes grow older, the situation in the minus-phosphorus series is exactly the reverse. Thus there is a general indication that the most active organs tend to maintain their relatively high phosphorus level by drawing on the older tissues.

Representative values for phosphorus content in various parts of the cane plant grown under field conditions are shown in fig. 185. It appears that the individual organs have distinct phosphorus levels and that the differences between these levels are quite nicely maintained throughout the life of the plant. The fact mentioned earlier, that the phosphorus content in the older internodes is higher than in the younger ones is again indicated.

The distribution of phosphorus within the various tissues and even within individual cells has been studied by LAZO and BONAZZI (392). These authors found that phosphorus generally is concentrated in the tissues of maximum activity. Thus the zone of the terminal bud contains much phosphorus which occurs here mainly in the nuclei, the cytoplasm being, apparently, devoid of it. Growing downward in the stem, the phosphorus content
Table 57.—Distribution of phosphorus ($P_2O_5$) in per cent of dry matter in complete and in deficient nutrient solutions. After Clements, Martin and Moriguchi (172)

<table>
<thead>
<tr>
<th>Plant Part</th>
<th>Complete</th>
<th>- N</th>
<th>- P</th>
<th>- K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle cluster</td>
<td>.57</td>
<td>.96</td>
<td>.27</td>
<td>.66</td>
</tr>
<tr>
<td>Green-leaf cane blades</td>
<td>.32</td>
<td>1.67</td>
<td>.14</td>
<td>.76</td>
</tr>
<tr>
<td>Elongating cane blades</td>
<td>.39</td>
<td>1.33</td>
<td>.07</td>
<td>.48</td>
</tr>
<tr>
<td>Green-leaf cane sheaths</td>
<td>.27</td>
<td>.11</td>
<td>.76</td>
<td>.85</td>
</tr>
<tr>
<td>Elongating cane sheaths</td>
<td>.32</td>
<td>.64</td>
<td>.53</td>
<td>.34</td>
</tr>
<tr>
<td>Elongating cane and meristem</td>
<td>.49</td>
<td>.26</td>
<td>.27</td>
<td>.48</td>
</tr>
<tr>
<td>Green-leaf cane</td>
<td>.34</td>
<td>.07</td>
<td>.32</td>
<td>.32</td>
</tr>
<tr>
<td>Top internodes</td>
<td>.27</td>
<td>.07</td>
<td>.27</td>
<td>.27</td>
</tr>
<tr>
<td>3rd 3 internodes</td>
<td>.30</td>
<td>.07</td>
<td>.27</td>
<td>.27</td>
</tr>
<tr>
<td>2nd 3 internodes</td>
<td>.34</td>
<td>1.01</td>
<td>.06</td>
<td>.27</td>
</tr>
<tr>
<td>1st 3 internodes</td>
<td>.41</td>
<td>.92</td>
<td>.02</td>
<td>.48</td>
</tr>
</tbody>
</table>

1 For description of the plant parts see p. 197.

decreases and is mostly concentrated in the companion cells of the phloem. In the leaf a considerable amount of phosphorus is found in the chloroplasts of the chlorophyll-bearing bundle sheath. The fact that phosphorus is largely concentrated in both the growing tissues and the organs active in carbon assimilation indicates that the function of this element is twofold and different in each case (392).

It has been stated earlier (p. 187) that in Barbados and Java more than 50 per cent of the phosphorus present in a crop harvested (millable cane plus green tops and adhering trash) is recovered in the juice (311).

Migration.—As in the case of nitrogen, the phosphorus content of dry leaves is considerably less than that of green leaves (78, 314, 490, 503) and this difference has been

![Fig. 185.—Distribution of phosphorus expressed on basis of ash in different parts of the cane plant. Stalks A, from tip of growing point six inches down stalk. Stalks B, C, D, E, successive three-foot sections of the stalk in basal direction. After Ayres (75).]
interpreted as evidence of a substantial translocation of phosphorus from the maturing leaves back to the stalk (503, 490). Ayres (78), however, who studied the chemical composition of individual leaves, found that although there is strong evidence that large proportions of the nitrogen and potassium contained in the green leaves migrate back to the stalk before the leaves become physiologically inactive, the behavior of phosphorus in this respect is indefinite (fig. 150).

**Trend of uptake.**—For a long time the belief was held that a correlationship exists between the phosphate content of the soil and the fertilizer requirement of the cane plant. In Java, a compilation of all phosphate experiments up to the year 1913 indicated that soils containing more than 0.025 and 0.008 per cent of phosphoric acid soluble in cold hydrochloric acid (of 22.9 per cent) and in 2 per cent citric acid respectively, did not respond to phosphate fertilization (270). During the subsequent years, however, when the number of phosphate experiments increased, and additional types of soils became involved, more and more exceptions were found (383). A compilation of all phosphate experiments with PoJ 2878 up to 1929 revealed a definite general tendency of the cane plant to respond more readily to phosphate applications the lower the concentration of this nutrient in the soil is. But there was no indication of a critical concentration, and a comparison with the former critical concentration resulted in 50 per cent and more exceptions (213). Consequently, this threshold concentration was no longer of value in determining the phosphate requirement of individual fields.

Neeb (471) studied the concentration of phosphate in the soil solution, the rate at which the phosphate absorbed from this solution by the plant is replaced by phosphate delivered by the soil particles, and the extent to which the phosphate concentration in the soil moisture is increased by the application of phosphate fertilizers. It appeared that the concentration of phosphoric acid in the soil solution is extremely low; values exceeding 1 mg of $P_2O_5$ per liter are very rare in Java cane soils and most values vary between 0.2 and 0.01 mg per liter. A close correlation was found between the concentration of phosphoric acid in the soil solution and the response of cane to phosphate fertilization in field experiments. For the brownish-gray, the gray and the black soils, a concentration of 0.03 to 0.05 mg of phosphoric acid per liter of soil solution was indicated as critical. Below this value, the soils responded to phosphate fertilization.

The question whether the cane plant is actually able to withdraw phosphate at a sufficient rate from such dilute concentrations has been answered by Van den Honert (310). Cane plants were grown in containers through which a continuous stream of nutrient solution flowed. The results are presented in fig. 186. With increasing concentrations of phosphoric acid in the nutrient solution, graph B shows first an increased uptake which gradually diminishes till the curve assumes an asymptotic form. At concentrations of 0.05, 0.2, 0.5, and 1 mg of phosphoric acid per liter, the rate of absorption is 20, 50, 78, and 96 per cent of the maximum respectively. At a concentration of 0.03 to 0.05 mg per liter, representing the critical concentration mentioned earlier, the rate of absorption is still 15 to 20 per cent of the maximum. This proves the ability of the cane plant to absorb considerable quantities of phosphoric acid from very low concentrations.
Fig. 186.—Rate of absorption of phosphoric acid by sugarcane as influenced by pH and by the concentration of phosphoric acid in the culture solution. Abscissa, milligrams of phosphoric acid per liter in the nutrient solution. Ordinate, milligrams of phosphoric acid absorbed per hour per plant. After Van den Honert (310).
At variance with curve B, it was found that the initial part of the curve sometimes assumed an S-form as shown by graph B_1, indicating that practically no phosphate is absorbed at the lowest concentrations. The curious fact was noted that the formation of tillers was associated with a sudden change of the S-curve into the normal form. It is suggested that the development of new vegetation points associated with tillering, and particularly their high content of phosphate, forces the plant to increased absorption, resulting in a change of the S-curve into the normal form.

The pH of the nutrient solution has a marked influence on the rate of phosphate absorption. A comparison of graph B with the other full-drawn curves (the dashes representing the B-graph) shows that lowering of the pH from 6.0 to 4.5 results in an increased absorption, whereas the rate of absorption diminishes when the solution becomes neutral (7.0) or slightly alkaline (7.5). This effect of pH on the rate of phosphate absorption indicates that the cane plant is able to absorb phosphate in the form of H_2PO_4^- ions but practically not in the form of HPO_4^{2-} ions.

It is interesting to speculate on the practical bearing of this pH effect. If a plant root in an alkaline soil were able to lower the pH of the adjoining film of soil solution to pH 6, this root could utilize very low concentrations of phosphate. This might give a clue to the particular ability of cane plants to absorb phosphorus from poorly soluble phosphates, e.g., rock phosphate.

Several observations in these experiments have proved that phosphate absorption and water intake are to a great extent independent of each other. One case is reported in which the quantity of phosphate absorbed was 500 times the quantity contained in the water absorbed.

These and various other observations of Van den Honert corroborate the theory of Von Wrangel on the function of the soil solution in phosphate absorption and lend support to her method of examining the phosphate requirement of soils.

Figures on the rate at which phosphate is absorbed by the cane plant in the course of its development have been presented earlier (fig. 151, 152, 154). In addition results shown in

![Graph](image)

**Fig. 187.**—Rate of phosphorus accumulation in the aerial parts of the cane plant. More than 50 per cent of the phosphorus present in the above-ground part of the full-grown plant is found in the stem. After Ayres (78).
fig. 187 indicate that during the first 6 months more than 50 per cent of the phosphate absorbed by the whole plant is accumulated in the green leaves. During the subsequent 8 months, the quantity of phosphate present in the leaves does not materially increase although seasonal fluctuations occur. The initial accumulation of phosphate in the leaves coincides with the gradual development of the leafy top, which reaches a maximum at about 6 months of age, and which does not change much during the subsequent months. The accumulation of phosphate in the stem during the first 3 months is negligible, but during the subsequent months it proceeds at a more or less uniform rate according to the formation of new internodes. The graph representing the quantity of phosphate accumulated in the dry leaves is the last to start and coincides with the occurrence of dead leaves. Once started, it proceeds at a uniform rate comparable to that of the stem.

An integration of the accumulation in the various organs shows the following picture: an initial rapid accumulation during the first 6 months, largely restricted to the leafy top, followed by a period during which the amount of phosphate contained in this organ remains practically constant, while the amount present in the stem and the dead leaves increases at a uniform rate.

The rate of phosphorus intake throughout the life of the crop, and the distribution of this element over the various parts of the plant have also been studied in considerable detail in Mauritius (53, 245; see also fig. 155).

Deficiency symptoms.—The symptoms of phosphorus deficiency in sugarcane have been studied in considerable detail by various workers (172, 309, 344, 442, 448, 469, 503) and may be summarized as follows:

The length and the diameter of the stem are reduced, resulting in shorter and more slender stalks. The color of the leaves is not particularly affected, or may even become somewhat darker. The older leaves show a definite drying at the tips, and before dying the color often turns to yellow or yellowish-brown. The leaves are reduced in both width and length, the reduction in width being greater than that in length. The ratio of leaf weight to stem weight decreases when the deficiency is slight but increases with increasing deficiency.

Tillering is markedly reduced, even more so than in the case of nitrogen deficiency. The root shoot ratio increases considerably.

Phosphorus deficiency affects the chemical composition of the cane plant to a considerable degree (table 58). The ash contains less phosphorus but larger amounts of silicon. Apparently the cane plant absorbs relatively more silicon when phosphorus is deficient. The ash of the roots of plants deficient in phosphorus is characterized by a very great accumulation of iron and a low concentration of potassium. In the ash of the stalks there is also a considerable amount of iron and less potassium than in the controls. The nitrogen content in all parts of the plant and particularly in the stem shows an increase.

Effects of phosphorus.—Application of phosphorus influences the cane plant in many respects, the effect generally being more apparent the more the plant has been lacking phosphorus prior to the application.

Growth.—Phosphorus has a striking effect on the rate of tillering. Even on soils which are not deficient in phosphorus and which consequently do not respond to this nutrient by
Table 58.—The effect of phosphorus deficiency on the chemical composition of the cane plant
After Saito and Kenjo (503)

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Green leaves</th>
<th>Dry leaves</th>
<th>Stalks</th>
<th>Roots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N</td>
<td>1.44</td>
<td>1.74</td>
<td>0.73</td>
<td>0.85</td>
</tr>
<tr>
<td>Total ash ¹</td>
<td>6.03</td>
<td>5.44</td>
<td>8.13</td>
<td>5.35</td>
</tr>
<tr>
<td>SiO₂ ²</td>
<td>0.64</td>
<td>1.65</td>
<td>0.95</td>
<td>1.90</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.10</td>
<td>0.09</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>CaO</td>
<td>0.38</td>
<td>0.32</td>
<td>1.09</td>
<td>0.49</td>
</tr>
<tr>
<td>MgO</td>
<td>0.29</td>
<td>0.31</td>
<td>1.12</td>
<td>0.44</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.16</td>
<td>1.70</td>
<td>0.63</td>
<td>0.87</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.52</td>
<td>0.32</td>
<td>1.07</td>
<td>0.52</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.46</td>
<td>0.16</td>
<td>0.48</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Percentage composition of the ash

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Green leaves</th>
<th>Dry leaves</th>
<th>Stalks</th>
<th>Roots</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>10.61</td>
<td>30.33</td>
<td>11.69</td>
<td>35.51</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1.66</td>
<td>1.65</td>
<td>1.72</td>
<td>1.50</td>
</tr>
<tr>
<td>CaO</td>
<td>6.30</td>
<td>5.88</td>
<td>13.41</td>
<td>9.16</td>
</tr>
<tr>
<td>MgO</td>
<td>4.81</td>
<td>5.70</td>
<td>13.78</td>
<td>8.22</td>
</tr>
<tr>
<td>K₂O</td>
<td>35.81</td>
<td>31.25</td>
<td>7.75</td>
<td>16.26</td>
</tr>
<tr>
<td>SO₃</td>
<td>8.62</td>
<td>5.88</td>
<td>13.16</td>
<td>9.72</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>7.63</td>
<td>2.94</td>
<td>5.90</td>
<td>0.75</td>
</tr>
</tbody>
</table>

¹ Included some impurities
² Soluble in saturated solution of Na₂CO₃

Increased yields, phosphorus may stimulate initial tillering as experience in Java and elsewhere has proved. Hence, a temporary effect of phosphate application on the initial rate of tillering does not of necessity imply a beneficial effect on ultimate yields.

The effects of phosphorus on the other organs of the plant are the contrary of those described under phosphorus deficiency. The internodes increase in length and diameter, the leaves become longer and broader but thinner (490). The ratio of top weight to stem weight decreases and so does the root shoot ratio.

Phosphorus Content.—The effect of phosphorus application on the phosphorus content of the cane plant has been studied by many investigators (77, 106, 172, 234, 316, 344, 359, 360, 433, 439, 464, 502, 503, 527), but the results obtained are greatly at variance. When phosphate is applied to soils deficient in this nutrient, the phosphorus content of the crop generally increases, but there are exceptions. These may be due partly to the fact that the phosphate applied is fixed by the soil and consequently is not available to the plant.

It is believed that the phosphorus content of various organs reflects the general phosphorus state of the cane plant. On this principle, various methods for estimating the phosphate requirement of the growing crop have been developed (41, 42, 53, 106, 169, 171). The
phosphorus concentration in the active leaves has attracted particular attention and holds promise as a reliable indicator of the general phosphorus status of the entire plant.

MATURITY.—Since it is generally recognized that phosphate fertilizers hasten the process of ripening in grain crops growing on soil low in phosphorus, it has often been assumed that this nutrient exerts a similar effect on sugarcane. A survey of the data so far available does not support this view. Though some results are indicative of a beneficial influence of phosphate on ripening, the great majority of experiments does not provide evidence of a significant effect in this respect (185, 309, 344, 347, 490, 503, 505, 564). Hundreds of field experiments in Java have shown that on the average phosphate application does not affect maturity (270). This does not, however, exclude the possibility that under particular conditions an effect may be obtained. One case has been reported in which a beneficial effect of phosphorus on ripening was observed with cane heavily fertilized with nitrogen (185).

FLOWERING.—Data on the influence of phosphorus on flowering are very scarce. It has been reported from India that application of phosphate promotes flowering (490) but more information is required.

Factors influencing the effect of phosphorus.—As in the case of nitrogen, the effect of phosphorus depends on many other factors. Our knowledge of these interactions is, however, rather poor and there is room for much more research on the problem.

VARIETY.—Experiments conducted in Hawaii (449) in which different varieties were grown in the same culture solution deficient in phosphorus showed only slight differences in development. This seems to indicate that varietal differences in tolerance to phosphorus deficiency are considerably less evident than in the case of nitrogen deficiency (p. 223).

CLIMATE.—Attention has already been drawn to the interaction between climate and the effect of fertilizers, indicating that favorable weather conditions increase the efficiency of fertilizers in general (p. 227). Although no data are as yet available on the interaction between climate and phosphate fertilization, it is very likely that such interaction does exist.

FORM OF PHOSPHATE.—The form in which phosphorus is applied to the soil may have a considerable influence. Although easily soluble phosphates give, in general, better results than less soluble, there are exceptions in which no differences are found or in which even the latter are preferred (570). The efficiency of less readily soluble phosphates is associated with the type of soil. At one time it was believed that these phosphates would offer the best possibilities on soils characterized by a high rate of phosphate fixation. Under such conditions, it was assumed that fertilizers like rock phosphate would be less subject to fixation by the soil than more readily soluble phosphates. Although there is no doubt that the rate of phosphate fixation by the soil plays an important role, the results of field experiments in Java and elsewhere suggest that other factors are involved.

OTHER NUTRIENTS.—As long as the cane plant is lacking phosphorus, additional applications of this nutrient will result in increased yields. As soon, however, as the supply of phosphate becomes so high as to cause a relative deficiency of one or more of the other nutrients, additional phosphate applications will remain without effect or may even be harmful. Increasing the application of the nutrients which are in deficiency, will render the
higher phosphate doses effective. Examples of this interaction between phosphate and other nutrients have been published in Java (214, 312).

The interesting fact that according to field experiments in Java the adverse effect of both supraoptimal and suboptimal applications of phosphate and nitrogen can be redressed by potassium has already been mentioned (p. 232).

**Quantity removed by a crop.**—A selected series of figures relating to the removal of phosphoric acid by various parts of a cane crop is listed in table 59. As in the case of nitrogen, the figures represent the pounds of $P_2O_5$ contained in the various parts of the plant associated with each ton of millable cane harvested. For the explanation of this presentation, the reader is referred to page 233.

<table>
<thead>
<tr>
<th>Country and author</th>
<th>Variety</th>
<th>Age in months</th>
<th>Cane yield tons/acre</th>
<th>Part of plant$^1$</th>
<th>C</th>
<th>To</th>
<th>Tr</th>
<th>CTo</th>
<th>CToTr</th>
<th>CTo(Tr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Java</td>
<td>HONIG (311)</td>
<td>POJ 2878</td>
<td>13–16</td>
<td>40–70</td>
<td>0.3–1.6</td>
<td>0.4–1.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mauritius</td>
<td>ANON. (53)</td>
<td>M 134/32</td>
<td>15</td>
<td>36</td>
<td>0.7</td>
<td>0.5</td>
<td>0.3</td>
<td>1.2</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANON. (53)</td>
<td>M 134/32</td>
<td>23</td>
<td>1.1</td>
<td>0.6</td>
<td>0.4</td>
<td>1.7</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANON. (56)</td>
<td>M 134/32</td>
<td>23</td>
<td>0.7</td>
<td>0.5</td>
<td>0.3</td>
<td>1.2</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Louisiana</td>
<td>FORT et al (265)</td>
<td>Co 281</td>
<td>20</td>
<td>2.1</td>
<td>0.9</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Co 290</td>
<td>30</td>
<td>1.7</td>
<td>0.5</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hawaii</td>
<td>BORDEN (121)</td>
<td>32/8560</td>
<td>17</td>
<td>150</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BORDEN (116)</td>
<td>32/8560</td>
<td>20</td>
<td>140</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BORDEN (125)</td>
<td>32/8560</td>
<td>20</td>
<td>133</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MAXWELL (458)</td>
<td>Rose</td>
<td>89</td>
<td>0.9</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bamboo</td>
<td>77</td>
<td>0.7</td>
<td>1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lahaina</td>
<td>76</td>
<td>0.9</td>
<td>0.2</td>
<td>0.3</td>
<td>1.1</td>
<td>1.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>STEWART (9)</td>
<td>H 109</td>
<td>118</td>
<td>1.0</td>
<td>0.1</td>
<td>1.1</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H 109</td>
<td>102</td>
<td>0.6</td>
<td>0.1</td>
<td>0.7</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>BEATER et al (90)</td>
<td>Co 290</td>
<td>15</td>
<td>30</td>
<td>0.7</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Co 281</td>
<td>15</td>
<td>30</td>
<td>0.7</td>
<td>1.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$ C Millable cane  
To Green top  
Tr Trash  
CTo Millable cane plus green top  
CToTr Above-ground part of crop  
CTo(Tr) Above-ground part of crop except the trash dropped on soil
There are considerable differences both between and within countries. An example of
the latter is represented by the figures of HONIG (311) which show that in Java the quantity
of phosphoric acid removed by the millable cane, the green tops and the adhering trash
combined, ranges from 0.4 to 1.9 lb per acre. These figures include crops grown on extrem­
ely rich as well as extremely poor soils.

Approximate averages of the figures presented in table 59 would be: millable cane 1.0,
green tops 0.4, trash 0.3, complete aerial parts 1.7, aerial part except abscised dry leaves
1.4 lb.

Additional figures on the removal of phosphoric acid from the soil have been reported
from Hawaii (74, 78, 119, 237, 459, 527, 528), Mauritius (245), Java (314, 315, 359, 360, 361,
362, 363, 364, 365, 366, 419), India (484, 490) and Queensland (345, 346).

POTASSIUM

General.—The sugarcane plant is a great lover of potassium, and its demand upon the
soil for this nutrient may run to well over 800 pounds per acre. The role of potassium in the
cane plant has been studied by various investigators and in this connection the outstanding
work of HARTT (283, 286, 287) deserves particular attention. Many attempts have been
made to assign one special function to potassium, e.g., photosynthesis, protein synthesis,
translocation, etc. The problem, however, is not so simple and it is more likely that potassium
affects directly or indirectly many, if not all, of the cellular activities of plants. Because of
its mobility, its special condensing properties, its radioactivity, and probably also other
properties, this element is involved in many life processes and it appears impossible
to assign one particular process as the special role of potassium in the physiology of
plants (287).

There is evidence that potassium aids in carbon assimilation, in the transformation and
translocation of sugars, and in starch formation. It influences both synthesis and trans­
location of proteins. There is also evidence that potassium affects transpiration.

Almost all of the potassium contained in the plant is readily soluble in water and this
largely accounts for its great mobility. Thus, potassium migrates from the older parts of the
plant toward the younger organs.

Distribution in the plant.—The distribution of potassium in the cane plant is given in
table 60. The column which relates to plants grown in complete nutrient solution shows
a high concentration of potassium in the youngest organs: the elongating cane and meristem.
Next come the elongating-cane sheaths and the spindle cluster which are followed by the
other leaves and the green-leaf cane. The internodes along the stalk show a considerable
decrease running from some 5.7 per cent in the top of the stalk to 0.75 per cent in the basal
internodes. Thus the distribution of potassium seems to be closely associated with me­
ristematic and growing organs on the one hand, and with organs active in carbon and
nitrogen assimilation on the other hand.

In addition to the figures presented in table 60, which relate to plants grown in culture
Table 60.—Distribution of potassium (K₂O) in per cent of dry matter in complete and in deficient nutrient solutions. After Clements, Martin and Moriguchi (172)

<table>
<thead>
<tr>
<th>Plant Part</th>
<th>Complete</th>
<th>- N</th>
<th>- P</th>
<th>- K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle cluster</td>
<td>2.98</td>
<td>3.18</td>
<td>2.77</td>
<td>1.37</td>
</tr>
<tr>
<td>Green-leaf blades</td>
<td>2.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elongating-cane blades</td>
<td>2.76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green-leaf cane sheaths</td>
<td>3.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elongating-cane sheaths</td>
<td>5.67</td>
<td>6.74</td>
<td>7.95</td>
<td>1.23</td>
</tr>
<tr>
<td>Elongating cane and meristem</td>
<td>2.69</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top internodes</td>
<td>1.66</td>
<td></td>
<td>3.03</td>
<td>.06</td>
</tr>
<tr>
<td>3rd 3 internodes</td>
<td>1.13</td>
<td></td>
<td>1.99</td>
<td>.22</td>
</tr>
<tr>
<td>2nd 3 internodes</td>
<td>.93</td>
<td>2.93</td>
<td>1.17</td>
<td>.16</td>
</tr>
<tr>
<td>1st 3 internodes</td>
<td>.75</td>
<td>1.91</td>
<td>.65</td>
<td>.05</td>
</tr>
</tbody>
</table>

1 For description of the plant parts see p. 197.

solutions, fig. 188 shows the trend of potassium content in various parts of plants grown under field conditions. The uppermost part of the stem (stalk A) contains as high as 6 per cent potassium or 45 per cent of the total ash in this region (not presented in fig. 188).

The distribution of potassium in various parts of the cane plant has also been studied by other investigators (53, 90, 245, 311) and it has been found that under Java conditions 30 to 80 per cent of this element present in cane plants (exclusive of roots and part of the trash) is present in the crusher juice. The interesting fact was noted that this percentage is higher (70 to 80) in plants rich in potassium and lower (30 to 40) in plants with low potassium content (311).

Analyses of individual leaves attached to one cane stalk have shown that the potassium content of successive leaves increases gradually from the oldest to the youngest leaves and that the percentage of this element in dry matter reaches its maximum in the uppermost leaf of the stalk (78, 343). The basal part of each leaf is highest in potassium and toward the tip of the leaf the content of this element decreases gradually (343).

Migration.—The fact that the potassium content of old or dead leaves is considerably lower than that of green leaves has been noticed by various workers, and it was generally taken as an indication that this element migrates from the leaves back to the stalk before the leaves become physiologically inactive (75, 78, 101, 286, 314, 490). That migration actually occurs in the aging leaves, has been proved by periodically analyzing comparable sections of individual leaves. In addition, a comparison has been made between plants adequately provided with potassium throughout their life and plants brought up in a solution containing an adequate amount of this element and later transferred to a solution deficient in potassium. The older leaves of the plants in the latter series showed a considerably lower potassium content than comparable leaves of the former series, but the differences in
Fig. 188.—Trend of potassium concentration in dry matter of various parts of cane grown under field conditions. For explanation of the symbols see fig. 147. After Ayres (75).

potassium content between the uppermost leaves of both series were rather small. This indicates that under conditions of a low potassium supply, the youngest leaves may make heavy draughts on the potassium in the older ones (343).

This preferential position of the youngest leaves is also nicely demonstrated in table 60. A comparison between the figures of the complete and the minus-potassium series shows that the potassium content of the spindle cluster in the latter series is reduced to about one half. In the older organs (leaves and internodes), the potassium content is decreased to about one-tenth of that of comparable values for plants of the complete series, thus once more demonstrating the preferential position occupied by young organs.

