

INTERCROPPING OF BAMBOO (*Dendrocalamus strictus* Nees) WITH  
SOYBEAN (*Glycine max* (L.) Merrill) - AN AGROFORESTRY STUDY

By

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THIS IS SUBMITTED IN PART FULFILMENT OF THE REQUIREMENTS FOR THE AWARD  
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## CERTIFICATE

This is to certify that the thesis entitled "INTERCROPPING OF BAMBOO (*Dendrocalamus strictus* Nees) WITH SOYBEAN (*Glycine max* (L.) Merrill) — AN AGROFORESTRY STUDY" submitted in part fulfilment of the requirements for the award of the degree of DOCTOR OF PHILOSOPHY IN AGRONOMY to the Tamil Nadu Agricultural University, Coimbatore is a record of *bona fide* research work carried out by Mr. P. SESHADRI under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.


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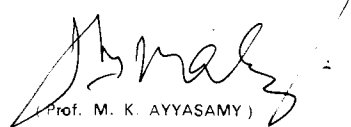
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## Abstract

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ABSTRACT

INTERCROPPING OF BAMBOO (Dendrocalamus strictus Nees) WITH SOYBEAN (Glycine max (L.) Merrill) - AN AGROFORESTRY STUDY

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Three field experiments (Experiments 1, 2, and 3) were conducted during three different seasons (August - November 1979, December 1979 - March 1980, and April - July 1980) at Coimbatore, India, to explore the feasibility of raising soybean (Glycine max) as an intercrop within a stand of 4-5 year old clumps of 'solid' bamboo (Dendrocalamus strictus Nees) planted at a spacing of 4 x 4 m. The intercrop was raised under irrigation. A sole crop of soybean was raised in an adjacent field, for comparison. Besides a comparison of the performance of the soybean under these two environments (i.e., 'within the bamboo stand' and 'in the open field'), the influence of two vigour levels (low, and high) of the bamboo clumps, as well as three levels of P application (0, 100 and 200 kg P<sub>2</sub>O<sub>5</sub>/ha) on the performance of the soybean was studied. Also, the growth (from age 3 1/4 years to about 6 years) and

culm yield (at about 6 years after planting) performance of the bamboo clumps (base crop) were also studied with reference to the two vigour levels and the three P levels. Additionally, the fluctuations in the light intensity, microclimate and soil moisture as well as weed infestation were studied under both the environments.

In soybean, attributes like plant height, number of branches, number of leaflets, total leaf area/plant, mean leaf area/leaflet, rpot: shoot ratio, number of pods, DMF, number of grains/plant, 100-grain weight and grain yield/plant were significantly influenced by the environment. The plants growing within the bamboo stand were taller, thinner, had less branches, shorter taproots, recorded lower root : shoot ratio, less number of flowers and lower DMF. However, the patterns differed between the first experiment (Expt.1) on the one hand and the two subsequent experiments (Expts.2 and 3) on the other. While initially (Expt.1) the plants growing within the bamboo stand had more number of leaflets, larger leaflets, and thus more leaf area, more pods, and recorded a higher biomass, more number of grains/plant, heavier grains, and yielded more grain/plant (44% more, significant), as compared to the plants growing in the open field, the pattern reversed in the subsequent experiments in favour of the open field, as the bamboo canopy progressively closed up and the root system of the bamboo expanded. While in the first experiment the intercrop soybean outyielded the sole crop by 24% (net

significant), subsequently the sole crop grain yields were 607% and 773% under Expts. 2 and 3 respectively. Partial shade (Expt.1) thus exerted a beneficial influence on the performance of the soybean, while deeper shade seriously curtailed its yields. The influence of the other two factors, viz., the vigour of the bamboo clump and P application were of lesser importance.

As regards the base crop of bamboo, neither the vigour of the clump nor P application exerted any significant influence on the height of culms (3.23 m average), basal diameter of culm (16.10 mm at 3 1/4 years and 26.96 mm at 5 3/4 years age), number of primary branches, and weight of culm. However, the number of culms/clump was significantly more in the 'high' vigour clumps (55% more at 5 3/4 years of age). The number of living culms/clump increased progressively over time, from 2.575 at 3 1/4 years age to 24.417 at 5 3/4 years age. The total number of culms/clump behaved similarly and increased from 4.667 to 27.458 culms. At the end of 6 years an average of 13.208 useable culms/clump of 3.18 m length and 14.6 mm mid-culm diameter, or 8,255 culms/ha were harvested. The fresh weight of a culm being 0.930 kg, culm yield by weight is thus 7.677 tonnes/ha at the end of 6 years after planting.

Ambient light intensity, microclimate, soil moisture and intensity of weed infestation differed between the two environments. Within the bamboo stand, the light intensity

was 60-75%, air temperature was cooler, the relative humidity higher, and the soil moisture higher, and weed infestation less, as compared to the open field.

Comparing the economics of cultivation of sole crops of soybean over a period of 6 years, and a crop of bamboo intercropped with soybean over the same period of 6 years, an extra profit of Rs.10,736/ha is realisable over a period of 6 years (i.e., Rs.1,789/ha/year). The cost: benefit ratios over 6 years work out to 3.97 for the bamboo + soybean system as compared to 3.56 for the sole crop soybean.

Summing up, the study demonstrated that the raising of an intercrop of soybean within a stand of Dendrocalamus Strictus bamboo during the first 6 years is technically feasible and economically viable, which practice may therefore be popularised for wider adoption by farmers. Through wider spacing of the bamboo clumps and judicious manipulation of the bamboo canopy, it appears that the period of intercropping could be extended further.

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## Introduction

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## CHAPTER I

### INTRODUCTION

The bamboos are plants of enormous importance to the rural people in several regions of the world, but nowhere is their usefulness as great as in South and Southeast Asia. It is indeed difficult to imagine what people in Asia would do without bamboo (Lessard, 1980). Bamboos are used for house construction, scaffolding, ladders, mats, baskets, fencing, containers, tool handles, pipes, toys, musical instruments, cooking pots, furniture, handicrafts etc. It is also used as fuel, food (i.e., bamboo seeds and tender sprouts) and as fodder for animals. It is an important raw material in the paper making industry. Several authors (Deogun, 1937., Mc Clure, 1966., Subba Rao, 1966) have furnished exhaustive lists of the diverse uses of bamboos. Several species of bamboos are widely cultivated in many countries, mainly in Southeast Asia.

India is endowed with a large number of bamboo species, and perhaps the world's largest reserves of bamboos exist in this country. Of a total of nearly 1000 known species (excluding the herbaceous bambusoid grasses), about 100 have already been recorded in India, and at present the total number of known taxa, both wild and cultivated, in India is about 113. A conservative estimate is that the forest area under bamboos in India (including plantations) is 9.57 million hectares, or about 12.8%

of the total forest area of the country. The estimated annual output of bamboos (air-dried) is 3.23 million tonnes, one-fifth of the country's total wood production, which is utilized for conventional as well as highly sophisticated purposes. More than half of the production (about 2 million tonnes) is consumed by the paper and rayon industries alone. Bamboos, therefore, constitute one of the most important renewable natural resources of India (Varmah and Bahadur, 1980).

In Tamil Nadu, the aggregate gross area of forests in which bamboos and reeds occur has been computed as 6,229 square kilometres (Aslam, 1971). The demand of bamboo for pulpwood purpose in Tamil Nadu, has been estimated variously, as 50,000 tonnes/year by Bhoja Shetty (1973) and as 60,000 tonnes/year by Balakathiresan (1973). Since no statistics are available on the exact area under bamboos in this State, it may be assumed to be about 3 lakh hectares, based on the above demand figure of 50,000 t/year of air-dried bamboo culms, average moisture content of 50% and average yield of 1 t/ha of green culms, and also a felling cycle of 3 years.

In Tamil Nadu, the two common bamboo species of India, viz., Dendrocalamus strictus ('solid' or 'male' bamboo) and Bambusa arundinacea (the 'thorny' or 'hollow' bamboo) dominate, occurring both within the reserved forests under the control of the Government, and outside, on farmlands. Both species are cultivated by farmers as farm crops, particularly in the districts of Thanjavur, South Arcot etc. Such cultivation is rather extensive,

even though no statistics are available as regards area and production. Between the two species, while Bambusa arundinacea is adapted only to moist situations, Dendrocalamus strictus is very hardy and thus widespread in its cultivation.

Farmers take to the cultivation of bamboos, more particularly Dendrocalamus strictus, because of certain needs, demands and advantages. Bamboos grow very fast, yield small timber almost continuously over a fairly long period, require least attention, perform well under rainfed conditions, meet several of the needs of the farmer (fencing, temporary structures, mats, baskets, pipes, containers etc.), and fetch high prices in the local retail market (being in great demand for construction purposes and for the handicraft industry) and thus readily saleable.

In recent times attention has been focussed on encouraging the cultivation of trees outside the reserved forests. This filip has stemmed from several reasons - to counteract deforestation, to ameliorate the climate, to augment wood supply, and to provide a variety of other benefits to society. Such activities have been called by different expressions with different shades of meaning, such as 'social forestry', 'community forestry', 'multi-purpose of forestry', 'all-purpose forestry', 'rural forestry', 'integrated village forestry', 'multiple-product forestry', 'small-scale forestry', 'agroforestry', 'silviculture', 'silvipasture', 'forest farming', 'tree farming', 'tree crops farming', 'multi-tier cropping', 'multi-storeyed cropping', 'three dimensional agriculture', etc. Whatever be

the name, the basic objective of these activities is the growing of trees outside a typical forest environment, chiefly in the agricultural ecosystem (i.e., rural areas), and to a limited extent in urban situations.

Of great importance among these activities is the recent development of the concept of 'agro-forestry'. 'Agro-forestry' has been defined as a sustainable land management system which increases the overall yield of land, combines the production of crops (including tree crops) and forest plants and animals, simultaneously or sequentially, on the same unit of land and applies management practices that are compatible with cultural practices of the people. Essentially 'agro-forestry' is a collective name for land use systems in which woody perennials are deliberately grown on the same piece of land as agricultural crops and/or animals, either in some form of spatial arrangement or in sequence. In agro-forestry systems, the woody component interacts ecologically and economically with the crop and/or animal components. Such interactions will take many different forms, both positive and negative and they need not remain stable over time (Singh, 1983).

The objectives of agro-forestry systems are (i) diversified and/or more sustainable production at a higher level from the available resources under the prevailing ecological, technological and socio-economic conditions; (ii) enhancement of land productivity in marginal lands, (iii) economically superior land use on

fertile soils of small farmers, and (iv) production of the basic needs of the farmers, viz., food, fuel, fodder, building materials etc. The urge for attainment of one or more of these objectives brings woody perennial crops into the picture of conventional farming practices wedded to purely annual or seasonal crops. Agro-forestry systems, therefore, offer the best solution for improving the agricultural economy of a country like ours, where the majority are small farmers.

While many tree species of great economic importance suggest themselves for inclusion in any projected agro-forestry system, bamboos which are perennial woody plants even though they are not trees in the strict botanical sense, are the best choice under Indian conditions. The importance of bamboos in Indian economy, as well as its entrenched position as a traditional farm crop, have already been brought out in detail as to need no reiteration. In addition, bamboos are superior to true tree crops in several ways as pointed out by Ueda (1960) and as modified where necessary, as shown below:-

Comparison of a tree woodlot with a bamboo stand

<u>Feature</u>	<u>Trees</u>	<u>Bamboos</u>
1. Growth	A single individual thickens annually.	Produces several culms annually, each one of which thickens within several months after emergence from ground.

<u>Feature</u>	<u>Trees</u>	<u>Bamboos</u>
2. Volume of annual growth (per ha)	Total increments of the single individual 3 - 30 cu.m/ha.	Total volume of annual new culms are 3-30 cu.m/ha.
3. Propagation	Artificial or natural regeneration	Mainly by asexual propagation
4. Cutting age	Long (over several decades) and only once, terminally.	Short (within a few years) and thereafter at regular intervals over a long span of time.
5. Yearly growth percentage	2 - 5 %	10 - 30%
6. Weight (fresh) of single log	Heavy (over 300 kg).	Light (below 60 kg).
7. Yield	Harvested after accumulation of annual increments.	Productivity is higher if culms are harvested annually by cutting (the amount of yield is equivalent to the annual increment)

The interspaces between tree crops, generally are left vacant, and in the case of bamboos, which are relatively wide spaced, the interspaces between the bamboo clumps represent a substantial land area. One way of utilizing this otherwise lost space, is to raise intercrops in between the bamboo clumps.

However, the species chosen for the intercrop must be relatively short-statured as not to interfere with or being interfered by the bamboo canopy. Annual crops answer this requirement. Further, the annual crop species chosen must be such, that, while it is capable of thriving within the bamboo stand, itself does not affect the growth of the base crop of bamboo.

Whether annual crop species can ever be grown economically under woody perennials, itself is by and large an unsettled question. While it is commonly thought that no herbaceous annual crop can successfully thrive and yield under trees, because of the so-called root-effect and shade-effect, there are also examples for the mixed cropping of trees and annual crops, as traditionally practised by farmers, in several parts of the world, particularly in the drier parts (for example, Seshadri et al., 1977). Regarding bamboos themselves, conflicting opinions have been voiced. While Siva Prasad (1980) stated that intercropping of any dryland vegetable, pulse or coarse grain crop with bamboo is possible upto 3-4 years, Nathan (1980) contested this and stated that nothing, not even the common thorny weed Prosopis juliflora will thrive under the shade of bamboos.

The reason for these apparently conflicting views could possibly be traced to the choice of the crop species and/or varieties that are combined as well as to the methods and levels of their management. It stands to reason that, given the right combination of the tree crop and the annual crop, and the correct

methods of management, intercropping annual crops between tree crops, including bamboos, must be an economically viable proposition. The lacuna exists only in finding out such successful combinations and ideal methods of management suited to both crops. No serious research work has been done on this interesting line of work, offering immense promises for substantially boosting agricultural production of both food and wood, in any part of the world, up till now. The reason for this paucity of information appears to be the dominance of the entrenched notion that trees and annual crops are mutually incompatible, and the insurmountable, though surmountable difficulties in the research methodologies themselves (for instance, the long-drawn out nature of such research, as they are bound to be).

Among the possible contenders for being chosen as a suitable intercrop between bamboo clumps, pulse crops suggest themselves foremost. The reasons for this are four - (i) there are reports that legumes generally tolerate shade better, (ii) there is an urgent need for augmenting pulses production in Tamil Nadu State, (iii) they mature within relatively short periods, and (iv) legumes are known for improving the soil fertility, a need which arises particularly when growing a graminaceous crop like bamboo. Among the pulse crops, soybean appears to be the best because of its high nutrients content - 43.2% protein and 19.5% oil. The oil is useful both for edible and industrial purposes.

Through common observation it is known that individual bamboo clumps in a stand differ in the vigour of their growth. Such differences manifest chiefly in the number of culms present in the clump at any point in time. When even the very question of the possible success or failure of raising annual intercrops within bamboo stands remains unanswered, it would be superfluous to point out the paucity of information on the possible effects of such vigour differences in the bamboo on the growth of any associated annual intercrop.

Another aspect that needs research attention is the influence of added plant nutrients on the intercrops growing between trees. Since, the so-called root-effect is basically a phenomenon of aggressive root competition on the part of the superior competitor (i.e., the trees) for plant nutrients and soil moisture, it may be expected that when plant nutrients are supplied so as to meet the needs of both the crops - viz., the base crop of trees, and the annual intercrop, the annual intercrop must not show any adverse effect being suffered by it, provided soil moisture is adequate. The plant nutrient so applied could be one or more, depending on crop preferences. Since it is fairly well established that legumes in general respond to phosphorus application better than to either potassium or nitrogen, and more particularly nitrogen, it would appear that it is worthwhile to study the ameliorating influence of phosphorus application on soybean in an intercropping situation.

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In any study on intercropping annual crops within tree stands, the study of the light climate becomes imperative, since the so-called shade effect is in essence a reduction of the ambient light by the canopy of the tall growing crop. Similarly, a tree stand invariably develops a microclimate of its own and thus may influence an associated annual intercrop, positively or negatively. Finally, the soil moisture and weed infestation are most likely to be influenced by the shade-effect of the trees. While all these aspects bear directly on any attempt to raise annual crops as intercrops between trees, precious little information is available on them, even which, is lying scattered in studies not specifically aimed towards such intercropping.

Hence, with the objective of investigating the feasibility of raising soybean as an intercrop within a stand of relatively young (4-5 years old) clumps of Dendrocalamus strictus, the present work was undertaken. The detailed objectives of the present investigation are:

1. Study the growth and yield performance of soybean raised as an intercrop within a stand of young (4-5 year old) clumps of Dendrocalamus strictus bamboo, as compared to a sole crop of soybean;
2. Investigating the influence, if any, exerted by differences in the vigour of individual bamboo clumps on the performance of the associated soybean plants;
3. Study the pattern of response of soybean to applied phosphatic fertilizer at different levels, and under

both the environments, viz., 'within the bamboo stand' (i.e., the intercrop), and 'in the open field' (i.e., the sole crop);

4. Study the rate of growth of young clumps of Dendrocalamus strictus over a period of nearly 1 3/4 years, from age 3 1/4 years, and also assess the yield of usable culms at first felling, carried out at the end of the 6<sup>th</sup> year;
5. Study the growth of the clumps and yield of culms as influenced by the vigour of the clump;
6. Study the pattern of response of the bamboo clumps to the phosphatic fertilizer added to the associated intercrop of soybean;
7. Elucidate the pattern of changes in the light intensity and its influence on the performance of soybean, both within and outside the bamboo stand;
8. Study the pattern of changes in the microclimates prevailing within the bamboo stand as well as in the open field and attempt to correlate these with the performance of the soybean crop;
9. Study the pattern of changes in soil moisture over time, under both the environments;
10. Study patterns of weed infestation in the two environments; and
11. Compare the economics of the agro-forestry system of bamboo + soybean with the sole crop of soybean, and based on it, formulate recommendations for adoption by farmers.

## Review of Literature

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## CHAPTER 2

### REVIEW OF LITERATURE

Unlike in conventional studies, very little published information bearing directly on the topic of the present investigation is available. This is understandable since the present work is of a pioneering nature, seldom touched in depth by earlier workers. However, a lot of information on connected aspects is available which have a bearing on the subject of study. The available information is reviewed under the following headings.

1. Bamboo;
2. Intercropping;
3. Microclimate and water use;
4. Light relations in soybean; and
5. Influence of phosphorus on soybean.

## 2.1. BAMBOO

Bamboos are giant woody type of grasses which develop into clumps, by habit. Two components can be distinguished, viz., (i) an underground rhizome system and (ii) an aerial shoot system made up of individual shoots called culms. Culms are transformed terminal extensions of rhizomes and they depend on the rhizomes for their growth, vigour and spacing.

There are 1,250 species of bamboos distributed over 47 genera, in the world (Subba Rao, 1966). Of these, 113 species occur in India and some 40 of these are cultivated. Dendrocalamus strictus Nees, commonly called the 'male bamboo' or 'solid bamboo' is cultivated throughout India in the plains and foot hills (Varmah and Bahadur, 1980). It is one of the two most important species of Tamil Nadu, the other being Bambusa arundinacea (the 'hollow bamboo'). It occurs not only in forests but also in cultivated fields, being treated as a farm crop, particularly in the Thanjavur district of Tamil Nadu where it is extensively cultivated by farmers on raised portions surrounded by rice fields. Andiyappan and Wilson (1963) have furnished an account of bamboo cultivation in Thanjavur district. It is cultivated by farmers, to a lesser extent, in the other districts also. No precise statistics are available.

Since bamboos are comparatively less familiar as farm crops, a brief account of Dendrocalamus strictus is furnished below.

### 2.1.1. A general description of *Dendrocalamus strictus*:

Deogun (1937), Sahi (1943) and others have furnished detailed descriptions of the morphology and biology of this bamboo. It is a medium-sized, densely tufted bamboo generally deciduous, possessing strong, thick-walled or solid culms, varying much in size according to the locality. A clump is composed of several culms which may grow to lengths of 5-12 m and diameter of 25-125 mm with a number of internodes whose length varies from 25 - 35 cm (Deogun, 1937). Below the ground, the culms are interconnected by a network of rhizomes provided with buds and many fibrous roots.

The seeds when husked resemble wheat. When germination takes place the plumule rapidly develops into a thin wiry stem. A tufted form commences to show itself at an early stage. This comes about by the production of an underground rhizome bearing successive pointed buds from which develop branch rhizomes, which curve first downwards and then upwards as aerial shoots, so that, successive shoots besides being larger than the preceding ones, arise from rhizomes deeper in the ground. (Troup, 1921).

The rhizome is woody, arched slightly and upturned with a narrow 'neck' at the proximal end where it is attached to the mother culm and bears a culm at the distal end (Kondas, 1980). The rhizomes have two kinds of buds - numerous, small buds which give rise to roots, and one or two, rather flat 'rhizome buds' or 'culm-buds' ('eyes') which give rise to daughter rhizomes. The rhizomes being comparatively short and thick (pachymorphic)

in this species, give rise to rather closely spaced culms which eventually leads to congestion in the clump. Clump congestion as seen in this species is an important aspect as it makes it difficult to harvest the crop ('working of the clump'). This aspect has been extensively reported upon by Deogun (1937), defined afresh by Chakravarti (1949) and experimentally studied by Kadambi and Rewat (1949) and Gupta (1964). Rao (1975) stated that clumps of this species look very much congested by the fourth year of establishment and a cleaning is essential.

The daughter rhizomes from the mother rhizomes start developing and as successive rhizomes are added to the clump there is a progressive increase in the size of individual rhizomes and a corresponding increase in the size of the subsequent culms till they attain normal size. Thereafter there is no increase in the size of the subsequent culms and it stabilizes. The size of an individual culm is thus proportionate to the rhizome from which it emerges (Kondas, 1980). This is the clump formation stage and it may take, for this species, 12 years to reach a commercially exploitable stage under natural conditions or 6 years in the case of artificial plantations (Deogun, 1937). Rao (1975) estimated this, to be 8 years for plantations, and that, from the fifth year onwards exploitable size culms become available. This species is hence said to be a 'clump-forming' or 'sympodial' type of bamboo.

The rootstock thus consists of a dense mass of short and thick rhizomes provided with clusters of small rootlets. The root system is superficial and does not penetrate more than

0.1 - 0.9 metre below ground level. Owing to the superficial root system, changes in soil moisture have a marked effect on the growth of the culms (Deogun 1937). Rao (1975) reported that it was observed that the rhizomes grow rapidly in the direction of loose soil.

As regards the growth and development of the culm, three phases are recognisable, viz., (1) culm elongation, which, on nearing completion, triggers (2) branch emergence, and finally (3) leaf appearance. The tender culm emerges from the ground as a conical structure, 30-40 cm high (called Komali in Tamil) and completely covered by sheaths, no internode being visible. Initially, the growth is slow. The komali is susceptible to fungal attack with serious consequences on yield of culms. After this, the growth is rapid and culm elongation takes place in spurts, by the elongation of individual internodes (there is no terminal bud in a culm), and after reaching a peak, which is maintained for a few days, the growth rate falls off.

The growth rate in bamboos in general, is remarkable in that, it is the highest among all plants. Maximum daily (24 hours) growth rates for other species of bamboos have reached values as high as 91.3 cm for Bambusa arundinacea in Kew Garden, England (1855) and 88.0 cm for Phyllostachys edulis observed by Shibata, K. at the Koishikiwara Botanic Garden, Tokyo (1898), recently, even values as high as 119 cm for Phyllostachys edulis (1955) and 121 cm for Phyllostachys reticulata (1956) have been reported (Ueda, 1960). The growth rate for Dendrocalamus strictus

though not as high as these, is still remarkable. An average daily growth rate of 9.12 cm (Narasimhiya, 1919) and minimum and maximum values of daily growth rates of 6.3 cm and 27.2 cm (Tomar, 1963), 18.4 cm and 26.9 cm under Coimbatore conditions (Shanmuganathan et al., 1980) have been reported. Ueda (1960), reported that the maximum daily growth for D. strictus, in India is 30 cm.

The main period of growth of culms is generally from 2 or 3 months (Deogun, 1937), Brandis (1899) mentions this to be even less than a month. Kadambi (1949) reported that the rate of growth for bamboos (in general) starts with a minimum, continues to increase till about the end of the 3rd week of emergence, remains at a high level till the end of the 8th week, and slows down gradually, and falls to about half of the original rate by the 10th week and comes to a close by the end of the 12th week.

After culm elongation is complete, it passes into the next phase, viz., production of side branches. Branches develop only after growth in height is complete (Varmah and Bahadur, 1980). During the last phase, leaves appear and the culm becomes fully leafy in about 5-6 months. Then silicification takes place and the culm hardens. During the following rainy season. (i.e., next year) vegetative activity restarts with the commencement of the development of daughter rhizomes (Kondas, 1980). The development of lateral branches takes place during the second

season except when damage to the terminal portion of the culm deflects the growth into branch formation (Deogun, 1937). Kadambi (1949) reported that in case the culms are cut before their side branches have been formed, i.e., before the second growing season is completed, the side branches which emerge are stronger, much thicker and grow more or less erectly upward (apogeotropic) and not horizontally like normal side branches. If the culm is cut at the end of the second growing season after the side branches have been fully formed, thin, long branchlets emerge on the culm on both sides of the insertion in the upper whorl(s) of branch(es) forming more or less a cluster. When a culm more than 2-year old is cut, it does not normally develop any more branches but dries up gradually. The side branches of D. strictus do not develop into pointed thorny structures as in the case of Bambusa arundinacea, and hence is referred to as 'unarmed bamboo' also. D. strictus is deciduous, shedding its leaves during summer, adding profuse quantities of litter to the soil (4.83 t/ha in 8 months, as reported by Seth et al., 1963). An interesting observation about the differential behaviour in foliage development between plantation - raised D. strictus clumps and those growing naturally in the forest has been reported by Rao (1975). It was seen that the branches and foliage borne on new culms in a plantation are heavier as compared to natural clumps. Consequently, peripheral culms bend down and almost touch the ground.

These processes repeat year after year and a clump develops, consisting of a subterranean network of rhizomes running in all directions along with a matting of roots, supporting a variable number of aerially borne culms whose ages, growth and spacings and locations in the clump vary. As already mentioned clump formation is complete in about 6 years, after which culms can be harvested. The clump gradually spreads from the centre outwards by the formation of new rhizomes from which spring new culms. Varmah and Bahadur (1980) observe that most young culms are in the periphery of the clump because of the centrifugal manner of clump expansion. Deogun (1937) reported that in a fully grown clump, new culms generally arise from rhizomes of last or previous year's culms, or, under favourable climatic conditions (rainfall being the most important) they even arise from rhizomes of 3 or 4 year old culms, but rarely from still older culms. It is also possible that a rhizome may branch and produce 2 or more culms in the same season. The new culms thus generally spring from these rhizomes which carry culms in full vigour. Generally culms begin to show signs of deterioration in their 5th year; hence new culms cannot be expected to arise from rhizomes of 5 years or more of age. Varmah and Bahadur (1980) summed up that the age of full maturity of the culm for D. strictus is about 3 years, the life of the culm is about 7-8 years and the felling cycle falls between 2 and 6 years, adding that, while too short a felling cycle brings about the deterioration of the clump, a long felling cycle may result in overcrowding; hence a felling cycle of 3-4 years is generally prescribed.

The culm of D. strictus has a comparatively thicker wall. Deogun (1937) says that the hollowness varies from a pinhole to 25 mm in diameter, and that, completely solid culms also occur.

After a variable number of years, (20-65 years), depending on the locality, flowering occurs, leading to seeding and shedding of the seeds, with the eventual drying up of the culms and ultimate death of the entire clump. Thus, the life cycle is completed.

#### 2.1.2. Adaptation of Dendrocalamus strictus

This is the hardiest of all Indian bamboos (Mc Clure, 1966). In India it occurs up to an altitude of 3,700 metres in the Himalayas (Varmah and Bahadur, 1980) within a temperature range of  $-5.6^{\circ}\text{C}$  to  $46.7^{\circ}\text{C}$  and a rainfall range of 760 mm to 5080 mm per annum, thriving on practically all types of soils provided there is adequate drainage (Deogun, 1937). Thus, it is found throughout India in deciduous forests. Three noteworthy features of this species are (1) its high degree of drought tolerance as compared to the other bamboos and many other tree species, (2) its sensitivity to high atmospheric humidity, and (3) its intolerance of water logging.

Its ability to withstand drought remarkably has been well documented (Deogun, 1937; Mc Clure, 1966, Rao, 1975). This makes it a boon to farmers and foresters. Atmospheric humidity is said to be one of the determining factors in the

distribution of this species. Thus, in Orissa, it flourishes well in drier tracts far away from the influence of the sea (Nicholson, 1922). It withdraws from areas where the more moisture loving species of bamboo, viz., Bambusa arundinacea grows.

It is intolerant to bad drainage (and thus of clayey soils) (Kadambi, 1949) and does not grow in waterlogged or heavy soils. Hence the reason of its occurrence along alopes of hills where drainage is better. Its presence in the Thanjavur delta is explained by the fact that it is always grown in raised bits of land even though such pieces of land may be surrounded by swamp rice crop.

The characteristics of the soils on which D. strictus occurs, under forest situations, have been reported by Mooney (1933) and extensively so by Yadav (1963). He concluded the soils are low in total as well as available phosphorous. Ueda (1960) based on his investigations on soils of Bhavanisagar (Tamil Nadu) growing the other important species of the State, viz. Bambusa arundinacea, concluded similarly.

D. strictus is a light demending species and does not tolerate heavy overhead shade as borne out by field studies (Chaturvedi, 1928; Kadambi, 1949).

### 2.1.3. New culm production in D. strictus

#### A. Rate of Production:

A study of the rate of new culm production (i.e., the

number of new culms produced per clump per growing season) is a very important aspect in bamboo investigations, because it is a measure of rate of addition of culms to the clump and thus of the ultimate yield of culms per clump. The production of new culms varies from locality to locality, between clumps in the same locality and from year to year in the same locality.

Deogun (1937) and Madambi (1949) have listed several factors affecting the rate of new culm production (i.e., the number of new culms produced per clump per growing season), viz., (1) soil, (2) climate, (3) size of a clump, (4) method of working (5) method of establishing the clumps, (6) march of time, (7) overhead cover, (8) fire, and (9) grazing. Under farm situations only the first six factors, perhaps, are significant as the rest are more or less well under control. Even among these six factors, the influences of soil and climate are more or less fixed for any particular locality. Hence the remaining four factors alone are reviewed below.

(1) Clump size:

By 'size of clump' is meant the total number of old (more than 1-season i.e., 1-year of age) culms present in the clump. The influence of the existing number of culms in a clump (i.e. clump size) on the rate of production of new culms has been investigated by several workers.

Deogun (1937) based on a study of 2,650 clumps of D.strictus spread over five States (Orissa, Madhya Pradesh, Punjab, Tamil

Nadu and Uttar Pradesh) reported that the average number of new culms produced per clump per year ranged from 1.2 for a clump size of 10 existing culms (Uttar Pradesh) to as much as 13.0 for clump size of 70 existing culms (Madhya Pradesh). Thus, in general there was a progressive increase in the absolute number of new culms produced as the clump size increased. However, he found that the variations in new culm production between clumps of the same size, to be considerable. For example, a scrutiny of Deogun's data reveal that, the variations within the same clump size, range from 176% (for clump size of 10 culms) to 350% (for clump size of 50 culms). Deogun's data for Tamil Nadu show that a clump size of 10 existing culms produces 1.7 new culms, that of 20 culms produces 2.0 new culms, etc., upto 50 culms producing 3.0 new culms. Deogun concluded that although bigger clumps (i.e. larger clump sizes) produce more number of new culms, the ratio between the new and the old culms in bigger clumps falls off with increasing size of clump, so that two small clumps produce more new culms than one big clump of a size equal to that of the two small clumps combined. Based on these considerations, he concluded that clumps of size 20-40 culms should be the ideal from the management point of view.

Kadambi (1949) termed this relationship between the existing old culms and new culms produced as 'numerical relationship of culms in a clump'. Based on investigations in Karnataka, he reported that this ranged from 1 to 12.5 new

culms per clump of sizes 10 to 75 old culms, respectively, depending on rainfall and felling intensity (i.e., harvesting). His data showed a curvilinear trend. He concluded that, with increasing size of the clump, upto a certain upper limit, new culm production also increases.

Dutta and Tomar (1964) studied 88 clumps in Madhya Pradesh and found a linear relationship between the two variables. They added that the data secured from another study (All India Co-operative Investigations on the Management of Bamboos) for D. strictus over a period of 12 years, in Madhya Pradesh, confirmed this. The percentage of new culm production decreased sharply from an initially high level for smaller clumps and then flattened for clumps containing over 30 old culms. They also observed that the percentage of new culm production was higher for small clumps as compared to the larger ones, which corroborates the earlier findings of Deogun (1937). They ascribed this to the fact that a small clump consists mostly of young culms (1-2 years age) while in a larger clump there is comparatively a higher proportion of more than 2-year old culms, which are not probably very effective in so far as new culm production is concerned. It is known that the majority of new culms are contributed mainly by rhizomes developing from 1- or 2- year old culms. They also adduced another reason for the higher new culm production by smaller clumps, by stating it may be due to the higher clump - periphery area as well as more utilizable area per culm.

Recently Shamsuganathan et al (1980) from Coimbatore working on 10 clumps of 16-years are concluded that there is no significant influence of the total number of old culms in a clump over the production of new culms.

(ii) Method of management:

Perhaps the only management practised in forests for bamboos is the regulation of the intensity of exploitation (i.e., harvesting). These go by the name of 'felling rules' which are 'prescribed' in the Working Plans prepared for the different forest divisions. The two principal components of felling rules are (1) the felling cycle (i.e., the number of years that elapse between two successive fellings) and (2) the felling intensity, usually expressed as a percentage (i.e., the number of culms older than 1-year age, that are to be felled in a clump, expressed as a percentage of the total number of old culms existing in the clump). Besides these, a few other restrictions may also be imposed, all of which constitute the felling rules for a particular locality. The actual prescriptions vary from locality to locality as seen from a perusal of the numerous Forest Working Plans, and the several published scientific papers (this being a fertile area of contribution). Varmah and Bahadur (1980) state that for D. strictus bamboo, felling cycle prescriptions have ranged from 2-6 years and recommend a felling cycle of 3-4 years. The felling cycle implies the removal of accumulated growth over a period of years corresponding to the cycle (Seth, 1978). In no case,

a new culm (i.e., equal to or less than 1-year of age) is allowed to be removed. Since felling rules have not been studied in the present investigation, they are not reviewed here excepting in so far as their effect on new culm production is concerned.

Venkataramiyer (1917) based on 8 years of field work in Tamil Nadu reported that the average number of new culms produced per year ranged from 4-5 per clump for a 50% felling carried out uniformly distributed throughout the clump, through 2-4 per clump under a 50% felling carried out on one side of the clump, to 1.5 - 2 per clump in 100% felling of all old culms. Deogun (1937) also reported intensive fellings to adversely affect the number of new culms produced, in Orissa. Kadambi (1949) from Karnataka reported similarly. Raghavan (1964) from Andhra Pradesh, who compared the new culm productivities of clumps growing in nature, in the forest and left untreated, with clumps treated (i.e., regularly felled on a 4-year cycle), however, concluded that the treated crop produced about double the number of new culms as compared to the untreated clumps. Hence, it is seen that leaving a clump to nature without any culm extraction does not imply that it will produce more new culms. Varmah and Bahadur (1980) concluded that while too short a felling cycle will lead to the deterioration of the clump, too long a felling cycle will lead to overcrowding. Dutta and Tomar (1964) remarked that with a longer felling cycle the clump will increase in size and consequently will produce a low percentage of new culms.

Clump management involves not only harvesting of culms but also cleaning it. Kadambi (1949) stated that mere cleaning (i.e., cutting away of all dry culms) of clumps results in an increased production of culms in the years following this treatment, the effect lasting for 2 or 3 years.

(iii) Method of establishing the clumps:

In an early experiment conducted at the Forest Research Institute, Dehra Dun (Uttar Pradesh) started in 1927 three methods of establishing D. strictus, viz. (1) planting of 'wildlings' (i.e., natural seedlings obtained from the forest), (2) direct sowing of seeds, and (3) planting of rhizomes, were compared. Five years after establishment, the average new culm production per clump per year was 3.7 for sowings, 4.4 for wild seedling transplants and 6.3 for rhizome plantings, while they were 5.0, 7.8 and 7.5, respectively, after six years (Deogun, 1937) and the averages after that over a further period of 12 years (1934 - 1946) were 4.1 for sowings, 6.6 for wild seedling transplants, and 5.1 for rhizome plantings (Kadambi and Rawat, 1946). It is evident that the initial superiority of rhizome plantings in so far as new culm production vanished as time passed and was overtaken by wildling transplants by the sixth year and thereafter the seedling transplants maintained their superiority. The results for the direct seedling treatment continued to be poor throughout. We may therefore conclude that transplanting of seedlings is the best from the point of new culm production.

(vi) Passage of time:

In the above mentioned experiment it was seen that the average new culm production per clump per year was 2.9 in 1934, 3.4 in 1937, 6.1 in 1940, 5.5 in 1943 and 3.9 in 1946. It is clear that there is a wide fluctuation in the above data. Kadambi and Rawat (1949) explained this variation by stating that the majority of the clumps were immature in the year 1934, the seed crop being 7-year old and the wild seedling transplants were about 10-years of age, while on the other hand, the crop produced by the rhizome plantings was perhaps 19-20 years of age. Probably, the average number of new culms produced per clump increases initially and after reaching a peak flattens, maintaining it for several years, and then gradually falls off as the clump advances in age and approaches flowering.

2.1.3. Time of production of new culms:

In bamboos in general, the new culms are not produced throughout the year but rather only during certain seasons, which varies according to the species, localities etc. A knowledge of the time of the year in which new culms are produced is essential for scheduling cultural operations and application of fertilizers, in such a way as not to retard new culm production or damage emerging new culms and to augment their production.

It is common knowledge that the new culms of bamboos emerge in India during the monsoon rain months. For D. strictus,

Gamble (1896) records that while in northern India new culms emerge in June or July when the South West monsoon begins, they appear in South India in September or October with the first burst of the North East monsoon, as seen in the Nilgiris. According to Deogun (1937) new culms begin to appear after the commencement of the monsoon and continue coming up, generally upto the end of August., late emerging culms either do not complete their growth, continuing it in the next season and if very late remain as scaly cones without any further development.

In Karnataka, the time of new culm emergence is from the middle of July to end of August, in the wet zone (Malnad) and from July to October in the dry plains, where it is irregular (Kadambi, 1949). Dutta and Tomar (1964) from Madhya Pradesh reported that the maximum number of new culms (72%) are produced in the second fortnight of August. Season of production of new culms is more irregular in young clumps and in nursery beds where it may be even from May to October (Deogun, 1937).

#### 2.1.4. Total number of culms per clump in *Dendrocalamus strictus*

The total number of culms in a bamboo clump is a measure of its productivity. Evidently it gradually increases as the clump advances in age and after reaching a particular value must remain more or less constant for a given clump, in a state of dynamic equilibrium, the rates of production of new culms and death of old culms being balanced. The total number

includes new culms also (Deogun, 1937, Rao, 1975).

As already mentioned clump formation in D. strictus is completed in about 6-8 years, after which it can be considered as an adult clump. The total number of culms in an adult clump varies within wide limits. Clumps with as many as even 200 culms have been observed in unworked forests of Angul (Orissa) but the general average is from 10-40 culms/clump, depending on the age of the clump, the past working and the locality (Deogun, 1937).

The range of variation encountered is illustrated by the average figures reported by different workers, as shown below:- Patil (1980) 6.20-9.88 (Dharwad, Karnataka; controlled experiment - less than 2-year old clumps); Kaul (1963) 2.0-9.2 (Chambal ravines, Madhya Pradesh - eroded soil; young clumps of upto 4 years age); Deogun (1937) 1.2 - 13.6 (Dehra Dun, U.P. - controlled experiment, 5-6 year old clumps); Shanmuganathan et al. (1980) 7-61 (Coimbatore, Tamil Nadu - observations based on 10 clumps of 16 years age); Narasimhiya (1919) 14.5 - 35.33 (Karnataka; the total is classified as 1-year old, 2-year old, 3 and more number of year old - and dying culms; age of clump not known; presumed to be a few decades old); Nicholson (1921) 27 (Angul, Orissa - age not known; presumed to be a few decades old); Deogun (1937) 23.2 - 30.2 (Angul, Orissa - pure bamboo unworked forest; age of clumps not known, but presumed to be a few decades); Ueda (1960) 10-30 (India - natural forests; age of clump not known; presumed to be a few decades)

and Verma and Bahadur (1980) (Clump ages not known, but presumed to refer to fully grown adult clumps of a few decades, growing in forests) 9.3 (U.P.), 27.0 (M.P.), 27.02 (Maharashtra).

From the foregoing data it is seen that the total number of culms per clump, for clumps of age upto 6 years, ranged from as low an average figure of 1.2 to an average figure of 13.6. For still older clumps, it ranges between 7-61, with values around 20-30 being common; this confirms Deogun's estimate of 10-40 mentioned earlier.