According to Hartt, there seems to be no relationship between the extent of migration and the percentage of potassium in the plant. In other words, migration does not occur most readily in those plants which need it most; therefore, translocation of potassium appears not to be an adaptation in potassium-deficient plants. There is evidence of a relationship between the migration of potassium and the moisture content of the leaves since the greatest migration of potassium was found in the blades having the lowest water percentage (286).

The top not only draws upon the potassium of the older leaves but also upon that of the aging internodes as is evident from table 60 and fig. 188. One of the factors enabling this migration is that potassium occurs largely in a simple form, while most of the other elements, with the exception of sodium, are known to enter into organic compounds, either in wall material or protoplasma. Another factor is the greater mobility of potassium, as compared with other elements (286). Almost all of this element contained in the cane plant occurs in water soluble form (343).
Trend of uptake.—In addition to the general information presented in a previous chapter (fig. 151, 152, 154), some data characteristic of the uptake of potassium by the cane plant will be given now.

The accumulation of potassium in the various parts of the cane plant grown under field conditions is shown in fig. 189 which relates to the above-ground part of plants, including trash.

As in the case of nitrogen and phosphorus, accumulation of potassium during the first 6 months is most pronounced in the green leaves, and during the subsequent months the total amount of potassium contained in these organs, apart from seasonal fluctuations, does not increase materially. Accumulation in the stem and particularly in the dead leaves starts later and proceeds at a rather uniform rate which keeps pace with the development of these organs. Thus, once the green leaves have attained full development, subsequent accumulation of potassium in the cane plant is practically limited to the stem and the trash (see also fig. 155). As in the case of other nutrients, there is evidence that the rate at which potassium is absorbed by sugarcane is not primarily a function of the rate of growth, but of the age or stage of development of the cane plant (76, 78).

Fig. 190 represents the uptake of potassium by complete plants (including below-ground parts) grown in controlled pot experiments. In the early stages, potash is taken up at a very rapid rate, but about midway in the growth period all four graphs show a sharp break. Since all dry trash was saved and included in the samples, this loss of potash cannot be explained as an actual loss of some of the dry matter. Hence it follows that potash has actually moved out of the cane plant, perhaps back into the soil. The interesting fact was noted that the loss took place from the above-ground parts only; the below-ground portions did not show corresponding losses (119).
It has been proved that sugarcane, like other plants, may indulge in a luxury consumption of potash and the need to differentiate between the actual potash uptake by the sugarcane crop and its potash requirement for optimum yields has been emphasized (113).

There is evidence that the effect of potassium on sugarcane is influenced by light intensity. On the other hand, experiments in Hawaii have shown that equal amounts of potassium are absorbed during day and during night. Thus it would seem that light must affect the utilization of potassium by sugarcane rather than its absorption. No evidence has been obtained showing that sugarcane can absorb the nutrient through its leaves (286).

The concentration of potassium in culture solutions required for the production of 50 per cent of the maximum cane yield is about 3.8 mg K₂O per liter (fig. 161) which is lower than that for nitrogen (about 21 mg N per liter) but higher than that for phosphorus (about 0.9 mg P₂O₅ per liter) (309).

Deficiency symptoms.—More study has been devoted to the symptoms associated with potassium deficiency than to those of any other deficiency in sugarcane (52, 172, 283, 286, 287, 309, 430, 442, 448, 449, 469, 535).

The first symptoms appear some 2 to 5 months after the plants have been deprived of potassium. The growth of the plant as a whole is depressed, the stems become thin and limp, tapering rapidly toward the growing point. Tillering decreases though to a considerably less extent than in the case of deficiency of nitrogen or phosphorus.

The leaves show a characteristic pattern of discoloration. In the most active leaves (+2 to +6), the color of a narrow strip along both margins turns yellow. The discoloration
starts at the tip and proceeds to about midway the length of the blade. This discoloration is followed by drying of the tip, and the dried region gradually spreads in the shape of an inverted V downward, ending in a very narrow dried marginal strip on both sides of the leaf. The dried strips are separated from the green part of the leaf by a narrow yellow band. The dried tip does or does not curl. Yellowing and drying up are accompanied by the appearance of specific red discolorations in the upper surface of the midrib.

The pattern of yellowing and drying associated with potassium deficiency is quite different from that occurring normally in aging leaves. In the latter case, abscission of the leaf margins from the stem results in an interruption of the vascular connections, causing the margins to wither and to turn yellow. Thus, contrary to what happens in the case of potassium deficiency, normal yellowing starts at the base of the blade and the yellowing marginal bands taper off toward the tip of the blade. Since the normal pattern of yellowing also occurs in the older leaves of plants deficient in potassium, both normal and abnormal symptoms may be present in older leaves, thus rendering a diagnosis of potassium deficiency difficult. The red discoloration of the midrib, however, remains clearly visible even in leaves which have totally dried up (309).

In addition to the dieback of leaves from the tip and margins as described before, numerous minute chlorotic spots have been observed in Hawaii in plants lacking potassium. These spots later become brown with necrotic centers and this type of leaf spotting is much more pronounced on the older leaves than on the younger ones (442, 448).

The youngest leaves are the last to manifest the discoloration associated with potassium deficiency, which is in harmony with the preferential position of these organs mentioned earlier.

The red discoloration of the midrib is not of necessity specific of potassium deficiency, since sugarcane responds to any injury by red discoloration (borers, insects, red rot). The red midribs associated with potassium deficiency are, however, characterized by the fact that the discoloration is confined to the upper surface of the midrib only, while the red color resulting from other causes extends to lower tissues as well. In Java, gum formation was observed in red midribs associated with potassium deficiency, but since gum formation may also result from other causes, the presence of gum is not specific of potassium deficiency. In Hawaii, no gumming of the epidermal walls in the midribs of plants deficient in potassium has been observed. There it was found that the development of red midribs is not a specific symptom of potash deficiency but a secondary reaction, developing when phloroglucin and sufficient phosphate occur simultaneously within the plant. The source of phloroglucin suggested is the decomposition of tannic acids, a possible result of potassium deficiency (286).

Cane plants deficient in potassium are generally characterized by a lower content of sugar (287, 535) and a lower rendement (yield per cent cane) (204, 208, 213, 309), while the ratio of top to millable cane increases (309). The development of the root system is stimulated by potassium deficiency (283) and since the development of the above-ground parts is adversely affected, the root shoot ratio increases (309).

As is the case with plants in general, sugarcane deficient in potassium accumulates
relatively more of certain other elements than does normal cane (172, 286, 535). This is true of total nitrogen, total ash, calcium, magnesium, phosphorus, silicon, iron and sulfur. Examples are to be found in table 36, 57 and 68, which show that different parts of the plant react differently in this respect. It is particularly in the younger organs that the content of nitrogen, phosphorus and calcium is increased, while the older organs show in many cases a decrease. In Hawaii (54) it was found that potash deficiency more than doubled the content of amide nitrogen in the green tops.

The increased absorption of iron has attracted particular attention. The percentages of this element in the blades, stems, and roots of plants deficient in potassium are higher than in plants grown in complete nutrient solutions, indicating that a deficiency in potassium leads to the absorption of a greater amount of iron. Iron is accumulated particularly in the nodes of the stem, possibly because of the presence of anastomoses of the vascular bundles in this tissue. Evidence indicates that the toxicity of iron in sugarcane is due to its unequal distribution rather than to its total concentration (286, 429). A similar accumulation of iron has been observed in corn, where the vessels in the nodes of plants deficient in potassium are clogged with iron. HOFFER (307) has developed a simple test to demonstrate this accumulation of iron. Longitudinal sections of the corn stalk are treated with a strongly acidified solution of 20 per cent potassium rhodanide. When a distinct reddening due to the formation of $\text{Fe(CNS)}_3$ occurs, potassium deficiency is indicated.

Unfortunately, iron accumulation in the nodes of sugarcane is not confined to potash deficiency. Both potassium and phosphorus aid in the distribution of iron and any factor tending to reduce growth may induce accumulation of iron and aluminum in the nodes of cane (429). Moreover, such accumulations have been observed in cane grown under conditions of both calcium and phosphorus deficiency (431) or of excess soil acidity (300). The HOFFER test has been examined with cane grown in potassium field experiments in Java, but the results were rather disappointing (470).

There is some evidence that symptoms of iron toxicity occur in Java. In the condition known as Kalimati disease (so called from the name of the principal plantation where it occurs), the symptoms are very similar to those of potassium deficiency and the addition of potassium has been found to overcome the disease. According to one conception (598) the disease is due to potassium deficiency, while according to another (368, 369), the disease results from iron toxicity. It is believed that iron toxicity is caused by the presence of ferrous iron in the soil and that the latter is associated with the application of ammoniacal nitrogen instead of nitrate nitrogen. The beneficial effect of potassium application on the diseased plants is attributed to a counterbalancing influence of potassium on the injurious action of iron or to a stimulation of nitrification in the soil by potassium.

Iron toxicity constitutes an essential factor which must be taken into account in any consideration of potash starvation. One of the most important derangements in potassium deficiency to which iron toxicity contributes is the disturbance in the translocation of sugars and nitrogenous compounds (286). The suggestion has been made that the interference with the translocation of carbohydrates and proteins is due to a necrosis of the phloem, since there is evidence of phloem necrosis in plants deprived of potassium (283, 286). This
evidence consists of a dark discoloration of the bundles of the stem and of both sieve tubes and companion cells of the vascular bundles in the midrib. Furthermore, it has been found in Hawaii (441) that similar discolorations of the bundles in cane stems known as "internal stalk necrosis", occur throughout the Hawaiian islands and there is some evidence that they are related to potash deficiency.

Addition of potassium to cane plants deprived of this element causes some of the iron which has accumulated in the roots and stems to pass up into the blades, possibly due to an increase in the rate of transpiration (286).

The interesting fact has been observed that cane plants in cases of extreme potassium deficiency do not shed their leaves. This is due to the failure of the development of an abscission layer in plants grown under these conditions (469).

It is believed that sodium can replace potassium in some plants. The results of experiments with sugarcane, however, have led to the conclusion that sodium does not even partially replace potassium in the nutrition of this plant (286).

Effects of potassium.—As mentioned previously, there is ample evidence that potassium affects almost all functions of the cane plant. However, our knowledge of this influence is still rather incomplete.

Moisture.—As in the case of nitrogen, additional applications of potassium tend to increase the moisture content thus rendering the cane plant more succulent (108, 168, 286). Examples of this effect are presented in table 63.

Potassium content.—Increasing rates of application of potassium result in a rise of the potassium concentration in all parts of the cane plant (41, 42, 55, 93, 112, 113, 126, 168, 169, 171, 183, 286, 308). This is illustrated by table 61 which relates to plants of the variety H 109 grown under controlled conditions in MITSCHERLICH pots. All parts of the plants (including all trash) were harvested at the age of 12 months. The amounts of potash recovered in the dry weight bear a linear relationship to the amounts of potash in the soil (originally present plus added as fertilizer). The increase in potassium is most obvious in the trash and tops. The totals show that the millable cane contains only about one-seventh of the total potash. Thus six-sevenths remain in the field in the form of roots, trash and tops.

The concentration of potassium in trash and tops varies widely in table 61. CLEMENTS et al (168) found that in leaf punches the concentration of potassium varied even from 0.17 to 5.10 per cent. BEAUCHAMP and LAZO (93) have reported that the concentration of potassium in crude chlorophyll bears a direct relationship to the increments of potassium in the fertilizer applied.

Content of other elements.—The effect of potassium, applied to plants deficient in this element, on the content of other elements is not always clear (55, 112, 124, 168, 172, 286). While the concentrations of ash, nitrogen, magnesium, phosphorus and silicon show a general tendency to decrease, there are several exceptions. There is evidence that the age of the plant plays a role (286). Moreover, the individual parts of the plant may respond differently as is suggested by the data presented in the tables 36, 57 and 68. These tables indicate that plants grown in a complete nutrient solution sometimes have greater percentages
of nitrogen and phosphorus in the younger and more active parts, than plants grown in a solution deficient in potash, while the reverse is true of the more mature portions.

ANATOMY.—The differences in anatomy occurring in plants supplied with different amounts of potassium have been described by HARTT (283). Potassium increases cutinization, while lignification is decreased. The suggestion has been made that the beneficial effect of potassium application on the resistance of cane plants to eye spot disease is partly due to thickening of the cuticle. Lack of potassium results in abnormal distribution of vessels in the pith of the roots, small size of the vessels and the parenchyma cells in the stem, large cavities in the cortex of the roots, and underdevelopment of the root hairs.

ENZYMES.—HARTT (283, 287) found also a definite effect of potassium on the activity of certain enzymes. Potassium seems to be a specific activator of invertase in sugarcane while amylase activity is reduced by potassium in both blades and stems. The activity of peptase and catalase in the above-ground parts of the plant is stimulated by potassium application.

MILLABLE CANE.—Total dry matter as well as cane yield generally increase when plants growing under conditions of potassium deficiency are supplied with readily available potassium (113, 208, 286). In cane plants grown under controlled conditions, the increases in total dry weight were found to have a linear relationship to the amounts of potash available (113, 283) (table 62).

SUGARS.—Potassium plays an important role in sugar formation. It has been found that application of potassium increases the potassium content in the crude chlorophyll of the leaves and the percentage of available sucrose in the juice (93). Potassium is necessary for the proper transformations between hexoses and sucrose as well as for their translocation. A positive correlation has been found between the amount of potassium supplied and the total sugar stored in the stem. There is some evidence that sucrose in the sugarcane plant is synthesized by invertase and that potassium is a specific activator for invertase in sugarcane (286).

Table 61.—Concentration of potassium in per cent of dry matter and recovery of potassium in variety H 109

<table>
<thead>
<tr>
<th>Grams K₂O added</th>
<th>Bagasse</th>
<th>Crusher juice</th>
<th>Trash and tops</th>
<th>Roots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% K₂O</td>
<td>Gm K₂O</td>
<td>% K₂O</td>
<td>Gm K₂O</td>
</tr>
<tr>
<td>0</td>
<td>.120</td>
<td>.344</td>
<td>.20</td>
<td>.149</td>
</tr>
<tr>
<td>.75</td>
<td>.122</td>
<td>.379</td>
<td>.20</td>
<td>.172</td>
</tr>
<tr>
<td>1.5</td>
<td>.148</td>
<td>.508</td>
<td>.20</td>
<td>.175</td>
</tr>
<tr>
<td>3.0</td>
<td>.146</td>
<td>.553</td>
<td>.20</td>
<td>.192</td>
</tr>
<tr>
<td>4.5</td>
<td>.171</td>
<td>.672</td>
<td>.20</td>
<td>.202</td>
</tr>
<tr>
<td>6.0</td>
<td>.212</td>
<td>.808</td>
<td>.23</td>
<td>.228</td>
</tr>
<tr>
<td>7.5</td>
<td>.223</td>
<td>.854</td>
<td>.27</td>
<td>.260</td>
</tr>
<tr>
<td>9.0</td>
<td>.245</td>
<td>.946</td>
<td>.43</td>
<td>.353</td>
</tr>
<tr>
<td>Totals</td>
<td>5.064</td>
<td>1.731</td>
<td>45.971</td>
<td>2.915</td>
</tr>
</tbody>
</table>
Table 62.—Effect of increasing rates of application of potassium. After Borden (113)

<table>
<thead>
<tr>
<th>Gm K₂O added</th>
<th>Stalk diameter (inches)</th>
<th>Cane (lb)</th>
<th>Brix</th>
<th>Purity</th>
<th>Rendt.</th>
<th>Sugar (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.02</td>
<td>3.55</td>
<td>14.4</td>
<td>79.6</td>
<td>8.01</td>
<td>.28</td>
</tr>
<tr>
<td>.75</td>
<td>1.05</td>
<td>3.93</td>
<td>15.5</td>
<td>81.9</td>
<td>9.07</td>
<td>.36</td>
</tr>
<tr>
<td>1.5</td>
<td>1.08</td>
<td>4.20</td>
<td>15.3</td>
<td>80.6</td>
<td>8.72</td>
<td>.37</td>
</tr>
<tr>
<td>3.0</td>
<td>1.20</td>
<td>4.68</td>
<td>16.8</td>
<td>85.8</td>
<td>10.70</td>
<td>.50</td>
</tr>
<tr>
<td>4.5</td>
<td>1.16</td>
<td>4.88</td>
<td>16.4</td>
<td>84.9</td>
<td>10.25</td>
<td>.50</td>
</tr>
<tr>
<td>6.0</td>
<td>1.27</td>
<td>4.65</td>
<td>16.5</td>
<td>86.7</td>
<td>10.65</td>
<td>.49</td>
</tr>
<tr>
<td>7.5</td>
<td>1.18</td>
<td>4.80</td>
<td>16.9</td>
<td>85.2</td>
<td>10.54</td>
<td>.50</td>
</tr>
<tr>
<td>9.0</td>
<td>1.18</td>
<td>4.38</td>
<td>17.3</td>
<td>88.6</td>
<td>11.53</td>
<td>.54</td>
</tr>
</tbody>
</table>

Table 63.—Influence of light on potassium effect. After Borden (108)

<table>
<thead>
<tr>
<th>K₂O (per acre)</th>
<th>Dry yields (grams)</th>
<th>% Moisture in cane harvested</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full ¹</td>
<td>A.M. ²</td>
</tr>
<tr>
<td>No K₂O</td>
<td>107</td>
<td>100</td>
</tr>
<tr>
<td>200 lb K₂O</td>
<td>145</td>
<td>123</td>
</tr>
<tr>
<td>300 lb K₂O</td>
<td>148</td>
<td>123</td>
</tr>
<tr>
<td>400 lb K₂O</td>
<td>173</td>
<td>134</td>
</tr>
</tbody>
</table>

¹ Full, full day sun; ² A.M., morning sun; ³ P.M., afternoon sun.

The beneficial effect of potassium on the rendement (yield per cent cane) has been reported by several investigators. An example is presented in table 62, which relates to the same pot experiments as those of table 61. Field experiments in Java have shown that on soils deficient in this element the application of potassium generally results in an increased rendement (204, 208, 213). Attention has already been drawn to the interesting phenomenon that under Java conditions potassium seems to correct the detrimental effect of both under- and overdosages of nitrogen and phosphate applications (p. 232).

Protein metabolism.—Hartt (283, 287) has provided evidence that potassium is indispensable for the synthesis and translocation of proteins in the sugarcane plant. Lack of potassium results in a derangement in the synthesis of proteins. Under such conditions, an accumulation of amino nitrogen in the blades and stems occurs. This is associated with a slight decrease of protein nitrogen, thus indicating that the potassium deficient plants are unable to synthesize proteins as usual. The importance of an adequate supply of potassium for the proper translocation of proteins has already been pointed out.

Diseases.—Potassium seems to increase the resistance of sugarcane against certain diseases, which is of considerable practical importance. It has been reported from Hawaii (402, 404) that this applies to eye spot (Helminthosporium sacchari) and the suggestion has been made (464) that the beneficial influence of potassium may be partly due to the fact...
observed by HARTT (283) that potassium increases the thickness of the cuticle. It has also been stated that the large cavities in the cortex of the roots and the poor development of the root hairs in plants deficient in potassium (283) may suggest one possible cause of the root failure complex or Lahaina disease (464).

**Factors influencing the effect of potassium.**—As in the case of other nutrients, the effects of potassium in sugarcane are conditioned by many factors. In other words, many interactions occur between potassium and other factors.

**Variety.**—The effect of potassium on sugarcane seems to depend to a certain degree on the variety used. A comparison of four varieties grown in culture solutions in Hawaii (449) has provided evidence that H 109 suffers most from potassium deficiency, with 31-2806 next. The growth of 32-1063 was better but 32-8560 was outstanding. The variety 32-8560 had the best juice and produced by far the greatest cane and sugar yields under the conditions of potash deficiency. These results indicate that this variety would be much superior to the other three canes for use on soils deficient in potash.

So far there are no data available as to varietal differences in potassium requirements under field conditions.

**Climate.**—For the interaction between climate and fertilizer requirements of sugarcane in general, the reader is referred to the chapter on nitrogen (p. 227). The specific interaction between potassium and climate has been studied in Hawaii using a technique by which cane plants were grown in pots under different climatic conditions, all other factors being uniform (p. 120). The results of these experiments have shown a significant effect of climate on the response of cane to this nutrient. While under favorable climatic conditions (particularly much sunlight), each increment in potash fertilization resulted in increased cane and sugar yields, there was no, or only a limited, response under less favorable climatic conditions (54, 55). In the latter case, the plants had higher concentrations of potassium (114, 163) indicating that the adverse climatic conditions did not permit the full utilization and assimilation of the potassium absorbed (table 6 and 64).

**Light.**—One of the dominant climatic factors is sunlight, as has been proved by BORDEN (108) in a pot experiment the technique of which has been referred to earlier (p. 228). The results of this experiment, as applying to potassium are summarized in table 63.

The apparent inability of the plants grown under a reduced amount of light to utilize effectively the heavier applications of potassium is clearly shown. The first potash increment of 200 pounds per acre gave very similar gains in dry weight (35 and 34 per cent respectively) for both the full-sunlight and the partial-sunlight series. But gains from potash stopped with this 200-pound application when the cane was grown under reduced light, while the plants that were grown in full sunlight gave a 20 per cent further increase in yield for a second 200-pound potash increment. These results clearly indicate that it would be a fallacy to expect that better results would be secured from lands that are subject to continued periods of overcast or cloudy weather, by boosting the potash applications in an attempt to compensate for the shortage of sunlight (108). It is interesting to note that the moisture content of the cane is increased by both potassium and reduced light.

Evidence obtained with plants other than sugarcane has suggested that potassium to
Table 64.—Influence of sunlight intensity on the effect of potassium. After BORDEN (112)

<table>
<thead>
<tr>
<th></th>
<th>Sunlight</th>
<th>Average K$_2$O</th>
<th>Extra K$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lb cane</td>
<td>Full</td>
<td>4.96</td>
<td>5.12</td>
</tr>
<tr>
<td></td>
<td>Decreased</td>
<td>3.82</td>
<td>3.85</td>
</tr>
<tr>
<td>Purity</td>
<td>Full</td>
<td>88.6</td>
<td>88.8</td>
</tr>
<tr>
<td></td>
<td>Decreased</td>
<td>78.3</td>
<td>81.1</td>
</tr>
<tr>
<td>Rendement</td>
<td>Full</td>
<td>13.38</td>
<td>13.72</td>
</tr>
<tr>
<td></td>
<td>Decreased</td>
<td>9.13</td>
<td>9.41</td>
</tr>
<tr>
<td>Lb sugar</td>
<td>Full</td>
<td>.66</td>
<td>.70</td>
</tr>
<tr>
<td></td>
<td>Decreased</td>
<td>.35</td>
<td>.36</td>
</tr>
<tr>
<td>% N in juice</td>
<td>Full</td>
<td>.064</td>
<td>.066</td>
</tr>
<tr>
<td></td>
<td>Decreased</td>
<td>.122</td>
<td>.140</td>
</tr>
<tr>
<td>% K$_2$O in juice</td>
<td>Full</td>
<td>.145</td>
<td>.222</td>
</tr>
<tr>
<td></td>
<td>Decreased</td>
<td>.187</td>
<td>.312</td>
</tr>
<tr>
<td>Total dry weight (grams)</td>
<td>Full</td>
<td>1121</td>
<td>1130</td>
</tr>
<tr>
<td></td>
<td>Decreased</td>
<td>801</td>
<td>795</td>
</tr>
</tbody>
</table>

some extent can assume the role of light. In order to study this question, BORDEN has grown sugarcane in pots under different conditions of light intensity (p. 229) and supplied with different amounts of potassium fertilizer. The results of this experiment are given in table 64. There is apparently no evidence in these data that under the poorer sunlight conditions an extra application of potash could be made to partially compensate for the deficiency in sunlight. The only significant interactions between sunlight and potash are those concerned with the concentrations of nitrogen and potash in the crusher juice. Under conditions of full sunlight, the extra potash apparently had no influence on the percentage of nitrogen in the juice, but under decreased light conditions the extra potash application definitely increased the nitrogen content. The data also show that extra potash application increased the concentration of potassium in the juice more under decreased sunlight than when full sunlight conditions prevailed (112).

Other nutrients.—As to the interaction between potassium and other nutrients, the reader is referred to the chapter on nitrogen (p. 232).

Quantity removed by a crop.—A selected series of figures on the removal of potassium from the soil is presented in table 65. For reasons explained previously, the figures are expressed in such a way that they indicate the quantity of potassium contained in the various parts of the crop associated with each ton of millable cane.

A glance at the table shows that the variation is considerably wider than in the cases of
Table 65.—Pounds of \( K_2O \) contained in the aerial parts associated with each ton of millable cane

<table>
<thead>
<tr>
<th>Country and author</th>
<th>Variety</th>
<th>Age in months</th>
<th>Cane yield tons/acre</th>
<th>Part of plant</th>
<th>CTo</th>
<th>CToTr</th>
<th>CTo(Tr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Java</td>
<td>HONIG (311)</td>
<td>POJ 2878</td>
<td>13–16</td>
<td>40–70</td>
<td>0.4–7.0</td>
<td>68–100</td>
<td></td>
</tr>
<tr>
<td>Mauritius</td>
<td>ANON. (53)</td>
<td>M 134/32</td>
<td>36</td>
<td>4.6</td>
<td>3.5</td>
<td>2.0</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>ANON. (53)</td>
<td>M 134/32</td>
<td>23</td>
<td>4.6</td>
<td>4.0</td>
<td>1.8</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>ANON. (56)</td>
<td>M 134/32</td>
<td>33</td>
<td>3.7</td>
<td>3.1</td>
<td>1.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Louisiana</td>
<td>FORT et al (265)</td>
<td>Co 281</td>
<td>20</td>
<td>5.3</td>
<td>4.3</td>
<td>9.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Co 290</td>
<td>30</td>
<td>6.2</td>
<td>3.8</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Hawaii</td>
<td>BORDEN (113)</td>
<td>32–8560</td>
<td>17</td>
<td>150</td>
<td>5.0–5.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BORDEN (116)</td>
<td>32–8560</td>
<td>20</td>
<td>140</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BORDEN (125)</td>
<td>32–8560</td>
<td>20</td>
<td>133</td>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BORDEN (113)</td>
<td>H 109</td>
<td>12</td>
<td>35</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>31–1389</td>
<td>12</td>
<td>36</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MAXWELL (458)</td>
<td>Rose Bamboo</td>
<td>89</td>
<td>2.9</td>
<td>12.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lahaina</td>
<td>77</td>
<td>1.6</td>
<td>12.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stewart (9)</td>
<td>H 109</td>
<td>76</td>
<td>2.4</td>
<td>1.3</td>
<td>0.6</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H 109</td>
<td>118</td>
<td>2.6</td>
<td>0.7</td>
<td>0.6</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H 109</td>
<td>102</td>
<td>2.0</td>
<td>1.3</td>
<td>0.6</td>
<td>3.3</td>
</tr>
<tr>
<td>South Africa</td>
<td>BEATER et al (90)</td>
<td>Co 290</td>
<td>15</td>
<td>30</td>
<td>1.9</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Co 281</td>
<td>15</td>
<td>30</td>
<td>1.4</td>
<td>4.3</td>
<td></td>
</tr>
</tbody>
</table>

1 C Millable cane  CTo Millable cane plus green top  CToTr Above-ground part of crop  CTo(Tr) Above-ground part of crop except the trash dropped on soil

nitrogen and phosphorus. In Java, for instance, the highest figure is ten times as great as the lowest. In the Hawaii figures, the highest value is about four times the lowest as far as millable cane is concerned. This wide variation is due to the phenomenon of luxury consumption, which means that the cane plant under certain conditions may absorb potassium far beyond its requirement. In view of this fact, it is of little use to give average figures.