In a few studies culms in a clump have been classified as 1-year old and more than 1-year old culms. The data of Narasimhiya (1919), on further scrutiny indicate that in a clump of D. strictus, 11.8% of the total number of culms are 1-year old culms, 16.0% are 2-year old culms, 63.6% are 3- or more years old living culms and 8.6% are dying culms. A similar scrutiny of the data of Nicholson (1921) for Angul Division (Orissa) indicates that the proportions are 5.8% of 1-year old culms, 8.7% of 2-year old culms and 48.1% of more than 2-year old culms and 37.4% of dead and dry culms. Scrutiny of data of Deogun (1937) for Angul, Orissa, which pertain to the data for the control plot in a felling intensity experiment, shows that the ratios were 6.6 - 8.6% of 1-year old culms and 91.4 - 93.4% of over 1-year old culms, at the start of the experiment; however, in these clumps, all dead and dry culms were felled and excluded from the data.

It may be summed up from the above culm analysis that in a clump, about 5-10% of the total culms are very young culms (1-year old), about 10-12% are 2-year old culms and the rest are still older culms.

#### 2.1.5. Culm parameters of *Dendrocalamus strictus*

The size of a culm decides its saleability and price. Therefore, the average size of culms per clump is a useful index. Three parameters, viz., (1) height (i.e. length) of the culm (2) diameter of the culm measured either near the base or breast height (DBH) or eye-height, and (3) weight of the culm, may be used to characterize the size of the culm. Besides, the average number of internodes or length of internodes may also be considered. The following review of culm size pertains to D. strictus.

2.1.5. A. Height of culm: Commercially, longer culms fetch a higher price. Hence a study of culm length becomes important. McClure (1966) states that the culm grows upto a height of 18.29 m. Deogun (1937) stated that the maximum height attained by the mature culm varies a good deal from locality to locality and figures from various localities showed a variation from 4.57 - 18.29 m, (in India) while Dutta and Tomar (1964) reported the maximum height to vary between 13-15 m in moist localities and from 6-7.5 m in dry and poorer localities, the average height being 9 m (in Madhya Pradesh), and Aslam (1971) stated that average height of a culm varied between 6 - 16 m (in Tamil Nadu). Wint (1978) stated that in Burma, culms of

D. strictus reach a length of 6.1 - 15.2 m and in drier localities they are often much smaller. All these figures are based chiefly on general observations and obviously pertain to mature culms in adult clumps. Data from actual measurements in studies are also available. Deogun (1937) reporting on the experiment on clumps raised by three different methods in 1927, furnished average heights of culms, after 5 years growth, as 4.02 m for direct sowing of seeds, 4.36m for transplanted seedlings (derived from forest) and 5.09 m for clumps developed by planting rhizomes. Height growths after 6 years were 4.91 m for sowing, 5.61 m for seedling transplants and 6.10 m for clumps from rhizome planting. It is seen that the average height growths in young clumps differ according to the method of raising the clump in one and the same locality.

Similarly, in the case of young clumps, the average heights of culms progressively increases year to year. Thus, Kaul (1963) reported that the average height of culms in Chambal ravines (India) was 1.37 m in the 1st season after planting the seedling, 8.40 m in the 2nd season, 13.99 m in the 3rd season and 15.44 m in the 4th season. Patil (1980) studying young clumps less than 2 year old, reported that the average height increases as the spacing between the clumps widens.

Shanmuganathan et al. (1980) based on a study of 29 culms from 10 clumps of 16-year age at Coimbatore, reported that the lowest height and maximum height recorded were 5.30 and 7.35 m respectively. Further, the height differences between different

culms within the same clump ranged from 0.10 to 1.66 m. This wide variation, though not explained by the workers, is understandable when we take into account the twin facts of a clump being composed of culms of different ages, and the remarkable growth rates of bamboo culms.

Summing up, it is seen that the maximum height of a mature culm is about 18 m while the average height of culm in a very young clump is about 4 or 5 m, and that the locality (rainfall, site quality etc.), method of raising (atleast in the early stages of clump development) and the spacing between the clumps influence the height of the culms.

#### 2.1.5. B. Diameter of culm:

Diameter of a culm is commercially important as thin culms are not saleable. Mc Clure (1966) states that the diameter of a culm reaches upto 127 mm (i.e., the maximum). In Thailand it is reported to vary between 30-80 mm (Chaiyapechara, 1976), while in Burma between 51-76 mm (Wint, 1978).

In India, the maximum diameter (calculated from data expressed as girth) varies between 36.3 - 121.3 mm while the average diameter (calculated from girth) range between 28.3 - 52.6 mm, as measured at the 3rd internode from the butt end of a cut culm (Deogun, 1937). Ueda (1960) reported that in the natural groves of India, the culm diameter for D. strictus, as measured at eye height ranged between 24 mm - 59 mm with the

average being 39 mm, while Dutta and Tomar (1964) stated that the maximum diameter ranged from 60 - 75 mm in moist and favourable localities and between 38 - 50 cm in dry and poorer areas, the average diameter being 50 mm, as measured at breast height (i.e., DBH, viz. at 1.37 m from ground).

All the above figures obviously refer to mature culms in adult clumps. As regards clumps of known age, Shanmuganathan et al. (1980) studying all the culms in 10 clumps of 16-year age, at Coimbatore, reported the mean diameter (the point along the culm at which measured, not being stated, diameter calculated from data expressed as girth) ranged between 23.2 - 31.8 mm and that the differences were significant.

Data for still younger clumps are also available. Deogun (1937) reporting the results an experiment started in 1927 at Dehra Dun to compare three methods of establishing clumps, stated that the average diameter of culm at 1.37 m height from ground, were 16.26 mm for sowings, 19.30 mm for seedling transplants, and 22.86 mm for rhizome plantings, 5 years after establishment and 21.59 mm, 23.62 mm and 26.42 mm for the three, 6 years after establishment. Kadambi and Rawat (1949) reporting on the same experiment, stated that the mean diameter of a new culm in 1937 (i.e., 10 years after establishment of clumps) was 18.03 mm for sowings, 21.34 mm for seedling transplants and 20.57 mm for clumps raised from rhizomes, which by 1946

(19 years after establishment) had changed for new culms, to 30.23 mm for sowings, 31.50 mm and 35.56 mm for seedlings and rhizome plantings respectively. These data indicate that there is no substantial difference between different methods of raising the clump, even though there is a progressive increase with passage of time, as regards mean culm diameter per clump, specially that of new culms. However, the data for the period 1934 to 1946, when only the years are compared, showed an initial increase in culm diameter, from 20.06 mm (in 1934) to 34.54 mm (in 1940) after which it fell and reached 32.26 mm (1946)

Spacing between the clumps appears to influence positively culm diameter as reported by Patil (1980) and Sheikh (1983). But weed control treatments do not influence the culm diameter (Patil, 1980). The intensity and method of felling culms significantly affects the mean diameter of new culms (Kadambi and Rawat, 1949).

It may be concluded that the maximum diameter of a mature culm of an adult clump for D. strictus is about 125 mm, the average diameter being about 35-65 mm for adult clumps and about 20 mm for clumps of around 5 years age. It is also seen that while, the methods of raising the clump and weed control do not influence the culm diameter, moisture of a locality and spacing between clumps exert a positive influence and felling intensity and method exert a significant influence, the result depending upon the particular treatment.

### 2.1.5. C. Weight of an individual culm of *D. strictus*:

Obviously this is a factor affecting final yield and thus the monetary returns. This has been reported in two ways by different workers - (1) as weight of a single culm, in absolute units, (2) as the number of culms that go to a unit weight. Culm length and weight relationships for different diameters, have also been worked out as culm length is commercially important.

Narasimhiya (1919) from Karnataka reported that 300 culms go to a (long ton) which works out to 3.39 kg per culm while Eagles (cited by Deogun, 1937) reported 250 culms per ton (=4.07 kg per culm). Gamaston F.C. (cited by Deogun, 1937) who determined the weights of 4,500 culms, concluded that freshly cut culms weigh 6.85 kg and air dry culms 4.18 kg, adding that the corresponding number of culms per (long) ton are 141 and 244. Deogun (1937) citing a study carried out in the then Hyderabad State, stated that 170 numbers of air dry culms go to a (long) ton, which works out to 5.98 kg and 3.76 kg respectively. Kadambi (1949) considered it would probably be correct to assume that 300 culms go to a (long) ton in the dry zone and 250 in the wet zone, which works out to 3.39 kg and 4.07 kg per culm in the respective zones. Ueda (1960) based on a study of natural bamboo groves in India, concluded that the air dry weight of a culm is 3.5 kg. Dutta and Tomar (1964) stated that the average weight of an air dry culm in Madhya Pradesh was 3.18 kg in one forest division (Umaria) while it was 7.08 kg in another (Bori). Recently, Rao (1975) from Andhra Pradesh based on experience with artificially raised plantations, reported that plantation-grown *D. strictus*, at 5 or more years of age, record 2-2.5 kg weight

per culm, while culms from natural forests weigh 3-4 kg. Varma and Bahadur (1980) reported that, in U.P., 400 green culms (2.50 kg per culm) or 700 dry culms (1.43 kg per culm), in Maharashtra, 303 green culms (3.30 kg per culm) or 412 dry culms (2.43 kg per culms) and in M.P., 310 green culms (3.22 kg per culm) go to a tonne.

The moisture content of freshly harvested culms is around 60% and it takes about 2-4 months for them to become air dry; the moisture content of air-dry culms is around 4.6% (Dutta and Tomar, 1964).

Seth (1978) has furnished tables relating running lengths with weight and vice versa, for different culm diameter classes, for green and dry bamboos. The range is from 0.595 kg per running meter for a diameter of 38 mm to 1.092 kg per running meter for a diameter of 57 mm. The ratio dry weight: green weight varies from 0.62 for 57 mm diameter to 0.65 for 38 mm diameter.

Summing up, it may be stated that the fresh weight of a bamboo (D. strictus) culm of average size at exploitable age is about 3.0 to 3.5 kg and that it loses approximately about 40% of this weight on being air dried.

#### 2.1.5. D. Number of internodes per culm and internodal lengths in Dendrocalamus strictus.

The length of the internode also is a parameter of some commercial importance since long internodes conduce for a

comparatively smoother culm and advantages in the manufacture of products from it. Internodal length is evidently dependent on the number of internodes for a given length of a culm.

Sahi (1943) reported that in D. strictus, the rhizome bud has more than 35 internodes, perhaps many more since it is difficult to count the exact number of internodes near the terminal portion where they are compressed. Shanmuganathan et al. (1980) though studied culm parameters only upto the 32nd internode, their data based on 28 culms indicate that the number of internodes per culm ranged from 28 for a culm of 5.95 m length, to 45 for a culm of 7.35 m length. So, it may be presumed that in D. strictus about 35 - 40 internodes will generally be patently visible.

Dutta and Tomar (1964) reported that length of an internode may vary from 12.7 - 50.8 cm (5" - 20") but the average length may be taken as 30.5 cm (12"). The length of the first few basal internodes and the last few (i.e., terminal) internodes is usually less than the internodes in the middle of the culm. The data of Shanmuganathan et al. (1980) based on only 4 culms from 2 clumps of D. strictus of 16 years age, and which were recorded only upto the 32nd internode, on further calculation, show that the 1st internode (basal) has a mean length of 10.6 cm, the mid-culm internodes (10th - 14th), 26.6 cm, and the internodes near the tip (30th, 32nd internodes) a mean length of 11.3 cm. Average internodal lengths, based on the data for 28 culms were 17.0 cm for the culm of 5.95 m (28 inter nodes) and 16.3 cm for the culm of 7.35 m (45 internodes)

It may therefore be concluded that in general, 15 - 20 cm could be taken as the length of an internode.

2.1.6. Spacing between clumps of *Dendrocalamus strictus*

The number of clumps per unit area has a direct bearing on final culm yields. Enumerations of stocking density (i.e., number of clumps occurring in a unit area) have been carried out in the past by the Forest Departments in different States, to assess productivities and decide on management strategies.

In natural stands, the number of clumps per unit area of land, varies a good deal, depending on the age of clumps, the past working, the locality and the size of the clumps (Deogun, 1937) while according to Dutta and Tomar (1964) the density varies widely even within short distances owing to variations in soil, drainage, incidence of grazing, intensity of exploitation and composition of overwood. Stocking density as low as 39 clumps/ha and a maximum of 716 clumps/ha, based on systematic line plot enumeration and other surveys from Madhya Pradesh (Dutta and Tomar, 1964) which work to average clump spacings of 16 x 16 m to 3.7 x 3.7 m have been reported. Ueda (1960) based on a study of natural groves of *D. strictus* in India, however, reported stocking densities of, a minimum of 150/ha to a maximum of 400/ha with an average of 280 clumps/ha, which on further calculation work out to average spacings of 8.2 x 8.2 m, 5.0 x 5.0 m and 6.0 x 6.0 m respectively, between clumps. Varmah and Bahadur (1980) reported stocking

densities of 60.9 clumps/ha in Maharashtra (average spacing of 12.8 x 12.8 m), 61.1 clump/ha (12.8 x 12.8 m spacing) in Uttar Pradesh, and 121.1 clumps/ha (9.1 x 9.1 m spacing) in Madhya Pradesh. Thus, it is seen that in nature, the average spacing varies usually from about 5 m to about 13 m, either way, between clumps, though extremes of very close (3.7 m either way) and very wide (16 m either way) spacings may be met with.

The question arises, which level of stocking could be considered as the optimum? Deogun (1937) concludes a stocking density of 148 - 222 clumps/ha (which work out to average spacings of 8.2 x 8.2 m to 6.7 x 6.7 m between the clumps) of an average quality and size could be considered a well-stocked bamboo forest. Interestingly, the data of Dutta and Tomar (1964) show that in Madhya Pradesh, while with a low stocking density of 200 clumps/ha in Balaghat Division, the mean number of culms/clump was 26, with a higher stocking density of 296 clumps/ha in Bilaspur Division, the mean number of culms/clump was 53, in good quality bamboo area. It appears that wider spacing between clumps per se does not guarantee more culms per clump, and obviously other factors like locality conditions etc. operate in deciding culm productivity.

As regards artificially raised plantations, the spacings ('espacement') vary from State to State according to the working plan prescriptions. Deogun (1937) states that 3 x 3 m or 4.6 x 4.6 m should be adopted. However, in most of the

States, the spacing adopted for plantation work is usually 5 or 6 m between the clumps, either way as in Andhra Pradesh (Rao, 1975). In Tamil Nadu, a spacing of 6.7 x 6.7 m (22' x 22') has also been followed (Venkatakrishnan, 1972) though, now the usual spacing is 6 x 6 m. In Maharashtra the recommended spacing for D. strictus, when raised as a shelterwood plantation is 3.66 x 3.66 m (12' x 12'), (Chaudhari, 1966). The author of the present investigation has observed the spacing to be as close as 3 m either way, in farmers' fields in Thanjavur district.

In conclusion it may be said that while in nature the spacing between clumps is comparatively large, it could be successfully reduced as borne out by the success of plantation work and as seen in farmers' fields.

#### 2.1.7. Yield of culms in Dendrocalamus strictus:

The economic product of all species of bamboos is essentially the valuable culms they produce which are put to a variety of uses. Culms are marketed both by numbers as well as by weight (to bulk consumers, like the paper industry). Hence, the yield has been expressed both in terms of the number of marketable culms produced per unit of land area per unit of time (for e.g., number of culms/ha) as well as in terms of weight per unit area. (for e.g., tonnes/ha) by different workers. Interconversion between the two expressions is possible using average weights of single culms, already detailed in an

earlier section. However, these could only be approximations as specifications for marketable culms vary in different localities.

Investigators have used yet another method of expressing the yield, viz. the number of exploitable culms produced per clump per year. In this case it is difficult, if not impossible, to compute per unit area yield, unless the spacing between clumps or stocking density is known. In the absence of information on this, approximations using assumed stocking densities could be misleading since stocking densities vary widely, even within the same locality as was seen earlier. Bearing this in mind, reported yields for D. strictus are reviewed below.

Deogun (1937) reported that the average annual production (i.e., the total number of culms harvested in a given felling cycle divided by the number of years for that cycle) of green culms was 650/ha in Orissa and 556/ha in the then Hyderabad State. Using the culm weight data furnished by Deogun for these localities, viz., 6.85 kg/green culm (Osmaston, F.C.'s data for Angul in Orissa) the yield by weight, works out to 4.45 tonnes/ha, and for Hyderabad, at 5.98 kg/green culm, works out to an yield level of 3.32 tonnes/ha.

On a weight basis, yields from natural stands have been reported. Seth (1978) observed that natural bamboo (all Indian species, but predominantly D. strictus, presumably) forests invariably give low yields per unit area. For example in Madhya Pradesh, it has been estimated that about 80% of the

bamboo forests would give 0.62 t /ha/year, another 11% of the area 1.25 t/ha/year and the remaining 9% of the area 2.5 to 5.0 t/ha/year. The estimate of Varmah and Behadur (1980) for natural stands of D. strictus was as low as 0.173 t/ha/year in Uttar Pradesh, 0.618 t/ha/year in the dry and 1.235 t/ha/year in the moist areas of Madhya Pradesh, 0.568 t/ha/year in N.Kanara and 1.952 t/ha/year in Maharashtra. The estimate of Watanabe (1972) for natural groves of D. strictus in India, however, appears to be on the high side, it being 2.8 -3.5 tonnes/ha/year.

In contrast, the yields reported for artificially raised plantations of D. strictus are higher. Thus, Chaudhari (1966) observes that while normally D. strictus yields 0.754 to 1.256 t/ha/year, a well-raised plantation is capable of giving an average yield of 3.705 t/ha/year of utilizable culms, of course depending on the clump spacing adopted and site quality. For the same plantations, viz., the plantations of the West Coast Paper Mills Ltd., Dandeli (Maharashtra), Seth and Kharbanda (1972) reported that annual yields of 3 t/ha were being obtained, thus more or less providing physical evidence for the prediction of Chaudhari (1966) made six years before. Rao (1975) based on the culm production performance of plantations raised in Andhra Pradesh during the early stages, forecasted an optimistic yield of 4 t/ha for the 1st cut, 6 t/ha for the 2nd cut and 8 t/ha for the 3rd and subsequent cuts for D. strictus. Elaborating on this he even predicted that a total yield of 74 t/ha could be secured from a properly managed plantation of D. strictus over a life cycle of 32 years, which works out to a mean annual yield of about 2.3 tonnes.

Since the expression of yield in terms of number of exploitable culms produced per year per clump is not a very useful measure unless the spacing is known, only a very brief review of such estimates is furnished below:

Average number of culms harvested per clump - 1.0 - 1.5 culms, annual yield (Kadambi, 1949) and 1.25 and 4.25 culms, annual yield, under two felling intensities (Deogun, 1937) for the same locality (Vellore Division, Tamil Nadu), 9.16 culms, calculated value (Venkatakrishnan, 1972; Salem Division, Tamil Nadu); and 9.7 - 25.4 in a felling experiment (Kadambi and Rawat, 1949; Karnataka).

Siva Prasad (1980) stated that (based on experience with plantations in Andhra Pradesh), in the 7th year 20 culms per clump will be ready for extraction which will give rise to 2,800 bamboos/acre (140 clumps per acre; spacing 5 x 6 m) out of which only 2000 culms are exploitable (which works out to 14 culms/clump) to maintain its life cycle. This on further calculation works out to an yield of about 15 t/ha at the first felling (in the 7th year) if we assume an average weight of 3 kg/culm.

In sum, it may be said that for D. strictus bamboo, while the annual yield of culms is very low, of the order of about 0.5 t/ha, in general, under natural conditions, plantation yields are about 3.0 t/ha/year which indicates the scope for yield improvement through better management.

#### 2.1.8. Fertilizer experiments on bamboos:

While bamboos have received substantial scientific attention encompassing diverse disciplines and many fields under each discipline, obviously because of their economic importance, regrettably very little attention has been paid to the vital area of investigating their response to manuring, particularly with chemical fertilizers. This is a very serious lacuna considering two aspects - (1) it is common knowledge that almost all green plants respond favourably to the supply of plant nutrients and fertilization is a pre-requisite for boosting and maintaining yield levels, and (2) bamboos as a group have the maximum highest height growth rates in the entire plant kingdom, and perhaps also have high rates of biomass production. It is surprising that even in Japan, where bamboos occupy a privileged position and despite a lot of serious scientific research on bamboos, the proportion of attention paid to fertilizer response studies has been meagre. Hence, precious little published information is available on the subject. The available literature is reviewed below, which is not exclusively confined to Dendrocalamus strictus alone as was the case in the preceding sections.

#### 2.1.8. A. Nutrient Uptake:

Ueda (1960) stated that the bamboo consumes a lot of inorganic nutrients in order to grow and propagate. Seth et al. (1963) from a litter study on D. strictus bamboo carried out at

Dehra Dun in India estimated the quantities of plant nutrient accumulation in the aerial portions as 680 kg/ha of N, 597 kg of P and 1121 kg/ha of K. Toky and Ramakrishnan (1963) who studied secondary vegetational succession in fallows (after slash and burn agriculture) in northeastern India, reported that bamboo (species not known) was found to have a high K concentration in the aerial biomass, which lends support to the findings of Seth et al. (1963). Ueda (1960) from a field experiment on the species Phyllostachys reticulata in Japan, reported that the average percentage contents of nutrients in the different parts of the bamboo clump on an air-dry basis, were (1) leaves - N = 2.3%, P<sub>2</sub>O<sub>5</sub> = 0.3%, K<sub>2</sub>O = 0.5% and SiO<sub>2</sub> = 5.0%, (2) culms and branches - N = 0.3%, P<sub>2</sub>O<sub>5</sub> = 0.1%, K<sub>2</sub>O = 0.4% and SiO<sub>2</sub> = 0.4% and (3) Rhizomes - N = 0.7%, P<sub>2</sub>O<sub>5</sub> = 0.2%, K<sub>2</sub>O = 0.5% and SiO<sub>2</sub> = 0.5%. Based on this data, he computed that 90 kg N, 50 kg P<sub>2</sub>O<sub>5</sub> and 60 kg K<sub>2</sub>O per ha per year will be required for increasing production (of biomass?) by 350 kg/ha, assuming absorption rates of 30% for N, 20% for P<sub>2</sub>O<sub>5</sub> and 50% for K<sub>2</sub>O. Ueda (1960) has furnished contents (air dry basis) of N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, SiO<sub>2</sub> and ash, in culms, leaves and rhizomes of very young (1-2 years old) plants of Phyllostachys reticulata, Phyllostachys edulis, Leleba multiplex and Melocanna bambusoides.

#### 2.1.8. B. Experience/suggestions on fertilizer applications:

Chaudhari (1966) stated that experiments conducted in Japan on the bamboo species Leleba multiplex had shown that

fertilizer application substantially (3-4 times) increased new culm production and thus the yield. Rao (1975), based on the practical experience gained in raising plantations of D. strictus in Andhra Pradesh (India), where no fertilizer was being applied to the said plantations, remarked that proper fertilization if done at the beginning of the 2nd growing season, should boost up the growth and early exploitability. He suggested that systematic trials should be undertaken. Siva Prasad (1980) also, from Andhra Pradesh, reported that recent trials revealed that, by applying N, P and K, the period for first felling cycle could be reduced.

Chaudhari (1966) stated that mixing a small dose of fertilizers (2 oz. of ammonium sulphate + 2 oz. of superphosphate per plant) with the soil, at the time of planting, has been reported to have given good results in Bihar and Tamil Nadu in India, on bamboos. He added that the fertilizer mixture should normally contain all the major nutrients (NPK) and their ratios will vary according to site. As for the quantity of the fertilizer mixture, he opined that 0.5 lb (i.e., 227 g)/plant would be adequate to start with and the dose should be gradually increased such that when the clump reaches the exploitable stage it receives upto 5 lb (i.e., 2.270 kg) per clump per year.

Ueda (1960) stated that the amounts of the three elements (N,P,K) to be applied, varied according to the soil. In a volcanic ash soil, which has a high absorption coefficient

for  $P_2O_5$ , the actual amount of P fertilizer to be applied must be more than the amount required by the bamboo. In Japan, for bamboos (Species not mentioned) a total quantity of 500 kg/ha of fertilizer containing N, P and K, in the ratio of 2:1:1 can be applied twice a year (Anon, 1978). As regards the response of clump-forming bamboos (D. strictus is one such) Ueda (1960) stated that although sufficient experimentation has not been conducted on them, some data on the contents of nutrients in their culms and rhizomes are available (the data refer to extremely young clumps of Leleba multiplex and Melocanna bambusoides only) based on which fertilizer experiments must be conducted on Dendrocalamus strictus, Bambusa arundinacea and Melocanna bambusoides.

#### 2.1.8. C. Experimental investigations on Response to fertilizers:

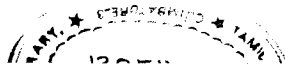
Ferrer (1949) is perhaps the earliest worker to investigate the effect of fertilizers on bamboos. He recorded a higher number of new culms in the fertilized clumps than in the control.

In a pot experiment on seedlings of Flecioblastus pubescens in Japan, 2-factor (NK, PK and NP) combinations and NPK application were compared with a control (no fertilizer) by Ueda (1960). The actual dosages applied per pot (0.7825 m<sup>2</sup> area) and the calculated per hectare levels (furnished within parenthesis herein) were: N - 26 g (=332 kg/ha),  $P_2O_5$ -13.8 g (=176 kg/ha) and  $K_2O$  - 23.5 g (=300 kg/ha). The results of one year growth after fertilizing, showed that though there was not much

difference between the fertilizer treatments themselves, as regards culm diameter, the control recorded the least diameter; culm length also did not differ much. But as regards the number of culms/pot, weight of leaves, weight of rhizomes and total weight of plant there was substantial (two-folds or more) improvement with the NPK treatment as compared to the other treatments, which were almost similar in their responses excepting for a slight superiority of the K-lacking (i.e., NP) treatment. He concluded that N is the element most required by bamboos, followed by K and P. It was also seen that the amount of K absorption by the plant is higher than that for N and P.

Watanabe (1972) conducted a pot experiment in Thailand, on seedlings of Thyrsostachys siamensis for fixing the optimum dose of a fertilizer mixture containing N - 34%,  $P_2O_5$  - 20%,  $K_2O$  - 24%,  $MgO$  - 8% and  $SiO_2$  - 14%. This mixed fertilizer was applied at 5 doses (5, 10, 20, 40, 80 g/pot) and compared with a control (unfertilized). The results showed that at the end of the 1st year, the new culms produced were more in the fertilized pots than in the control but the variation was not much; culm diameter also did not differ much; However, in the 2nd year, the number of new culms produced did not differ much, but as regards height as well as diameter of the culm, there was very good response to fertilizer application. Dry weight of the plant significantly increased with fertilizer application.

In the Philippines, Uchimura (1978) experimented with seedlings of Bambusa arundinacea, Bonkawe and Schizostachyum lumampao, in a pot experiment, using a fertilizer mixture



containing N, P and K, in the ratio of 2:2:1. Doses tried were 500 kg and 1000 kg per hectare along with the Control (unfertilized). The results revealed, that 280 days after fertilizer application, Bonkawe and Schizostachyum lumampao showed better growth in the fertilizer treatments than in the control. However, Bambusa arundinacea (for which observations were recorded only for 110 days after fertilization) did not show any difference in growth.

In a field experiment on Phyllostachys bambusoides, in Japan (Numata and Ogawa, 1959) 10 treatments were tried, 5 of which were non-fertilizer treatments (absolute control, culm harvesting intensity, weed removal and top dressing new soil) and the remaining 5 were fertilizer treatments on all of which were super-imposed the harvesting and weed removal treatments. As regards the fertilizer treatments N, P and K were compared singly along with NPK and NPK + Ca SiO<sub>4</sub>. The dosages adopted were 84 kg N/ha, 45 kg P<sub>2</sub>O<sub>5</sub>/ha, 80 kg K<sub>2</sub>O/ha and 240 kg/ha of Ca Si O<sub>4</sub>. They concluded that N-fertilizer induces fast growth and a large increment in the standing crop, but deteriorated the mechanical properties of the timber. P - and K - fertilizers did not give a notable positive effect, even though they promoted good quality of the timber. Three element (NPK) fertilization and NPK + Ca SiO<sub>4</sub> gave the best results quantitatively and qualitatively.

Ueda (1960) conducted a field experiment in Japan on Phyllostachys reticulata, comparing NK, PK, NP and NPK treatments with control (unfertilized). Levels of application were 150 kg N/ha, 56 kg P<sub>2</sub>O<sub>5</sub>/ha and 56 kg K<sub>2</sub>O/ha. The results of 1 and 2 years after fertilization, showed that, application of NPK was the best from the point of new culm production and weight of culms; as regards culm diameter, however, all the fertilizer treatments were almost similar in their response, though recording a slightly higher diameter than the control.

Kim (1966) working on the same species, viz., Phyllostachys reticulata tried a number of fertilizer treatments applying the fertilizers annually for 5 years on a newly planted grove. He concluded that application of a mixture of compost + urea + superphosphate was the most effective and that KCl was the least effective fertilizer which depressed the response to the others.

Suzuki and Narita (1975) reported that the number of sprouts from fertilized plots was 1.7 - 1.9 times as many as those in the control.

Patil (1980) compared in a field experiment on Dendrocalamus strictus (in Karnataka, India) 2 doses of application of N, P and K, viz., 100 kg N + 50 kg P<sub>2</sub>O<sub>5</sub> + 50 kg K<sub>2</sub>O per hectare and 200 kg N + 100 kg P<sub>2</sub>O<sub>5</sub> + 100 kg K<sub>2</sub>O per hectare, besides control (unfertilized). Besides the fertilizer treatments, there were spacing treatments combining them with

the fertilizers. The material was young plants (less than 2-year age). He concluded that application of fertilizers increased the number of culms/clump, mean height and mean diameter of culms, as compared with the control. Although application of the higher dose of fertilizer (i.e., the 200:100:100 treatment) resulted in more number of culms/clump than in the lower dose of fertilizer (i.e., the 100 : 50 : 50 treatment), the differences were not significant as regards height and diameter of the culms. Dry matter accumulation also increased with fertilizer application, even though the higher dose did not improve it further. A similar trend was seen as regards dry matter accumulation in rhizomes and roots. Total DMP increased from 4 t/ha in the control, to 12.51 t/ha in the medium dose. Uptake of N increased from 6.44 kg/ha in the control to 16.15 kg in the medium dose and 27.09 kg/ha in the high dose. Rate of DMP accumulation, leaf area per clump, leaf area index (LAI), leaf area duration (LAD) and crop growth rate (CGR) registered considerable increases due to fertilizer application.

As regards studies on fixing the optimum dose for a single nutrient, viz. nitrogen, field experiments on Phyllostachys reticulata (Ueda, 1957) and Phyllostachys edulis (Ueda, 1958) conducted in Japan, revealed that 60-70 kg N/ha is needed for an increase in annual production of 350 kg. Response to N extends only upto 250 kg/ha beyond which response cannot be expected (Ueda, 1960). He also reported that, experiments conducted comparing F.Y.M., night soil, ammonium sulphate,

ammonium chloride, ammonium nitrate, urea and calcium nitrate revealed that there was no difference between the different sources of nitrogen as regards their effect on bamboo.

2.1.8. D. Time of application of fertilizers:

Ueda (1960) stated that if slow acting fertilizers are used, the application, to be effective, should be done about a month in advance of each season of growth, so that the effect occurs at the season of sprouting and rhizome growth. He furnished examples from Japan (February - March and June - July for Phyllostachys edulis, March - April and June - July for Phyllostachys reticulata). Spring application evokes sprouts in the same year and summer application makes the rhizomes grow thick. Therefore, the general effect will be seen in the growth of the culm after 1-2 years. This was confirmed by him in experiments conducted at the Kyoto University, Japan, on Leleba multiplex where the effects of application of fertilizers in July-August were felt on the production of new culms in the same year and an increase by several folds in the number of new culms in the next year, as compared to unfertilized plots.

Watanabe (1972) in Thailand, conducted a pot experiment on Thyrsostachys siamensis to study the effect of the time of application of a fertilizer mixture containing 10% N, 6% P<sub>2</sub>O<sub>5</sub>, 7% K<sub>2</sub>O, 2.5% MgO and 4% SiO<sub>2</sub>, applied at a uniform dose of 20g/pot; there was also an unfertilized control. He tried 4 times of application - April, June, August and September.

The results were inconclusive over the short period (one year) of observation and he inferred that if the experiment had been continued for a few more years the effect of season of application would have given statistically significant results.

In Japan fertilizer can be applied twice a year, once during March to April before the bamboo shoots sprout and again during July to August when the rootstocks start growing (Anon., 1978).

Chaudhari (1966), presumably based on the practical experience gained through the management of plantations of Dendrocalamus strictus and Bambusa arundinacea by the West Coast Paper Mills Ltd., Dandeli (Maharashtra) in India, suggested that the best time for application of fertilizers is the season when new shoots begin to sprout.

#### 2.1.8. E. Method of application of fertilizers:

Ueda (1960) stated that the fertilizers may be scattered over the ground, but in that case the results will be slow to appear since the fertilizers do not dissolve without rainfall. It was established experimentally (radio isotopic study on Phyllostachys reticulata) that foliar application of the fertilizer is very effective, but the amount of absorption is restricted as bamboo leaf is smooth, which thus necessitates multiple spraying.

Chaudhari (1966) stated that fertilizers are best applied in a shallow ring, 7.5 cm deep and 30 cm away from the clump, and then covered by soil.

2.1.8. F. Distance on the ground upto which the fertilizer's effect is felt:

In bamboo species which extend their rhizomes in the form of net works, most of the assimilates produced tranlocate in the direction of growth of the rhizome. When fertilizers are applied near the mature bamboo, the effect on the development of new culms are detected upto 5 - 6 m away, along the growth direction, the effect being maximum near the mature bamboo and in one particular experiment, the effect was detected as far away as 9 m from the place of application of the fertilizer (Ueda, 1960).

The above phenomenon was confirmed by radio tracer studies using isotope  $P^{32}$  by Ueda (1956).

## 2.2. INTERCROPPING

Several systems of combining two (binary) or more crops in space and time, for maximising productivity, reducing risk or for other reasons have been evolved. These go by the names of 'multiple cropping', 'mixed cropping', 'intercropping', 'alley cropping', 'multi-tier' or 'multi-storeyed' cropping or '3-dimensional agriculture', 'sequential cropping', or 'relay cropping' etc. Of these, some refer to simultaneous combinations and some others sequential combinations. 'Mixed cropping' and 'intercropping' belong to the first category. 'Mixed cropping' has been defined (Aiyer, 1949) as the system of growing two or more crops (or varieties) in the same field, garden or plantation, not in separate blocks, each carrying a single crop but all of them mixed together and occupying jointly the same ground and sharing in common the cultural operations of the field as though the latter were intended for one single crop, and sown or planted either promiscuously in the midst of each other or systematically in alternating rows or otherwise; the cropping may apply to permanent crops of the plantation type or those which occupy the ground for only one crop season, whether this be for a few weeks, months or a year. Other workers have suggested that the expression 'intercropping' to refer to a situation where the component crops are grown in separate (i.e., distinct) rows (Andrews and Kassam, 1975; Freyman and Venkateswarlu, 1977; Ruthenburg, 1971). The term 'alley cropping' was coined by Wilson and Kang (1981)

to describe a cropping system in which crops, especially food crops, are grown in alleys formed by trees or shrubs, established mainly to hasten soil fertility restoration and enhance soil productivity. Alley cropping may be regarded as an organized form of bush fallow in which selected species are planted in organized patterns, designed to facilitate crop growth and easy crop management in systems based on nutrient cycling by plants. Willey (1979) has defined 'intercropping' as the growing of two (or more) crops simultaneously on the same area of ground, the crops not necessarily being at exactly the same time, and may be differing in their harvest times, but they are usually 'simultaneous' for a significant part of their growing periods, which thus distinguishes it from 'relay cropping' in which growing periods overlap only briefly. The expression 'establishment intercropping' to describe cases where relatively shorter duration crops (mostly herbaceous annuals) are intercropped between trees during the initial phase of the establishment of the tree crop, has been coined (Wilson and Kang, 1981).

Whereas sequential combination of crops of same or different species in quick succession is one of the aspects of 'multiple cropping' in annuals, parallel combinations of compatible crops of different species is the strategy to be adopted for perennials, where the land remains committed to the crop for decades. Thus, 'multiple cropping' in plantations amounts to crop diversification. Considering all the above

points, the expression 'intercropping' is used for the present investigation in preference to such expressions as 'mixed cropping', 'multi-tier cropping', 'multi-storeyed cropping', 'alley cropping' etc. But, in the case of intercropping between trees, the period during which this is possible is rather restricted, it being generally for only a few years (depending upon the growth rate and habit of the tree species concerned and the spacing at which it is planted) during the initial phases of 'establishment intercropping' (Hartley; 1977). The present investigation falls under this category.

#### 2.2.1. Forms of combining crops

Basically three possibilities suggest themselves, depending on the nature of the stem of the crops concerned, viz., (i) woody crop(s) + woody crop(s), or in simpler terms tree(s) + tree(s), (ii) herbaceous crop(s) + herbaceous crop(s), or in simpler terms seasonal crop(s) + seasonal crop(s) and (iii) a combination of tree(s) + seasonal crop(s). Since it is obvious that trees are comparatively long lived, i.e., perennial, another way of designating the above three systems would be to use the expressions 'perennial' and 'seasonal' (or more freely, 'annual'). This terminology would appear to be more appropriate to a situation like the present investigation, in which bamboo is studied, which is a woody perennial but not generally regarded as a tree by foresters.

#### 2.2.2. Intercropping of annual crops in tree crops:

Aiyer (1949) recognized three categories under this

combination of perennial and annual crops, based on the functional role or utility of the annual crop(s) concerned. These are (1) nurse crops, (2) green manure crops and (3) catch crops. The present investigation falls under the third category i.e., 'catch crops', which is reviewed in full in the following sections.

#### 2.2.2.1. Catch crops:

These crops are of very short duration especially in comparison with the main crop and are grown until the main crop comes into bearing and only during such time that they can be grown satisfactorily and without detriment to the main crop. In these cases, it is a question of utilizing the inter-spaces between the young plants of the main crop which otherwise will not only remain unutilized (and thus lower land utilization efficiency for substantial periods of time) but also lead to other undesirable effects such as weed growth, soil erosion, leaching away of nutrients etc. In essence, it is multiple land-use.

In forestry, plantations of useful tree crops are often artificially established. For economizing on the cost of establishment of such plantations a system of shifting cultivation called taungya commonly, and Kumri in Tamil, is practised. A cleared forest area is planted with seedlings of the desired tree species and the farmer to whom the right to cultivate the planted up area for the first two or three years, raises annual crops like sweet potato, which act as nurse crops to the young

forest tree crop, by protecting the recently exposed forest soil from erosion. Teak (Tectona grandis) is by far the most popular tree species used in taungya.

A number of agricultural crops are grown in conjunction with the forest trees under the taungya system (of course, only during the initial phases of the tree crop). It is difficult to assign these crops either to 'nurse crops' or to 'catch crops', for they are both. While, from the point of view of the forest department which owns the land it is a nurse crop for a young tree crop in the initial stages, these crops are the sustenance for the small lessee cultivator who reaps a harvest from between the young tree crop and so these are 'catch crops' as well. However, they are reviewed as 'nurse crops'. The most common crops are pearl millet (Pennisetum typhoides) barley (Hordeum vulgare), rye (Secale cereale), wheat (Triticum sp), minor millets (Panicum spp.), Oats (Avena sativa), grams/beans (Phaseolus spp., Vigna spp.), pigeonpea (Cajanus cajan), groundnut (Arachis hypogaea), gingelly (Sesamum indicum), castor (Ricinus communis), linseed (Linum usitatissimum), mustard (Brassica spp.), soybean (Glycine max), cotton (Gossypium spp.), Chilli (Capsicum spp.), turmeric (Curcuma longa), ginger (Zingiber officinale), potato (Solanum tuberosum), sweet potato (Ipomoea batatas), cocoyam (Colocasia antiquorum), 'Chinese potato' or tanna (Xanthosoma sagittifolium), and many vegetables like brinjal (Solanum melongena), tomato (Lycopersicon esculentum), bhendi (Hibiscus esculentus), cabbage (Brassica spp.), cucumber (Cucumis sativus).

dasheen (Colocasia esculenta), melon (Citrullus vulgaris/Cucumis melo), pumpkin (Cucurbita maxima) and fruits like pineapple (Ananas comosus) and papaya (Carica papaya) (FAO, 1978).

There are also several agricultural crops which are excluded from such systems, as foresters hold that these crops will suppress the growth of the tree crop. Though the list of such precluded crops is controversial, generally bananas (Musa spp.), Cassava (Manihot utilissima), rice (Oryza sativa), maize (Zea mays), sugarcane (Saccharum officinarum), tobacco (Nicotiana tabacum) and yam (Dioscorea spp.) are generally avoided (FAO, 1978). However, there have been exceptions (hill rice in Assam, and Kerala in India, Malaysia and Senegal, sugarcane, with success, in Assam in India, and Burma; maize in Nigeria; and banana in Africa). It must be remembered that in the taungya system the aim is to establish a tree crop and the raising of agricultural crops is only subsidiary and initial, solely to reduce expenditure and if possible improve the early growth of the tree crops (thus acting as nurse crops).