BORDEN (113) who made a detailed study on the potash requirement of cane grown in pots, arrived at relatively low figures, as can be seen from table 66. Only 0.7 lb of potassium
was contained in each ton of millable cane, which represents as little as one-tenth of the potassium contained in the complete crop.

As in the case of nitrogen, there is an inverse relationship between the age of the crop and the quantity of potassium associated with each ton of millable cane. This is illustrated in table 67, giving figures calculated by BORDEN from data collected by STEWARD.

Additional figures on the quantities of potassium removed by a cane crop have been reported from Hawaii (74, 78, 119, 237, 459, 527, 528), Java (314, 315, 359, 360, 361, 362, 363, 364, 365, 366, 419), Mauritius (53, 245) and Queensland (345, 346).

Table 66.—Pounds of potassium (as K₂O) contained in the various parts of a cane crop associated with each ton of millable cane. After BORDEN (113)

<table>
<thead>
<tr>
<th>Part of plant</th>
<th>Age in months</th>
<th>Cane yield tons/acre</th>
<th>Lb K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>H 109</td>
<td>12</td>
<td>35</td>
<td>0.5</td>
</tr>
<tr>
<td>Bagasse</td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>Crusher juice</td>
<td></td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>Millable cane</td>
<td></td>
<td></td>
<td>5.6</td>
</tr>
<tr>
<td>Tops plus all trash</td>
<td></td>
<td></td>
<td>6.3</td>
</tr>
<tr>
<td>Aerial portion</td>
<td></td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td>Roots</td>
<td></td>
<td></td>
<td>6.7</td>
</tr>
<tr>
<td>Complete crop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31–1389</td>
<td>12</td>
<td>36</td>
<td>0.5</td>
</tr>
<tr>
<td>Bagasse</td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>Crusher juice</td>
<td></td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>Millable cane</td>
<td></td>
<td></td>
<td>6.6</td>
</tr>
<tr>
<td>Tops plus all trash</td>
<td></td>
<td></td>
<td>7.3</td>
</tr>
<tr>
<td>Aerial portion</td>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Roots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete crop</td>
<td></td>
<td></td>
<td>7.8</td>
</tr>
</tbody>
</table>

Table 67.—Pounds of potassium (as K₂O) removed by a cane crop per ton of millable cane. After BORDEN (113)

<table>
<thead>
<tr>
<th>Plant portion</th>
<th>At 5 mos</th>
<th>8 mos</th>
<th>12 mos</th>
<th>17 mos</th>
<th>24 mos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millable cane</td>
<td>6.3</td>
<td>3.4</td>
<td>2.5</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Entire plant</td>
<td>21.4</td>
<td>13.7</td>
<td>6.5</td>
<td>5.6</td>
<td>4.1</td>
</tr>
</tbody>
</table>
CALCIUM

General.—The role of calcium in the cane plant is still little understood. The fact that the highest concentration of this element is found in the meristematic tissues and in the active leaves, in addition to the fact that cane plants grown in calcium deficient culture solutions exhibit a dying off of the vegetation tip and the youngest leaves of the spindle cluster, suggests that calcium is in some way associated with the formation and growth of new tissues, and with leaf activity.

Calcium is an essential component of the middle lamella, the layer which connects the cell walls of adjoining cells. As stated earlier, calcium pectate is able to swell by absorbing water and there is some evidence that it is associated with the degree of succulence of the cane plant.

Calcium seems to play an important role in the absorption of other elements, for the adverse effect of omitting calcium from a culture solution on the development of the cane plant is more pronounced than that resulting from the omission of any other element (442).

Distribution in the plant.—The distribution of calcium in the different parts of the cane plant has been studied by various investigators (76, 77, 78, 172, 245, 311, 361) and some of the results obtained have already been discussed in the chapter on chemical composition. In addition, table 68 is presented which shows that the concentration of calcium in plants grown in a complete culture solution is highest in the active leaves, and in the elongating cane and meristem. This is in harmony with the results obtained by most other investigators, who found that the highest calcium content occurs in the green leaves. The table shows further that deficiency of potassium or magnesium results in an increased calcium content.

Evans (245) found that the average content of calcium in the leaves (including trash) gradually increases from some 0.25 per cent in dry weight to about 0.5 per cent in the course

<table>
<thead>
<tr>
<th>Compl.</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle cluster</td>
<td>.12</td>
<td>.17</td>
<td>.31</td>
<td>.28</td>
<td></td>
</tr>
<tr>
<td>Green-leaf blades</td>
<td>.46</td>
<td>.41</td>
<td>.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elongating-cane blades</td>
<td>.23</td>
<td>.27</td>
<td>.74</td>
<td>.46</td>
<td></td>
</tr>
<tr>
<td>Green-leaf-cane sheaths</td>
<td>.17</td>
<td>.22</td>
<td>.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elongating-cane sheaths</td>
<td>.14</td>
<td>.19</td>
<td>.38</td>
<td>.73</td>
<td></td>
</tr>
<tr>
<td>Elongating cane and meristem</td>
<td>.24</td>
<td>.10</td>
<td>.42</td>
<td>.32</td>
<td></td>
</tr>
<tr>
<td>Green-leaf cane</td>
<td>.09</td>
<td>.23</td>
<td>.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top internodes</td>
<td>.07</td>
<td>.14</td>
<td>.18</td>
<td>.30</td>
<td></td>
</tr>
<tr>
<td>3rd 3 internodes</td>
<td>.06</td>
<td>.10</td>
<td>.14</td>
<td>.22</td>
<td></td>
</tr>
<tr>
<td>2nd 3 internodes</td>
<td>.06</td>
<td>.08</td>
<td>.10</td>
<td>.02</td>
<td>.16</td>
</tr>
<tr>
<td>1st 3 internodes</td>
<td>.04</td>
<td>.05</td>
<td>.10</td>
<td>.02</td>
<td>.09</td>
</tr>
</tbody>
</table>
of development of a crop. The content in the stems and in the roots fluctuated around 0.25 per cent. Analyses of individual leaves (77) have provided evidence that the calcium concentration slightly increases as the leaves grow older (fig. 150).

Trend of uptake.—In addition to the information given earlier (fig. 151, 153, 154) on the absorption of calcium by the plant as a whole, fig. 191 represents the accumulation by the various portions of the cane plant. It will be noticed that the amount of calcium contained in the leaves remains more or less constant after the latter have attained full development. The calcium present in the stalks increases gradually as the latter develop, and so does the amount of calcium contained in the dry leaves. At the age of 14 months, the amount of this element in the trash appears to be as large as that contained in the stem and the green leaves together.

Deficiency symptoms.—The symptoms associated with calcium deficiency have been described by MARTIN (442, 448, 449). Some weeks after calcium is omitted from the culture solution, the leaves become slightly chlorotic and in the older leaves minute chlorotic spots develop that later turn to a dark reddish-brown color with dead centers. The necrotic areas frequently coalesce, thus giving the entire leaf a brownish or rusty appearance.

The innermost leaves of the leaf spindle become extremely weak, fail to make further growth and ultimately the entire leaf spindle and the terminal bud die. The stalks are small in diameter, taper rapidly toward the growing point, and the rind is very soft.

Quantity removed by a crop.—A selected series of figures on the removal of calcium by the cane plant is presented in table 69 which is composed in the same way as that relating to nitrogen (p. 233). The quantities removed from the soil vary considerably, both between and within countries. Part of the differences may be due to leaching, since calcium is easily washed out from the dry leaves. Approximate average values associated with each ton of millable cane would be: millable cane 0.5, green tops 0.6, trash 1.2, complete above-ground plant 2.3, above-ground part except abscised leaves 1.7 lb of calcium.
### Table 69.—Pounds of CaO contained in aerial parts of a cane crop associated with each ton of millable cane

<table>
<thead>
<tr>
<th>Country and author</th>
<th>Variety</th>
<th>Age in months</th>
<th>Cane yield tons/acre</th>
<th>Part of plant</th>
<th>C</th>
<th>To</th>
<th>Tr</th>
<th>CTo</th>
<th>CToTr</th>
<th>CTo(Tr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Java</td>
<td>POJ 2878</td>
<td>13–16</td>
<td>40–70</td>
<td>0.2–0.5</td>
<td></td>
<td>0.5</td>
<td>0.1</td>
<td>1.4</td>
<td>0.6</td>
<td>2.0</td>
</tr>
<tr>
<td>HONIG (311) v. L. CAMPAGNE (419)</td>
<td></td>
<td>12</td>
<td>50</td>
<td>0.3–0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mauritius</td>
<td>M 134/32</td>
<td>23</td>
<td>0.8</td>
<td>0.9</td>
<td>1.4</td>
<td>1.7</td>
<td>3.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANON. (46)</td>
<td></td>
<td>33</td>
<td>0.8</td>
<td>0.8</td>
<td>1.8</td>
<td>1.6</td>
<td>3.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANON. (56)</td>
<td></td>
<td>Co 281</td>
<td>20</td>
<td>0.8</td>
<td>0.8</td>
<td>1.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Louisiana</td>
<td></td>
<td>Co 290</td>
<td>30</td>
<td>0.5</td>
<td>0.7</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FORT et al (265)</td>
<td></td>
<td>Co 281</td>
<td>20</td>
<td>0.8</td>
<td>0.8</td>
<td>1.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hawaii</td>
<td>Rose</td>
<td>89</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAXWELL (458)</td>
<td>Bamboo</td>
<td>77</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lahaina</td>
<td>77</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stewart (9)</td>
<td>H 109</td>
<td>76</td>
<td>0.4</td>
<td>0.1</td>
<td>0.7</td>
<td>0.5</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H 109</td>
<td>118</td>
<td>0.4</td>
<td>0.1</td>
<td>0.7</td>
<td>0.5</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H 109</td>
<td>102</td>
<td>0.3</td>
<td>0.1</td>
<td>0.8</td>
<td>0.4</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>Beater et al (90)</td>
<td>Co 290</td>
<td>15</td>
<td>30</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Co 281</td>
<td>15</td>
<td>30</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 C Millable cane CTo Millable cane plus green top
To Green top CToTr Above-ground part of crop
Tr Trash CTo(Tr) Above-ground part of crop except the trash dropped on soil

Additional figures on the removal of calcium by cane crops have been reported from Java (314, 315, 361, 362, 363, 364, 365, 366), Hawaii (74, 237, 459, 527, 528) and Mauritius (245).

### MAGNESIUM

Magnesium is one of the constituents of chlorophyll and thus it is essential for the normal functioning of the cane plant. In addition to the information given previously (p. 183), fig. 192 is presented to show the accumulation of this element in the various parts of the cane plant. The rate at which magnesium is taken up by the plant as a whole resembles largely that of calcium. A marked difference, however, appears in the distribution of these two nutrients, since the amount of magnesium accumulated in the dry leaves is considerably smaller than in the case of calcium. The distribution and uptake of magnesium has also been studied by KOBUS (363) and HONIG (311).
Fig. 192.—Rate of magnesium accumulation in the aerial parts of the cane plant. After Ayres (78).

The deficiency symptoms as described by Martin (442, 448, 449) resemble to a certain extent those of calcium. The young leaves lose some of their dark green color, but not to the extent of the older ones. On the latter, minute chlorotic spots appear, that later turn to a dark-brown color. They are uniformly distributed over the leaf surface and at times coalesce, thus giving a rusty appearance. The spotting is most pronounced on the older leaves and decreases in severity on the younger ones. In severe cases of magnesium deficiency, the leaves are chlorotic and badly spotted, and the stalks may manifest internal browning while the diameter and the length of the internodes are reduced.

The same author (449) obtained evidence of varietal differences in tolerance to magnesium deficiency.

Selected figures relating to the quantities of magnesium removed by the above-ground parts of a cane crop are listed in table 70. Explanatory notes on this method of presentation have been given previously (p. 233). As in the case of potassium and calcium, the quantities of magnesium associated with each ton of millable cane vary considerably. Approximate average figures would be: for millable cane 0.8, for green tops 0.4, for millable cane plus tops 1.2, for trash 0.4, and for the entire above-ground part about 1.6 lb of magnesium.

Additional data on the removal of magnesium by the cane plant have been reported from Hawaii (74, 459, 527, 528).

MANGANESE

This element is essential to sugarcane although only very small amounts are required for normal development. The manganese content of dry-leaf cane is approximately 0.01 per cent on a dry weight basis. It is less in the green-leaf cane and the non-millable top, and still lower in the leaves (table 21). Little is known about the function of manganese in plants; several theories have been advanced to explain the action but apparently none of these rests upon adequate experimental evidence. There is evidence that, by some mechanism at
present unknown, manganese aids in the normal formation of green tissue (200). Only extremely small quantities of manganese have been found to be necessary for normal cane growth in nutrient solutions, viz., 0.25 p.p.m., which is equivalent to approximately 0.75 of a pound per acre (449).

The symptoms associated with manganese deficiency are identical with those of a disease known in Hawaii as Pahala blight (14, 200, 405, 442, 448, 449). Plants growing in culture solutions deficient in manganese are characterized by an alternation of yellow-white tissue with green tissue in the leaf blades. This leaf striping is somewhat similar to the early symptoms of iron deficiency. In the case of manganese deficiency, however, the striping develops more abundantly toward the middle and tips of the leaves and seldom continues the full length of the latter.

Small necrotic regions often appear in the white stripes which later may coalesce, thus resulting in stripes of dead, dry tissue. Since the latter often split or crack longitudinally, this disease at one time was called leaf-splitting disease. The leaves are often severely twisted and intertwined.

Table 70.—Pounds of MgO in the aerial parts of a cane crop associated with each ton of millable cane

<table>
<thead>
<tr>
<th>Country and author</th>
<th>Variety</th>
<th>Age in months</th>
<th>Cane yield tons/acre</th>
<th>Part of plant ¹</th>
<th>C</th>
<th>To</th>
<th>Tr</th>
<th>CTo</th>
<th>CToTr</th>
<th>CTo(Tr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Java</td>
<td>POJ 2878</td>
<td>13–16</td>
<td>40–70</td>
<td>0.2–0.8</td>
<td></td>
<td></td>
<td></td>
<td>0.3</td>
<td></td>
<td>0.3–1.1</td>
</tr>
<tr>
<td>Mauritius</td>
<td>M 134/32</td>
<td>23</td>
<td>1.0</td>
<td>0.6 0.4 0.4 1.6 1.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANON. (46)</td>
<td></td>
<td>33</td>
<td>0.4 0.6 0.4 0.7 1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Louisiana</td>
<td>Co 281</td>
<td>20</td>
<td>0.9</td>
<td>0.4 1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Co 290</td>
<td>30</td>
<td>0.6</td>
<td>0.4 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hawaii</td>
<td>Rose</td>
<td>89</td>
<td>0.4</td>
<td>2.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bamboo</td>
<td>77</td>
<td>0.3</td>
<td>2.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>Co 290</td>
<td>15</td>
<td>30</td>
<td>1.7 2.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Co 281</td>
<td>15</td>
<td>30</td>
<td>1.4 2.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ C Millable cane  CTo Millable cane plus green top  
To Green top      CToTr Above-ground part of crop  
Tr Trash          CTo(Tr) Above-ground part of crop except the trash dropped on the soil
IRON

This element occurs only in very minute quantities in sugarcane (table 21). Iron is essential for the formation of chlorophyll although it is not a component of this pigment. According to MARTIN (442, 448, 449), the deficiency symptoms start in the youngest leaves in the form of pale stripes which develop into white stripes extending over the full length of the leaves. The striping is caused by the fact that the normal green color disappears from the leaf tissue between the small vascular bundles with only the chlorophyll-bearing tissues immediately surrounding the large bundles remaining green. In a later stage, the latter tissues also become chlorotic, resulting in a more uniformly pale or chlorotic appearance of the leaf. The subsequently formed leaves are perfectly white except for a trace of light green color in the lower surface of the midrib. Thus, there is a strong contrast between the white youngest, the striped intermediate, and the green older leaves. Spraying with a 2 per cent solution of iron sulphate results in a definite greening of the leaves.

The roots develop an abnormal type of growth which is characteristic of plants grown in solutions deficient in iron. The growth of the primary roots is greatly retarded, while the second and third order roots remain extremely short or "stubby".

<table>
<thead>
<tr>
<th>Country and author</th>
<th>Variety</th>
<th>Age in months</th>
<th>Cane yield tons/acre</th>
<th>Part of plant 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Java HONIG (311)</td>
<td>POJ 2878</td>
<td>14</td>
<td>64</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13</td>
<td>70</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14</td>
<td>63</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14</td>
<td>58</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>53</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>66</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13</td>
<td>43</td>
<td>0.3</td>
</tr>
<tr>
<td>Hawaii ECKART (237)</td>
<td>Demera-</td>
<td>130</td>
<td>130</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>rata 74</td>
<td></td>
<td></td>
<td>2.2 2</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>94</td>
<td>0.2</td>
<td>1.7 2</td>
</tr>
<tr>
<td></td>
<td>Bamboo</td>
<td>89</td>
<td>0.7</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Rose</td>
<td>77</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lahaina</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 C Millable cane  CTo Millable cane plus green top
To Green top      CToTr Above-ground part of crop
Tr Trash          CTo(Tr) Above-ground part of crop except the trash dropped on soil

2 Including dead stalks
The phenomenon of iron toxicity has already been discussed earlier (p. 251).

Some figures on the quantities of iron associated with each ton of millable cane are presented in table 71, which is composed in the same way as the table on nitrogen (p. 233). The order of magnitude of the figures on iron resembles greatly that for calcium (table 69). The quantity of iron present in a ton of millable cane averages approximately 0.4 lb.

**SILICON**

Silicon is present in considerable amounts, particularly in the dry and in the green leaves. Ballard (82) found the following percentages expressed in dry weight: dry leaves 2.6, green leaves 1.8, non-millable top section of the stem 0.28, dry leaf cane 0.20 and green-leaf cane 0.15. The high content in the leaves as compared with the stem is also apparent from fig. 193. In this figure, the content of silicon decreases toward the base of the stem. This is largely due to a general decrease of the total ash content in the same direction. When silicon is expressed in per cent of total ash, the picture becomes different (fig. 194). In this case, the percentage of silicon is lowest in the top of the stem and increases toward the base. The same was found in the case of phosphoric acid and indicates that the less readily translocated elements actually increase in the ash, as the internodes mature (fig. 148).

The variation in silicon content among plants grown under different conditions is perhaps greater than that of any other element. The composition of the soil plays an important role in this respect. An example is presented in table 72 in which the silicon content of cane grown under different conditions as to climate and soil is listed. The figures relate to Mauritius conditions and show that the silicon content decreases as the climate becomes

![Fig. 193.—Trend of silica concentration in various aerial parts of the sugarcane plant. Data presented as percentage of dry matter. For explanation of symbols see fig. 147. After Ayres (75).](image-url)
Table 72.—Effect of climate on the silicon content of cane in Mauritius (50)

<table>
<thead>
<tr>
<th>Climate</th>
<th>Silicon (SiO₂) in per cent of dry matter</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Millable cane</td>
<td>Trash</td>
</tr>
<tr>
<td>Sub-humid</td>
<td>1.02</td>
<td>7.92</td>
</tr>
<tr>
<td>Humid</td>
<td>0.74</td>
<td>5.78</td>
</tr>
<tr>
<td>Super-humid</td>
<td>0.68</td>
<td>5.46</td>
</tr>
</tbody>
</table>

more humid. Since the rate at which silicon leaches from the soil increases with rainfall (laterization), the figures indicate that the differences in silicon of the cane plant grown in the three regions is largely due to different quantities of silicon available in the soil.

As already mentioned, considerable quantities of silicon are accumulated in the dying leaves. The content of this element expressed in per cent of dry weight may increase from 0.4 per cent in young leaves to more than 6 per cent in old ones (fig. 150).

The trend of silicon accumulation in the various parts of the cane plant is shown in fig. 195. After six months, the amount of silicon contained in the green leaves remains fairly constant. In the stem, and particularly in the trash, accumulation continues at a more or less uniform rate. At harvest more silicon is present in the dead leaves than in the entire living part of the crop.

Little is known about the function of silicon in the cane plant. The fact that cane develops normally when only minute quantities of silicon are available indicates that the large quantities usually absorbed are not necessary.

Data on the removal of silicon by the cane crop are presented in table 73 which is com-
Fig. 195.—Rate of silicon accumulation in the aerial parts of the cane plant. After Ayres (78).

Table 73.—Pounds of SiO₂ contained in the aerial parts associated with each ton of millable cane

<table>
<thead>
<tr>
<th>Country and author</th>
<th>Variety</th>
<th>Age in months</th>
<th>Cane yield tons/acre</th>
<th>Part of plant ¹</th>
<th>CTo</th>
<th>To</th>
<th>Tr</th>
<th>CTo</th>
<th>CToTr</th>
<th>CTo(Tr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Java</td>
<td>POJ 2878</td>
<td>13-16</td>
<td>40-70</td>
<td>5.4-9.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.4-15.3</td>
</tr>
<tr>
<td>Mauritius</td>
<td>M 134/32</td>
<td>33</td>
<td>6.3</td>
<td>4.6</td>
<td>12.7</td>
<td>10.9</td>
<td>23.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Louisiana</td>
<td>Co 281</td>
<td>20</td>
<td>5.6</td>
<td>7.8</td>
<td>13.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Co 290</td>
<td>30</td>
<td>4.2</td>
<td>9.1</td>
<td>13.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hawaii</td>
<td>Rose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bamboo</td>
<td>89</td>
<td>5.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46.0</td>
</tr>
<tr>
<td></td>
<td>Lahaina</td>
<td>77</td>
<td>3.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>45.2</td>
</tr>
<tr>
<td>Stewart (9)</td>
<td>H 109</td>
<td>76</td>
<td>4.4</td>
<td>1.7</td>
<td>22.4</td>
<td>6.1</td>
<td>28.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H 109</td>
<td>118</td>
<td>4.9</td>
<td>0.8</td>
<td>14.6</td>
<td>5.7</td>
<td>20.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H 109</td>
<td>102</td>
<td>2.4</td>
<td>1.1</td>
<td>11.5</td>
<td>3.5</td>
<td>15.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ C Millable cane       CTo Millable cane plus green top
To Green top            CToTr Above-ground part of crop
Tr Trash                CTo(Tr) Above-ground part of crop except the trash dropped on the soil
posed as explained previously (p. 233). It shows that this element is removed in considerable quantities especially by the trash. Taking into consideration the fact that silicon is often taken up far in excess of the requirement, the variations in table 73 are relatively small. Approximate averages of silicon associated with each ton of millable cane would be: millable cane 5.0, green tops 4.0, trash about 16.0, entire above-ground plant 25.0 lb.

Additional figures on the removal of silicon have been reported from Hawaii (74, 527, 528).

SULPHUR

This element is essential for the formation of protein, an important constituent of protoplasm.

When cane is grown in nutrient solutions deficient in sulphur, the first symptoms, according to Martin (442, 448, 449) are somewhat similar to the early symptoms of nitrogen deficiency. The younger leaves begin to lose their normal green color and develop a uniform light yellowish-green color. Later, the young as well as the older leaves show a faint purplish tinge. Since plants deficient in nitrogen do not develop the purple color in the leaves, the latter may be associated with sulphur deficiency. The purplish color is due to the development of anthocyanin, a coloring matter found also in other parts of the cane plant (p. 8). The leaves become narrow and fail to develop their full length. The plants lack growth and vigor, and the stalks are small in diameter, tapering rapidly toward the growing point.

BORON

This element, constituting approximately 0.01 per cent of the dry weight of the cane plant (table 21) is essential for normal development, but a concentration as small as 0.1 p.p.m. in culture solutions is sufficient to prevent symptoms of boron deficiency (309).

Serious malformations resulting from lack of this element have been reported by Martin (443, 448, 449). The most marked symptoms are the retardation of growth, the development of distorted leaves, the chlorotic condition of the young leaves and the presence of definite lesions on the leaves and within the stalks.

The first symptoms appear on the young leaves in the form of minute, elongated, watery spots developing parallel to the vascular bundles and thus producing a definite leaf striping. The initial lesions enlarge and are characterized by the presence of small longitudinal sunken areas or depressions in their centers. On the lower leaf surface, minute, elongated, gall-like bodies frequently develop. The young leaves are very narrow, short, and chlorotic.

In the mature lesions, the leaf tissues separate, forming definite cracks or fractures in the leaf. The inner edges of these fractures are serrate, giving the appearance of ladder-like lesions.

Internal, narrow, brownish streaks at and slightly below the growing point are sometimes present which may show the ladder-like arrangement somewhat similar to that in the leaf. These symptoms resemble closely those of the pokkahboeng disease caused by Fusarium.
moniliforme Sheldon, but the microscopic symptoms differ considerably (222a, 223).

Varietal differences in tolerance of boron deficiency have been reported from Hawaii (449) where H 109 proved to be superior to the varieties 31-2806, 32-1063 and 32-8560.

COPPER

This element has played a considerable role in the development of the sugar industry on raw peat soils in Florida where, without the application of this element, cane made no growth. The leaves of plants deficient in copper are chlorotic and in many instances the green is broken up into sharp, more or less rectangular blotches. The plants are exceedingly poor in development and color, while the leaves fail to unroll, especially in the heavier types of cane. Injection of weak solutions of copper, or better still a small amount of precipitated copper in the form of Bordeaux mixture, into the stems of seed cane gives a very pronounced response. It has become common practice to use from 75 to 100 pounds of copper sulphate per acre on the soils involved in Florida. This is distributed in the furrow before planting or the salt is incorporated directly into the fertilizer mixture (6).

Little is known about the function of copper in plants. The content of this element in the cane plant is very low, about 0.001 per cent of dry weight (table 21).

Table 74.—Pounds of \( Al_2O_3 \) contained in the aerial parts associated with each ton of millable cane

<table>
<thead>
<tr>
<th>Country and author</th>
<th>Variety</th>
<th>Age in months</th>
<th>Cane yield tons/acre</th>
<th>Part of plant¹</th>
<th>C</th>
<th>To</th>
<th>Tr</th>
<th>CTo</th>
<th>CToTr</th>
<th>CTo(Tr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Java</td>
<td>POJ 2878</td>
<td>14</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13</td>
<td>70</td>
<td></td>
<td>0.11</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>14</td>
<td>63</td>
<td></td>
<td>0.05</td>
<td></td>
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<td></td>
<td></td>
<td>15</td>
<td>53</td>
<td></td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>56</td>
<td></td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hawaii</td>
<td>Demarara 74</td>
<td>130</td>
<td>0.4</td>
<td></td>
<td>2.3 ²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eckart (237)</td>
<td>White Bamboo</td>
<td>94</td>
<td>0.7</td>
<td></td>
<td>2.1 ²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rose Bamboo</td>
<td>89</td>
<td>0.5</td>
<td></td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxwell (458)</td>
<td>Lahaina</td>
<td>77</td>
<td>0.6</td>
<td></td>
<td>1.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ C    Millable cane CTo Millable cane plus green top
    T Green top CToTr Above-ground part of crop
    Tr Trash CTo(Tr) Above-ground part of crop except the trash dropped on the soil

² Including dead stalks
Aluminium occurs in small quantities in the cane plant. Its concentration is about the same as that of copper, viz., approximately 0.001 per cent in dry weight (table 21). As in the case of iron, cane plants growing on acid soils containing soluble aluminium are characterized by abnormal accumulations of this element in the nodes of the stalk, associated with a severe toxic action of aluminium on the growth of sugarcane (429).

The concentration of sodium, strontium, barium and lead is approximately 0.01, 0.0005, 0.0005, and nil, respectively, in dry weight of the dead-leaf cane (table 21).

Table 74 gives an idea of the quantity of aluminium removed from the soil by a cane crop and its constituent parts. With the exception of the Java figures, which are extremely low, the order of magnitude resembles greatly that of iron (table 71).

CHAPTER 13
WATER
GENERAL

The total fresh weight of a cane crop consists of more than 70 per cent of water, leaving less than 30 percent of dry matter (fig. 174). Thus the ratio of water and dry matter is roughly 2.5 to 1.

These figures, however, relate only to a small fraction of the total quantity of water absorbed by the plant. It is estimated that for each part of dry matter produced, the cane plant has absorbed some 250 parts of water. A comparison with the figure of 2.5 mentioned before indicates that only 1 per cent of the total amount of water absorbed is retained in the plant.

The amount of water actually utilized in the building process is still smaller. For the matter of simplicity, it is assumed that dry matter consists largely of carbohydrates and that half their weight is carbon and the other half water. With reference to the ratio of 250 to 1 mentioned before, this means that only one part out of 500 parts of water is incorporated in the dry matter. Or in other words, 998 parts of every 1000 parts of water absorbed by the plant are not incorporated in the dry matter. In this respect, water differs widely from nutrients like nitrogen, phosphorus, etc., which are absorbed more or less according to requirement and which once being taken in, remain largely in the plant. If water would behave in a like manner, the water requirement of a cane crop would be reduced to 1 per cent of the actual amount and irrigation would no longer constitute a problem.

The large quantities of water which are absorbed in excess of the amounts required for building purposes and for maintaining the turgor of the tissues are lost by transpiration. This has at one time led to the opinion that transpiration is a harmful or at least a superfluous process. This view has culminated in a statement by CURTIS that transpiration is a necessary evil that evolution would at some time correct (188).

Actually transpiration fulfills a definite task in plant life. It prevents the temperature of
the leaves from rising too high, it aids in the absorption of nutrients through the roots and in the translocation of these nutrients within the plant, and it is involved in many other vital processes.

As stated before, approximately 250 parts of water are consumed by the cane plant in the production of one part of dry substance. This figure is based on the results obtained by various workers. MAXWELL (456) in Hawaii grew cane in pots up to an age of 7 months and found an average utilization of 148 grams of water per gram of dry substance produced. LEATHER (396a) in India arrived at a figure of 200. TEMpany (541) in Mauritius who grew cane plants in pots up to 7 months of age, found values of 275 and 300 at two different localities. From data reported by SHAW and WADSWORTH (14), it appears that plants grown to full maturity in large tanks evaporated 124.5 pounds of water per pound of cane produced. This would indicate a transpiration of approximately 250 pounds of water per pound of total dry weight. In experiments with plants grown in culture solutions, PARDO (478) obtained values ranging from some 200 to 300. Thus the data so far available, with the exception of the low figure of 148 reported by MAXWELL, roughly range from 200 to 300, and 250 seems to represent a fair average. HARDY (280) mentions a figure of 500 but since no experimental evidence is presented it is not clear whether this figure is an assumption or not.

The amount of research devoted to the water relations in the cane plant is considerable. This is due to the fact that irrigation constitutes an important economic factor in many sugarcane growing countries. In areas where water has to be supplied by irrigation, it may even constitute one of the largest single factors in production cost. This applies especially to countries where, as a result of lack of surface water, water has to be pumped up from underground sources. This is, for instance, the case in Hawaii, where more than $4,000,000 have been spent by the sugar industry in irrigation equipment alone (184), amounting to more than $300 for the average irrigated acre (536). It is, therefore, small wonder that Hawaiian investigators, stimulated by the urgency of this problem, have achieved pioneer work in this field of research.

**INTAKE OF WATER**

**Absorption by aerial parts.**—It is generally recognized that plants acquire water largely through their roots. As to their ability to obtain water through the aerial parts, the views are widely divergent. Although it has been proved that leaves in general are capable of absorbing limited quantities of water, it was long held that the conditions for this kind of absorption seldom occur in nature and that the amounts thus absorbed are of no physiological significance (462). Carefully controlled experiments have indicated, however, that the behavior of sugarcane, as in so many other respects, may be quite different from that of most other crops.

Sugarcane planters have been long aware of the beneficial effect of heavy dewfall and light showers, even if these are too small to moisten the soil.

The first experimental evidence in support of this observation was reported by
WADSWORTH and Das (577), who cut a wilted cane stalk at soil surface and sealed the cut end with wax. When suspended under a fine spray, the stalks retained full turgidity over night. Subsequent detailed studies by Shaw and WADSWORTH (573, 574) have provided additional proof of this peculiar ability. To this end, single cane plants were grown in large tanks, the top surfaces of which were made water tight by means of warm asphalt so that no moisture could reach the soil from outside. When such plants were exposed to natural rain or to artificial showers (sprinkling with a garden hose) significant gains in weight were recorded. The most spectacular case was one in which a gain of 80 pounds per tank was observed after three hours of garden hose sprinkling.

Examination of the soil in the tanks revealed the surprising fact that the moisture content at a depth of six inches below the soil surface had considerably increased, while the surface layer of soil was at practically the same moisture content after sprinkling as before.

The results obtained by Shaw and WADSWORTH suggest that, contrary to what is known from most other plants, sugarcane seems to have an amazing capacity of absorbing moisture through its above-ground parts, of conveying this moisture to its roots, and of discharging it through the roots into the soil.

This process is exactly the reverse of that occurring normally, when water is absorbed by roots and transpired through the leaves.

The above results endorse, in a striking manner, the opinion held by many planters about the beneficial effect of heavy dewfall and light showers on sugarcane.

The parts of the leaves which are most actively engaged in the absorption of water are apparently the bulliform cells of the epidermis, since their cuticle is thinner than that of the other epidermis cells. The fact that the bulliform cells are the first to lose water when the leaves start wilting indicates that they may be capable of rapid absorption. In the stem there is evidence that absorption of moisture is most marked in the nodal zone. For Sanyal (504) found that when cane stalks were subjected to moisture, the entrance of water occurred almost wholly through the nodal region. This fact is in harmony with the common observation that sections of a stem subjected to drying manifest the greatest degree of shrinkage in the growth ring.

Absorption by roots.—The bulk of the water used by the plant is taken up by the roots, and more especially by the root hairs. From the root hairs it is transported through the older roots and the stem to the leaves where it is transpired. The forces involved in the translocation of water within the plant are, among others, the pressure exerted by the roots (root pressure) and the suction exerted by the transpiring leaves (leaf pull). Both forces can be demonstrated in a simple way by severing a cane stalk near the soil surface. Under favorable conditions, the cut surface of the remaining stump will exude liquid, thus indicating the existence of root pressure. The severed stalk, when placed with its cut end in water, will take up considerable quantities of moisture, demonstrating in this way the action of leaf pull.

Root pressure.—Evans (252) removed cane stools together with soil, from a rectangular block, leaving undisturbed the portions of the roots outside this block. To the cut ends of the roots left in the soil, test tubes were fixed in order to collect the liquid exuded by the
roots. It appeared that root exudation was very active, positive pressures being obtained almost throughout the year if conditions of moisture were favorable (242). Since the pressure exerted by the individual roots extends into the stem, it follows that when a stem is severed near the soil surface, a marked root pressure will be exerted by the remaining stump. Weller (591), who connected mercury columns to such stumps, recorded pressures up to 140 cm of mercury, corresponding to water columns of more than 60 feet in height.

Root pressure is greatly influenced by internal and external factors. Weller (591) examined the root pressure of four varieties every 3 hours during 3 weeks and found that root pressure generally rises at night and falls during day (fig. 196). He also noticed varietal differences; H 109 showed the lowest value, and root pressure progressively increased in Yellow Caledonia, D 1135 and Uba (fig. 197). The fact that the drought resistance of these varieties increases in the same order is indicative of a direct relationship between root pressure and drought resistance in the varieties mentioned (591, 592).

Some interesting relationships have been established between soil moisture and root pressure. As mentioned previously, Evans (252) observed that under the conditions of pronounced drought no liquid was exuded from the surface roots in the first 8 inches of soil; exudation gradually increased as the roots were located at greater depth and was greatest from the roots below 3 feet. When copious watering was applied, the surface roots, in addition to the deeper roots, resumed exudation vigorously. Therefore, there is little doubt that during a dry period, absorption by the surface roots is almost at a standstill.

![Fig. 196.—Trend of root pressure of a plant of H 109 measured at 3-hour intervals. Ordinate, root pressure in centimeters of mercury. Note the rise in root pressure during night and the drop during day. Applications of water (cross hatching) temporarily stop the general downward trend of the curve. After Weller (591).](image-url)
Absorption by the deeper roots, on the other hand, is continuous since even in a drought the moisture content of the deeper soil layers is adequate. In Uba, exudation was recorded from roots severed at a depth of 15 feet, indicating that this liquid had been absorbed from depths greater than 15 feet. The fact that during periods of drought only the deeper roots are capable of absorbing to any extensive degree, has a particular bearing on the nutrition of the cane plant. For, since the subsoil is generally much poorer in mineral nutrients, it is obvious that the plants will suffer from mineral starvation in addition to inadequate water supply.

Weller (592) also found a close relationship between root pressure and soil moisture content. Cane plants were grown in pots with soil containing different amounts of water. When the stems were cut near the soil surface and their stumps connected with mercury columns, the root pressure appeared to be in direct proportion to the water content of the soil.
As stated before, a positive correlation is indicated between drought resistance and root pressure. In addition, WELLER (591) found that when irrigation was withheld from Uba, D 1135, Yellow Caledonia and H 109, the falling off of the root pressure was greatest in H 109, less in Yellow Caledonia, still less in D 1135, and least in Uba. Since this order corresponds to the order of increasing drought resistance, these results indicate that drought resistance is associated with an ability to maintain a high root pressure under dry conditions. This phenomenon offers a possibility of developing a method of estimating the drought resistance of seedlings in an early stage of selection (592).

**ABSORBING SURFACE.**—For a long time the root system of cane varieties has been judged by its total length and mass. Contrary to expectation, it appeared that high-yielding varieties are not of necessity those exhibiting an extensive visible root system. In other words, there is no necessary correlation between yielding capacity and root mass.

STEVenson and McINTOSH (526), when comparing five varieties, found the following relative root masses:

<table>
<thead>
<tr>
<th>Variety</th>
<th>Total length of roots</th>
<th>Total surface</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>%</td>
</tr>
<tr>
<td>BH 10 (12)</td>
<td>810,911</td>
<td>100</td>
</tr>
<tr>
<td>Ba 11569</td>
<td>1,733,376</td>
<td>214</td>
</tr>
<tr>
<td>B 726</td>
<td>1,387,712</td>
<td>171</td>
</tr>
</tbody>
</table>

Although Ba 11569 in this case had only about one-fourth as many roots as B 726, it nevertheless gave very satisfactory yields. Therefore, the suspicion was raised that mass of roots is not the deciding factor as far as absorbing capacity is concerned.

This led EVANS (253, 255) to a very detailed study of the root composition of several varieties, including the measurement of length and surface of all roots. For this purpose plants were grown 9 feet apart in order to prevent intermingling of roots of adjacent plants. The root systems were examined when the plants were 12 to 14 months of age. Part of the results thus obtained are presented in table 75, which shows some interesting features. There is, in the first place, the total length of roots which ranges, for the plants grown under these conditions, from 8 to 17 km. The actual extent of the absorbing surface of the root hairs of POJ 2878, BH 10 (12) and White Tanna is in the relation 100, 60 and 12 respectively. The total lengths, on the other hand, are, on the same basis, 100, 214, 171. There is thus no correlation between total length of all types of roots, and extent of absorbing
surface at this age. POJ 2878, for instance, with total root length of only 58 per cent of that of White Tanna has, at this age, an absorbing system over eight times as extensive.

The development of root hairs depends on many factors, such as variety, age and growing conditions. Evans (38, 253, 258) found the root hair density to be considerably higher in dry environments than in wet localities. Root hair density was markedly affected by the age of the plants, reaching its maximum at 6 months. The lowest density occurred in the 15 month old plants.

Soil moisture.—The rate at which water is absorbed by the cane plant is greatly influenced by the amount and the availability of soil moisture. Considerable progress has been made in our knowledge of the water relationships between plant and soil, and these are of considerable economic importance.

The popular conception some fifty years ago, and one which is still widely accepted by cane growers, is that there exists for each soil type an “optimum” moisture content, at which a given plant species will display its maximum growth rate. It was generally accepted that the optimum was about 60 per cent of the maximum water holding capacity of the soil. It was furthermore held that water in the soil is able to move by capillary action. The moisture evaporated from the soil surface was supposed to be replenished by water from deeper soil layers ascending by capillary forces. Preventing the loss of water through surface evaporation has been one of the major objects of the dry farming system.

This conception has been abandoned since the classic studies of Briggs, Shantz et al., and the validity of the results obtained by these investigators has been corroborated for sugarcane by Shaw, Swezey, Wadsworth and other workers in Hawaii.

One of the interesting results corroborated by Shaw (510, 513) is the physical impossibility of wetting a soil to a uniform moisture content, other than its maximum field capacity. The latter indicates the maximum amount of water that can be held by the soil against the force of gravity. This is being demonstrated by the experiment depicted in fig. 198. Five waterproofed cardboard cartons were filled with an oven-dried soil of 35 per cent field capacity. Various amounts of water, sufficient to bring the average moisture content of the soil to 10, 20, 25, 30 and 40 per cent respectively, were added to the soil surface. The distribution of the water after 40 hours is represented in fig. 198 which shows a rather sharp line of demarcation between the wet and the dry soil. The soil within the wetted area is at its maximum field capacity, while the dry soil is as dry as it was before. Apparently a given soil has the capacity of holding around its granular structure a certain quantity of water. When the surface layer of dry soil has satisfied its capacity for moisture, water descends to the next lower soil level, where sufficient moisture is absorbed to satisfy the capacity of this additional layer. This process is continued until all of the water is held by the soil.

In the past, several experiments have been conducted on the effect of soil moisture on cane development. Plants were grown in pots to which so much water was added as to keep the moisture content at certain levels, for instance, 10 per cent, 20 per cent, etc. It will be obvious that in the light of the findings just mentioned, the results obtained by this kind of experiments become rather questionable (510).

When furrows in a cane field are irrigated, a picture similar to that obtained in the
THE DISTRIBUTION OF MOISTURE IN A SOIL OF 35 PER CENT FIELD CAPACITY WHEN VARYING AMOUNTS OF WATER ARE APPLIED TO THE SURFACE

Fig. 198.—Distribution of moisture in a soil of 35 per cent field capacity to which varying quantities of water have been added to the surface. After Shaw (513).

DISTRIBUTION OF SOIL MOISTURE UNDER THE LONG LINE-BORDER COMBINATION METHOD OF IRRIGATION

EWA PLANTATION CO.

Trench A
250' Feet From Level Ditch

48 Hours after irrigation

Trench B
475' Feet From Level Ditch

48 Hours after irrigation

Fig. 199.—Cross section of four furrows showing the distribution of moisture 48 hours after irrigation. Upper figure, 250 feet from irrigation ditch; lower figure, 475 feet from irrigation ditch. After Shaw (511).
previous experiment results. Fig. 199 shows how the water applied to four furrows has wetted a more or less elliptical zone below each furrow, thus forming a kind of moisture reservoir. Again there is a rather sharp line of demarcation between the wetted and the dry zones. Additional details are presented in fig. 200, which shows the results of moisture determinations of soil samples taken inside and outside the wetted area. It appears that the soil at all points within the wetted area is at its maximum field capacity. The soil immediately outside this area is considerably below its field capacity, and in all probability has received no water from the current irrigation.

Subsequent investigations, including moisture determinations at later intervals have provided evidence that no appreciable movement of moisture in either a lateral or vertical direction had taken place after 48 hours (510). Therefore, little reliance may be placed in capillary action as a means of conveying water through a loam soil as used in these experiments. The second important conclusion to be drawn from these experiments is that it is impossible to bring the moisture content of a soil to a predetermined percentage (e.g., optimum soil moisture) by adding water to the surface.

An aspect of practical importance is shown in fig. 199. The upper and lower parts of this figure represent the situation at 250 feet and 475 feet from the irrigation ditch respectively.
More water had been received in the former than in the latter case. The figure shows that the application of a greater amount results mainly in a deeper vertical penetration of the moisture while the lateral penetration is less affected. Shaw (511) reports that the lateral penetration of moisture to each side of the furrow seldom exceeds 24 inches, regardless of the quantity of water applied. The vertical penetration, on the other hand, is roughly proportional to the quantity of water applied at the surface.

This implies that quantities of water applied in early irrigations and not used by the plant will pass to lower soil horizons, until each successive layer of soil is filled to its maximum field capacity. As more of such excessive applications of water are made, the water eventually may percolate through the soil until it reaches the subterranean water table. In view of the failure of capillary attraction to convey water from any distance through the soil, it appears improbable that any water penetrating below the normal root range is ever recovered by the plant. Consequently, it is lost for the cane crop (510).

Wilting Point.—Briggs and Shantz (145) found the interesting fact that all plants, regardless of age, species, or environment, when grown in the same soil, wilt at approximately the same moisture content, the so called permanent wilting percentage or permanent wilting point. The latter is defined as the moisture content of the soil (expressed as a percentage of the dry weight) at the time the plants wilt to such an extent that the leaves cannot regain turgidity in an approximately saturated atmosphere without the addition of water to the soil. The wilting percentage is characteristic for each soil and varies from 1 per cent for coarse sand to more than 15 per cent for heavy clay soil.

The standard procedure for estimating the wilting percentage of a soil is to grow plants in pots which are sealed in order to prevent loss of water from the soil surface by evaporation. As soon as the plants show signs of wilting, the moisture content of the soil is determined and the figure thus obtained represents the wilting percentage of that particular soil.

This procedure is, however, unsuited for sugarcane, since the leaves of this plant possess a decided capacity for absorption of moisture from a saturated atmosphere (577). When Shaw (513) conducted comparative pot experiments with sunflower and sugarcane growing side by side in the same soil, he observed that cane did not exhibit external symptoms of wilt for several days after the wilting point, as indicated by the sunflower, had been reached. The elongation of cane, however, is severely affected and may cease entirely when the wilting point is reached. The practical conclusion to be drawn from this observation is that the general appearance of the cane plant in the field (wilting) is not a safe standard on which to base the need for irrigation.

The relationships between soil moisture and cane elongation are presented in fig. 201. A comparison of the trends of soil moisture and cane growth shows that other factors being uniform stalk elongation proceeds at a constant rate as long as soil moisture is above the wilting percentage. Or, in other words, the rate of elongation appears to be independent of the soil moisture percentage as long as the latter is above the wilting point. This proves once more the non-existence of an “optimum” moisture content.

As soon as soil moisture is reduced to the wilting percentage, it apparently becomes inadequately available to the plant, since growth is severely depressed. As soon as the soil
moisture is replenished above the wilting percentage, cane growth resumes a rapid and constant rate.

Estimating the wilting percentage by growth measurements is a rather laborious task since it involves the raising and observation of plants under strictly controlled conditions. Simple methods have been developed by correlating the wilting percentage with other soil characteristics which can be determined easily in the laboratory. One of these characteristics is the moisture equivalent, being the residual moisture percentage present in small samples of soil which have been subjected for a certain time to a centrifugal force 1,000 times the force of gravity. For Hawaiian soils, the following relationships have been found (512, 513):

\[
\text{Moisture equivalent} = \text{wilting percentage} \times 1.2
\]

\[
\text{Maximum field capacity} = \text{moisture equivalent} \times 1.1
\]
Although the ratio of moisture equivalent to wilting percentage proves to be remarkably constant for Hawaiian soils the fact should be stressed that this ratio may differ considerably for soils of different origin and of different chemical composition (512).

As already mentioned, the wilting percentage in the case of sugarcane is the lower limit of soil moisture readily available to the plant, at which the normal rate of elongation ceases. Subsequent investigations have shown that when the soil moisture falls to the wilting percentage, the rate of elongation is not reduced abruptly. Instead of a sharp discontinuity, a transitional curve (wilting range) has been observed. Fig. 202 relates to an experiment in which precise growth measurements were made twice a day. It shows that reduced elongation was first noted when the moisture content had become 27.4 per cent. Essential growth ceased four days later when the soil moisture content had dropped to 23.1 per cent. Additional evidence has shown that the cane plant is able to extract soil moisture to a level which is 2 to 4 per cent below that formerly defined as wilting percentage. Consequently, it has become necessary to distinguish between a first and an ultimate wilting percentage which represent the beginning and the end of the wilting range respectively.

During the wilting range, the cane plant does not show visible symptoms of distress, but the growth is gradually retarded. Since there is no evidence that cane which has suffered in this way grows abnormally fast after water has been applied, it follows that a significant and unrecoverable loss in cane tonnage is associated with each period of soil moisture deficiency (513, 536). But photosynthesis and sucrose accumulation in the stem may proceed at such a rate that the ultimate sugar yield is not seriously affected. Apparently it does not harm the crop to dry out to a certain extent (536). This fact is of considerable economic importance since it offers the possibility of producing the same amount of sucrose by less irrigation, which means saving water and labor.

This has been clearly shown by Sweezey and Wadsworth (536) who reported the results of an irrigation experiment in which the effects of three treatments were compared. In one treatment irrigation was applied as soon as soil moisture had reached the first wilting percentage. In the second and third treatments, irrigation was delayed 4 and 8 days after

Fig. 202.—Length growth history of a sugarcane plant showing a transitional growth ranging from 27.4 to 23.1 per cent of soil moisture. Ordinate, cane length. Abscissa, time. After Wadsworth (572).
this percentage had been reached, respectively. The results of this experiment were remarkable. All three treatments produced the same quantity of sugar per acre. But 7.73 million gallons of water and 16.07 man-days were required to produce that amount of sugar under the first treatment, and only 4.66 million gallons of water and 9.22 man-days under the third. The total cost of irrigation per ton of sugar was $13.90 and $8.30 respectively (536).

In the studies on the relationships between soil moisture and cane elongation referred to so far, the elongation rate has been estimated in the conventional way by measuring the displacement of the highest visible dewlap (no + 1). WADSWORTH (575) has reported on some interesting results obtained by measuring simultaneously the displacement of the upper visible dewlap and of a fixed point on the innermost leaf of the leaf spindle. Some of his results are reproduced in fig. 203, which shows that the displacement of the dewlap proceeded at approximately a uniform rate until soil moisture became a limiting factor on July 19. After irrigation was applied, growth was resumed. The datum point on the young leaf of the spindle moved uniformly and quite independently of soil moisture deficiency within the limits covered by these observations. These and other observations indicate that the apex or growing top of the stem exercises a preferential demand as far as water supply is concerned. Apparently during periods of soil moisture deficiency, the remainder of the stem below the top will supply the lacking water to the extent of its ability (180, 536).
LOSS OF WATER

Water is given off by the cane plant in two ways, viz., in liquid form and in the form of vapor. The first process is called exudation, the second transpiration.

Exudation.—Transpiration is only possible as long as the air surrounding the plant is not saturated with water. As soon as it is saturated, transpiration ceases and the only way for the cane plant to get rid of water under this condition is by exudation. A case has been reported from Hawaii in which cane plants were found to throw off water from their leaves during rain showers (15).

The phenomenon of exudation has been nicely demonstrated by Evans (259) who injected a one per cent solution of acid fuchsin into the stems of plants growing in the field. The following day he noticed that the leaves of plants which were not injected but which grew in close proximity to the injected canes were spattered with drops of red dye, and on examination it was apparent that the dye had been exuded from the margins of the leaves of the treated plants during the night. Exudation had been particularly active through the margin of the upper third of the leaf.

Transpiration.—Transpiration takes place through the stomates and the cuticle, the latter being a thin cork layer which covers the outer side of the epidermis. Stomatal transpiration in most plant species is considerably greater than cuticular transpiration, but there is evidence that cane may be different in this respect. The cane leaf has approximately twice as many stomates on its lower surface as on its upper. Yet according to Evans (258), the rate of transpiration from both sides is approximately equal, indicating a significant cuticular evaporation from the upper surface. It is obvious that the large bulliform cells with their thin cuticle are largely responsible for this phenomenon.

Both leaves and stems participate in transpiration but the share of the latter is negligible. Kamerling (334) found that the surface of the stem transpires approximately 1 to 3 grams per internode per day. Assuming that some 20 internodes of a stalk are engaged in transpiration, this would result in a daily loss of 20 to 60 grams of water per stalk. Since a complete stalk transpires approximately 250 to 750 grams of water per day, it follows that the share of the stem is only about ten per cent. Transpiration of the internodes is almost entirely restricted to the nodal region (p. 272) and this is most probably associated with the occurrence of wax on the remaining part of the internode. Lauritzen (387) found that dewaxing cut stalks of sugarcane nearly doubled the transpiration rate.