In China, intercropping is generally applied in forestry. There are examples of agricultural crops being planted between rows of poplars (Populus spp.), Cunninghamia lanceolata, and pines (Pinus massoniana, P. taeda or P. elliotii) for a period of two years. In some plantations, particularly pine, tung oil trees (Aleurites spp.) are interplanted concurrently with the agricultural crops (FAO, 1978).

In general, raising of intercrops of annuals between perennial tree crops is feasible during the early stages of the main crop when the canopy has not closed in. On the other hand, intercropping of annual field crops in mature stands of trees is generally not economic because of the severe curtailment of yield, chiefly of grain, in the intercrops. However, such depressing effects must vary from situation to situation depending on such factors as comparability of the two species, shade tolerance of the intercrop species, elevation at which shade occurs (high or low shade), spacing between the trees (base crop), rooting patterns of the two crops, age of the tree crop etc.

The available literature is reviewed in the following sections. First, the typically plantation crops raised by farmers are presented. Under this are listed the tall-growing palms (whose canopy height and thus the shade cast by them make them stand out from the other trees) - coconut, arecanut, oil palm and date palm; and then rubber, cashew, leucaena and country pear. Then follow tree crops whose chief economic product is wood and which are generally raised by the forest departments, like the acacias ( which, however, is typically a farmer's crop), teak, eucalyptus, Holoptelia, Gmelina, Cordia, Cedrela, poplars and conifers, and finally bamboo.

#### 2.2.2.1.1. Coconut - based intercropping systems:

Coconut (Cocos nucifera) is one of the very few tree crops in which intercropping is extensively practised and on

which the amount of published information is quite substantial. The chief reasons for this are: (1) coconut is essentially a small farmer's crop (Thomas Varghese et al., 1978) who is naturally compelled to diversify, (2) it has a long life span of 60 to 80 years and thus the land is committed to it for several decades, (3) it is planted wide, usually about 7.5 m either way, and it has been estimated that only about 28% of the land area is utilized by it (Leela and Bhaskaran, 1978), (4) it has the peculiar advantage of having two periods (initially upto 8 to 10 years after planting and again 20 years after planting upto senescence of the crop) in its life span during which it allows sufficient light to penetrate to the ground when intercropping could be practised (Nair et al. 1974), (5) many annual crops are compatible with it, and (6) its root zone is confined laterally to a radius of 2 metres only (Kushwah, et al., 1973) and vertically between the depths of 30 and 120 cm from the surface (Central Plantation Crops Research Institute, 1973).

A variety of crops are being raised as intercrops or have been tested for their suitability with varying degrees of success. In India (chiefly in Kerala State) banana is commonly raised, as mentioned earlier (Nelliat, 1976; <sup>Nair and</sup> Thomas Varghese, 1976; Nair et al., 1974). A number of workers have reported the growing of a variety of annuals as intercrops between coconuts. Thus, Cassava (Manihot utilissima / Manihot esculenta) (Nelliat, 1976; Nair and Thomas Varghese, 1976., Nelliat et al., 1974.,

Nair et al., 1974., Thomas Varghese et al., 1978a., Potty, 1978., Ramanujam et al., 1984; Sethumadhava Menon and Ramakrishnan Nayar, 1978); Yam (Dioscorea alata) also known as 'greater yam' (Nelliatt, 1976; Nair et al. 1974; Sethumadhava Menon and Ramakrishnan Nayar, 1978); Elephant foot Yam (Ampelophthalus campanulatus) (Nair and Thomas Varghese, 1976; Nelliatt et al., 1974; Nair et al., 1974; Thomas Varghese et al.; 1978a; Sethumadhava Menon and Ramakrishnan Nayar, 1978); Lesser Yam (Dioscorea esculenta) (Nair et al., 1974; Thomas Varghese et al., 1978a); Sweet potato (Ipomoea batatas) (Nelliatt, 1976)., Nair and Thomas Varghese, 1976., Nelliatt et al., 1974; Nair et al., 1974, Thomas Varghese et al., 1978a; Potty, 1978); Chinese potato (Coleus parviflorus/Coleus barbatus) (Nair et al., 1974; Thomas Varghese et al., 1978a); Colocasia (Xanthosoma sagittifolium) (Thomas Varghese et al., 1978a); Ginger (Zingiber officinale) (Nair and Thomas Varghese, 1976; Nelliatt et al., 1974; Nair et al., 1974; Thomas Varghese et al., 1978a); Turmeric (Curcuma longa) (Nair and Thomas Varghese, 1976; Nair et al., 1974; Thomas Varghese et al., 1978a); Pepper (Piper nigrum) (Nelliatt, 1976; Nair and Thomas Varghese, 1976; Nelliatt et al., 1974, Nair, 1980; Nair et al., 1974); Upland, i.e., rainfed (generally) Rice (Oryza sativa) Nelliatt, 1976; Nair and Thomas Varghese, 1976; Nelliatt et al., 1974; Potty, 1978); sorghum (Sorghum sp.) (Aiyer, 1949); Finger millet (Eleusine coracana) (Aiyer, 1949); Italian millet (Setaria Italica) (Aiyer, 1949); Black gram (Vigna mungo) (Aiyer, 1949; Nair and Thomas Varghese, 1976; Nelliatt et al., 1974); Green gram (Phaseolus radiatus) (Aiyer, 1949, Nair and Thomas

Varghese, 1976); Red gram (Cajanus cajan) (Potty, 1978); Horse gram (Dolichos biflorus) (Aiyer, 1949; Nair and Thomas Varghese, 1976; Nelliat et al., 1974; Potty, 1978); Cowpea (Vigna unguiculata) (Nair et al., 1974; Potty, 1978) Groundnut (Arachis hypogaea) (Aiyer, 1949 Nair et al., 1974; Potty, 1978; Leela and Bhaskaran, 1978); Gingelly (Sesamum orientale); (Potty, 1978); Sunflower (Helianthus annuus) (Nair et al., 1974); vegetables (Nelliat, 1976); Pine apple (Ananas comosus) (Nair and Thomas Varghese, 1976; Nelliat et al., 1974, Nair, 1980; Ramaratnan, 1981); and forage crops - grasses and legumes (Sahasranaman and Pillai, 1976; Vikraman Nair et al., 1976; Ramakrishnan Nayar and Sahasranaman, 1978).

The above list testifies to the diversity of seasonal crops (25 different crops excluding forages) that are being grown or have been attempted to be grown as intercrops in coconut stands, in India. In addition, if we consider the variety of economically very valuable woody perennials, for the sake of comprehensiveness - short bushes like Robusta Coffee (Nair, 1980) or short statured trees like Cacao (Nair and Thomas Varghese, 1976; Nelliat et al., 1974; Nair, 1980; Nair et al., 1974; Thomas Varghese et al., 1978b), Clove (Nair and Thomas Varghese, 1976; Nair, 1980, Nelliat et al., 1974), Cinnamon (Nair and Thomas Varghese, 1976; Nelliat et al., 1974) and Nutmeg (Nair and Thomas Varghese, 1976; Nelliat et al., 1974; Nair, 1980); the green manure crops (Nair, 1980), and cover crops like Calopogonium, Pueraria (Nelliat, 1976) etc., the list expands further.

It is not surprising that all the above publications but one, have stemmed from Kerala when we consider the fact that 60% of the total coconut area of India (Indian area = 906,000 ha) is situated in Kerala State and it contributes 70% of the total production (Plucknett, 1979). Liyanage et al., (1984) have listed a total 30 different crops as being inter-planted in coconut groves in Sri Lanka. This list comprises most of the intercrops grown in India, besides maize (Zea mays), soybean (Glycine max), winged bean (Psophocarpus sp.), chillies (Capsicum spp.) betel leaves (Piper betel), fruit crops like passion fruit (Passiflora edulis), papaya (Carica papaya), pomegranate (Punica granatum), Citrus (Citrus spp.), not to mention the plantation crops including coffee. Cacao is a profitable intercrop in coconut gardens in the Philippines (Rodrigo and Mangabat, 1964). Plucknett (1979) reported that a variety of forage crops are cultivated under coconuts, in the Philippines, Indonesia, Malaysia, Papua New Guinea, Sri Lanka, India, Fiji, Western Samoa, the Pacific islands, etc. Indeed, it is correct to say that coconut is one of the few tree species, perhaps the only one, to boast such a diversity of intercrops.

As regards experimental studies, most of them have been confined to merely testing the suitability of specific crops for intercropping - and in almost all, the aim had been to evaluate the effect of such intercropping on the main crop, viz. coconuts. Nair et al. (1974) reported the results of experiments on intercropping of several tuber crops, rhizome

crops, oilseeds (groundnut and sunflower), cowpea, banana and pineapple conducted at Kasargod (Kerala State) and stated that earlier work had shown that elephant foot yam and cassava had no adverse effect on coconut, provided the main crop and the intercrop were adequately and separately manured. They concluded from their experiments that maximum cost benefit ratio (2.46) was obtained from the intercrop of ginger. Again, from Kasargod, Thomas Varghese et al. (1978a) who studied seven tuber crops besides the rhizome crops ginger and turmeric, corroborating the earlier finding, concluded that the raising of tuber crops as intercrops in coconuts exerted no adverse effect on the coconuts provided that both the intercrop and the main crop are manured adequately and separately. They observed that the coconut yield was lower in the treatment where the intercrop (elephant foot yam or cassava) alone had been manured as compared to the yield of the sole crop of coconut which was manured. This yield depression was ascribed by them to the competition for nutrients and they concluded that this competition effect was overcome by fertilizing both the main and the intercrops. Besides, they stressed the importance of rotating the intercrops, reporting that elephant yam, if continuously grown as an intercrop between coconuts will depress the yield of the latter. They also stated that, while monoculture of coconut provides employment of 150 mandays/ha/year, intercropping doubles it.

At Trivandrum (Kerala State) it was observed that the productivity of cassava was reduced when intercropped in coconut, since the light inside the coconut stand was very much less (about one-seventh) than that in the open (Ramanujam et al., 1984).

Potty (1976) using eight different crops (including three pulses) studied the influence of 'moisture modulation' (i.e., raising the intercrops under two different moisture regimens created by forming trenches and raised beds inside the coconut stand) at Nileshwar (Kerala). This study is essentially an investigation on increasing the efficiency of one of the resources, viz. rainfall. He concluded that the yield of the intercrops under the moisture modulation system was far better than in the conventional intercropping system. Again, from Nileshwar, Leela and Bhaskaran (1978) who tried groundnut as intercrop, reported that the intercrop occupied 72% of the land area and the intercrop yield was not adversely affected, while it suppressed weeds effectively, besides increasing the employment potential (extra 85 women and 20 men/ha). This study brings out the several advantages of intercropping, viz., better land utilization, better weed control, increased employment etc. The work of Sethumadhava Menon and Ramakrishnan Nayar (1978) from Kayangulam (Kerala State) highlights another facet of intercropping, viz., disease relationship. They found that the disease intensity of coconut was higher when cassava was intercropped even though the tuber yield of cassava was the highest as compared to yam and elephant foot yam.

The general conclusions that emerge from an analysis of all the foregoing literature are:

- 1) coconut allows a large number of seasonal crops to be intercropped because of its peculiar morphological features and the wide spacings adopted;
- 2) almost all the intercrops give economic yields besides other benefits like weed suppression, increased employment, improved land use, increased water use, efficiency etc;
- 3) in general the yield of coconut is not adversely affected, provided it is adequately manured separately, in addition to that for the intercrop(s);
- 4) in all the experiments the emphasis had been on the main crop, viz, coconut, as regards its yields, and not on the performance of the intercrops. Hence in all these experiments on 'open field' treatment had not been included, which seriously hampers interpretation of the results as regards the intercrops.

2.2.2.1.2. ARECANUT - based intercropping systems:

Arecanut (Areca catechu) is raised as an irrigated crop, to a considerable extent in South India and is a very valuable cash crop. According to Nelliat (1976) the desirable space for its proper growth and productivity is  $7.3 \text{ m}^2$ , which works out to a spacing of about  $2.7 \text{ m} \times 2.7 \text{ m}$ ; in actual practice, however, the spacing is much closer, being about 2 metres

either way. Normally, fertilizers are spread on the ground within a radius of 1 metre from the base, around the palm.

Usually, betel vines are raised as intercrops in areca gardens training the vines on the palms as standards; the shade provided by the closely planted arecanut helps the betelvine for which shade is indispensable. A different type of intercropping is seen in the malnads of Karnataka State, where bananas, arecanuts, pepper and cardamom are grown together, without any wastage of space (Aiyer, 1949). This system of multistoreyed cropping as practised in the spice gardens of Uttar Kannada (Karnataka), which mimics a tropical rain forest, has been described by Madhava Gadgil and Hegde (1981). The spice garden is started by planting banana as the nurse crop, followed by arecanut which is planted at a wide spacing of 3.5 to 5 metres (which, however, will be closed in, by interplanting arecanute, again, in the 6th year). In the interspaces, cardamom (Elettaria cardamom) a valuable spice and export crop, is planted, in the seventh year, at the rate of 1,500 cardamom bushes per hectare.

In Sri Lanka and Kerala, coconuts, cloves, cacao and coffee (and sometimes even tea) are mixed with arecanuts, as intercrops and in the fruit gardens of Karnataka, arecanuts are mixed with coconuts, mango, jack, guava, orange and other citrus trees (Aiyer, 1949). Liyanage et al. (1984) reported that in Sri Lanka, arecanut and coconut are mixed.

Shama Bhat (1978) studied the intercropping of cacao (Theobroma cacao) with arecanut in the ratio of 50 : 50, comparing it with arecanut stand planted along its border with cacao as well as with sole crop arecanut, at Vittal (Karnataka). The spacing for the arecanut was 4 x 4 m. He concluded that interplanted cacao yielded more than the border planted cacao, which was sun scorched. This, while pointing at the shade-loving nature of cacao, brings out the value of shade under certain circumstances, wherein woody perennial crops have a useful role to play. Further, he observed that the arecanut was not adversely affected by the intercropping; in fact the arecanut yield in the intercropping treatment was higher than that for the sole crop.

Muthuswamy and Thangaraj (1961) from Coimbatore (Tamil Nadu State) reported the results of an experiment in which 5 different varieties of ginger (Zingiber officinale) were raised as intercrops in an arecanut plantation. The fresh rhizome yields ranged from 3.500 to 7.166 t/ha. They concluded that though the yields were lower as compared to a sole crop of ginger, ginger was promising as a subsidiary crop and added that it was the first time that the suitability of ginger for growing under the shade of an arecanut plantation had been demonstrated.

#### 2.2.2.1.3. OIL PALM - based intercropping systems:

The oil palm (Elaeis guineensis) is extensively cultivated in Africa for its vegetable oil, and in that country, it is the

equivalent of coconut to India. In recent times, the cultivation of this new crop has been on the increase in India also.

In Africa, 'establishment intercropping' (i.e., intercropping with annuals during the initial establishment period of the oil palm) is temporary cultivation and is generally practised by the small farmer. Several trials on establishment intercropping have been carried out in Africa (Sparnaaij, 1957). In Zaire (I.N.E.A.C., 1955), the planting (alone, or in succession, or combination) of cassava, maize, hill rice and banana for 1, 2 or 3 years had, in general, a beneficial effect on palm yields and, after 16 years, no deleterious effect had appeared. These catch crops were planted immediately after the palms and the control plots with Pueraria phaseoloides (Hartley, 1977).

In another trial conducted in Nigeria in 1940, intercropping for 2 years as well as cropping for as long as crops could be obtained were experimented with. In practice, the latter treatment entailed cropping with maize, yam and cassava until shade made the growing of cocoyams (Colocasia antiquorum) the only possible culture, and this was continued until the twelfth year. In the 2-year cropping plots and the early years of 'cropping-to-exhaustion' plots, good crops were obtained and were similar to the results secured in Zaire. They showed that intercropping of food crops for 2 or 3 years may, in these circumstances, be an attractive proposition to a small holder. In both trials there was a tendency in the oil palm

for early bunch yields to be improved by intercropping; in the Nigeria trial, both leaf production and early yields were significantly increased. And, in neither trial, after 16 or more years of harvesting, was there any significant fall in yields following the early inter-cropping treatments, though in Nigeria a tendency for yields to fall in later years had been noticed. In areas already degraded by food crop farming (before oil palm establishment) or by annual burning, in Nigeria, the beneficial effect of 'establishment intercropping' was short-lived, and to secure even moderate yields (of oil palm) heavy fertilizer dressings had to be applied, thus indicating the harmful effect of regular tillage (Hartley, 1977).

Soybean has also been raised as an intercrop for the first 2 years, between oil palms, carrying the cultivation to 1.8 m from the young palms, in an experiment conducted in Malaysia. It was found that there was no effect on the growth or early yield of the oil palm, as compared to the treatment 'intercropping with a legume cover'. There was, however, a suggestion that if deep tillage is undertaken for two annual crops, then palm growth is slightly impaired through root damage. Two cassava crops grown in successive years severely retarded growth and reduced early yield by 14% through competition for both light and nutrients, particularly N and P (Chew Poh Soon and Koo Ka, Thye, 1976).

Grubben (1972) experimented with the growing of two leafy vegetables (Amaranthus and Celosia argentea) as intercrops in oil palm, in Dahomey (Africa), where these crops are often

cultivated in an environment more or less shaded, especially by oil palms. It was observed that shade had a depressing effect on Celosia (in an artificial shading experiment) and in the case of Amaranthus growth was retarded when grown under oil palms since the light intensity within the palm stand was as low as 60% of that intercepted by it; the effect diminished as the distance away from the trunk of the palm increased. He concluded that Celosia is a heliophyte and that its yield decreased by 10.3% for each 10% additional shade, provided that irrigation was sufficient. He recommended the use of unshaded sites for intensive growing of Amaranthus and Celosia.

Plucknett (1979) stated that raising pasture crops in oil palm stands could be useful and that such oil palm tree/pasture/livestock systems are employed in Asia and Latin America and research in this area being carried out in Nigeria and Sierra Leone.

#### 2.2.2.1.4. DATE PALM - based intercropping systems:

Baldy (1963) reported that in desert oases date palms are intercropped with apricots, which are short trees, and vegetables. In such oasis communities, the shading and windbreak effect of the upper layer(s) creates a favourable microclimate for the layer below: the component chosen for each successively lower layer is more mesophytic and less light-demanding than the one above. The shortest component

(the vegetable crop) escapes suppression possibly because soil cultivations tend to prevent intermingling of the root systems. He has argued that the many-layered mixed communities traditionally grown in desert oases may use applied water more efficiently in biomass production than pure stands.

#### 2.2.2.1.5. RUBBER TREE - based intercropping systems:

Rubber (Hevea brasiliensis) is commercially very important. In India 99% of the rubber plantation units are with small holders which cover about 70% of the total area under rubber cultivation. The immaturity period of rubber (i.e., the period from planting to the first tapping of latex) usually exceeds 7 years and hence small holders are forced to take up intercropping in order to get additional income and employment during this period. In India cassava, banana, rice and ginger are the intercrops commonly raised in small holdings of rubber. Very little experimental evidence exists on the economics of such intercropping.

Hali (1979) narrated the successful intercropping of rubber with cacao var. 'Forestero' trees plus banana, in Kerala State. In between the young replanted rubber (5-year old) at a spacing of 20' x 10' (6 x 3 m), 3-month old cacao seedlings were planted at a spacing of 10' (3 m). The nurse crop of banana planted in the young rubber provided the shade and protection to the cacao. The cacao flowered early and did not affect the rubber in any way.

Mathew et al. (1978) conducted an experiment to assess the suitability of 6 different intercrops (dryland rice, banana var. 'Nendran', banana var. 'Palayancodan', cassava, green gram and Pueraria phaseoloides) and the economics of intercropping, at Chethackal (Kerala State). In the case of rice, it was followed by banana var. 'Nendran' or cassava, and in the case of green gram, it was followed by banana var. 'Nendran', in rotation. Banana var. 'Palayancodan' and Pueraria phaseoloides were raised as single crops. It was found that the growth of the main crop of rubber was retarded by the non-Nendran banana ('Palayancodan') and cassava due to their shade effect; highly significant differences arose in the stem girth of rubber. On the contrary, 'Nendran' banana not only did not retard the growth of rubber but actually recorded the maximum stem girth for rubber. This brings out the differential behaviour of varieties even within one and the same intercrop species. Evidently the differences arise because of morphological differences in stature, leaf areas etc., which contribute to shading, as also rooting patterns. Banana has long been recognised as a nurse crop for young arecanuts and cloves.