The transpiration rate of complete cane plants has been examined mainly in two ways. The best method is to grow cane plants in pots or large containers, taking care that no water is lost by evaporation from the soil surface. Transpiration is estimated by weighing the pots at periodic intervals.

Another method consists of placing severed stalks in a container with water and covering the water surface with a thin layer of oil in order to prevent evaporation. This procedure has the disadvantage that conditions of the plant are not natural. The vessels of the stalk may be blocked up partially by enzymic action, thus affecting the uptake of water seriously. Kuijper, who used this method, limited his observations to periods shorter than
ten hours, since during this time the plants did not behave very differently from plants growing under field conditions. The disadvantage of this method can be partly overcome by placing the stalks in a dilute solution of sulphurous acid (0.03 per cent), according to the well known technique developed in Hawaii for the conservation of flowering stalks.

The rate of transpiration is so greatly influenced by environmental factors that it is hardly possible to give average figures. Kamerling (334) found that a stalk including top and leaves, transpired from 210 to more than 1000 cc per day while Kuijper (378) mentions 200 to 600 cc. These figures give a general idea; more detailed figures will be presented in the discussion of the effect of various factors on the transpiration rate.

Stomates.—Stomates are minute pores in the epidermis which enable the exchange of gas between the interior of the plant and the surrounding atmosphere. They are most numerous on the leaf blades, less so on the leaf sheaths and rare on the stem. Even when fully opened, they occupy less than one per cent of the blade surface. The general structure of stomates has been shown in the figures 50, 51 and 54, which indicate that below each stomate a cavity, the so called air chamber, occurs. Through the stomates, the surface of each air chamber is in direct contact with the atmosphere outside the plant. Consequently, the actually transpiring surface of a leaf is considerably larger than the total surface of its stomates.

The stomates serve two main purposes, viz., transpiration of water and the exchange of the gases carbon dioxide and oxygen.

The structure of the stomates of the cane plant has been studied by Kobus (356, 357), Wakker (578), Went (594), Kamerling (334), Wilbrink and Ledeboer (599), Dickhoff (212), Kuijper (374) and others. The stomates of cane resemble largely the general type of stomates occurring in the grass family. Kuijper (374) stresses the fact that owing to the particular structure of the cane stomates, differences in the degree of opening are hardly visible. Consequently, the study of their movement requires indirect methods, e.g., infiltration with liquids such as paraffin oil or petroleum (374, 377).

In this way Kuijper (377) found that the degree of opening of the stomates is not only greatly affected by external conditions but that it also varies within one plant. The degree of opening is generally maximal in leaf no. +1, while the leaves +2 and +3 do not differ very much from no. +1. In the leaves +4 and older, the degree of opening gradually decreases until a minimum is found in the leaves which are no longer active in transpiration and assimilation. The youngest leaves, nos. 0, -1, etc., do not differ appreciably from leaf no. +1. The maximum opening of the stomates in the individual leaf generally occurs in the region of its greatest width.

The number of stomates in different varieties shows a wide variation. An example is presented in table 76 which shows in the first place that the number of stomates in the lower epidermis is about twice that in the upper. In the second place varietal differences appear to be considerable; the maximum figures are about twice as great as the minimum figures. Dunlop (229) found similar varietal differences in stomatal density in a series of West Indian varieties.

The movement of stomates is greatly affected by external factors, of which light, temper-
Table 76.—Number of stomates per mm². After KUIJPER (378)

<table>
<thead>
<tr>
<th></th>
<th>SW₂₃</th>
<th>Ceram</th>
<th>B 247</th>
<th>F 160</th>
<th>POJ 100</th>
<th>POJ 826</th>
<th>POJ 139</th>
<th>POJ 979</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper epidermis</td>
<td>156</td>
<td>143</td>
<td>167</td>
<td>119</td>
<td>122</td>
<td>81</td>
<td>78</td>
<td>59</td>
</tr>
<tr>
<td>Lower epidermis</td>
<td>351</td>
<td>307</td>
<td>270</td>
<td>264</td>
<td>258</td>
<td>216</td>
<td>176</td>
<td>182</td>
</tr>
<tr>
<td>Total</td>
<td>507</td>
<td>450</td>
<td>437</td>
<td>383</td>
<td>370</td>
<td>297</td>
<td>254</td>
<td>241</td>
</tr>
</tbody>
</table>

ature and humidity are dominant. KUIJPER (377) found that stomates open in direct sunlight. Weak diffuse light results in a partial closure, the stomates of the lower epidermis closing more than those of the upper. In complete darkness the stomates first close completely and subsequently reach a situation in which they are slightly opened, thus permitting a small degree of diffusion. In order to cause an early maximum opening, direct sunlight is required, and once this situation has been attained, a subsequent decrease in light intensity is of little influence. This explains the beneficial effect of early morning sunshine on sugarcane. The general behavior of the stomates is indicative of the large requirement of the cane plant for sunlight.

High air humidity and high temperature promote the opening of stomates and so does irrigation. KUIJPER (377) was even able to induce stomates to open in complete darkness by raising the temperature above 40°C.

Due to diurnal fluctuations in light, temperature and air humidity, the opening of the stomates exhibits a daily periodicity. But there is evidence that this daily periodicity persists to a small extent when external conditions are kept uniform, thus indicating that it is partly autonomous (377).

According to KUIJPER (377), the daily trend of stomatal movement during a bright day starts with a wide opening which persists or even slightly increases up to 10 a.m., the increase resulting from the higher temperature. At 10 a.m. conditions of light, temperature and moisture are apparently optimal. After this time the stomates gradually close. Since light and temperature conditions remain more or less optimal, the cause of this closure is most probably to be sought in a decrease of air humidity. In this connection it is interesting to note that the highest yielding varieties in Java are the first to close their stomates, thus reducing the loss of water to a minimum. In other varieties, closing seems to proceed more gradually.

Factors influencing the loss and intake of water.—Since factors which affect transpiration also affect the absorption of water, the influence of internal and external factors on both processes will be discussed together. In addition, the reader is referred to the preceding paragraphs on factors influencing the number and movement of stomates since the behavior of the stomates influences the loss of water.

Variety.—The first varietal differences have been reported by KAMERLING (334) who obtained evidence that different varieties require different quantities of water for their development.
The most extensive comparative study including more than eight varieties has been made by Kuijper (378) who experimented with severed cane stalks placed with the cut end in water. He recorded the loss of water from such stalks from 7 a.m. till 4 p.m. A comparison of the results obtained by Kuijper with those of other workers who used complete plants growing in pots, indicates that the behavior of severed stalks is more or less normal until noon, but that in the course of the afternoon their rate of transpiration decreases more rapidly than in normal plants. Therefore the absolute figures obtained by Kuijper during the afternoon are to be considered as subnormal.

By comparing the transpiration rate of single stalks of various varieties, Kuijper found differences which seem to be characteristic of the varieties involved. According to their daily trend of transpiration, varieties may generally be grouped into two classes. Varieties belonging to the first class start transpiring in the morning at a high rate and those of the second group start at a lower rate. Examples of both types are represented in fig. 204, which also shows that the variety with the highest initial transpiration rate exhibits a more rapid decrease during the afternoon than the variety which starts at a lower level. Although the figures for the afternoon hours have only a relative value, they show such typical differences for the two classes that they are suggestive of inherent differences, characteristic of the two groups. It is interesting to note that the best commercial varieties involved in this study belong to the first group (POJ 100 and 247B). Apparently a high transpiration rate during the early morning hours when moisture conditions are maximal, followed by a rapid decrease when moisture conditions become less favorable, are properties associated with high productivity. The characteristic varietal differences in the behavior of the stomates stated previously, are in harmony with this concept.

The question arises whether varietal differences are correlated with differences in stomatal numbers; in other words, whether varieties with many stomates transpire at a higher rate than those with a lower stomatal density. Kuijper compared eight varieties in this respect and his results are presented in table 77.
There appears to be no relationship between stomatal density and transpiration rate, a result which has been corroborated by Evans (258). This was to be expected, since besides the number of stomates many other factors are involved, e.g., the structure and daily movement of the stomates, cuticular transpiration, etc.

Varietal differences in the rate of transpiration have also been reported by Evans (255) who experimented with detached leaves and found that the mean weight of the water lost per cm² of leaf surface per 10-minute interval for POI 2878, White Tanna and BH 10(12) was 0.196, 0.218 and 0.184 mg respectively. These values represent the average of the second, fourth and sixth leaf from the apex, and the difference between BH 10(12) and White Tanna is fully significant.

AGE.—When a cane plant grows older, its leaf surface increases to a certain extent, and so does its total transpiration rate. Maxwell (456) in Hawaii was perhaps the first to make daily records of the quantities of water transpired. A cane plant was grown in a pot, and a second pot, filled with the same soil but not planted, was kept as a control. The rate of transpiration of the cane plant was estimated by comparing the quantities of water lost by the two pots, and the results thus obtained are presented in fig. 205. The rate of transpiration started at a very low level shortly after planting and subsequently increased until a maximum was attained at an age of approximately 6 months.

The physiological process of transpiration differs from the purely physical phenomenon of evaporation in that a regulating factor is involved in the former. Ability to regulate the rate of transpiration biologically is one of the factors determining the degree of drought resistance. Mallik (439a), in a preliminary experiment, has grown Co 421 and S. spontaneum in pots in which the moisture of the soil was maintained at 15 per cent. At the age of 2 months, some of the plants were transferred to conditions of higher air humidity,
Table 77.—Stomatal density and transpiration rate. After Kuijper (378)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Number of stomates per cm²</th>
<th>Daily transpiration in grams per stalk</th>
<th>Transpiration in grams per stalk per hour from 7 to 10 a.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW 3</td>
<td>507</td>
<td>540</td>
<td>81</td>
</tr>
<tr>
<td>Ceram</td>
<td>450</td>
<td>558</td>
<td>98</td>
</tr>
<tr>
<td>247 B</td>
<td>437</td>
<td>503</td>
<td>63</td>
</tr>
<tr>
<td>F 160</td>
<td>383</td>
<td>401</td>
<td>49</td>
</tr>
<tr>
<td>POJ 100</td>
<td>380</td>
<td>462</td>
<td>77</td>
</tr>
<tr>
<td>POJ 826</td>
<td>297</td>
<td>361</td>
<td>53</td>
</tr>
<tr>
<td>POJ 139</td>
<td>254</td>
<td>439</td>
<td>87</td>
</tr>
<tr>
<td>POJ 979</td>
<td>241</td>
<td>620</td>
<td>86</td>
</tr>
</tbody>
</table>

Table 77a.—Absolute and relative transpiration in two varieties. After Mallik (439a)

<table>
<thead>
<tr>
<th></th>
<th>Co 421</th>
<th>S. spontaneum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A.T.¹</td>
<td>R.T.²</td>
</tr>
<tr>
<td>Humid exposure</td>
<td>0.28</td>
<td>0.36</td>
</tr>
<tr>
<td>Dry exposure</td>
<td>0.34</td>
<td>0.19</td>
</tr>
</tbody>
</table>

¹ A.T., Absolute transpiration in grams per cm² of leaf surface per day.
² R.T., Relative transpiration.

while the others remained under conditions of lower humidity, the average values of relative humidity being 38 and 30 per cent respectively. The transpiration of the green leaf area and the evaporation of Piché's evaporimeter were measured and expressed in grams per square centimeter per day. From the figures thus obtained, the relative transpiration, i.e., the ratio of transpiration to evaporation was calculated.

The average results obtained are presented in table 77a. They show that the relative transpiration is much lower in Co 421 than in the wild cane, both under the arid and humid conditions. This indicates that Co 421 has a better economy of water, as far as transpiration is concerned, than the wild cane. Moreover, under dry exposure the relative transpiration of Co 421 is only half that under humid exposure, which is indicative of a regulatory activity. In the case of the wild cane, the values of relative transpiration are practically the same under dry and humid conditions. This cane apparently loses water like any ordinary evaporimeter and there is no evidence that the loss of water is cut down by internal regulation.

Mallik considers his technique a simple and quick method of testing cane varieties for drought resistance. Drought resistance, however, is a complex phenomenon which is
largely governed by the ratio of water loss to water intake. Although the ability to cut down transpiration during periods of drought is of considerable importance, it is only one of the factors involved, and the ability to maintain an adequate water intake is of no less significance (see p. 297).

In Mauritius, TEMAPNY (541) studied the transpiration rate of cane plants grown in pots. The results of one of his experiments are shown in fig. 206. The ascending branch of the curve largely resembles that of fig. 205.

Results of a very detailed study in Formosa have been reported by TAMAI and CHEN (539, 540) who grew cane in auto-irrigators while the daily intake of water by the plants was recorded automatically. Since observations relating to meteorological factors were also recorded daily, the results obtained by these investigators are the most complete available so far. Some of these results will be given below.

Figures about the quantities of water transpired during shorter intervals have been reported by various investigators. KAMERLING (334) states that the average daily transpiration of a single cane stalk is at least 250 cc; KUIPER (378) gives figures ranging from 200 to 600 cc, while according to DE SORNAY (523), the averages range from 400 to 600 cc.

**Diurnal Variation.**—As stated earlier, the transpiration rate is subject to variations in the course of a day. Fig. 207 gives an example of the hourly intake of water by a cane plant during two successive days, one bright day followed by a rainy day. On the bright day, the absorption rate started to increase about one hour after sunrise, reached a maximum after midday (2 to 3 p.m.), and decreased during the afternoon and night until a minimum was attained in the early morning hours. On the rainy day there was hardly any variation and the absorption rate did not surpass that during night. On cloudy days the daily trend resembled that on bright days but the maximum was markedly depressed (fig. 208).

Fig. 206.—Trend of daily transpiration rate of a plant of White Tanna grown in a pot at Reduit. Abscissa, months. Ordinate, daily transpiration in grams. Drawn after figures from TEMAPNY (541).
Differences in the rate of water intake between day and night have also been reported by Went (594), Wadsworth (572), Duncan and Cooke (228), and Van den Honert (310). According to their results the average ratio of transpiration between the day and the night seems to range from 5 to 1, to 10 to 1.

Daily fluctuations are the result of variations in external factors of which light intensity, air humidity and temperature are dominant. Tamai and Chen (539) have collected many data on the rate of water intake under different climatological conditions.

Light.—The depressive effect of cloudiness and darkness on the rate of water intake by cane stalks has been known since the studies of Kamerling (334) and Kuiper (378). In later years, Hawaiian workers discovered that even slight differences in light intensity, caused by drifting clouds, affect the rate of water intake (427) thus indicating that sugarcane is a very sensitive sunshine recorder. This fact has led to the construction of a device based on the principle of the Franklin pulse glass which records the intensity of sunshine very
It appears that the rate of water intake by the cane plant varies directly with the intensity of sunlight (15). During a solar eclipse in Formosa, the absorption rate of sugar-cane was reduced to 60 per cent of the normal rate (539). TAMAI and CHEN (539) found the following relative values for the absorption rate of cane: bright days, 4 to 5; bright days with showers, ca. 3.3; cloudy days 2 to 2.5; rainy days 1.0. Thus on bright days the rate of transpiration was double that on cloudy days.

AIR HUMIDITY.—As was to be expected, a negative correlation exists between the rate of water intake by a cane plant and air humidity. TAMAI and CHEN (540) found a correlation coefficient of $-0.818$ between the rate of water intake and the rate of evaporation from an atmometer.

TEMPERATURE.—The same authors (540) found a high positive correlation between rate of water intake and air temperature ($+0.771$). In addition, soil temperature plays a role. DUNCAN and COOKE (228) grew cane plants in soil containers suspended in a water bath. By lowering the temperature from 28°C to 21°C, 15°C and 10°C, progressively greater decreases in the rate of water absorption were recorded. This fact has a practical bearing in subtropical cane countries where water intake during the cool season may become inadequate. Under such conditions, a cane crop may suffer from water deficiency, even when the soil is amply supplied with moisture, a phenomenon known as physiological drought.

SOIL MOISTURE.—The marked effect of soil moisture on the transpiration rate has been demonstrated by KUIJPER (378). A 7-month old cane plant growing in a pot transpired 550 grams of water per day when the moisture content of the soil was more or less normal. Addition of water to the pot immediately increased the rate of transpiration to 1270 grams per day.

This effect is associated with an increase in root pressure, since according to WELLER (592) a direct correlation exists between the moisture content of the soil and the root pressure of cane plants. This relationship is shown in fig. 209 which represents the root pressure of cane plants grown in pots to which various amounts of water, sufficient to bring the moisture content of the soil to 0, 35, 50, 65 and 100 per cent of the total field capacity, were added.

FERTILIZERS.—A striking effect of the application of nitrogen fertilizer on the transpiration rate of sugarcane has been reported by MAXWELL (456). In the course of his experiment on the transpiration rate of cane growing in a pot, already referred to, an application of 100 grams of Chile saltpeter was made, to which the plant responded with a doubling of its transpiration rate. In this connection it is interesting to note that WELLER (591) in his experiments on root pressure, found that greater amounts of liquid were exuded by canes which had been fertilized than from canes which had not. The striking response of the transpiration rate to the application of Chile saltpeter has an economic bearing since it indicates that nitrogen application should be made preferably when soil moisture is adequate.

WIND.—The effect of wind on transpiration rate is obvious but as yet only few quantitative data are available with respect to sugarcane. Indirect evidence, however, is provided
Fig. 209.—Root pressure of 5-month old H 109 plants grown in pots to which various amounts of water were added sufficient to bring the moisture content of the soil to 0, 35, 50, 65, and 100 per cent total field capacity. Ordinate, root pressure in cm of mercury. After Weller (592).
by the experiments mentioned earlier in which the development of cane plants exposed to the artificial wind of a fan was adversely affected, even when the velocity of the air current was moderate (p. 122).

Tamai and Chen (539) found a correlation of $+0.92$ between the rate of water intake by sugarcane and wind velocity.

Leaf curling.—Involute curling of the upper leaves is a characteristic exhibited by most varieties during periods of relative moisture deficiency, viz., when the rate of transpiration exceeds the rate of absorption. Its effect should, however, not be overestimated. Evans (258) found only a reduction of 10 to 20 per cent in the rate of transpiration as a result of leaf curling.

In view of the fact that stomatal density on the lower surface of the leaf is double that of the upper surface, it may appear curious that curling protects the upper surface. The fact, however, that the transpiration rate is about equal from both surfaces makes it immaterial which way the leaf curls (258).

The mechanism of involute curling has been described in considerable detail by Wakker (578). It is closely tied up with the presence of bulliform or motor cells in the upper epidermis of the leaf (fig. 50 and 54). These large, thin-walled cells, contrary to the other epidermis cells, are not covered by a cuticle. They are arranged in bands several cells wide and run along the entire length of the leaf blade. Due to the unprotected outer wall, they are the first to lose moisture during periods of drought, resulting in loss of turgor, shrinkage, and ultimately, collapse. This induces two kinds of movements: the shrinkage in longitudinal direction causes the total length of the bands to shorten, resulting in an erection of the leaf; the shrinkage in width causes the leaf to curl involutely.

Structure and arrangement of the motor cells vary widely in different varieties and even within a single leaf. Wakker (578) found that in Black Cheribon the bands formed by motor cells are widest in the neighborhood of the midrib, about midway between base and tip of the leaf blade. Toward the tip and toward the margins their width gradually decreases. Fig. 210 A illustrates the situation about midway of the leaf blade and near the midrib, showing a broad band of motor cells. Fig. 210 B, C and D relate to the top portion of the leaf; the bands here are only 2 or 3 cells wide. Moreover, the form of the motor cells exhibits characteristic differences. Near the midrib they are large, protruding and exposing a considerable surface. Toward the margin of the leaf they become smaller, they no longer protrude, and the surface exposed to transpiration is considerably reduced. Moreover, transpiration is reduced by the presence of protecting hairs.

Although involute curling is a habit of most varieties, they differ widely as to the extent of curling, and there are varieties which do not curl at all. Evans states that some varieties are very sensitive to water loss from the leaves; they start curling when their moisture content has been reduced by 1.5 or 2.0 per cent. Others, not so sensitive, continue to lose water at a fast rate, without showing any outward sign of distress (258).

Dunlop (229) has made a comparative study about leaf curling in several West Indian varieties. He found that though most varieties exhibit involute curling of the leaves during a period of dry weather, D 642 and White Transparent do not readily curl even under
conditions of drought. In the varieties B 1735 and D 1108, on the other hand, curling is a pronounced habit even under normal conditions of growth. According to DUNLOP, the following anatomical characteristics are common to varieties which readily curl involutely:

- The motor cells are not prominent;
- The cells immediately interior to the motor cells are generally comparatively large and thin-walled;
- The upper epidermis is not greatly lignified;
- The number of stomates on the upper surface is relatively large;
- Leaves are never very broad and are generally erect.

Revolute curling, protecting the lower surface, has been observed in B 4030, B 6450, B 3839 and B 3696. It appears to be a permanent habit of these varieties and is not affected by light, darkness or changes in weather.

The characteristics common to the leaves of these varieties are:

- The motor cells are prominent and large;
- The motor cells are generally firmly attached to the vascular bundles opposite them by woody cells;
- The vascular bundles are comparatively close together;
- The number of stomates on the lower surface is relatively large;
- The upper epidermis is greatly lignified.

These observations indicate the existence of certain relationships between the anatomy of the leaf and its curling habit. Some characteristics which promote transpiration from the upper surface are associated with the habit of involute curling, which protects the upper surface. The degree of prominence of the motor cells, however, forms an exception. A renewed study of the whole problem, including a detailed examination of the leaf anatomy and the curling habit of different varieties under conditions of prolonged drought would be worth while.

Leaf pruning. — It is common practice to prune the leaves of plants which are used for filling gaps in young cane fields. Transplanting ordinarily entails some root damage which decreases the absorbing capacity of the root system. Leaf pruning aims at restoring the disturbed balance between absorption and transpiration.

WENT (594), who questioned the soundness of this procedure, studied this matter in some detail under laboratory conditions. He found that although transpiration decreases greatly as a result of leaf pruning, it does not cease altogether. When no leaf pruning is applied, transpiration also decreases greatly. In the latter case, the tip of the leaf dies but the remaining part exhibits a rapid recovery and resumes normal transpiration. Moreover, root development is more vigorous in untreated than in pruned plants. This is largely due to the fact that photosynthesis is more active in the former. WENT concluded from his experiments that leaf pruning applied during transplanting is in no way advisable.

DE BODE (99), who conducted experiments under field conditions, arrived at a quite different conclusion. He found that the omission of pruning resulted in a slower recovery
Fig. 210.—Cross sections of a leaf blade of Black Cherryb. A, about midway between base and tip, and close to the midrib. B, in the tip of the blade close to the midrib. C, in the tip of the blade between midrib and margin. D, in the tip of the blade close to the margin. e, Epidermis; b, bulliform or motor cells; p, parenchyma; v, fibers of vascular bundle; ch, chlorophyll containing cells; s, stomate; d, hair. After WAKKER (578).
and a greater mortality; the mortality of untreated plants was twice, and more, that of pruned plants.

The explanation of this difference in results is to be sought in the fact that Went experimented under carefully controlled conditions. Therefore his plants were less subject to damage, especially as far as the roots were concerned, than plants transplanted under field conditions. In the latter case the absorbing capacity of the roots is more severely affected, and consequently the transpiration rate has to be cut down more drastically.

Leaf pruning has also been recommended for full-grown cane in order to reduce transpiration during periods of drought (334) but although it has been applied occasionally in Java it never has become standard practice.

DISEASES.—Bremekamp (143a) has studied the uptake of water by plants suffering from serer disease. Stalks were severed and placed in a solution of methylene blue. The dye ascended more rapidly in healthy than in serer stalks, due to the fact that the vascular bundles of the latter were partially occluded. The experiment was repeated with intact plants growing in baskets. The plants were irrigated with a 2 per cent solution of lithium nitrate and the movement of the latter in the stems was examined by means of a spectroscope. Again, movement in the healthy plants was more rapid than in the serer plants. Since the rate of transpiration was only slightly different between the two kinds of plants, the serer plants were unable to maintain their water balance and consequently suffered severely from lack of moisture (leaf curling).

MOISTURE CONTENT

Distribution of moisture in the plant.—Clements and Kubota (170) have made periodical determinations of the moisture content of the constituent parts of cane plants in the field from about 2 months after planting until they had reached an age of 22 months. The results of one series of determinations are listed in table 78 which is composed in the same way as table 34, for which a detailed description of the various parts of the plant has been given. As in the case of nitrogen, each type of tissue or organ appears to have its characteristic moisture level even though it is directly attached to another tissue of a quite different level. Thus the moisture content of the elongating-cane blades is between 10 and 15 percentage points lower than that of the associated sheaths, and the latter in turn is considerably lower than the moisture content of the elongating cane to which the sheaths are attached. Another point of interest is that in any given tissue or organ, the range in moisture level between conditions of extreme drought and extreme wetness is comparatively narrow. Thus, in table 78, the collection made July 26, 1940 was from a completely dried out crop ready for harvest, while that collected October 27, 1939, was taken after a period of heavy irrigations as well as rainfall, yet the range of moisture level in each tissue or organ is for the most part within 10 percentage points.

Since it is of importance to have available an indicator tissue which is representative of the general moisture content of the entire plant, the same authors calculated many correlations. The moisture level of the elongating-cane sheaths was chosen as moisture index,
Table 78.—Distribution of moisture in cane plants (moisture as per cent of green weight). After Clements and KUBOTA (170)

<table>
<thead>
<tr>
<th></th>
<th>1939</th>
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<tbody>
<tr>
<td>Meristematic</td>
<td></td>
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<tr>
<td>material</td>
<td>92.9</td>
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<tr>
<td>Spindle cluster</td>
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<tr>
<td>Elongating-cane</td>
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<tr>
<td>blades</td>
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<td>75.0</td>
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<tr>
<td>Elongating-cane</td>
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<tr>
<td>sheaths</td>
<td>87.3</td>
<td>84.7</td>
</tr>
<tr>
<td>Green-leaf-cane</td>
<td></td>
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<tr>
<td>blades</td>
<td>75.8</td>
<td>75.8</td>
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<tr>
<td>Green-leaf-cane</td>
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<tr>
<td>sheaths</td>
<td>87.5</td>
<td>84.1</td>
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<tr>
<td>Elongating cane</td>
<td>92.9</td>
<td>91.9</td>
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<tr>
<td>Green-leaf-cane</td>
<td>89.6</td>
<td>87.9</td>
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<tr>
<td>1st 3 internodes</td>
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</table>
since it appears to be a true index to the moisture levels of the growing tissues of the cane plant, as well as of the mature millable cane. The moisture index may prove valuable as an aid in developing efficient irrigation programs (170).