As regards the economics of intercropping Mathew et al. (1978) concluded that, 'Nendran' banana gave the maximum net profit followed by cassava. Rice and green gram intercropping resulted in substantial losses due to their labour intensiveness and unfavourable rainfall, and thus were unprofitable as

intercrops in rubber. They concluded that planting 'Nendran' banana 6 months after planting rubber was the best.

Work done in Malaysia had shown that growth of rubber plants, intercropped with banana was better compared to that under legume cover crop during the first  $3\frac{1}{2}$  years of the immaturity period (Anon., 1972). It was also reported that there was no adverse effect on the growth of rubber when intercropping was done at a distance of 0.9 m away from the rubber rows during the 1st year and 1.2 m in the 2nd and 3rd years. Groundnut and maize were suggested as suitable intercrops on flat gently undulating land (Anon., 1973). Plucknett (1979) stated that the raising of pastures in rubber plantations is a workable system.

#### 2.2.2.1.6. CASHEW - based intercropping systems:

On the poor soils of the savannah in southern Guinea, cashew (Anacardium occidentale) has been successfully raised under the Taungya system (shifting cultivation) together with maize and sometimes cotton (FAO, undated).

Plucknett (1979) stated that pastures are combined with cashewnut trees.

#### 2.2.2.1.7. LEUCAENA - based intercropping systems:

Leucaena leucocophala has, in recent times gained great importance, particularly in the developing countries, as a wonder tree because of its many advantages (fast rate of growth, possibility of close spacings, abundant biomass production, production of small timber, and fuel wood and above all,

production of protein-rich fodder). This leguminous tree fixes atmospheric nitrogen also and thus improves soil fertility. Torres (1983) estimated the contribution to be 45 grams of N/linear metre of hedgerow of leucaena.

Kang et al. (1981) from southern Nigeria reported that intercropping of maize in the alleys between hedgerows of leucaena planted 4 m apart gave sustained annual yields of about 3.8 t/ha without any supplementary nitrogen and still higher yields with supplementary nitrogen at 20-80 kg N/ha. The prunings from the 5-6 - year old leucaena yielded 5-8 t/ha dry tops/year equivalent to 180-250 kg N/ha which was responsible for the sustained annual yields of maize.

Wilson and Kang (1981) who coined the term "alley cropping" to describe such intercropping systems, reported the results of an experiment in which leucaena was established in association with maize and maize/cassava. The initial phase of the 2-year rotation involving maize/leucaena followed by yam/leucaena was established in a similar pattern. The leucaena was planted at a spacing of 2.0 x 0.5 m and in the alley, a paired row of cassava, spaced 1.0 x 1.0 m was planted. Maize was sown in hills along the cassava rows at the rate of one hill between two cassava plants; the spacing for maize also, thus works out to 1.0 x 1.0 m. Crop yield and leucaena development indicated no serious disadvantage to the intercropping establishment of leucaena. In the 1st year the yields of maize ranged from 1.840 to 3.058 t/ha and the differences

between the treatments (maize sole crop, maize + leucaena + cassava, maize + cassava, maize + leucaena) were not significant. Similarly cassava yields were 20.187 and 29.229 t/ha in the two treatments maize + cassava and maize + cassava + leucaena respectively; the difference was not significant. In the 2nd year, yam yields ranged from 12.333 to 14.905 t/ha and differences between the treatments were not significant. It is thus evident that intercropping was successful in leucaena but it has to be borne in mind that the height of the main crop of leucaena in alley cropping is contained to hedgerow height only, perhaps to not more than 1.5 metre and not allowed to grow into trees.

Verinumbe (1983) who studied the economics of small-scale farming in Nigeria, reported that the maximum yearly net profit was obtained if a farmer produced a combination of 95% of the farm area under maize + leucaena and 5% of the area under maize + stylo. This, in essence, underscores the success of maize intercropping in leucaena.

In India, at the Central Soil and Water Conservation Research and Training Institute, Dehra Dun, the results of various experiments, in general indicated that all the annual crops intercropped between paired rows of leucaena, yielded more grain as compared to the 'expected' yield of the sole crops. Increase in productivity was recorded more in pigeon pea (Cajanus cajan) followed by castor (Ricinus communis) and least in sorghum (Singh, 1983).

At the Indian Grassland and Fodder Research Institute, Jhansi different silvopastoral and agripastoral systems have been studied for the past several years. Intercropping of leucaena with gingelly (Segamum indicum), groundnut and pigeonpea (Cajanus cajan) revealed that gingelly yield was increased when grown in association with leucaena; however the yield of groundnut and pigeonpea were reduced (Singh, 1983).

#### 2.2.2.1.8. COUNTRY PEAR - based intercropping systems:

Nanjan et al. (1980) studied the performance of pine apple (Ananas comosus) var. 'Kew' raised both as a sole crop in the open and as an intercrop under the diffuse shade of country pear (Prunus sp.) trees in the Shevoroy hills (Tamil Nadu State). The crop came to harvest in 22 months and the shade-planted crop yielded 58.8 t/ha of fruits. The performance under the shade was as good as in the open. They recommended pine apple as an intercrop in new coffee plantations in the first 3-4 years after planting, as a catch crop, for weed suppression, prevention of soil erosion and maintenance of soil fertility. They observed that the crop came up well under rainfed conditions.

#### 2.2.2.1.9. Other tree species raised for wood:

##### A. TEAK (Tectona grandis):

Teak is a large deciduous tree with a rounded crown of great commercial importance producing high value timber. It grows tall and a maximum height of 155' (47.24 m) and a maximum girth of 26' (7.92 m) have been reported. The oldest teak

plantation in the world ('Conolly's plot' in Nilambur, Kerala State) is situated in India and is now 140 years old (Surendran, 1977). It is extensively raised as 'canal bank plantations' in the Thanjavur district (Tamil Nadu) and is commonly raised by farmers in Tamil Nadu.

While in the forest ecosystem, teak is raised almost exclusively by the taungya system in which agricultural crops, chiefly tuber crops, are grown as intercrops during the first one or two years, intercropping of teak is not common on farm lands. But, since adult teak trees being fairly tall their shade is high shade and also since it is a deciduous species it would appear that intercropping of annuals under teak may be possible.

King (1968) reported that experience gained in Nigeria showed that there was no significant difference in the yields of maize raised as a sole crop and as an intercrop in teak, in the first year. Mishra (1979) reported the laying out of experiments involving the raising of different sequential combinations of annual crops and herbs (pigeonpea, maize, finger millet, rice, groundnut, gingelly, castor, soybean, sweet potato, ginger, Solanum khasianum Vinca rosea, mesta and daincha) in conjunction with teak, and Dalbergia sissoo trees under rainfed conditions in Bihar. Based on the preliminary results of the yields and economics for maize, finger millet and rice, he concluded that these crops were remunerative when grown in conjunction with the tree species and that the growth

of the tree crops was satisfactory.

B. ACACIAS:

The acacias as a group are hardy trees growing not only naturally in marginal and wastelands but are deliberately permitted to occur in cultivated fields in the midst of annual crops by the farmers. Thus Seshadri et al. (1977) reported the extensive occurrence of white babul (Acacia leucophloea) trees in farmers' fields in the drier tracts of Coimbatore and Periyar districts of Tamil Nadu. Stocking densities as high as 750 trees/ha were observed.

While in Africa, Acacia albida, A. senegal and A. tortilis play a dominant role in farming, A. leucophloea, A. planifrons, A. ferruginea, A. nilotica (syn. A. arabica) are common farmland trees, in South India.

In the drier parts of Coimbatore (Tamil Nadu) a silvi-pastoral system is in existence in which the farmers allow self-sown seedlings (spread by sheep browsed on the pods) of Acacia leucophloea to reach adulthood, and all the time a variety of annual crops (sorghum, pearl millet, field lab lab (Dolichos lab lab), cowpea, horse gram, dew gram (Phaseolus acutifolius), groundnut, gingelly, castor and even onion and tobacco under irrigation) are cultivated in the inter-spaces between the trees. (Seshadri et al., 1977). Seshadri and co-workers studied the performance of sorghum sole crop raised for fodder, a grain-cum-fodder sorghum and natural pasture chiefly composed of Cenchrus ciliaris, growing under

the canopies of Acacia leucophloea trees of ages ranging from 20 to 30 years. They reported highly significant increase in the yield of sorghum dry fodder as compared to the crop in the open and a similar increased yield of natural grasses in the shade.

Similar results were secured for four different forage crops (Sorghum, Cenchrus grass, cowpea and Guar - Cyamopsis psorolioides) at the Central Arid Zone Research Institute, Jodhpur (Rajasthan State) where significantly higher forage yields were obtained when the annual crops were grown in the interspaces of 5-year old trees of Acacia tortilis planted at a spacing of 4 x 4 m (Singh, 1983).

In Africa, agricultural crops such as pearl millet, sorghum, maize, cowpea and groundnut are often grown by Sahelian farmers under a 'park' of Acacia albida ('apple-ring acacia' or 'gao') as the crop yields more when grown in close proximity to Acacia albida stands. This has been called by the new term 'agro-silvo-pastoralism' (Anon., 1983). Felker (1978) reported that intercropping between Acacia albida trees has substantially increased the welfare of small farmers in West Africa and the Sahel by increasing soil fertility and crop yield besides providing pods for animal feed. He stated that about 45 large trees/ha are required to complete soil cover and that the trees flower at 7 years age and produce pods when 8 years old. Charreau and Poulain (1963) reported that in regions of seasonal rainfall of 250 mm or more per annum, judicious interplanting

of Acacia albida trees increased the yields of pearl millet by 500 - 600%.

The author of the present investigation has observed a similar agro-silvi-pastoralism in the drier parts of Tirunelveli district (Tamil Nadu) where stands of Odai trees (Acacia palmifrons) are intercropped with banana and brinjal (Solanum melongena), the catch crops supporting the farmer till the acacia trees start bearing pods when sheep are started to be raised, they being fed with the acacia pods.

The importance of acacias under situations of marginal farming is clearly brought out by the foregoing review. Acacias can be said to be the mainspring of farming in the semi-arid tropics.

#### C. CASUARINA:

The 'Indian Christmas tree', Casuarina equisetifolia, an exotic, was introduced into Tamil Nadu a century ago and spread very rapidly establishing itself as a regular, sole stand farm crop, often irrigated and fertilized, particularly along the east coast. It is planted by farmers, rather close, about 1 metre apart and the crop is clearfelled in 5 - 7 years. It is economically very valuable furnishing prized firewood and poles for temporary constructions.

The author of the present investigation has observed that in parts of south Arcot district (Tamil Nadu) small farmers interplant the young casuarina crop with groundnut or cucumber (Cucumis sativus) as catch crops. However, when the main crop

is 2 or more years old intercropping ceases, presumably because the ground is covered by abundant needle fall rather than due to a reduction in the light intensity, since the diffuse light under casuarina appears to be capable of supporting green plants. However, no published evidence is available on the intercropping of casuarina.

D. EUCALYPTUS:

Eucalyptus are a large group comprising several hundred species adapted to a variety of agro-climatic and edaphic conditions. Even though essential oils of commercial importance are obtained from a few species of eucalyptus in Tamil Nadu (for example, Eucalyptus globulus in the hills and E. citriodora in the plains) their chief value is as pulpwoods. In Tamil Nadu three species of eucalyptus, viz., the so-called eucalyptus 'hybrid' (which, for all practical purposes has come to be reckoned as E. tereticornis), E. camaldulensis, and E. grandis, are extensively raised on a plantation scale by the Forest Department. E. tereticornis which is admirably adapted to the plains, has in recent times been taken up by the farmers encouraged by the short supply of raw material for the paper mills. Besides, the recently launched SIDA (Swedish International Development Agency) - aided 'Social Forestry' programme has given a filip to the cultivation of E. tereticornis in farmlands despite the prevalent fear about the adverse effects of this tree on ground water table held by many sections, which is yet to be conclusively proved or disproved.

Sharma (1983) stated that the feeling that nothing grows under eucalyptus is not correct as this depends upon how closely or widely the trees are planted. He reported that some farmers in Kolar (Karnataka) space out eucalyptus and intercrop finger millet (Eleusine coracana) for 1 to 3 years. Similarly, Pant (1980) has reported the successful cultivation of several species of fodder grasses (Guinea, Rhodes, Para, Napier-Bajra hybrid and Blue Panic grasses) under eucalyptus, by a farmer in Gujarat (India). The Eucalyptus globulus in the Nilgiri hills (Tamil Nadu) similarly permits the growth of shade-loving grasses during the first 5 years was reported by Samraj (1977).

Eucalyptus citriodora was one of the 4 tree species (the others being Dalbergia sissoo, Populus deltoides and Salmalia malabarica) in a study conducted at Peshawar (Pakistan). The trees were spaced 4.3 x 4.3 m and wheat was sown when the trees were 2 years old, in drills 45 cm apart, between the tree lines and harvested in about 6 months. At the time of harvest the eucalyptus trees were 3 - 7 m in height. It was observed that there was no significant difference in the yield of the wheat intercrop between the different treatments (i.e., under the 4 different tree stands) and also that grain yields did not differ at distances of from 80 - 215 cm away from the base of the trees (Khattak and Sheikh, 1980).

At Coimbatore (Tamil Nadu) the physiological aspects of 11 different genotypes of black gram (Vigna mungo) raised within

a stand of 2 year old E. tereticornis planted 1 x 1 m apart was studied by Ramachandran (1981). The intercrops were fertilized with a uniform dose of 5 t FYM, 25 kg N, and 50 kg  $P_2O_5$ /ha. He observed differential responses in growth and other physiological parameters between the different genotypes and concluded that 2 genotypes (JLU 5-1 and No.55) performed well in the shade and thus were suitable for 'canopy cropping' (as he called the system).

Couto et al. (1982) studied intercropping of soybean in Eucalyptus grandis in southeastern Brazil. Their aim was weed suppression in young eucalyptus plantations to economise on weed control costs. They tried 7 treatments involving a variation in the number of sowing lines (and thus varying the inter-row spacing) of soybean with concomitant variations in the distance between the tree base and the nearest soybean row. There was also a control i.e., a sole stand of the eucalyptus without any intercrop. However, there was no corresponding 'open' treatment with a sole crop of soybean. The trees were planted at a spacing of 3 x 2 m and both the eucalyptus seedlings and soybean were planted at the same time. The soybean was fertilized with 100 kg  $P_2O_5$  + 50 kg  $K_2O$ /ha. Soybean was harvested in 5 months and the grain yields ranged from 1.533 to 2.449 t/ha., the maximum being recorded by the treatment '0.5 m inter-row spacing, 0.5 m away from the base of the tree seedling'. This yield was similar to the yield normally obtained in the region for a sole crop of soybean. The soybean also

effectively suppressed the weeds in all the treatments. As regards the growth of the eucalyptus seedlings, as observed 24 months after planting, it was seen that the treatments had no significant effect on survival, height, diameter of stem or volume. It was concluded that the experiment demonstrated the feasibility of interplanting soybean with eucalyptus at the time of stand establishment, that the production of soybean was equal to local monoculture soybean yields, that more intensive land use was made possible and the cost of tending the plantation was reduced by eliminating the need for weeding.

Adverse effect on the main crop of eucalyptus by the intercrop (maize) has also been reported from Brazil (Gurgol, 1962).

E. Holoptelia integrifolia:

This is another common economic tree of villages and is receiving attention recently in the context of integrated land use systems.

In an experiment conducted at the Central Arid Zone Research Institute, Jodhpur (Rajasthan State) the interspaces between the 8-year old trees of Holoptelia integrifolia planted at a spacing of 5 x 5 m were sown with 2 intercrops - green gram (Phaseolus radiatus) and guar (Cyamopsis psoralioides); besides the annual crops were sown in the 'open' also (i.e., as sole crops). In addition there was another factor, viz., lopping of the trees or not. The results revealed that, as expected the grain yields

of the two legume intercrops were lower under the 'unlopped' trees, which increased under the 'lopped' trees, and remarkably so in the case of guar. Surprisingly, the grain yields were the highest under the 'lopped' trees, higher than those for the 'Open' plot, in the case of both the intercrops (Singh, 1983).

This experiment is significant in three respects and thus stands out from all the studies reviewed upto now. They are, 1) the inclusion of an 'open' treatment (i.e., sole crop of the annual) through which alone the effect of the tree crop on the annual intercrop can be really assessed on a comparative basis; 2) the study was conducted with fairly well-grown trees (8 years age) where the canopy must have developed reasonably fully, which is in contrast with almost all the other studies which have been conducted with young seedlings of trees during the initial phase of tree stand establishment; rightly speaking they are studies on 'establishment intercropping', and 3) this study brings out the important fact that exposure to full sunlight (as is obtained in the 'open' field), by itself, does not guarantee maximum yield, at least in the 2 legume crops studied, and emphasizing the yield improvement under partial shade. Besides, the tree loppings are an additional yield.

#### F. Gmelina arborea:

This is a pulpwood species, extensive plantations of which have been raised in Africa. The taungya system of establishing tree plantations has been widely used for this species (FAO, 1978).

In an agri-sylvicultural experiment conducted in southern Nigeria, (Ojeniyi and Agbede, 1980a) sole crop of Gmelina was compared with Gmelina intercropped with maize or cassava or yam or a combination of all the three annual crops. Gmelina was spaced 2.4 x 2.4 m and the food crops 1.2 x 1.2 m. Maize was harvested in 6 months, yam in 12 months and cassava in 15 months. The results indicated that the stem girth of Gmelina, as measured 30 months after planting, was smaller when intercropped with cassava (thereby justifying the exclusion of cassava cultivation in the forests of some countries). As regards the yields of the intercrops, the authors concluded (based on comparative data on sole crop yields for the annual crops obtained from long-cultivated and unfertilized shifting cultivation farms) that they were greater than those for sole crops. It must, however, be borne in mind that the soil was fertile, it having been cleared freshly of forest growth for the purpose of establishing the Gmelina plantation. In contrast, the soils of long-cultivated and unfertilized shifting cultivation farms must evidently be lower in fertility status.

Ojeniyi and Agbede (1980b) also reported that there was no significant change in the soil fertility, as a consequence of intercropping young Gmelina trees with maize, cassava or yam.

G. Cordia spp. and Cedrela spp.:

In the southern Pacific coast of Colombia small farmers intercrop the tree species Cordia alliodora and Cedrela odorata.

with banana, maize and cacao (FAO, undated). In forest plantation work also other species of these two genera had done well, in Mexico. Thus Cordia alliodora, Cedrela mexicana and Sweetgum were successfully raised through taungya with maize as the intercrop, in Mexico (FAO, 1978).

#### H. POPLARS and CONIFERS:

In an experiment conducted in Italy, a 5-year old poplar tree stand (Populus sp.) was subjected to different systems of treatment (intercropping), no intercropping but cultivation, no intercropping and no cultivation etc.). The intercrops used were maize, grass, legumes or cereals. It was observed that 6 years after planting the trees, intercropping as compared with cultivation, had no effect on tree growth and that cultivation for the first 4 years was advantageous (Sekawin and Prevosto, 1973).

In Peshawar (Pakistan) wheat was successfully intercropped in poplar (populus deltoides) planted at a spacing of 4.3 x 4.3 m and the height of the trees were from 6 - 10 m at the time of wheat harvest (Khattak and Sheikh, 1980).

In China, poplars, Cunninghamia lanceolata and Pinus spp. (P. massoniana, P. taeda or P. elliotii), particularly pines, are interplanted with tung oil trees (Aleurites sp.) which are intercropped concurrently with sweet potato, soybeans, groundnut, water melon or maize. The tung oil trees yield oil

from the 4th to the 10th year after which they are felled leaving the pine as the final tree crop. Intercropping is not only regarded as a tending operation to replace weeding but also as a multiple land - use practice for joint production of wood and food. Depending on crops and on the management skill, intercropping may yield 1.4 - 4.0 tonnes of food per hectare and in some places, 20 tons/ha of green leaves which are used for feeding animals (pigs) or as manure. The effect on the trees is very favourable (FAO, 1978).

Göller (1984) from West Germany reported results of an experiment in which winter rape (Brassica sp.) was drill sown between rows of conifer seedlings, following their transplanting at 30 x 10 cm. The rape was cut during the 2nd growing season and by the 3rd year the conifers formed a close canopy. The method successfully controlled almost all the weeds and saved 40% in weed control costs.

#### I. BAMBOOS:

The economic importance of bamboos has already been pointed out. However, bamboos planted at normal spacings, are not generally intercropped. Farmers, in general, hold the view that bamboos will allow no green plant to grow under them. This notion is strengthened by the common observation of the presence of a thick layer of dry bamboo litter marked by conspicuous absence of even weed flora in bamboo groves.

Further, it is well-known that the underground development of bamboos is very vigorous, marked by the presence of several knotted rhizomes and innumerable, long fibrous roots which are relatively superficial; in fact the ground surface inside a well grown bamboo grove is one continuous mat made up of a net-work of fine roots.