Factors influencing the moisture content.—The moisture content of sugarcane is influenced by both internal and external factors but the effects are relatively small.

Variety.—Cornelison (178) reports that in his experiments POJ 2878 rather consistently had a lower moisture content in its stalks than the varieties H 109 and 31-1389. In general, no such differences were found between the two latter varieties.

Age.—As the plants grow older, the moisture content generally decreases; in other words, the plants become dryer. Examples of this phenomenon are presented in table 78, and in the figures 164, 174 and 227.

Diurnal variation.—The first evidence of a diurnal fluctuation in the moisture content of cane stems was indicated by brix determinations of the stem in Java (219, 411, 412) which showed that the brix is lowest in the early morning and gradually increases toward noon. This indicates that the moisture content is maximal in the early morning hours and that it decreases subsequently. Similar results have been reported from Hawaii (575).

Detailed determinations of the actual moisture content of cane plants by Hartt (285, 288, 289, 290, 292) and Wadsworth (576) have proved that not only the stem but also the leaf blades and leaf sheaths exhibit a diurnal periodicity. Moreover, the interesting fact was noted that the diurnal variation in the leaf sheath is greater than in any other part of the cane plant (289, 290). Apparently the tissue of the leaf sheath has an outstanding capacity to acquire water when available and to supply it on command, thus acting as a kind of storage tissue for water (576).

Fertilizers.—Application of nitrogen increases the moisture content, thus rendering the cane plant more succulent. Detailed data on this effect have been presented in an earlier chapter (p. 209). Potassium has a similar effect (p. 252).

Light.—Borden (108) found plants grown in full sunlight to be less succulent than plants grown under the conditions of reduced light (table 63).

WATER BALANCE AND DRAUGHT RESISTANCE

General.—Since the moisture content of a cane plant is fixed within rather narrow limits, it is obvious that the rates of water intake and water loss require a rather precise balance. In view of the huge amounts of water which continually flow through the plant, it is evident that even a slight disturbance of the equilibrium between the two processes involved may lead to grave consequences for the entire plant. When the intake of water exceeds transpiration, no harmful results are to be expected, even if transpiration comes to a standstill, since the cane plant can get rid of the excess of water through exudation. When, however, the rate of transpiration exceeds the rate of absorption, a dangerous situation arises due to the fact that the possibilities of reducing the rate of transpiration are rather limited. The extent to which sugarcane is able to keep absorption and transpiration in balance governs its degree of drought resistance.
The rate of transpiration depends on the total transpiring surface and the transpiration rate per unit of surface. Several of the factors which influence the rate of transpiration have already been mentioned. To these can be added the orientation of the leaves and their thickness. There is some evidence that an erect position of the leaves is associated with a lower transpiration rate than a pendulous position. Another factor of importance is the concentration of cell sap in leaves and stem. Many desert plants are characterized by a high osmotic pressure in their cells. It is assumed that this characteristic enables the plants to develop a considerable suction tension and to draw moisture from the soil more rapidly. There is evidence that this factor also plays a role in sugarcane (p. 300).

The cane’s ability to control the rate of transpiration must be considered rather poor. Its main tool consists of the ability of leaf curling but even this does not reduce the transpiration rate by more than 10 to 20 per cent (258). Moreover, leaf curling as a protective measure against drought is not a habit of all cane varieties. The effect of stomatal movement is also rather limited.

A factor of more importance is the total transpiring leaf area. This may be different for different varieties and it may even change within one variety as a result of adaptation to growing conditions (abscission of leaves).

Contrary to the rather rigid organization of the transpiring system, the absorbing apparatus exhibits a greater degree of elasticity in its adaptability to changing conditions. Since the factors influencing the absorbing system have been discussed earlier, it may suffice to recall here only that it is a common feature for sugarcane to produce an absorbing surface three to four times greater in dry localities than that produced in wet localities (258).

Various attempts have been made to find a correlation between one or more physiological characteristics of cane varieties and their ability to withstand drought. As stated before, osmotic pressure of stem and leaves are related to drought resistance, and so is root pressure, which reflects the absorbing capacity of the root system. A very promising approach has been made by EVANS (256, 258) by introducing the ratio of total leaf surface to total absorbing surface. This ratio appears to be a valuable criterion of drought resistance, which is understandable since the ratio takes into account the two dominant factors governing water relationships in the plant.

The determination of this ratio constitutes a laborious task which renders it unsuitable as a standard practice. Therefore, EVANS (256, 258) has developed a simpler method. The latter is based on the fact that during periods of prolonged drought, it is the upper part of the root system which becomes inactive while the roots reaching into the moist subsoil continue functioning. The method developed by EVANS aims at imitating this condition by pruning off the major portion of the superficial roots, thus creating artificial drought conditions. For this purpose, a circle of 6 to 12 inches radius is drawn, taking the center of the stool as the center of the circle. A trench 3 feet wide is dug outside this circle to 1 foot in depth. All the roots in the first foot of soil are removed and the plants thus have to exist on the deeper roots. It is assumed that the ability to withstand this treatment of root pruning is indicative of the degree of drought resistance. Some of the results obtained with this method will be given later.
Factors influencing drought resistance.—The dominant factor governing drought resistance is variety. But even within one variety growing under a given set of conditions, drought resistance may be different at different stages of development. Thus the factor of age enters into the picture. Of the external factors, the moisture conditions under which a crop has developed play a dominant role. Cane raised under conditions of ample moisture is less resistant to subsequent drought than cane grown under less favorable moisture conditions.

Variety.—Evans (258) found very considerable differences in the ratio of transpiring to absorbing surface between varieties grown under similar conditions. Table 79 gives the ratio of several varieties in first ratoons at the ages of 4, 8, and 12 months. SC 12/4 is outstanding in having a very low ratio at all times. Selangor seedling and BH 10 (12) follow, while POJ 2878 and M 106/30 are characterized by having low ratios as mature canes. According to these figures, SC 12/4 would be expected to be the most drought resistant cane of the varieties examined, while Selangor seedling and BH 10 (12) would also be expected to show considerable resistance. Field data prove that the latter two are, in fact, well suited to the drier localities of Mauritius, while field data on SC 12/4 are not available (258).

In other experiments the same author compared the ratio of transpiring to absorbing surface of three varieties with their drought resistance. The comparison related to 14-month-old plants of POJ 2878, BH 10(12) and White Tanna. At that age POJ 2878 had by far the most favorable absorbing surface and ratio, BH 10(12) being second and White Tanna a bad third. Drought resistance was determined by root pruning. White Tanna died, BH 10(12) lost a considerable proportion of its leaves, while POJ 2878 lost very few. The behavior of the plants was thus in accord with what might be expected from the data on the absorbing surface and the ratio transpiring to absorbing surface (258).

In another experiment Evans (256, 258) found that at an age of 11 months the transpiring surfaces of D 109 and POJ 2364 were 32.039 and 55.156 cm² respectively, while the absorbing surfaces were 36.979 and 10.055 cm² respectively. This gives for D 109 a ratio of 0.84 and for POJ 2364 a ratio of 5.14, the former being much more favorable than the latter. Artificially induced drought by root pruning proved D 109 to be much more resistant to drought, which is in harmony with general field observations. Thus in this experiment

<table>
<thead>
<tr>
<th>Variety</th>
<th>Age in months</th>
<th>Mean of all ages</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>POJ 2727</td>
<td>14.05</td>
<td>20.73</td>
</tr>
<tr>
<td>SC 12/4</td>
<td>2.47</td>
<td>4.22</td>
</tr>
<tr>
<td>POJ 2878</td>
<td>12.60</td>
<td>13.43</td>
</tr>
<tr>
<td>M 196/31</td>
<td>13.55</td>
<td>19.30</td>
</tr>
<tr>
<td>BH 10(12)</td>
<td>9.83</td>
<td>5.56</td>
</tr>
<tr>
<td>Selangor seedling</td>
<td>9.91</td>
<td>4.73</td>
</tr>
<tr>
<td>M 106/30</td>
<td>20.90</td>
<td>9.91</td>
</tr>
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</table>
also there was a close correlation between ratio and drought resistance. These results indicate that the long and tedious procedure of determining the surface of transpiring and absorbing surfaces may be replaced by the simple method of root pruning, thus providing a rapid method for the estimation of drought resistance in seedlings.

Osmotic pressure and root pressure also are different in different varieties. Harris and Lee (282) in Hawaii found as a result of preliminary investigations that osmotic pressure of either the leaf or the cane stalk juice is correlated to a certain degree with drought resistance. Uba, the most drought resistant cane grown in Hawaii, had the greatest freezing point depression while Lahaina, which is sensitive to drought, showed a low freezing point depression.

Evidence of the existence of a relationship between root pressure and drought resistance has been provided by Weller (p. 273).

According to Evans (243) drought resistant varieties are generally characterized by a better development of the buttress roots and rope systems, which enables these varieties to draw moisture from the deeper layers of soil during periods of drought, when the surface layer has lost most of its moisture.

In addition to these differences, Venkatraman and Thomas (557) have drawn attention to various anatomical adaptations in roots of sugarcane. Under dry conditions, the cell walls of the parenchyma in the roots become thicker, the thickening consisting of both suberin and lignin. It is assumed that this aids in preventing losses of the ascending sap.

Thuljaram Rao (544a) has studied xeromorphic adaptation in a series of sugarcane species and varieties in India. Plants were dug up and examined at an age of 5 months, being the time when drought conditions in North India are severe. It was found that drought resistance was generally associated with a better development of the roots both in vertical and horizontal direction. The number of vessels per cm² in stems and roots showed a positive relationship with the degree of drought resistance.

The mechanical tissues of the roots showed no differences but in the stem marked differences were noticed. The mechanical tissues surrounding the vascular bundles were better developed and the sclerenchymatous cells were more lignified in the drought resistant varieties.

The data concerning the leaves are presented in table 80 showing that the thickness of the cuticle corresponds closely with the drought resistance of the varieties examined. The stomatal density and the size of the stomates decrease as the varieties are more drought resistant. In addition, the stomates of resistant varieties are often sunk in the leaf thus forming an external air chamber which reduces the rate of transpiration. The Russian forms of S. spontaneum (G. 1680 and G. 1703) are characterized by the presence of hairs protecting the air chamber.

The mechanism of the rolling of the leaves is more efficient in the drought resistant varieties, since the latter have more bulliform cells per unit of leaf surface than the susceptible varieties.

Finally, the number and the size of the leaves is more or less reduced in drought resistant varieties, which results in a reduction of the total leaf area per plant.
Table 80.—Xeromorphic characteristics of cane varieties. After Thuljaram Rao (544a)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Thickness of cuticle (μm)</th>
<th>No. of stomates per mm²</th>
<th>Length of stomates (μm)</th>
<th>Width of stomates (μm)</th>
<th>No. of green leaves</th>
<th>Length of leaf</th>
<th>Maximum width</th>
<th>Total area of leaves in cm²</th>
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<tbody>
<tr>
<td>S. spontaneum G. 1688</td>
<td>14.15</td>
<td>8.25</td>
<td>20.50</td>
<td>40.50</td>
<td>22.75</td>
<td>13.65</td>
<td>5</td>
<td>2' + 6.9&quot;</td>
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<tr>
<td>G. 1703</td>
<td>15.25</td>
<td>9.25</td>
<td>20.00</td>
<td>40.00</td>
<td>22.75</td>
<td>13.65</td>
<td>5</td>
<td>2' + 8.2&quot;</td>
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<tr>
<td>Coimbatore</td>
<td>15.00</td>
<td>9.50</td>
<td>20.00</td>
<td>40.00</td>
<td>25.00</td>
<td>13.65</td>
<td>10</td>
<td>3' + 9.8&quot;</td>
</tr>
<tr>
<td>Lahore</td>
<td>14.85</td>
<td>9.25</td>
<td>20.50</td>
<td>41.50</td>
<td>25.00</td>
<td>13.65</td>
<td>6</td>
<td>2' + 7.5&quot;</td>
</tr>
<tr>
<td>Katha</td>
<td>15.00</td>
<td>8.25</td>
<td>20.50</td>
<td>41.50</td>
<td>27.30</td>
<td>18.20</td>
<td>8</td>
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<tr>
<td>Saretha</td>
<td>13.50</td>
<td>8.25</td>
<td>19.00</td>
<td>41.00</td>
<td>27.30</td>
<td>18.20</td>
<td>9</td>
<td>3' + 8.2&quot;</td>
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<tr>
<td>Co 205</td>
<td>14.25</td>
<td>11.00</td>
<td>27.00</td>
<td>43.50</td>
<td>34.50</td>
<td>16.00</td>
<td>11</td>
<td>5' + 1.8&quot;</td>
</tr>
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<td>Co 285</td>
<td>13.50</td>
<td>9.50</td>
<td>25.00</td>
<td>40.00</td>
<td>31.85</td>
<td>16.00</td>
<td>10</td>
<td>4' + 8.5&quot;</td>
</tr>
<tr>
<td>Co 421</td>
<td>12.50</td>
<td>8.25</td>
<td>20.00</td>
<td>25.50</td>
<td>40.40</td>
<td>18.20</td>
<td>12</td>
<td>4' + 1.5&quot;</td>
</tr>
<tr>
<td>Vellai</td>
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<td>5.00</td>
<td>39.50</td>
<td>81.50</td>
<td>31.85</td>
<td>16.00</td>
<td>10</td>
<td>5' + 1.2&quot;</td>
</tr>
<tr>
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<td>5.00</td>
<td>40.25</td>
<td>82.00</td>
<td>36.40</td>
<td>16.00</td>
<td>9</td>
<td>5' + 9.5&quot;</td>
</tr>
<tr>
<td>Kaludai boothan</td>
<td>9.50</td>
<td>4.50</td>
<td>36.00</td>
<td>72.50</td>
<td>31.85</td>
<td>18.20</td>
<td>10</td>
<td>5' + 4.9&quot;</td>
</tr>
</tbody>
</table>

¹ Negl. = Negligible

Age.—As is the case with many other characteristics, drought resistance expressed as the ratio of transpiring to absorbing surface is not uniform at different stages of development of the cane plant but changes with age (table 79). According to Evans (258) this ratio is generally high in young plants and decreases with age until it reaches a minimum at 10 to 15 months of age (dependent on environmental conditions). The ratio is favorable (i.e., low) from 6 months up to 10 to 15 months under good growing conditions; thereafter it increases very rapidly. Canes would, therefore, be expected to show the greatest drought resistance between the ages of 6 and 15 months, the actual age of greatest resistance being dependent on environmental conditions. The change of ratio with age, however, may differ considerably in different varieties (see table 79). In a comparison of POJ 2878, BH 10 (12) and White Tanna on several soil types, the latter two varieties showed the most favorable ratio in young canes, but POJ 2878 attained the best ratio in mature canes (258).

Moisture.—Sugarcane has the capacity of adapting itself to a considerable degree to the environmental conditions in which it grows. Evans found that in Mauritius the ratio of transpiring to absorbing surface is highest in those regions where the soil moisture is high and the air is also highly humid. The ratio is intermediate in the environments having a plentiful supply of soil moisture but a dry atmosphere and high transpiration rates. The ratio is lowest in the dry regions where soil moisture is deficient and the rate of transpiration high. In dry localities, the cane may produce an absorbing surface three to four times greater than that produced in wet localities (258).

Irrigation Policy.—When irrigated areas are subject to seasonal water shortage, it is a good policy to increase the drought resistance of a crop gradually by lengthening the interval between successive irrigations. As stated earlier (p. 112), Java is characterized by water shortage by the end of the dry monsoon (September, October) when the cane crop
is 4 to 6 months of age. Experience has taught that cane which has been amply supplied
with water during the preceding months will suffer badly from subsequent water shortage,
whereas cane that has been weaned gradually from water will be able to withstand the
critical period much better. Similar observations have been made in other countries and
the explanation is to be found in the ability of cane plants to enlarge their absorbing
surface according to conditions as mentioned before.

From what is known so far, it appears that apart from the use of resistant varieties,
the main tool in the hand of the cane grower in protecting his crop from the adverse effects
of periods of drought, is a sensible irrigation policy.

CHAPTER 14
PHOTOSYNTHESIS

GENERAL

The fresh weight of a cane plant consists of 99 per cent of the elements oxygen, hydrogen
and carbon. Of this 99 per cent, almost 75 per cent is water and the balance is made up
of dry matter. While the water is largely taken up from the soil, the overwhelming part
of the dry substance is synthesized by the plant in a process in which carbon dioxide and
water are combined to form carbohydrates. This is a rather intricate process, which in
a very simplified form may be represented by the equation

$$6 \text{CO}_2 + 6 \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2$$

indicating that the union of six molecules of carbon dioxide and water results in the for­
formation of one sugar molecule and six oxygen molecules.

Sugars belong to the chemical group known as carbohydrates. They are composed
of carbon, hydrogen and oxygen, the latter two elements in the proportion in which they
occur in water. The process by which carbon dioxide is incorporated in the plant in the
form of carbohydrates is referred to as carbon assimilation or briefly assimilation. Since
it only takes place in the presence of light, it is also called photosynthesis.

Carbon assimilation is associated with the accumulation of energy. Thus when the
process is reversed, energy is liberated:

$$\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{energy}$$

This process, called respiration, occurs in all living tissues and is of particular importance
in the growing organs.

The assimilates which are not utilized in the production of energy are incorporated
in the plant in the form of dry matter and thus constitute a reservoir of potential energy.
The green plant is the sole agent by which the kinetic energy emitted by the sun can be
transformed into potential energy. All energy which is utilized by modern industry has
been accumulated in this way (oil, coal). At some future time these sources of energy
which have been stored in the course of millions of years, will become depleted and other
sources will have to be drawn upon. One of the possibilities suggested is the conversion of plant products into alcohol, as has already been done occasionally with sugar and coffee. In this respect sugarcane occupies a prominent position since it is capable of accumulating more energy per hectare than most other crops. This fact has been stressed by Lyon (426) who pointed out that the production of dry substance, expressed in equivalents of gallons of 99.5 per cent alcohol per acre, from sugarcane in Hawaii is 444.5 units, as compared with sugar beet 287, apples 140, carrots 102, oats 36, wheat 33, and plums 22 units. These facts have induced Lyon to suggest the storage of sugar as a source of energy for future generations when the present sources will be exhausted.

NOMENCLATURE OF CARBOHYDRATES

The nomenclature of carbohydrates may cause some confusion, especially since several compounds pass under two or more different names.

In general, one can distinguish between three different groups of carbohydrates: the simple sugars or monosaccharides, the double sugars or disaccharides, and the multiple sugars or polysaccharides.

Glucose is a monosaccharide, containing six carbon units: C₆H₁₂O₆. Glucose is also called dextrose or grape sugar. Fructose, another monosaccharide, has the same formula, but differs in other respects from glucose. Fructose is also called levulose or fruit sugar. Both simple sugars are reducing sugars, owing to their ability to reduce Fehling's or Soxhlet's solutions. A mixture of both simple sugars is referred to as invert sugar since it results from the inversion of cane sugar.

Cane sugar is a disaccharide, since it is made up of two simple sugars. Consequently, it contains double the number of carbon units of monosaccharides: C₁₂H₂₂O₁₁. It is also called sucrose or saccharose. Chemically it is identical with beet sugar.

Starch is a polysaccharide; it is composed of many sugar units but its exact formula is not yet fully understood. Another important polysaccharide is cellulose, the main component of the fiber of sugarcane.

Enzymes play an important role in the conversion of one kind of carbohydrates into others, since they accelerate the rate of conversion. Thus diastase promotes the conversion of starch into glucose, and invertase promotes the conversion of sucrose into invert sugar (glucose plus fructose).

ASSIMILATION IN THE LEAF BLADE

Thanks to the remarkable studies of Hartt (284, 285, 289, 290, 291, 292, 293, 294, 295, 296, 297), the processes involved in photosynthesis and sugar formation in the cane plant are at present perhaps better understood than in any other crop grown on a commercial scale.

In the intricate chain of chemical reactions which, through the fusion of carbon dioxide and water first result in the formation of simple, and later in more complex compounds,
two distinct phases are of particular importance. The first consists of the process by which
the fusion of carbon dioxide and water leads to the formation of the first sugars. This
process takes place only in the presence of chlorophyll and light. Consequently it is called
photosynthesis.

During the second phase, simple sugars are converted into sucrose and polysaccharides.
This process requires neither chlorophyll nor light. In contrast with photosynthesis, the
second phase is a synthesis in the dark.

Excised green blades, sheaths, stems and even entire cane plants, when supplied with
simple sugars in the dark, are capable of absorbing these sugars and converting them into
sucrose (175, 291, 293, 294), thus proving that light is not required for this conversion.
Roots, the leaves of albino plants, and the colorless leaves of the leaf spindle possess the
same faculty, showing that chlorophyll is not required for this process (175, 291, 294).

The fact that leaves of albino shoots are capable of converting simple sugars into sucrose
provides an explanation for the fact that these shoots may develop very vigorously although
lack of chlorophyll prevents them from any photosynthetic activity. Apparently they
draw on the assimilates of the mother plant. It may also explain the fact that the general
development and sucrose content of all stalks belonging to one stool tend to become
uniform although the differences in age are sometimes considerable. That a stool has to
be considered as a unit, and that the different stalks are capable of interchanging food
material, is moreover indicated by an experiment in which radiocarbon was fed by photo-
synthesis to one stalk of a stool. Forty hours later one third of the total carbon had
migrated to other members of the stool, and in one stalk the specific activity of the sap was
even greater than that of the fed stalk itself (55).

The blades have a particularly efficient mechanism for the formation of cane sugar from
simple sugars. This is demonstrated by fig. 211 which shows the accumulation of sugars
in excised green blades in the dark when supplied with a 5 per cent glucose solution. The
concentration of sucrose in the blades increases for nearly two weeks, yet the percentages
of glucose and fructose show only minor fluctuations. Normal leaves attached to a stalk
never attain as high a sugar content as that found in these detached blades, because
normally the sugars are translocated from the blade to the stem. Toward the end of the
experiment the blades became yellow and dried at the tips, but the accumulation of sucrose
continued. This does not mean that yellowed blades make sucrose in the field, because for
the manufacture of sucrose raw materials in the form of simple sugars are required, and
the latter are formed during the first phase (photosynthesis) which occurs only in the
presence of chlorophyll (293, 294).

Since the synthesis of sucrose takes place when the excised blades are supplied with
glucose or fructose alone, and since cane sugar contains both, a transformation from glucose
into fructose and from fructose into glucose must occur in the blades. This interconversion
takes place equally well whichever sugar is applied (291, 294). Aeration is essential for
this interconversion (294).

The optimum temperature for the synthesis of sucrose is approximately 30°C (293, 294). Blades taken from different levels on the stem differ in their ability to make sucrose
Fig. 211.—Formation of sugars in excised green blades in the dark when supplied with a 5 per cent solution of glucose. After Hartt (293).
from glucose. Since the same differences are found when blades store sucrose as a result of photosynthesis, it is suggested that the synthesis of sucrose takes place by the same mechanism whether glucose is supplied artificially or naturally by the process of photosynthesis. The lower third of the blade is the most efficient in synthesis, the middle third being the poorest. Cutting the blades into pieces approximately one inch in length does not decrease synthesis but grinding the blades inhibits synthesis completely, and also inhibits the conversion of glucose into fructose (294).

Phosphate plays a role in the conversion of glucose into fructose and in the formation of sucrose. There are indications that it is organic phosphorus which is essential for the formation of sucrose. When plants are grown with different amounts of nitrogen, both the synthetic efficiency and the activity of invertase are greatest in the plants grown under conditions of high nitrogen (295).

As to the mechanism of sucrose synthesis in the cane plant, HARTT arrived at the following conclusion:

"The mechanism of the synthesis of sucrose in the sugarcane includes phosphorylation and aeration. With the aid of hexokinase, some of the glucose absorbed by the blades is phosphorylated by the energy-rich phosphate bond of the adenosine triphosphate already present in the blades. This aerobic process results in the formation of more energy-rich phosphate bonds, perhaps by the dehydrogenation of malic acid, and these bonds are used for the reformation of adenosine triphosphate. Some of the phosphorylated glucose is converted to fructose monophosphate and then to fructose diphosphate. Some of the fructose diphosphate may be broken down anaerobically, but most of it combines with glucose using the energy released by phosphorylation, forming a sucrose phosphate. A phosphate acceptor such as thiamin or riboflavin, with perhaps the aid of a specific phosphatase, accepts the phosphate and thus sucrose is formed.

"These reactions, though long in the telling (and in the reading) probably take place practically instantaneously in the plant.

"Fructose is just as good a substrate as glucose for the synthesis of sucrose. Following the outline presented for glucose, the phosphorylation of fructose should result in the formation of fructose-6-phosphate. Some of this fructose monophosphate would need to be converted to fructose diphosphate, while some would be changed to glucose monophosphate and then to glucose. The glucose would then combine with the fructose diphosphate, resulting in the formation of sucrose phosphate. Thus the formation of sucrose would take place by the same mechanism whether glucose or fructose is the starting point. The only difference is that both of the reactants have to be made when fructose is supplied, whereas only one reactant has to be made when glucose is supplied.

"The formation of sucrose in the plant results not only in a storing of sugar which thus is not all broken down at once, but also in the release of phosphate which can be used again." (297).

Many substances have been tested as to their possible effect on the synthesis of sucrose. Growth regulating substances were found to prevent the conversion of glucose into fructose and the formation of sucrose in detached roots supplied with glucose (295). The vitamins
nicotinic amide, pyridoxin, ascorbic acid, 2-methyl-3-phytyl-1, 4-naphthoquinone, the diphosphoric acid ester of dihydro \( \text{K} \), phthiocol, and folic acid did not affect synthesis significantly when applied to detached roots supplied with glucose in the dark. Both thiamin chloride and riboflavin, used separately, were found to increase the synthetic efficiency, but the error was high. Although aeration, thiamin chloride and riboflavin all aid synthesis in detached roots, they do not enable roots to make sucrose at a rate as high as in blades, which indicates that some factor necessary for synthesis is still deficient in detached roots (295).

The effects of a large series of inhibitory agents upon the interconversion of glucose and fructose, and on the formation of sucrose in detached blades have also been studied by Hartt (296).

There has been some controversy as to the nature of the first sugars formed in photosynthesis. Went (595, 596) assumed that sucrose is the first sugar product of photosynthesis and this opinion was shared by Prinsen Geerligs (485). Viswa Nath (569) arrived at the conclusion that simple sugars are formed in the leaves and transformed to sucrose in the stem.

Hartt has provided increasing evidence that simple sugars are formed first in photosynthesis and subsequently converted into sucrose (291, 293). When plants were fed radioactive carbon dioxide through the leaves, it appeared that during the first seconds 100 per cent of the gain in sugars was due to glucose and fructose while sucrose was formed later. This indicates that sucrose is a storage product and it was found that its formation starts at about the same time as the formation of the acid-hydrolyzable pentosans and cellulose (55, 299).

**TRANSLOCATION OF CARBOHYDRATES**

The sugars formed in the leaves move to all other parts of the plant where they are partly utilized in respiration and in the building up of the plant body. The remainder is stored in the stem in the form of sucrose. Translocation takes place in the phloem. The rate and the way of translocation of sugars has been traced in some interesting experiments in Hawaii. Radioactive carbon dioxide was fed to the blade of a stem. In 20 hours material manufactured by this blade had reached the blades of sister stalks of the same plant. The part of the plant which received the greatest amount of photosynthate was the stem immediately below the joint to which the fed blade was attached. But the mature joints also were radioactive, which proves that the active storage of sucrose is not restricted to the joints to which the assimilating leaves are attached. As to the rate of translocation, it was found that photosynthate made by the upper half of a single blade fed radioactive carbon dioxide, was respired by the roots six hours later. Since the distance between these organs was 258 cm, this indicates a translocation rate of at least 43 cm per hour (299).

The formation of sugars by photosynthesis occurs only during day time since light is required for this process. Translocation, on the other hand, proceeds day and night. Both sucrose and simple sugars are translocated in the sugarcane plant and one of the
dominant factors determining which form of sugar is translocated the more predominantly is the moisture content. Since the rate of sugar formation during day time exceeds the transportation capacity of the phloem, part of the sugars have to be stored during day time in the leaf blade in the form of starch and other insoluble polysaccharides. This temporary storage aids in translocation by furnishing a supply of sugars for translocation during night when no photosynthesis occurs. The discrepancy in the rates of formation and translocation of sugars accounts for the diurnal fluctuations of the sugar concentration in the blades (p. 324). It is obvious that there are two main sources of supply of sugar for translocation: photosynthesis which is limited to the daylight hours, and the digestion of polysaccharides stored during day time, which occurs chiefly during the night. A point of interest is that in passing from the leaves to the stem, sugars go from a place of low to a place of high concentration, thus against a concentration gradient (289).

STORAGE OF SUCROSE IN THE STEM; RIPENING

The assimilates produced in the leaves are utilized partly in the production of energy and partly in the building up of the plant frame. The balance is stored in the stem in the form of sugar, a process known as ripening.

A cane stem consists essentially of a series of joints, the age of which varies according to their time of formation. Ripening is a joint to joint process and the degree of maturity of the individual joints depends on their age. The processes involved in ripening have been studied in considerable detail in different countries. A diagram of the normal trend of ripening is presented in fig. 212. In the young plants (left hand curves of the figure), the sucrose content exhibits a distinct maximum which is located approximately at soil surface. The sucrose content in these plants shows a rapid decrease both toward the base and toward the top of the stem. As the plant grows taller (indicated by a broadening of the curves), two changes take place: the maximum of the sucrose curve rises and the right hand branch of the sucrose curve, with the exception of the uttermost top section, is gradually raised till it approaches the horizontal, indicating that the stalk has attained full maturity. Thus under the conditions prevailing in Java, mature cane is characterized by a more or less uniform sucrose content along the stalk with the exception of the top and the below-ground butt. The low content of the top is associated with the fact that the joints of this section are not full-grown, while the low content of the butt is associated with its high fiber content.

The trend of glucose content is almost the contrary of that of sucrose. It is highest in the youngest internodes and decreases as the internodes grow older. In mature cane, glucose almost disappears except in the top section. Little is known about the factors which are responsible for the gradual disappearance of glucose in maturing internodes. Kamering (338) has made some interesting observations. He examined the respiration of individual internodes and found that the rate of respiration fully accounts for their gradual loss of glucose. According to these observations, there would be no need for
assuming a conversion of glucose into sucrose in order to explain the gradual disappearance of glucose in maturing joints.

Indian and Hawaiian workers have introduced the distinction between the green-leaf section of a stalk and the dry-leaf section. The green-leaf part is defined as that portion where the attached leaves are still wholly or partly green. The green-leaf section is believed to be the section of most active sucrose accumulation (193). This distinction has proved to be of considerable value in studies of cane physiology. It should, however, be understood that the distinction between the two sections is not always a sharp one. The sucrose curves of fig. 212, for instance, do not exhibit any sudden break, except in very young and in mature stalks. Moreover, sucrose accumulation in the dry-leaf section of the stalk continues long after the leaves have died. This has been proved in experiments on defoliation and by feeding cane with radiocarbon. Both indicate that the sugars produced by the green leaves are distributed to all internodes of a stalk rather than being retained in the joints of the green-leaf section.

Hartt found the invertase activity in the green-leaf section to be double that in the dry-leaf part, and equal to that in the blades. This indicates that wherever sucrose is actively formed and stored, the activity of invertase is great, whereas, where the process of storage is more or less completed, a low order of invertase activity is found. These and other observations offer indirect evidence that sucrose in the sugarcane plant is synthesized by invertase (284). This process is greatly influenced by the water content of the tissues involved. Even small changes in moisture content of the green-leaf cane affect the equilibrium.
The distribution of sucrose in the successive joints depicted in fig. 212 relates to normal non-flowering stalks. Examples relating to other types of stalks are presented in fig. 213. All stalks were derived from the same field and only the above-ground millable part of the stalks was examined. The curves represent the brix (percentage of total solids in juice) of the successive internodes. Due to the high positive correlation existing between brix and sucrose concentration, the curves for brix and sucrose are very similar (219, 414, 415).

The upper curve relates to normal, non-flowering stalks. The second curve shows the situation in stalks which have flowered. Due to flowering, growth of the top section has come to a standstill, thus enabling the upper internodes to complete maturity. This has resulted in a straightening of the right hand part of the curve. The same effect is apparent in the third curve which relates to stalks the tops of which have died from top borers or top rot. These stalks have sent out lateral shoots near the dead top thus keeping the stalks alive. The fourth curve refers to top-defective stalks which have failed to produce lateral shoots and consequently have started deteriorating. It is interesting to note that as far as brix and sucrose are concerned, the first signs of deterioration are found in the bottom section of these stalks. A subsequent stage of deterioration is represented by the last curve which relates to top-defective stalks which have failed to produce lateral shoots and which, moreover, have lost all green leaves. These stalks are, however, still millable. The

Fig. 213.—Distribution of brix in different types of stalks. a, Normal non-flowering stalks; b, stalks which have flowered; c, top-defective stalks which have produced lateral shoots; d, top-defective stalks which have failed to develop lateral shoots and which have started deteriorating in their lower section; e, the same stalks in an advanced state of deterioration. Ordinate, brix. Abscissa, no. of successive internodes of the millable stem from bottom (2) upward. After LEVERT, VAN DER WOODE and VAN DILLEWIJN (219, 414).
process of deterioration has proceeded in the bottom section and has also spread to the middle section, thus producing a curve which is almost the opposite of that of normal non-flowering stalks. These five types of curves are so characteristic that they permit of ascertaining the type of stalk from their joint-to-joint brix curve. Top-defective stalks which have developed a healthy lateral shoot show a curve which is identical with that of normal non-flowering stalks (fig. 214), indicating that the lateral shoot has fully assumed the function of the original top (219, 414).

An interesting case of a damaged stalk has been reported by Das. It is reproduced in fig. 215 and relates to a primary stalk 26 months old with one joint broken some time previously, leaving only a slender connection of the rind and a little tissue. The general level of the brix above the broken joint is some 6 degrees higher than that below. This indicates that translocation of sugars from the leaves down to the stem has been interrupted partly or entirely after the joint was injured.

The examples presented so far relate mostly to Java, where conditions are conducive to normal maturing. In regions where growing conditions are different, other types of curves may occur. Under the conditions of a temperate climate, for instance, where the growing season is short, the cane plants seldom attain full maturity; their curves never become horizontal but remain in a stage represented by the second from the last curve in fig. 212. Another case has been reported by Das (193) from Hawaii, in which the maximum content of sucrose at an age of 18 months was found in the bottom section of the stalks; at 21 months the maximum had shifted to the middle section, and at an age of 26 months it was located in the top section.

The distribution of brix and sugars within the individual joints is not uniform. In the millable section of the stalk, both brix and sucrose are highest in the internode and lowest in the node (101, 178, 201, 219, 381, 412, 488, 600). These differences are clearly shown
In fig. 216. In the joints of the green-leaf section, the trend of the brix exhibits a maximum about the middle of the internode and this maximum is about 6 degrees higher than the brix in the node. When passing to the dry-leaf section, the difference between node and internode tends to become smaller.

In the non-millable top section, the situation is reversed; here the brix is highest in the nodes and depressed in the internodes (178, 488). It is obvious that the smoothly running curves depicted in the figures 212, 213 and 214, only represent the average of the successive internodes. The precise trend would show the fluctuations within the individual joints to be superimposed on the general trend of the stalk. An example is presented in fig. 217 which shows also the differences in the node-internode relationships between the millable and the non-millable cane sections.

When it is desired to follow the progress of maturing in a crop, the average of the millable cane section is generally plotted against time. This results, under normal growing conditions, in a S-curve (Java-curve in fig. 218).

In its early stage when the plant consists only of green-leaf cane, the average sucrose content is low. Once a dry-leaf section has developed, the ratio between dry-leaf and green-leaf sections gradually increases as the plant grows taller and this is reflected in a gradual

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**Fig. 215.**—Effect of a broken joint on the brix gradient in a stalk. The brix in the joints below the injury has remained on a markedly lower level than in the section above the injury, indicating that the broken joint has limited or prevented the downward translocation of sugars. After Das (193).
Distribution of brix within single joints of millable cane. The differences in brix between node and internode are greatest in the green-leaf section. After Cornelson (178).
increase of the average sucrose content. Toward the end of the growing period, the increase in average sucrose content slows down. Deviations from this normal trend are known in various countries. In Hawaii (178), India (548), Formosa (367) and other subtropical countries, bimodal ripening curves have been found with maxima during the cool, and minima during the warm season (fig. 218). During the cool season when growth is at a minimum, much sugar is available for storage; during the warm season a greater share of the assimilates is utilized in growth, thus leaving less for storage. In the latter case, stored sugar may even be reutilized. Both CORNELISON (178) and HARTT (292) have provided evidence that sucrose once laid down in the stem is not static but dynamic and interchangeable under the influence of season, weather and age. There is a seasonal ebb and flow in sugar concentration of the stem, the fluctuations in the green-leaf section being greater than those in the dry-leaf cane.
Temporary depressions in the ripening curve may also be due to other causes. When a period conducive to active sucrose storage is followed by a period of rapid elongation, the low sucrose content of the newly-formed joints may depress the average of the entire stem. Minor depressions may also result from differences in moisture content, e.g., during rainy days with little sunshine, since both excessive moisture and lack of sunshine tend to increase the moisture content of the cane. Even diurnal variations have been recorded which are due to differences in transpiration rate between day and night (p. 297 and 326).

**ACCUMULATION OF STARCH IN THE STEM**

Sometimes carbohydrates in the stem are partly stored in the form of starch, which may cause considerable difficulties in the factory. Went (595) did not mention the occurrence of starch in mature joints due to the fact that he experimented with stalks of *S. officinarum* which does not show this peculiarity. The first reference to the presence of starch came from Kramers (370a) in Java, who found it in stems of *Erianthus*. Honig has corroborated this observation in the case of lodged POJ 2878 (verbal communication). The presence of starch is easily demonstrated by cutting stalks longitudinally and treating the cut surface with an iodine solution.

Natal Uba (*S. sinense*) is particularly ill-famed because of its starch content. Haddon (278) found in Portuguese East Africa that at 8 months of age stems of Uba contained starch throughout their entire length. At 20 months, starch was only found in the top and the bottom, and more so in the bottom. Large amounts of starch were found on acid soils while alkaline soils showed none. Other varieties did not contain appreciable amounts of starch.

The occurrence of starch in Uba has been confirmed by Feuilerade (264) in South Africa, by De Sornay (523a) in Mauritius, by Weller (12, 589) in Hawaii, by Von Stieglitz (529) in Queensland, by Neel (469a) in Java, and by Dutt and Narasimhan (233) in India.

Weller (589) who has studied this phenomenon in some detail distinguishes between two types of starch accumulation. In the first, starch occurs only in the growth ring above the nodes in the first two or three layers of parenchyma cells surrounding the vascular bundles. Weller found this type without exception in all varieties of cane examined in the section of the stalk subtended by functioning leaves. It occurs also in the mature sections of several varieties (H 109, D 1135 and MD 1).

In the second type, starch is present in, above and below the node. It occurs in all of the parenchyma cells, both in those immediately adjacent to the bundles and in all of those cells lying between the bundles. This type occurs only in Natal Uba, and only in the mature section of this variety, the green-leaf section exhibiting the first type.

Quantitative data about the occurrence of starch in several varieties have been reported by Von Stieglitz (529) in Queensland. This author found that although Uba contains slightly greater amounts, the quantities of starch in Co 210 and Co 213 are considerable.
The relationship between soil acidity and occurrence of starch claimed by HADDON could not be confirmed.

DUTT and NARASIMHAN (233) have made a general survey of the occurrence of starch in stalks of different varieties and species of sugarcane, as well as in some related genera. Sections of both the first joint above the ground and the oldest joint of the green-leaf section were examined. In the 78 varieties of S. officinarum studied, no accumulation of starch occurred except in 10 varieties in which traces or very small quantities were observed. Examination of 85 varieties of S. barberi showed a relatively large accumulation of starch in almost all of them, both in the base of the stalk and in the top section. In most of the 25 varieties of S. sinense (to which Natal Uba belongs) the quantity of starch was not as great as in S. barberi, but a fair quantity was present in all excepting 3 or 4 in which only traces were met with. In 26 varieties belonging to S. spontaneum only small quantities of starch were noticed though in 8 or 9 types a fair accumulation but less than in S. sinense and much less than in S. barberi was noticed. Preliminary observations on other genera showed no starch accumulation in Sclerostachya and Narenga, while starch was noticed in Panicum maximum (Guinea grass), Pennisetum purpureum (Napier grass) and Sorghum. In the eight types of Erianthus examined, fair to large quantities of starch were noticed.

It is known that cuttings of roses develop shoots and roots more readily if their nodes contain starch and it has been suggested that the accumulation of starch in cane cuttings may exert a similar effect (589). DUTT and NARASIMHAN (233) compared the development of set roots in cuttings of S. spontaneum Burma and Katha (S. barberi). In the first, root development was late, in the second it was early and profuse. Examination showed that there was more accumulation of starch in the latter than in the former.

Little is known about the factors which are associated with starch accumulation in cane stems. Starch cannot be translocated in the plant without first being changed into a soluble form. In this connection it is interesting to note that according to HARTT (289) the activity of the starch-splitting enzyme amylase in the growing point of Uba was found to be weaker than that in six other varieties of sugarcane, growing side by side.

PRIMARY INDEX

In their search for an index reflecting the general welfare of a crop, Clements et al (163, 171) introduced the concept of primary index. Production of sugars (assimilation) is mainly governed by solar energy in the form of heat and light, while utilization of sugars (dissimilation) depends largely on moisture and growth. The balance between production and utilization is reflected in the sugar content of the cane plant.

In order to select the most reliable tissue which could serve as an indicator for this balance, detailed analyses of the sugar content of the constituent parts of cane plants were made at different ages. The result of one series of analyses is represented in table 81. For a description of the plant parts analyzed, the reader is referred to p. 197. The results of these and other analyses led to the selection of the leaf sheaths of the elongating section.
Table 81.—Distribution of total sugars in plants grown at Waipio (% dry weight). After Clements (163).

<table>
<thead>
<tr>
<th>Plant part</th>
<th>1939</th>
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<tbody>
<tr>
<td>Meristem</td>
<td>6.4</td>
<td>10.2</td>
</tr>
<tr>
<td>Spindle cluster</td>
<td>5.9</td>
<td>6.4</td>
</tr>
<tr>
<td>Elongating blades</td>
<td>3.2</td>
<td>3.0</td>
</tr>
<tr>
<td>Green-leaf blades</td>
<td>2.9</td>
<td>3.2</td>
</tr>
<tr>
<td>Elongating sheaths</td>
<td>10.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Green-leaf sheaths</td>
<td>6.1</td>
<td>6.2</td>
</tr>
<tr>
<td>Elongating cane</td>
<td>21.4</td>
<td>25.2</td>
</tr>
<tr>
<td>Green-leaf cane</td>
<td>41.4</td>
<td>37.8</td>
</tr>
<tr>
<td>Top internodes</td>
<td>51.2</td>
<td>48.4</td>
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<td>17th 3 internodes</td>
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<td>16th 3</td>
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<td>1st 3</td>
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</tr>
</tbody>
</table>

PHOTOSYNTHESIS

317
of the stem as indicator organ, and the amount of total sugars in this tissue, expressed as per cent of dry matter, is referred to as primary index. It is assumed that the temporary storage of sugars in these leaf sheaths is correlated with the balance between photosynthetic production on the one hand, and utilization or growth on the other. Thus, with a primary index of about ten per cent, the two contrasting processes appear to be in balance under Hawaiian conditions. When the primary index drops below that level, it is apparent that the growth rate is relatively greater than the rate of photosynthetic production, e.g., during periods of high temperatures, both night and day (high growth rate), combined with low light intensity (low rate of photosynthesis). When conditions are such that photosynthesis exceeds utilization, the primary index will surpass ten per cent. Toward the end of the crop season when the cane matures, the primary index may increase to 15 and more per cent.

It is interesting to note in table 81 that sugars are lost from the bottom of the stem during the period of rapid growth (summer) and that apparently they are not replaced. This once more indicates that sugar once laid down in the dry-leaf cane is not static. The fluctuations in the green-leaf section are less pronounced indicating that sugars laid down in this part of the stem are not easily obtainable for growth purposes (163).

Clements considers the primary index in the first place as a general index, indicating whether there is something wrong with the crop, and he uses partial indices (nitrogen index, moisture index, etc.) to trace the cause (164, 165, 171). The proper interpretation of these indices requires considerable skill and although cases have been reported in which the primary index failed or was difficult to interpret (116, 125), the primary index has been used successfully in many others (169, 171).

ENERGY RELATIONS

Photosynthesis consists essentially of a conversion of kinetic energy (solar radiation) into a potential form (carbohydrates). Sugarcane, like most other plants, is very inefficient as far as utilization of solar radiation is concerned. Ozawa (367), who has analyzed the energy relations in sugarcane, found that only about one per cent of the total incident radiation is utilized in photosynthesis. This fact is demonstrated in fig. 219, showing curves for total energy falling on the plant in the course of a year and for the quantity used in photosynthesis. The balance of approximately 99 per cent is partly reflected by the leaves and partly used in transpiration.

Only part of this one per cent is fixed in the plant in the form of dry substance; a considerable portion is utilized in the production of energy required in the various processes associated with growth (respiration, water intake, etc.). Fig. 220 shows that the curve for energy accumulated by photosynthesis exhibits the form of a grand period and so does the curve which represents the energy utilized in growth. During the first half of the growing period, the curves of both processes run closely together, indicating that the major part of the assimilates is used in the production of energy for growth. Only a little of the energy is fixed in the form of dry matter. During the second half of the growing period
the situation improves rapidly. Some months prior to harvest, the curves for dry matter and growth even cross, indicating that from that moment onward the quantity of energy laid down in the form of dry substance exceeds that utilized in growth. By harvest time a situation is reached in which almost 100 per cent of the energy accumulated by photosynthesis is laid down in the form of dry matter, nothing being utilized in growth.

The energy fixed in the form of dry matter is distributed among the stem, the leaves and the roots. Fig. 221 shows that the rate of fixation in leaves plus roots reaches a maximum in July, in accordance with the grand period of growth of these organs. After this date the rate of fixation in the stem surpasses that in the leaves plus roots, and attains a maximum in October.

The energy fixed in the stem in the form of dry substance is distributed between fiber and sugar. This is illustrated in fig. 222. Prior to August the major share of the energy is laid down in the form of fiber with little left for storage in the form of sugar. From August onward an increasing proportion of the energy goes into sugar. It is interesting to note that the curve for fiber exhibits the form of a grand period. This is what was to be expected since fiber formation is closely associated with cane elongation. The sugar curve, on the other hand, shows an S-form which reaches high values at the time that growth (as indicated by the fiber curve) drops markedly. A comparison of both curves shows that as the crop

![Fig. 219.—Photosynthetic utilization of solar energy by sugarcane in Formosa. T, Total energy falling on a stalk of POJ 2878; F, energy utilized in photosynthesis. Ordinate, energy in calories. Abscissa, number of 3-weekly periods. After Ozawa (367).]

![Fig. 220.—Rate of energy accumulation and utilization by a cane stalk of POJ 2878 in Formosa. P, Rate of energy accumulation in photosynthesis; G, rate of energy utilization in growth; F, rate of energy utilization in fixation (formation of dry substance). After Ozawa (367).]
approaches maturity, the major part of the energy fixed in the stem is laid down in the form of sugar.

Although the studies of Ozawa are of a preliminary character, they clearly demonstrate: 1) that only a small fraction of the incident radiation is utilized in photosynthesis; 2) that a great share of this fraction is utilized in the production of energy for growth, leaving little for the formation of dry matter and 3) that only a small fraction of the latter is available for sucrose formation. Nevertheless, sugarcane is capable of fixing more energy per acre than most other crops (p. 303).

RATE OF ASSIMILATION

Carbon assimilation is so greatly affected by internal and external factors that its rate varies widely. The factors involved and their influence will be discussed under the subsequent heading. At present only some average figures will be presented in order to give a general idea of the rate of this process.

The rate of assimilation can be determined in various ways: by measuring the intake
of carbon dioxide, by measuring the liberation of oxygen, or by determining the increase of the dry weight of leaves or parts thereof. None of these methods, however, is satisfactory. The first two do not take into account respiration which is associated with the intake of oxygen and the liberation of carbon dioxide. The last mentioned method consists of taking leaf punch samples and comparing their dry weight with that of comparable samples taken one or more hours later. This method has the additional disadvantage that during the period elapsing between the two samplings, part of the assimilates produced is translocated to the leaf sheath and the stem. Consequently, the apparent assimilation determined in this way gives only the balance between actual assimilation on the one hand, and respiration and translocation on the other.

The leaf punch method consists essentially of taking a certain number of punches from one half of a leaf and repeating this procedure after a certain time in the other half. When applying this method to sugarcane, Kuijper (379) encountered difficulties due to the asymmetric structure of the cane leaf. The overlapping half is heavier and contains more vascular bundles than the underlying half. By adjusting the method accordingly, more reliable results were obtained by him.

The leaf punch method has been applied to sugarcane by several investigators. Kamering (340) obtained values ranging from less than 0.5 to more than 1.5 mg of dry matter produced per cm² of leaf per day for poorly growing and vigorously growing plants respectively. The average for normally developed plants was about 1 mg. Kuijper (379) found an increase of 0.4 mg per cm² per day, while Gooding (273) reported a value of 0.5 mg.

Yap (613) and Gooding (273) who estimated the rate of assimilation by measuring the intake of carbon dioxide, found the daily absorption of carbon dioxide per cm² of leaf to be 0.5 and 0.7 mg respectively.

Factors influencing assimilation and ripening.—Since assimilation and maturing are closely related, the factors influencing both processes will be treated together. More details about the ripening process and the methods of estimating maturity will be presented in a subsequent volume.

Variety.—Varieties differ widely in their capacity of producing sucrose on a net basis. This may be due partly to differences in total leaf surface, and partly to differences in the rate of assimilation per unit of leaf surface. Varietal differences in total leaf area are generally known (p. 301), but so far no data are available on varietal differences in the rate of assimilation per unit of leaf surface.

Varieties also differ in their average rendement and three classes are generally distinguished: those with low, medium and high rendement.

Another classification relates to the time of ripening. There are early and late maturing varieties with many intermediate forms. This characteristic is closely related to the length of the growing period. Varieties with a short growing period generally ripen earlier and vice versa.

Age.—Age of the individual leaves affects their assimilation rate. Yap (613) found that this rate decreases with age, while Komatsu (367), on account of the content of moisture,
chlorophyll and other pigments of successive leaves, judged that the leaves nos. 3 to 8 are the most active. SINGH and LAL (518) found that the young and the mature leaves show a high and a medium efficiency respectively, while the old ones exhibit a low photosynthetic rate (fig. 223).

The age of the plant as a whole influences assimilation in two ways. Directly, in that the rate of assimilation per unit of leaf surface increases from the early stages up to a certain stage of development and decreases during the period of ripening off. SINGH and LAL (518), who studied this relationship, found that this trend is most marked when the carbon dioxide of the atmosphere is kept high. Under field conditions where the carbon dioxide of the atmosphere is low, the rate of assimilation is almost constant, showing only a slight increase as the plant grows older (fig. 223). In addition, the age of the plant influences assimilation indirectly as the total surface of leaves changes.

GROWTH RATE.—KAMERLING (340) found the rate of assimilation per unit of leaf surface to be greatest in vigorously growing plants. When weather conditions were favorable, the rate was more than 1.5 mg of dry substance per cm² leaf surface during the forenoon in vigorously growing plants, 1.0 to 1.5 mg in normally growing plants, 0.5 to 1.0 mg in poorly growing plants and less than 0.5 mg in non-growing plants.

There is an inverse relationship between elongation rate and rendement due to the fact that as more assimilates are utilized in the growth process, less are left for storage in the stem. A crop growing at a fast rate has a lower sucrose content in the stem than one growing at average rate. The reverse holds for the glucose content. This relationship is demonstrated in fig. 224. Das has compared glucose with a man’s current account and sucrose with his capital. Vigorous growth means large drawings on current account, leading to drafting the greater part of income to glucose formation (196), with little placed to reserve in the form of sucrose.

This raises the question whether or not the rate of elongation should be controlled in order to limit the utilization of assimilates in the process of growth and to promote the

![Fig. 223.—Effect of age of the cane plant and of its leaves on the rate of assimilation. Abscissa, age of the plant. Ordinate, real assimilation per 100 cm² of leaf surface per hour. The upper three curves relate to experiments in which the CO₂ concentration of the air was maintained at 0.35 per cent. The lowest curve relates to a CO₂ concentration of 0.06 per cent which prevails in cane fields. After SINGH and LAL (518).]
storage of sucrose in the stem. Experience has taught that the question is not as simple as this. Studies about the relationships between cane tonnage and rendement in Java have proved that in general the rendement decreases with increasing cane tonnage. But this relationship is not proportional since the per cent decrease in rendement is less than the increase in cane tonnage. The explanation is obvious. Growth is not restricted to cane elongation, but includes the development of roots and leaves as well. Since the latter two constitute the main production apparatus of the plant, it follows that a good development of these organs is a necessary prerequisite to the production of a maximum sucrose yield per acre. There are, however, limits. When growth becomes too luxurious, as in the case of excessive nitrogen application to one-year crops (fig. 179), the sucrose yield per acre may decrease.