However, the author of the present investigation in the course of a survey in the Thanjavur district (Tamil Nadu State) came across a few farmers, very few though, who cultivate leafy vegetables (Amaranthus spp.) and vegetable nurseries, chiefly of brinjal (Solanum melongena) in the interspaces between clumps of the 'hollow bamboo' (Bambusa arundinacea), aged ca. 15-20 years. The soil is alluvial clay loam and the intercrops are raised under irrigation.

Andiyappan and Wilson (1963) described the successful artificial establishment of a plantation of Bambusa arundinacea bamboo in Udayarpalayam of Tirchirapalli district (Tamil Nadu), a dry locality, by the kumri (i.e., taungya) system. They reported that the kumridars (i.e., the taungya lessee farmers) intercropped the minor millet varagu (Paspalum scrobiculatum) and groundnut (Arachis hypogea) during the first year of the plantation. No further details are available on this.

Sheikh (1983) reported the results of a spacing experiment (2 x 2, 3 x 3 and 6 x 6 m spacings) conducted in Pakistan, on Dendrocalamus strictus (?) bamboo. During the first 5 years

after planting, intercrops of maize, berseem, and wheat were raised. But, after this, intercropping was possible only under the 6 x 6 m spacing because of the size of the bamboo clumps.

Patil (1980) conducted an intercropping experiment in Dendrocalamus strictus at Dharwar (Karnataka State). Five different intercrops - four fodder crops and one firewood -cum-small timber species - viz., Sesbania grandiflora, siratro (Macroptilium atropurpureum), Leucaena leucocephala, Lotononsis bainesii and Casuarina equisetifolia were tried in addition to a sole stand of the bamboo. There were, however, no pure stands of the intercrops concerned. Both the bamboo and the intercrops were planted simultaneously. Bamboo was spaced 1.5 x 1.5 m. The intercrops Sesbania grandiflora, Macroptilium atropurpureum, Leucaena leucocephala and Lotononsis bainesii were planted in a single paired row (spacing of 30 cm x 15 cm) between the rows of bamboo, such that the distance between an intercrop plant and the nearest bamboo seedling was 60 cm. Casuarina equisetifolia seedlings were planted in a single row at a spacing of 75 cm, such that each seedling occurred at the centre of a square whose four corners were occupied by four bamboo clumps. Thus, the distance between a casuarina plant and the nearest bamboo clump works out to 1.06 m. A uniform dose of fertilizers to supply 50 kg N, 30 kg P<sub>2</sub>O<sub>5</sub> and 30 kg K<sub>2</sub>O /ha was applied to the crops.

The results revealed the intercrops had no effect on the growth or DMP (dry matter production) of the bamboo as on 200 DAP (days after planting), the mean total DMP of the bamboo being 1.508 t/ha at this stage. As regards the intercrops, however, there was considerable variation (which is to be expected because of the differences in the sizes of the plants of different species whose growth rates vary) in their DMPs; Sesbania grandiflora produced the highest DM of 2.458 t/ha followed by Casuarina equisetifolia with 1.274 t/ha. The total biomass production also was naturally higher in the treatments involving these two intercrops.

2.2.3. General conclusions on trees + annual crops intercropping experiences:

From the foregoing review the following conclusions emerge:

1. Intercropping of annual crops between tree crops is fairly extensively practised, particularly by small farmers;
2. It is practised for the several well known advantages attendant on intercropping such as better use of the resources (land, water, nutrients, sunlight), risk avoidance or minimising, weed suppression, spreading labour demand peaks, soil conservation, feeding of livestock etc..
3. A variety of annual crops, mostly food crops and forage crops are involved;

4. In almost all cases, intercropping is practised only during the early stages of growth of the base crop of tree, which is termed 'establishment intercropping' (Hartley, 1977) as opposed to 'permanent intercropping', since the trees are planted at spacings optimum for them and not to suit intercropping specifically. In general, such 'establishment intercropping' is practised for the first 5 years only, by which time, the trees outgrow the intercrops and competition becomes intense;
5. The notable exception to this, is the coconut tree, which allows intercropping for two spells during its life span - initially upto 8 years after its establishment, and again from the 20th year after establishment onwards upto senescence. This is because, between 8-20 years the closed canopy casts intense shade, after which there is only high shade through which sunlight filters down;
6. It would therefore appear that tree + annual intercropping systems could be developed, provided the trees are wide spaced. In such case, maximum biological productivity can be aimed at by optimising the spacing and crops and their combinations. This area has not been touched by research as of date.
7. In almost all studies the aim had been to evaluate the influence of intercropping on the base crop of tree. Evaluations of the reciprocal relationship have suffered from the serious lacuna of not providing for an 'open' field treatment (i.e., sole crop of the intercrop concerned) and

8. The mechanisms underlying the relationships between the tree crop and the intercrop have not been investigated in depth.

### 2.3. MICROCLIMATE AND WATER USE

Rosenberg (1974) reported that in a soybean crop, the profile of dry-bulb temperature goes from sharply lapse during mid-day to an inversion condition in early evening and that vapour pressure profiles remain lapse throughout the day although the intensity of the gradients varies.

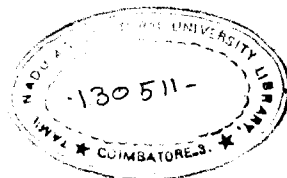
The influence of the crop cover on water relations have been studied in some detail. Brun *et al.* (1972) have shown that in soybean fields the proportion of water lost as transpiration is closely correlated to the LAI (leaf area index) with transpiration being approximately 50% of the total evapotranspiration at an LAI of 2. This proportion increases to 95% of the total evapotranspiration at an LAI of 4. Blanchet *et al.* (1977) in a pot experiment found that transpiration/unit leaf area to be almost a constant, with maximum transpiration, but water use (WU) varied; dry conditions decreased both leaf area and transpiration/unit leaf area. Total DM production was linearly related to WU. Seed production depended on water supply and on 'seed: total DM' ratio which was high when WUE was high. Among yield components the number of pods/stem was the most affected by water deficit.

Rosenberg and Powers (1970) compared soybean evapotranspiration under field conditions to pan evaporation. They found that during the period June 26 - July 26, 1969 the height of soybean increased from about 30 to 102 cm. On the 20 days uninterrupted

by rain or irrigation, the average daily lysimeter ET (mean of 2 lysimeters) was 8.33 mm/day and the pan evaporation was 6.39 mm/day or about 23% less than the ET. They concluded that free water evaporation need not always indicate the upper limit or PET (potential evapotranspiration) in sub-humid and arid regions, as it does, apparently, in humid regions.

Stanley and Shaw (1978) developed 'PET: open pan evaporation' ratio curves for soybean cultivars for their entire growth cycles. Results showed that a direct relationship existed between LAI and the ratio curves, with the maximum ratio curves being reached shortly after maximum LAI was reached.

Thompson (1978) who studied the effect of irrigation interval and plant population in soybean in a semi-arid environment concluded that the crop water use at an irrigation interval of 70 mm of pan evaporation of 786 mm or 75% of pan evaporation and that the peak demand for soil moisture coincided with the end of flowering to early pod-filling period. The estimate of Kadam et al. (1978) based on calculations from climatic data was, however, lower for soybean; it was 353.4 mm of consumptive use.



## 2.4. LIGHT RELATIONS IN SOYBEAN

### 2.4.1. Light intensities and photosynthesis in soybean:

Bohning and Burnside (1956) reported that a single soybean leaf reaches light saturation at approximately 2000 to 3000 ft-c. (or at about 23,680 lux, which is about 20% of full sunlight) and the compensation point was 100 to 150 ft.c. The estimates regarding light saturation intensity, of other workers were - 2000 ft.c. by Brun and Cooper (1967), 3000 ft.c. by Kriedeman et al. (1964) and 4000 ft.c. (or 43 Klux) by Curtis et al. (1969). A still higher estimate has also been reported; thus, Bowes et al. (1972) observed that the light saturation for excised leaves of soybean occurred approximately around a light intensity of 80 K lux. In all these cases, although there is a variation in the reported light saturation for individual leaves, in general the values were less than one-third of full sunlight. All these values were obtained on non-field-grown soybean plants.

Beuerlein and Pendleton (1971) based on field studies reported that, field-grown canopy plants became light saturated at 10,000 ft-c. (1,07,640 lux) but the leaves of widely spaced (76 x 76 cm) plants were not light saturated even at 15,000 ft-c. (1,61,460 lux). Evidently the behaviour of chamber-grown and field-grown soybean plants differ as regards their saturation behaviour to light intensities.

Soybean is a  $C_3$  plant assimilating  $CO_2$  by the Calvin cycle and is characterized as "non-efficient" since it saturates at low light intensities and has low maximum rates of photosynthesis (Black et al., 1969). But, Boves et al. (1972) stated that the foregoing opinion has been based on measurements made on chamber-grown soybean plants, adding that, since soybean is capable of photosynthesis at high rates and utilizing high light intensities when grown in full sunlight, it is likely that the differences between "non-efficient" and "efficient" plants in the field may not be as large as literature suggests. Recently, Baldocchi et al. (1984) reported that a developed soybean canopy with an LAI of 4.1 did not become light saturated at photosynthetically active radiation levels exceeding  $400 \text{ W/m}^2$ .

Zharkikh (1976) observed increased respiration intensity under reduced light intensity. Although lower leaves apparently are not parasitic to the plant (Shibles and Weber, 1965), it is likely that soybean productivity could be increased by increased lighting of lower leaves. Incidentally, as regards the influence of daylength soybeans are classified as 'short day plants'.

#### 2.4.2. Studies on response of soybean plants to alteration of light intensity (shading or enrichment):

##### (1) General observations:

Isbagio (1974) compared the growth and seed yields of soybean varieties during the dry and wet seasons and found that the wet season yield was significantly higher and was

closely and positively correlated with light intensity, when water was not limiting. Enyi (1973) who studied the effect of plant population (density) observed a severe yield reduction as a consequence of shading. Wail and Ohlrogge (1976) who also studied interplant competition in soybean divided the canopy into 5 different strata. They observed an interaction between canopy level (i.e., stratum) and plant density during the pod-filling period and stated that this might have been due to alteration in the pattern of translocation and due to the inability of the lowest leaves to respond to increased light intensity, provided by thinning the plants. A similar study involving the reduction of plant density and its influence on the remaining plants is that reported by Hiebach and Mc Collum (1980). They reported that the delayed removal of maize from a maize-soybean mixture decreased soybean yields by 50-75% of its monoculture yield. It was also observed that the gain in weight (28-96%) by the intercropped soybean during the reproductive stage was linearly related to the percentage of incoming photosynthetically active radiation.

(11) Growth and its parameters:

Ismail (1977) who studied the effect of shading on soybean (among other crops viz., maize, sorghum and sweet potato) reported shading had no effect on young plants, possibly because the trial was conducted during the wet season and because the plants were still very young.

(1) Height of plants:

Beuerlein et al. (1971) who studied the effect of branch removal and plant populations on the light use efficiency of soybean canopies, observed that while normal plants which had a light intensity of 45 to 60 ft-c. at ground level during the blooming stage, recorded an average plant height of 100 cm, while debranched plants which allowed more light to penetrate through them (50 to 120 ft-c. at ground level during blooming stage) were shorter (average 95 cm). Major and Johnson (1974) reported increased plant height and internode number as light intensity increased from 2 to 100 lux under a 24-hour day length regime established with incandescent flood lights. Asanuma (1977) tried 3 levels of shading (0, 48 and 76% reduction in light intensity) applied during different crop growth stages (bud formation, early, full or late flowering or young pod development). He observed that shading increased plant height. The effect was more pronounced with earlier and higher application of the treatment.

Wahua and Miller (1978) found that unshaded plants registering a height of 1.05 m were significantly shorter than plants subjected to graded levels of shading ranging from 20% to 93% shading. Under shade treatments, the height progressively increased from 1.26 m under 20% shade, to 1.41 m under 47% shade, 1.57 m under 63% shade to 1.81 m under 80% shade, after which it fell to 1.22 m under the highest degree (93%) of shading tried in the experiment.

Jeyaraman (1979) who compared sorghum-based cropping systems involving soybean also, observed that soybean recorded more plant height under the paired rows of sorghum system as compared to the uniform row system, and he ascribed this to competition for light. Rabie and Kumazawa (1979) studied the effect of continuous shading. They found that stems were markedly elongated in shade. Prine (1980) reported that shading prior to flowering caused severe elongation of some stem internodes and resulted in greater lodging than other shade periods.]

(2) Branching:

Kan and Oshmia (1952) reported light intensity of 50% of normal, reduced the number of branches and nodes. Johnston et al. (1969) experimenting with supplemental light (i.e., light enrichment) reported that light-rich plants had more nodes (39.6 nodes/plant as compared to 29.7 for normal plants; a 33.3% increase) and more branches. Asanuma (1977) reported that while shading increased plant height, it reduced the degree of branching as compared to the untreated control. Earlier application and higher degree of shading increased the effects. Wahu and Miller (1976) recorded decreasing number of branches/plant with progressively increasing shade, it being 5.40, 5.95, 4.35, 3.70, 2.45 and 1.00 per plant under 0 (full sunlight), 20, 47, 63, 80 and 93% shading respectively. It is evident that there is an increase in the number of branches/plant under light (20%) shading which had a light intensity of 9,200 ft-c. or 99 K lux.

Jeyaraman (1979) reported the number of branches/plant was more under a uniform row system (1:1) than under a paired row system (2 of sorghum:1 of soybean) of planting, in an intercropping trial. He ascribed the increase to less shading of the soybean intercrop by the base crop of sorghum, in the uniform row system.

(3) Leaf:

Euwerlein et al. (1971) reported that the average leaf area/plant was  $81.2 \text{ dm}^2$  in plants with normal canopies (which recorded a light intensity of only 45 to 60 ft-c. at ground level during the blooming stage) while it was reduced to  $42.4 \text{ dm}^2$  in debranched plants (which allowed more light to penetrate through the canopy such that the light intensity was 50 to 120 ft at ground level, during the blooming stage).

Ciha and Brun (1975) observed that the leaf area of the terminal leaflet of the third trifoliate leaf was reduced and the stomatal frequency increased on both surfaces, when the light intensity was increased from 19,300 to 32,300 lux. Peet and Kramer (1980) also experimented with chosen leaflets; shading of the side leaflets and illuminating the central ones showed that the rate of photosynthesis was higher in the unshaded leaflet and it was related to the mesophyll and stomatal conductance. They found there was a 6% reduction in LA (leaf s:

Wenkert et al. (1978) found that the rate of elongation of soybean leaves grown in the field was constant in diffuse light,

decreased immediately and recovered gradually on exposure to full sunlight, and increased rapidly when again in shade, so as to recover growth lost during periods of full sunshine. The reasoning of Jayaraman (1979) who studied soybean as an intercrop in sorghum, that the significantly higher leaf area recorded in the uniform row system (sorghum: soybean = 1:1) as compared to the paired row system (sorghum: soybean = 2:1) was due to more availability of sunlight in the uniform system, is in conflict with the numerous reports which state that it is under reduced light intensity leaf area increases.

Lugg and Sinclair (1980) examined seasonal changes in SLW (specific leaf weight) of soybean leaves. They concluded that the final SLW and leaf thickness obtained were modified by solar radiation levels during the period of leaf development. Boves et al. (1972) reported that the SLW was low at low light intensities and that high light intensities promoted the thickness of the leaf. Beuerlein and Pendleton (1971) reported that the SLW of widely spaced debranched plants was as high as  $0.54 \text{ g/dm}^2$  while that for closely spaced normal plant was as low as  $0.35 \text{ g/dm}^2$ . A strong correlation between SLW and apparent photosynthesis (AP) rate has been demonstrated by Dornhoff and Shibles (1970) in soybean itself.

Beuerlein et al. (1971) calculated the quantity "leaf efficiency" (LE) which is the number of grams of seed produced/ $\text{dm}^2$  of leaf area. They found that the de-branched plants (which

allowed more light to penetrate through the canopy) had a higher leaf efficiency (average 0.86 grams seeds/dm<sup>2</sup> leaf area) as compared to normal plants (average 0.47 grams seeds/dm<sup>2</sup> leaf area). Evidently, shaded leaves of soybean are less efficient.

(4) Root, nodules and nitrogen fixation:

Trang (1977) reported that roots were more affected than shoots, by shading. Several workers have studied the effect of light intensity on nitrogen fixation in soybean. Lawn and Brun (1974) reduced N<sub>2</sub> - fixation by imposing 50% shading but increased N<sub>2</sub>-fixation by supplying 25% more light to the lower leaves. Trang (1977) studied the effect of graded levels of shade (0, 18, 40 and 62% shade), in combination with different rates of N application. They found that both shading and N significantly reduced the number of nodules and total nodule weight. Mahua and Miller (1978) found that shading accelerated the loss of total nodule N<sub>2</sub>-fixing activity (TNA) as the soybean plants developed. The average TNA and dry weight of plant tops were highest at 20% shade (99.5% lux) and decreased curvilinearly as shading increased linearly. They concluded that cropping practices should allow at least 60% of ambient illumination measured at the height of 50 cm for substantial soybean N<sub>2</sub>-fixation. Eriksen (1978) who studied the effect of 4 light intensities (27, 45, 70 or 100% of full daylight) reported that acetylene reduction was lower only at 27% of daylight, in the case of soybean.

Rabie and Kumazawa (1979) observed in pot trials that nodule size and number were decreased by shading. In natural light, however, the highest values of nodule size corresponded to lower nodule numbers. Nitrogen fixation was decreased by shading as well as by N-application. Trang and Giddens (1980) also in pot trials involving 4 levels of shading (0, 18, 40 and 60% shading) and two levels of N application, observed that unshaded plants produced higher nodule mass and number of nodules than shaded plants. Tanaka *et al.* (1980) reported that shading nodulating and non-nodulating isogenic lines of soybean caused little reduction in  $N_2$ -fixation/unit nodule weight or N-uptake/unit root weight. The greater deleterious effect on symbiotic plants than on non-symbiotic plants supplied with N fertilizer was attributed to a greater reduction in the weight of nodules than of roots in response to shading.

Schweitzer and Harper (1980) experimented with light enrichment using foiled reflectors comparing it with black board reflectors as well as wire-mesh screen reflectors (to separate temperature and light effects). They reported foil reflector treatment increased nodule activity (i.e., acetylene reduction and delayed nodule senescence), as compared to the other treatments. They concluded that light penetration in a closed canopy environment may limit  $N_2$ -fixation by the root nodules and nitrate reduction by the leaves. Trang and Giddens (1980) stated unshaded plants produced more number of nodules, more nodule mass and N than shaded plants.

(5) DMP (Dry Matter Production):

The data of Beuslein et al. (1971) reveal that normal plants (i.e., without branch removal) recorded a higher dry weight of stem (average 47.2 grams/plant) as compared to de-branched plants (average 28.1 grams). The stem dry weight included the weights of the main stem + branches + petioles. The authors did not explain this difference of 68% in stem dry weights. Since branches also contribute to this weight, evidently, the de-branched plants recorded less weight and it is difficult to hazard any further explanation. Schou et al. (1978) reported that light enhancement using aluminium foil reflectors during late flowering and early pod formation, increased stem + fruit weight by 50%.

That DMP suffers under reduced light intensities is amply borne out by the results of several studies. Popescu and Axinte (1977) stated that the yield of aerial parts was decreased by decreased light intensity. Asanuma (1977) tried 3 levels of shading (0, 48 and 76% reduction in light intensity) imposing them during bud formation or during flowering (early, full or late flowering) stages or during late pod development. He found the DMP to be reduced by the two shading treatments, the depression being accentuated by higher shade and earlier application of shade. The DMP, however, increased after the treatment.

Wahus and Miller (1978) reported highly significant negative correlation between fresh as well as dry weights of

plant and shading. His data reveal that all the components of aerial dry weight, were progressively reduced as shading intensity increased. Thus, the dry weights of stem, leaves and pods per plant were 19.44, 24.44 and 21.44 grams respectively at full light (0% shade) whereas they were reduced to 12.88, 14.88 and 16.00 grams under 47% shade, and to 10.13, 10.38 and 13.94 grams under 63% shade, 5.25, 4.63 and 6.50 under 80% shade and finally, to a mere 1.63, 1.56 and 1.00 grams under 93% shade. These would represent reductions of 92% for stem, 94% for leaves and 95% for pods, under the 93% shading intensity as compared to corresponding values under no shading (i.e., full sunlight) which are taken as 100%. This clearly shows that severe shading curtails DMP severely. One interesting feature of the data is the stimulating effect of light (20%) shade. Surprisingly, this treatment had recorded higher values of DMP for all the 3 components of aerial parts, the increases (again, taking the value for unshaded condition as 100%) being + 9% for stem, + 4% for leaves and + 34% for pods. This would suggest some slight shading is actually beneficial to soybean as compared to growing it under full sunlight.