The practical conclusions to be drawn from these facts is that a sensible policy of regulating a moderate and uniform growth rate will result in the highest sugar yields. Toward harvest time a gradual check of the elongation rate may aid in promoting the process of ripening off. In this way the ratio between the dry matter stored as sucrose and that used for growth may gradually increase.

The ideal would be that the greatest part of the energy accumulated by photosynthesis be fixed in the form of dry matter (right hand part of fig. 220), and that moreover this dry matter be largely stored in the stem in the form of sucrose (right hand part of fig. 222). A near approach to this ideal is presented in table 82, showing that the percentage of the dry matter accumulated in the form of sucrose increases steadily throughout the season.
By August almost all of the dry matter accumulated is retained in the plant as sucrose (53).

DIURNAL VARIATION.—The rate of assimilation is subject to considerable fluctuations in the course of a day. KAMERLING (340) observed that the accumulation of dry matter in the leaf blade is greatest during the morning hours and this observation was corroborated by KUIJPER (379). The latter stressed the importance of the morning hours for the assimi-
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Subsequent investigations by McLEAN (434), YAP (613) and GOODING (273) have proved that the rate at which carbon dioxide is absorbed by the cane leaf shows a depression about midday. Examples of this phenomenon are presented in table 83 and 84. The results listed in these tables were obtained with leaves attached to the plants. The depression around midday is striking; in one case the rate of assimilation decreases to 20 per cent of the morning maximum, while in the other case it decreases to 50 per cent. The diurnal trend of assimilation thus follows a bimodal curve with one maximum between 8 and 10 a.m., and a second in the afternoon. The latter is only slightly lower than that in the morning. The depression is partly due to high temperature (p. 327), while also high light intensity may be involved. The temporary rolling up of the leaves indicating excessive loss of water by transpiration may also affect the rate of assimilation. Bimodal curves of assimilation have been observed in many other plant species.

Since the capacity of the vascular bundles to translocate carbohydrates from the blades to the sheaths and the stem is limited, translocation cannot keep pace with the high rate of sugar formation in the blade during day time. Consequently the sucrose content of the latter increases during the day. An example is presented in fig. 225, showing that both

![Graph showing diurnal variation of sucrose, starch, and reducing sugars in the blade of sugarcane.](image)

Fig. 225.—Diurnal variation of sucrose, starch and reducing sugars in the blade of sugarcane (expressed on residual dry weight basis). After HARTT (288).
sucrose and starch increase during the day and reach a maximum at sunset. This peak is followed by a rapid decrease during the night, resulting from the fact that translocation continues during the night, whereas photosynthesis ceases. The manufacture of starch and other insoluble saccharides during day time removes considerable quantities of soluble sugars from solution. If this were not the case, the accumulation of all the soluble sugars formed in photosynthesis might interfere with that process seriously. Moreover, temporary storage of polysaccharides in the blades during the day aids in translocation by furnishing a supply of sugars for translocation after nightfall when photosynthesis ceases (289). Reducing sugars are present in much smaller amounts than sucrose and their daily fluctuations are less obvious.

The fluctuations in the blade are reflected in the leaf sheath. Here also, the sucrose content expressed on a dry weight basis increases during day time and reaches a maximum about nightfall, followed by a decrease during night. When the supply of sugars entering the sheaths is greater than that which is passing on immediately into the stem, the balance is temporarily stored in the sheaths in the form of polysaccharides (289).

Even in the stem these variations are reflected, though only weakly. As stated earlier, the brix of the cane juice exhibits daily variations which used to be ascribed to variations in moisture content (p. 297). HARTT has, however, proved that these differences are not caused solely by changes in water content, but that they are, at least partly, actual differences in the percentage of sugar on a dry weight basis (292).

From the foregoing it follows that due to daily changes in external conditions, the assimilation rate is subject to diurnal variations, which result in considerable fluctuations of the carbohydrate content of the blades. These fluctuations are transmitted to the sheaths and even, though to a smaller degree, to the stem.

Climate and season.—In the chapter on growth, the striking effect of climate has been indicated. There it was stated that under conditions of bright sunlight sugarcane is capable of producing up to three or four times as much sucrose as in a more cloudy climate (p. 120).

These and other observations have provided increasing evidence that, other factors not being limiting, carbon assimilation is largely determined by the atmospheric conditions of light intensity and temperature. The quantity of solar energy available is perhaps the most important single factor in the quantity of crop produced (163).

Differences in atmospheric energy influence the rate of assimilation. In addition to this, they may affect the quantity of chlorophyll in the leaf since KOMATSU obtained evidence that during periods of cloudiness the chlorophyll content of cane blades is reduced (367).

Data on seasonal variations in the rate of assimilation have been collected by YAMASAKI and ARIKADO. These authors determined the rate of assimilation in young leaves during bright days in successive months. Assimilation was estimated according to the half-leaf method. The average figures obtained in the course of three years are listed in table 85. These show that in the months of May and December the rate of assimilation was about half that of September.

Carbon dioxide content of the atmosphere.—SINGH and LAL (519) have shown that
the rate of assimilation in sugarcane increases considerably with increasing concentration of the carbon dioxide of the atmosphere (fig. 226). They found that the carbon dioxide concentration of the air in sugarcane fields exhibits a diurnal variation with a minimum during the afternoon and a maximum during the second half of the night. During day time the concentration was about 0.05 per cent and during the second half of the night about 0.09 per cent, measured two feet above the soil surface (518). Although these concentrations are higher than those normally occurring in the atmosphere outside the fields (0.03 per cent) they still are so low as to be limiting.

LIGHT.—One of the dominant factors is light intensity. Kamerling (340) noticed the adverse effect of cloudiness on the rate of assimilation fifty years ago. This observation was corroborated by Kuiper (379) who found that the rate of starch accumulation in the blade decreases under conditions of reduced light intensity.

This matter has been studied in more detail by Singh and Lal (519) who found that, other factors remaining constant, the rate of assimilation increases with increasing light intensity within the range from 90 to 1,875 foot-candles studied (fig. 226).

TEMPERATURE.—Another dominant factor in assimilation is temperature. As stated before, Hartt (293) found that the optimum temperature for the synthesis of sucrose in excised leaf blades of sugarcane is approximately 30°C. Singh and Lal (519) observed that the rate of carbon assimilation increases from 23° to 30°C; between 30° and 34°C there is an initial rise, followed by a decrease at 34°C. This explains, at least partly, the occurrence of a depression in the rate of assimilation about midday when temperature is maximal (table 83 and 84).

The combined effects of light and temperature are greatly responsible for the rate at which dry matter is produced by plants in general. At high light intensities carbon assimilation exceeds respiration by many times. When light intensity is reduced, assimilation
diminishes accordingly, while respiration, which is not appreciably influenced by light intensity, continues at approximately the same rate. Eventually a situation will be reached at which both processes are in equilibrium, the so-called compensation point. Under these conditions, neither carbon dioxide nor oxygen are absorbed from or released to the surrounding atmosphere, and the dry weight of the plant remains constant.

Lauritzen, Brandes and Matz (391) have studied these relationships in sugarcane grown under various combinations of light intensity and temperature. Plants grown under the conditions of a certain temperature and a relatively high light intensity developed normally, indicating that assimilation exceeded dissimilation. Similar plants grown under reduced light intensity and at the same temperature showed no appreciable growth, indicating that the compensation point, at which assimilation and dissimilation are more or less in equilibrium, was reached. Plants exposed to the same temperature and a still lower light intensity died, indicating that the rate of dissimilation exceeded that of assimilation. These results are in harmony with those obtained in Hawaii with cane grown under favorable light conditions. These plants yielded approximately three times as much sugar as plants grown under unfavorable light conditions at approximately the same temperature (p. 120).

The beneficial effect of low temperature on juice quality is generally recognized. In Formosa, for instance, a negative correlation was found between the monthly mean minimum temperature from October to April, and the rendement (per cent available sugar) at harvest. This beneficial effect is largely indirect, since low temperature decreases the growth rate, thus enabling the storage of a greater share of assimilates in the form of sucrose.

Moisture.—Moisture affects assimilation and sucrose storage directly and indirectly. In a series of experiments, Hartt (285, 290, 292) has proved that a plentiful supply of water is essential for the formation of sucrose in the blades, for its transport to the stem, and for the expression of sugar in the juice. She found, in one instance, that the blades of plants supplied with water made ten times as much sucrose as the blades of plants deprived of water (292). The green-leaf cane of the former gained a large amount of sucrose while that of the latter lost sucrose. The juice extracted from the dry-leaf cane of the former had

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Table 85.—Rate of assimilation in milligrams of dry matter per hour per 100 cm² of leaf surface

<table>
<thead>
<tr>
<th>Season</th>
<th>Assimilation</th>
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<tbody>
<tr>
<td>May</td>
<td>7.8</td>
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<tr>
<td>June</td>
<td>10.9</td>
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<tr>
<td>July</td>
<td>12.6</td>
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<td>October</td>
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<tr>
<td>November</td>
<td>9.2</td>
</tr>
<tr>
<td>December</td>
<td>7.7</td>
</tr>
</tbody>
</table>

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After Yamasaki and Arakado (607)
a better quality ratio than that from the latter. Actually the tissues of the dry-leaf cane of
the plants deprived of water contained more sucrose expressed on a dry matter basis, but
since less sucrose was recovered in the juice, it is indicated that the extraction of sugar in
the mill is adversely affected in plants deprived of water (290, 292).

Photosynthesis can take place in plants at or below the wilting point but the quantity of
sugar produced under these conditions is much smaller than that made by plants ade­
quately supplied with water. Moreover, the sucrose produced in the former is less readily
expressed in the mill than that of the latter (290, 292). Small changes in moisture content
of the green-leaf cane affect the equilibrium between simple sugars and sucrose (292).

These results are in harmony with those of TENGWALL and VAN DER ZUL (542), who
found a high positive correlation between rainfall and rendement in Java (p. 112).

Moisture affects the sucrose content of cane indirectly through its action on other vital
functions of the plant, especially growth. The greater the share of assimilates utilized in
growth, the less remains available for storage. A certain growth is required in order to
provide an adequate stem volume for sugar storage, its minimum being determined by
the fact that the rendement of millable cane rarely surpasses 15 per cent. In the sugar beet
where the rendement may surpass 20 per cent, the situation is more favorable, since a
smaller volume will be sufficient to store a certain quantity of sucrose. As stated before,
with a sensible policy of irrigation, much can be gained in this respect.

This is of particular importance toward the end of the growing period. In ripening
off a crop, growth in its broadest sense (including the formation of leaves and roots)
should be reduced gradually, in order to direct an increasing share of the assimilates to
the stem for storage. An example of this process has already been presented (table 82).

CLEMENTS et al (164, 165a, 167) found that biennial crops of good quality grown under
Hawaiian conditions are characterized by final moisture index values of 73 to 74 per cent
(moisture content of the young leaf sheaths). These final values have to be approached
gradually by an adequate irrigation policy. The moisture conditions under which a crop
has grown up are of importance. Crops which have been kept at a high moisture level
throughout their growing period generally give high cane tonnages, but are likely to be of
mediocre quality. Crops which have developed at a very low moisture level usually give
light cane tonnages, but do not necessarily yield good juices (167).

CLEMENTS et al have developed a system of ripening off which aims at gradually lowering
the moisture index until the desired value is attained. This system is illustrated in fig. 227.
The crops are sampled at regular intervals and irrigations are withheld until the moisture
content has dropped to a pre-determined level.

FERTILIZERS.—Assimilation and sucrose formation are influenced by fertilizers directly
and indirectly. Nitrogen increases the rate of assimilation (p. 220), increases the chlorophyll
content of the leaves (p. 220), influences the rendement (p. 215), the juice quality (p. 213),
and the formation of sugars (p. 213). Little is known about the effect of phosphorus on
assimilation, and the influence of this nutrient on the ripening process is still doubtful
(p. 243). Potassium is known to promote sugar formation and it plays a role both in the
transformation between hexoses and sucrose, and in their translocation (p. 253). Moreover,
Fig. 227.—Examples illustrating the system of ripening off cane by gradually lowering the moisture index. After Clements and Akamine (167).

potassium tends to reduce the deleterious effect of excessive nitrogen dressings on juice quality (p. 232). For more details, the reader is referred to the chapter on nutrition.

DEFOILATION.—Removal of active leaves affects the sucrose content of the millable part of the stalk. The adverse effect is greater the younger the leaves involved. This is partly due to the fact that the younger leaves are more active. A factor of greater importance is that the younger leaves, if not removed, would have been active for a longer time than the older ones.
The question often arises whether the assimilates manufactured in a particular leaf are mainly directed to the joint attached to this leaf. KUIJPER (376) has studied this matter by removing individual leaves and found that the question has to be answered in the negative. CORNELISON (178) also made some preliminary observations and found that the stripping off of leaves affects the sugar content of a great part of the stem rather than that of single internodes.

The effect of defoliation has been studied in considerable detail by YAMASAKI and ARIKADO (605, 606). They found that defoliation permanently decreases the brix and sucrose content of the stem section deprived of leaves as well as of all the lower internodes (fig. 228). This effect is greater when young leaves are removed than when the same is done with older ones. The effect also depends on the time of the treatment; in Formosa the adverse effect at harvest is greatest when defoliation is practiced in October (606). In addition to its effect on sucrose formation in the stem, defoliation also decreases the length and the diameter of growing internodes. The results of the experiments on defoliation provide an explanation of the adverse effect of leaf injury by wind (cyclones), leaf diseases and leaf pests.

Fig. 228.—Trend of brix in normal stalks (dotted curves) and in stalks of which the leaves of the middle and the lower sections had been removed in July (solid lines with heavy sections indicating the defoliated joints). Abscissa, numbers of successive joints from the base (left) to the top (right) of the stalk. Ordinate, brix. After YAMASAKI and ARIKADO (605).
The process of respiration provides the plant with the energy required in its various functions, such as growth and water intake. Respiration consists essentially of the oxidation of organic matter and this process may be expressed in a simplified form by the equation

\[ C_6H_{12}O_6 + 6 O_2 \rightarrow 6 CO_2 + 6 H_2O + \text{energy} \]

indicating that for each molecule of oxygen absorbed, one molecule of carbon dioxide is liberated. The process of respiration is essentially the reverse of that of assimilation. While assimilation is largely limited to the green parts of the plant, respiration is active in all living tissues, particularly so in the younger ones.

The first preliminary experiments on respiration in the cane plant were made by WENT (593) at the end of the past century. This author found that in the white top internodes of the stem the rate of respiration was about twice that in the adjacent green internodes.

A more elaborate study was conducted by KAMERLING (338) in the beginning of the present century. KAMERLING determined the rate of respiration by measuring the amount of carbon dioxide liberated by internodes of the intact plant growing in the field. He found that respiration was the more active the younger the stems examined. The quantity of carbon dioxide liberated per 24 hours and per kilogram of green weight was 0.221, 0.333 and 0.425 grams for plants 12 months or more, 7 months, and 5 months of age respectively. This indicates that the rate of respiration in the stem decreases as the plant grows older. KAMERLING stresses the fact that the measurements were made in day light and that assimilation may have interfered with respiration. Thus the quantity of carbon dioxide liberated as measured by KAMERLING actually constitutes the difference between respiration and eventual assimilation in the stem. This difference was exactly what KAMERLING was interested in. For he wanted to know whether the gradual disappearance of glucose in the maturing stem could be accounted for by respiration, with or without an eventual slight assimilation. The rate at which glucose disappears in the internodes during the process of ripening was estimated from the detailed figures collected by WENT (595). A comparison of the rate at which both processes occur, proved that the rate at which glucose gradually disappears in full-grown internodes can be entirely accounted for by the rate of respiration. Consequently, KAMERLING concluded that there is no need of assuming a conversion of glucose into sucrose. Although the results obtained by KAMERLING indicate that the disappearance of glucose in the course of the ripening process may be explained without a conversion of glucose into sucrose, this does not prove that the latter process is not involved.

Of even more importance is the respiration in roots, since this process has a direct practical bearing on the culture of sugarcane on poorly aerated soils. KAMERLING (338) obtained evidence that respiration in roots is very active even when the atmosphere surrounding the roots contains little oxygen. This indicates that under such conditions oxygen is partly derived from above-ground portions of the plant by diffusion through the
intercellular system of stem and roots. It has been pointed out that sugarcane exhibits wide variations in its ability to grow on poorly aerated or water-logged soils (p. 156). Plants other than sugarcane growing in water are generally characterized by an extensive intercellular channel system which permits oxygen of the aerial parts to diffuse into the roots. Since the inadequate development of the cane root system in poorly aerated soils constitutes a major problem in cane culture, it is surprising that during the fifty years which have elapsed since Kamerng tackled this problem, nothing has been done in this respect.

Yap (613) in the Philippines made some preliminary observations on the respiration of cane leaves during the night. Using the active leaves +2 and +3, he found in one case 4.2 and in another 1.8 grams of carbon dioxide released per m² of leaf surface per 12 hours.

The effect of external and internal factors on the rate of respiration has been studied in considerable detail by Khan and Raheja (351a, b, c) in India. These investigators determined the rate of respiration in situ in a series of varieties by enclosing the entire leaf spindle in a respiration chamber which was painted black.

They observed a diurnal fluctuation in the rate of respiration. Respiration was low in the morning and increased with the rise in temperature till the latter became supra-optimal (about 2 p.m.) when the rate fell considerably. With temperature becoming more favorable in the evening, the rate of respiration tended to regain a normal value. The optimum temperature for respiration was found to lie below 100°F, and above 104°F respiration decreased distinctly. The depression in the rate of respiration at about 2 p.m. was associated with temperatures between 104 and 110°F.

Varietal differences were found to be very marked. The daily fluctuation in Co 313 was very small, that in Co 213 rather large. It was indicated that varieties with higher concentrations of chlorophyll possess a narrower range of fluctuations in their respiratory activity as compared to those with lower ones.

During the hot season the rate of respiration decreased and here, also, varietal differences were observed. While Co 213 exhibits a steep decline (from 1.90 to 0.29 cc of carbon dioxide evolved per hour per gram weight of fresh material), the decrease in Co 313 is relatively small (from 0.72 to 0.54). In general, the drought susceptible varieties cut down their respiratory activity more rapidly than the more drought resistant ones.

Since in North Bihar no other crop can withstand stagnation of water, lands liable to flooding are usually cropped with sugarcane. Under conditions of partial submergence, maize is most affected while sugarcane can withstand the stagnation of water for a considerable time. Khan and Raheja found that the rate of respiration in maize was more affected by partial submergence than that in cane which may partly explain the greater susceptibility of the former to stagnant water.

Great varietal differences were found in the response of sugarcane to partial submergence. Although the results obtained by Khan and Raheja are not clear cut, it is indicated that after five to eight days the submerged organs (stem and roots) generally exhibited a higher rate of respiration while the response of the leaves was variable.

Striking differences were noticed in the response of a plant crop and a ratoon crop of Co 213 to flooding. In both cases partial submergence resulted in an initial rise of
### Table 86.—Percentage of carbon dioxide and oxygen in various sections of the cane stem
After Bonazzi (103)

<table>
<thead>
<tr>
<th>Tissue</th>
<th>CO&lt;sub&gt;2&lt;/sub&gt;</th>
<th>O&lt;sub&gt;2&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical buds</td>
<td>53.23</td>
<td>0.87</td>
</tr>
<tr>
<td>Subapical internodes</td>
<td>35.52</td>
<td>9.36</td>
</tr>
<tr>
<td>Median internodes</td>
<td>17.46</td>
<td>16.32</td>
</tr>
<tr>
<td>Basal internodes</td>
<td>7.73</td>
<td>14.10</td>
</tr>
</tbody>
</table>

**Fig. 229.—Distribution of oxidases in the cane plant. After Bonazzi (103).**
respiration rate. But in the plant crop this increase was followed by a decline, and the respiration rate was low from the seventh to the fourteenth day after submergence. The fall in the ratoon crop was much less and when the water had receded, it was noticed that the plant crop had been extensively damaged by the flood, while the ratoon crop was standing almost undamaged.

The fact that respiration is most active in the young tissue of the cane stem and that it decreases gradually as the internodes grow older, suggests that the young tissue will show a higher concentration of carbon dioxide than the older ones. The reverse will be true of the oxygen concentration.

This is exactly what has been found by BONAZZI (103) who examined the concentration of the two gases in various sections of the cane stem. A summary of the results obtained by him is presented in table 86. It shows a distinct gradient of the gaseous composition of the tissues along the cane stem. Although relationships between this and other gradients (germinability, moisture content, sugar concentration, chemical composition) are indicated, nothing is known with certainty.

The gradient in respiratory activity along a cane stem can also be demonstrated in a qualitative way by examining the distribution of oxidase, a group of enzymes that promote oxidation and consequently are closely associated with the respiration process. To this end the stem is split longitudinally and the cut surface flooded with guayac tincture. This results in a deep blue coloration of the top section which rapidly decreases toward the bottom section (fig. 229).

As a result of his work, BONAZZI emphasizes the fact that studies about parasitic organisms which pass the greater part of their life in the apical and rapidly growing tissues, e.g., mosaic, should be conducted in a gaseous environment of high carbon dioxide tension and low oxygen concentration.

Finally, mention must be made of the strange coincident that the latest contribution to the respiration of sugarcane by a young Java worker (304) starts with the statement that no quantitative information about respiration processes in sugarcane is available, at least not in the Java literature. Thus a half century of work in this particular field of research has been ignored.
BIBLIOGRAPHY

8. ANON. 1926. Report of the Puerto Rico Agricultural Experiment Station for 1924.
17. ———. 1933. Third Annual Report of the Sugar Cane Research Station, Mauritius, for the year 1932.
18. ———. 1933. Report of the Department of Science and Agriculture, Barbados, for the year ending the 31st March, 1933.
20. ———. 1934. Eighth report of the Sugar Cane Breeding Station, Mauritius, for the year 1933.
21. ———. 1934. Thirty-fourth annual report of the Bureau of Sugar Experiment Stations, Brisbane.
22. ———. 1935. Fifth annual report Sugar Cane Research Station, Mauritius.
23. ———. 1935. Sixth annual report Sugar Cane Research Station, Mauritius.
32. ———. 1936. Third annual report British Indies Central Sugar Cane Breeding Station, Barbados, for the year ending Sept. 30, 1936.
38. ———. 1938. Eighth annual report of the Sugarcane Research Station, Mauritius, for the year 1937.
39. ———. 1939. Ninth annual report of the Sugarcane Research Station, Mauritius, for the year 1938.
40. ———. 1939. Thirty-ninth annual report of the Bureau of Sugar Experiment Stations, Brisbane, pp. 66.
41. ———. 1940. Tenth annual report of the Sugarcane Research Station, Mauritius, 1939.
42. ———. 1941. Eleventh annual report of the Sugarcane Research Station, Mauritius, 1940.
44. ———. 1944. Annual report of the Director of the Institute of Tropical Agriculture of Puerto Rico, 1943-44.
46. ———. 1945. Fifteenth annual report of the Sugarcane Research Station, Mauritius, 1944.
64. ——. 1897. De uitkomsten van eenige cultuurproeven. A. Waterproeven. Archief Java Suikerind. 5, 687–693.
95. —. 1891. Nieuwe waarnemingen van abnormale verschijnselen bij het suikerriet. Semarang.
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151. ——— and F. MASTIO. 1925. Acción del frio sobre la germinación de las yemas de la caña de azúcar. La Revista “Chaparros Agricola” 2.


156. CHEN, N. S. 1950 (A preliminary report on the quick methods of propagation of sugarcane.) Jour. Sugarcane Res. (Formosa) 4, 45–60. (Chinese with English summary.)


159. CHOW, N. P. 1950. (Number of buds per seed piece in relation to germination, growth and yield of sugar cane.) Rept. Taiwan Sug. Exp. Sta., No. 5, 91–108. (Chinese with English summary.)


BIBLIOGRAPHY

210. DEOMANO, F. V. 1931. A study of the chemical composition of four sugar cane varieties of the same age and grown under similar conditions. Philipp. Agric. 20, 139-145.
217. ——. 1948. (The culture of sugar cane and some of its problems.) Aluloum Azziraiya 1, 1-28. (Arabic with English summary.)
239. ——— and C. C. MORELAND. 1921. Fungi and cane germination. Results of experiments at the Louisiana University Experiment Station. Sugar 1921 (1), 16-17.
262. FAWCETT, G. L. 1925. La impermeabilidad de las yemas de la caña a la solución de sal. Rev. Ind. y Agric. de Tucumán 16, 50-54.
263. ———. 1929. La clasificación de algunas antiguas variedades de caña con referencia al sistema RUES. Rev. Ind. y Agric. de Tucumán 20, 114-120.
286. ———. 1934. Some effects of potassium upon the growth of sugar cane and upon the absorption and migration of ash constituents. Plant Phys. 9, 399-452.
287. ———. 1934. Some effects of potassium upon the amount of protein and amino forms of nitrogen, sugars, and enzyme activity of sugar cane. Plant Phys. 9, 453-490.


334. ——. 1900. De waterverzorging van de rietplant. Handel. 4de Suikercongr., Semarang, 14-44.


348. ---. 1940. Does fertilizer affect the arrowing of cane? Cane Growers' Quart. Bull. 8, 76.
350. ---. 1936. Scientific report of the Sugarcane Research Station, Bihar and Orissa, for the year ending the 31st March 1935.
361. ---. 1900. Onderzoek omtrent de samenstelling van suikerriet op verschillenden leeftijd en de opname van stikstof, kali, kalk en phosphorzuur. Archief Java-Suikerind. 8, 453-489.
417. ——, P. M. TSENG and T. C. CHENG. 1949. (The effect of growth substances on the germination of sugarcane seed pieces.) Jour. Sug. cane Res. 3 (4), 103-130. (Chinese with English summary.)
418. ——, Y. G. WEN and B. W. SHEE. 1948. (The effects of topping on the young canes.) Jour. Sug. cane Res. 2 (7), 1-23. (Chinese with English summary.)


PAO, T. P. 1950. (A review of the past experimental results on the performance of upland and lowland cuttings of sugar cane in Taiwan.) Rept. Taiwan Sug. Exp. Sta. 5, 47-76. (Chinese with English summary.)


PARRIS, J. W. 1859. The Liberal, 12 Febr. 1859.


583. ———. 1922. Miscellaneous publications. R. Alfred Observatory, No. 5.
604. Wray, L. 1848. The practical sugar planter; a complete account of the cultivation and manufacture of the sugar-cane, according to the latest and most improved processes... London, pp. 415.
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