Schweitzer and Harper (1980) based on results of field trials reported that light enhancement using foiled reflectors increased total DM accumulation. While this result shows that supra-normal light increases DMP it conflicts with the results of Wehner and Miller (1978) reviewed above who found a slightly sub-normal light is beneficial. However, it is possible that

this discrepancy is due to differences in environmental conditions between the two experiments.

Some investigations show the possibility for mitigating, at least partially, the depressing effect of shade on DMP, through fertilizer application. Thus, Rabie and Kumazawa (1979) reported that shade-grown plants had low DM accumulation, but it could be compensated for by N application. Similarly Trang and Giddens (1980) in pot trials involving 4 levels of shading (0, 18, 40 and 60% shading) and 2 levels of N fertilization (0 or 30 ppm N as ammonium nitrate, applied at sowing) observed that plants with no shade (i.e., grown in full light) produced higher DM. They also observed the beneficial influence of N fertilization.

(iii) Yield parameters and Yield:

(6) Podding:

Catedral and Lantican (1977) reported that the number of pods/plant was reduced by 38% under shade (50% of full sunlight). Eriksen and Whitney (1977) observed that the number of pods/plant was reduced at low light intensities. Wahua and Miller (1978) observed the number of pods/plant to significantly differ under the 6 shade treatments, it being as low as 4.47 pods/plant under 93% shading, 31.50 under 80% shading, 51.10 under 63% shading, 69.45 under 47% shading, 98.03 under 20% shading and as high as 115.15 under 0% shading (i.e., no shading). A high negative correlation between number of pods/plant and shading was observed. Schou et al. (1978) using aluminium foil reflectors

enriched the illumination and found that the light-enriched (57% more light i.e., PAR) plants had 48% more pods/plant than the controls. Similarly, in another experiment, involving not only reflectors, but also black boards (with same position as the reflectors) they found that the number of pods/plant was increased by both the treatments - by 31% for reflectors and 28% for black boards, as compared to untreated controls. In both the experiments, the treatments were applied during the late flowering and early pod formation stages. In the second experiment, besides light enrichment (reflectors and blackboards), shading (53% light reduction) was also applied during the same periods as the other treatments. It was seen that the number of pods/plant was 16% lower than that for the control. All plants aborted 27.34% of pods. Asanuma (1977) in a shading experiment observed that the number of fertile pods/plant and dry matter production (DMF) at early and late flowering stages, were positively correlated.

Johnston et al. (1969) in a field experiment in which supplemental light was provided (by fluorescent lamps and white polythene strips spread on the ground) found that the light-enriched plants had 79.2 pods/plant while the normal untreated plants had only 55.5 pods/plant, an increase of nearly 43%. However, there were only marginal increases for light-enriched plants as regards the number of pods/node (3.2% increase) and the number of seed/pod (2.9% increase).

(7) Number of seeds/plant:

Johnston et al. (1969) who experimented with light enrichment using fluorescent lamps in combination with white plastic strips spread on the ground, reported that light-enriched plants had more number of seeds/plant (196 numbers) as compared to untreated normal plants (134 numbers). Guffy et al. (1981) applied shade treatments (approximately 60%) for 10 days prior to flowering, after flowering during initial pod development and during the linear phase of seed filling, in a field experiment. Pre-anthesis shade did not reduce the number of seeds/pod and had no significant effect on final seed size, seed growth rate (SGR) or effective filling period (EFP). Post-anthesis shade (during initial pod and seed development) did not reduce seed size, SGR or EFP. Linear phase shade did not significantly reduce the number of seeds/pod but the SGR was reduced and this was coupled with a longer EFP to produce seed equal in size to the control.

(8) Seed size:

In a light-enrichment experiment (field trial) Johnston et al. (1969) observed the 100-seed weight for light-enriched plants to be lower (14.8 grams) than that for the normal untreated plants (15.3 grams). Beuerlein et al. (1971) in a study on branch removal as a means of increasing the efficiency of light in soybean canopies, recorded a higher 100-seed weight (19.11 grams) for the debranched plants (which admitted more light through the canopy) than for the normal plants (17.88 grams). The

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results of the above two studies are conflicting since while in both studies light enhancement within the canopy has been achieved - in the first case through fluorescent lamps and white plastic strip reflectors and in the second case through canopy manipulation (i.e., branch removal) - the 100-seed weight was reduced in the second case. It is possible that the extra assimilates that became available in branch - removed plants, which otherwise would have been diverted for branch development, were responsible for increased seed weight in the second case. It is not clear whether the lower seed weight recorded in the study of Beuerlein et al. (1971) could be ascribed to the auto-shading of leaves in the normal canopy.

Results from experiments aimed at testing exclusively the effect of shading demonstrate that shading depresses 100-seed weight, excepting under certain circumstances. Thus Cathedral and Lantican (1977) reported a 12% decrease in 100-seed weight under 50% shading as compared to full sunlight. Again, the investigations of Wahua and Miller (1978) reveal that the 100-seed weight was highly significantly and negatively correlated with shade. The 100-seed weight was 13.27, 15.10, 15.77, 18.25, 18.50 and 16.24 grams under 93, 80, 63, 47 20 and 0% shade, respectively. It is seen that a certain amount of shading (20 and 47% of full light, in this case) actually increases the 100-seed weight (14% and 12% increase for 20% and 47% shading respectively as compared to full sunlight) even though more

intense shading reduces it progressively. This stimulating effect of light shade perhaps may be responsible for the conflicting evidences of the different experiments.

Quite apart from the intensity of shading, the time of imposition of shade appears to influence seed weight. Prine (1980) observed that shading at the pod enlargement stage usually resulted in increased seed weight, while later shading during the seed-filling stage resulted mainly in reduced seed weight with little change in seed numbers. Guffy et al. (1981) reported that pre-anthesis shade had no significant effect on final seed size and post-anthesis shade did not reduce seed size.

(9) Grain: stover ratio:

Schweitzer and Harper (1980) reported light enrichment with foiled reflectors increased the grain: stover ratio, as compared to black board and wire-mesh screen reflector treatments.

(10) Grain Yield:

Johnston et al. (1969) experimented with supplemental light (fluorescent lamps fixed at 3 canopy levels - 23, 46 and 69 cm above ground; additionally, spreading of white polythene strips on the ground for reflection of light). They observed that light-enriched plants yielded 4,132 kg/ha of seed as against 3,538 kg/ha for untreated (i.e., normal illumination) plants. Since lodging did not occur either in light-rich or check plots, the 17% yield increase was ascribed by them to more light being made available to the middle and lower leaves. Further, the response to light was more pronounced at the bottom and middle positions

where yields were increased by 30% and 20% respectively, as compared to corresponding levels in the normal (untreated) plants. As regards the yield in the top position of the canopy there was no difference between the treated and untreated plants since the light intensities there were almost the same.

In pot trials, Zharkikh (1976) observed that reducing the light intensity during the flowering-pod formation, as well as the pod-filling periods, produced a non-significant decrease in seed yields. Popescu and Axinte (1977) who conducted lysimetric studies tried 2 levels of illumination (68-75% and 100% of natural light). Seed yields were reduced under shading. The yields were 1.66 t/ha (86.5%), 1.88 t/ha (93.1%) and 2.08 t/ha (92.4%), for 3 different times of application of H, viz., during vegetative stage, at the beginning of flowering, and at pod formation; the figures within the parentheses indicate the yield under shade as a percentage of the corresponding yield in full sunlight. Wien (1977) reported 50% shade throughout the growth period (i.e., continuous shade) reduced grain yield by 50%.

Asanuma (1977) subjected soybean to 48% or 76% reduction in light intensity during bud formation, early, full or late flowering, or young pod development. Seed yields were reduced as compared to the unshaded control, and the effect was pronounced with higher degree and earlier application of shading. Cathedral and Lantican (1977) subjected 20 cultivars of soybean, among other

treatments, to two levels of light intensity (50% and 100% sunlight). While the unshaded crop gave 1.02 t/ha, the shaded (50% natural light) crop gave only 0.71 t/ha, which represents an yield reduction of 30%. Eriksen and Whitney (1977) grew soybean (besides bush bean and cowpea) under 4 light intensities (100, 70, 45 and 27% of daylight). They observed a significant yield decrease as the light intensity decreased and this was related to the reduced pod numbers/plant.

Eriksen (1978) studied the effect of shading on 10 different plant species, including 3 grain legume crops, using 4 light regimes (27, 45, 70 and 100% of full daylight). He found that seed yield of soybean was decreased with decrease in light intensity. Wahua and Miller (1978) using light transmission saran screens subjected soybean plants at the 4-trifoliolate leaf stage to 5 levels of shading (sunlight reduced by 93, 80, 63, 47 and 20%, the average ambient illumination being 124.2 K lux). They found that seed yield was highly significantly and negatively correlated ( $r = -0.93$ ) with shading, the grain yields under different shade levels being 2% (at 93% shade), 18% (at 80% shade), 48% (at 63% shade), 75% (at 47% shade) and 90% (at 20% shade).

In field trials Schou et al. (1978) studied the effect of light enrichment using aluminium foil reflectors and black boards positioned at 45° angle to the ground, as well as shades; on soybean growth and yield. The reflector treatments were established weekly, on the north side of E/W rows and increased amount of PAR (photosynthetically active radiation) received by

the plants, by 57%. In one experiment (1973) reflector treatment during the period of late flowering and early pod formation increased seed yields by 57% as compared to controls. In another experiment (1974) reflector treatment imposed during the same period as before (late flowering or early pod formation) increased the seed yield by 40% over the control. In this experiment a shade treatment (which gave a light reduction of 63%) was also included, which reduced the seed yield by 29% as compared to the control.

Schweitzer and Harper (1980) also studied the effect of light enhancement on soybean in field trials. Their experiment involved 5 treatments (1. light enhancement using foiled reflectors positioned on both sides of the row; 2. black boards, 45° on either side; 3. wire mesh screens, 45° on either side, to separate temperature effects from light effects; 4. accelerated floral induction; and 5. control). They found that seed yield was increased by the reflector treatment as compared to the other treatments and concluded closed canopy shading may reduce DM accumulation and seed yields.

An experiment in which the shade intensity was held constant but varying the duration of imposing the shade as well as the stage of crop growth at which such shade is imposed was conducted by Prine (1980). Three durations of shading (7, 5 and 0 days) of which one was zero (i.e., no shading, full light)

which served as control were tried. The shade was caused by stretching black plastic fabric which allowed about 25% light transmission. The shade treatments were applied during different stages of crop growth encompassing practically the entire life cycle. It was seen that shading reduced seed yields by 15%, the greatest yield reduction occurring when shading was imposed just prior to flowering, after flowering at the pod enlargement stage or during seed filling.

Guffy et al. (1981) also had studied the influence of the time of imposition of shade during crop growth, from 10 days prior to flowering up to the linear phase of seed filling. Their results have already been presented under 'seed size'.

Canopy manipulation as a means of increasing the efficiency of light through improved penetration, has also been experimented with. Thus Buerlein et al. (1971) attempted removal of all vegetative branches by clipping them with scissors when they were 3 to 8 cm long, combining this with 3 plant spacings (25, 30 and 35 cm). The light intensities recorded at ground level (among a total of 5 levels) were ranging between 45-60 ft-c. under the different spacings for the normal (i.e., no branch removal) plants, and between 50-120 ft-c. for the de-branched plants, at the blooming stage. At pod-filling stage, the light intensities were almost identical under both treatments, the differences having vanished. Grain yields (averaging over the 3 plant spacings) were 4,080 kg/ha for normal and 4,054 kg/ha

for de-branched plants, showing no difference due to treatments. However, there was an interaction between branch removal and plant spacing with de-branched 25 cm spacing plants recording the maximum yield of 4,397 kg/ha which would suggest that de-branching is helpful when the plant spacing is very close.

2.4.10. Summary of the review of investigations on shading:

The following broad conclusions are inferable from the foregoing review:

1. Information on the response of annual herbaceous plants has been gathered through indirect observations (e.g., yield differences under different climatic environments) as well as through direct observations.
2. Though in some intercropping experiments, information on light climate also may be recorded, the elucidation of the primary effect of light on the growth of the shaded plant is difficult. Experiments involving artificial shading using inanimate shades will furnish a more or less accurate picture of response of plants to shade.
3. However, the results of such artificial shade experiments suffer from the serious lacuna of simultaneously altering the other parameters also of the microclimate (for e.g., air temperature, relative humidity, soil moisture and soil temperature).

4. Many experiments involving both artificial shading as well as artificial enhancement of light reaching the canopy of an annual crop have been conducted, particularly during the last decade. Besides, a few experiments have been conducted on source: sink manipulations also.
5. All these experiments bring out the deleterious influence of reduced light intensity on plant growth.
6. However, a slight reduction in the intensity of light appears to exert a stimulating influence on plant growth, as is seen in the case of soybean. But, as seen in soybean, such stimulation of growth does not get reflected in yield.
7. The stimulatory effect is perhaps ascribable to reduction in  $CO_2$  and latent heat flux and moderation of temperature, and probably also to the avoidance of the destruction of the photosynthetic mechanism at extremely high levels of intensity, far above the light saturation point.
8. As regards soybean, the compensation point is around 1.1 to 1.6 K lux and light saturation, in a field-grown crop at normal spacing, appears to occur around 80 to 100 K lux.
9. In soybean, shading reduces the plant parameters- height of plant, number of branches, number of pods and seed size, appears to exert little effect on number of seeds, and increases leaf area. Root nodules are negatively affected by shade. DMP and final grain yield are reduced by shade.

## 2.5. INFLUENCE OF PHOSPHORUS ON SOYBEAN

As early as 1925 Ginsburg reported soybean when grown in culture solutions lacking in Phosphorus to produce non-viable seeds. Eaton (1950) described the effect of deficiency of P on the growth and metabolism of soybean. He reported that the plants were stunted, low in moisture content and the leaves were initially deep green in colour which subsequently became chlorotic and died. The deficient plants accumulated more carbohydrates and soluble N fractions due to interruption of protein synthesis, particularly at the amide stage. Bagaev (1953) confirmed the lack of P at the beginning of flowering reducing the protein synthesis.

### 2.5.1. Grain Yield:

#### (a) Response to applied P:

As early as 1918 Fellers observed a beneficial effect for the application of 100 to 120 lb  $P_2O_5$ /acre. Gandhi (1956) recommended a phosphorous dose of 60 lb/acre. Islam (1964) found P to increase grain yield upto a dose of 200 lb  $P_2O_5$ /acre. Miyasaka et al. (1964) reported an yield increase of 276% for P application. Subsequently they (Miyasaka et al., 1966) secured increased soybean yields for applications of 60 and 120 kg  $P_2O_5$ /ha. Anthony (1967) concluded that an annual application of atleast 45 lb  $P_2O_5$ /acre was necessary to keep up soybean yields. Singh and Singh (1968) got a linear response to applied phosphorus

upto 80 kg/ha. Jethmalani et al. (1969) recommended 80 kg  $P_2O_5$ /ha for profitable soybean yields. Singh and Saxena (1969) advocated the application of 100 kg  $P_2O_5$ /ha.

Tomar and Dev (1973) recorded grain yield increases of 33,86,100 and 123% over control for P application levels of 30,60,90 and 120 kg  $P_2O_5$ /ha respectively. Ravankar and Badhe (1975) obtained the highest yield with an application level of 80 kg  $P_2O_5$ /ha. Agerwal and Nerang (1975) applied P at 3 doses. (0, 40 and 80 kg  $P_2O_5$ /ha) in combination with N (0 or 20 kg N/ha). A maximum grain yield of 1.72 t/ha was obtained with 80 kg  $P_2O_5$ + 20 kg N/ha. Varieties differed in their responses.

Fauconnier (1976) studied the influence of both P and K each at 3 levels (0, 100 or 200 kg  $P_2O_5$  or  $K_2O$ /ha). Yield increased from 1.22 t/ha in the control (i.e., zero P) to 2.23 t/ha in the 100 kg  $P_2O_5$ /ha treatment but it decreased to 2.17 t/ha at the highest dose of 200 kg/ha. Ferrari et al. (1976) also studied the response to P and K besides Ca. Four levels of P viz. 0, 100, 200 and 300 kg of  $P_2O_5$ /ha were tried. They found that the grain yield increased significantly at several locations. They also observed a favourable Ca X P interaction.

Nogueira et al. (1977) studied the residual effect in the second year of application of 3 levels of P (100, 200 and 400 kg  $P_2O_5$ /ha) and of 4 different phosphate sources (natural phosphate, superphosphate, thermophosphate and triple phosphate).

They found as regards levels of application, irrespective of the P source, grain yield was higher with 400 kg  $P_2O_5$ /ha than with 100 or 200 kg. Further, as regards sources, grain yield was significantly higher with superphosphate. Rana and Chand (1977) who tried 4 levels of P (0, 40, 80 and 120 kg  $P_2O_5$ /ha) reported P application increased yields from 1.07 t/ha for control to 1.51 t/ha for the 40 kg level and to 2.03 t/ha for the 80 kg level; however, the yield declined after that, to 1.81 t/ha at the highest dose of 120 kg  $P_2O_5$ /ha. In this experiment a uniform dose of 20 kg N/ha had also been given. Sharma (1977) who studied the response of 3 cultivars to P at graded levels from 0 to 60 kg  $P_2O_5$ /ha as well as to N at graded doses of 0 to 40 kg N/ha, found a response to the application of 20 kg  $P_2O_5$ /ha but no response to  $\chi^N$  application.

Milanez et al. (1978a) in field trials at two localities studied the response to 3 levels of application of P (0, 80 and 160 kg  $P_2O_5$ /ha) besides to N and K at graded levels. In both the localities grain yield increased with application of P and also with the higher dose of application. The yield increases ranged from about 260% to as much as 606%. Again, in another experiment at 3 localities they studied the response to 4 graded levels of  $\chi^P$  (0, 60, 120 and 180 kg  $P_2O_5$ /ha) besides, to 3 graded levels of K and 2 of Ca (Milanez et al. 1978b). They reported grain yield was significantly increased to 269% and 367% over control by 60 and 120 kg  $P_2O_5$ /ha respectively.

Hampaih and Sinha (1979) reported grain yield to increase with increasing application of P from 0 to 60 kg  $P_2O_5$ /ha; However, even though the yield increased with the next higher dose (90 kg  $P_2O_5$ /ha) it was not significant. Souza et al. (1979) tried 8 graded levels of P (0, 30, 60, 90, 120, 150, 180 and 210 kg  $P_2O_5$ /ha) and compared to two methods of application (row application vs. broadcasting). Yield increased from 2.29 t/ha with no P application to 3.78 t/ha with 210 kg  $P_2O_5$ /ha application. Calculated rates of  $P_2O_5$  to give the highest yields were 177 kg/ha for row application and 152 kg/ha for broadcast application. Locational and varietal differences in response to applied P has been reported by Rolim et al. (1979) who tried 4 levels (0, 110, 220 and 330 kg  $P_2O_5$ /ha); however, applied P increased grain yield in all cases.

Cassman et al. (1981) found that unfertilized soybean recorded only 26% of the yield recorded with optimum P application. Touchton et al. (1981) compared rates and times of P application. Annual rates 0, 30, 60 and 120 kg  $P_2O_5$ /ha were adopted. Grain yield responded to applied P but there was no response primarily with the first applied increment; times of application did not affect yields. Bodrero and Racca (1981) studied the effect of different levels of P application ranging from 0 to 150 kg  $P_2O_5$ /ha (besides, varying levels of N as well as N + P) and reported yield responses to applied P of the order of 2.45 t/ha with 100 kg  $P_2O_5$ /ha and 2.85 t/ha with 150 kg  $P_2O_5$ /ha.

(b) Absence of response to applied P:

While positive response to applied P has been reported by a number of workers, reports are also not uncommon on the non-responsiveness of soybean to P application. Kurtz (1976) who reviewed response to fertilizer application concluded soybeans are relatively insensitive to direct fertilizer applications and improved soil fertility, the residual fertility levels after growing maize being adequate.

In field experiments on soils of low P and K, varieties responded significantly to K but not to P (De Mooy, 1965). Thompson and Brown (1967) applied a high dose of 900 lb/acre of a 0-20-20 fertilizer mixture to soybean. The high level of fertilizer did not increase yield during the treatment years, but generally increased it in the subsequent years. Patrascioiu et al. (1976) who tried total application/rotation of 3 levels of P (100, 200 and 400 kg  $P_2O_5$ /ha) found that soybean yields were not affected while the other crops (wheat and sugar beet) of the rotation gave yield increases to the P application. Lawrence et al. (1977) who tried 4 levels (0, 30, 60 and 90 lb/acre) in each of P and K found no significant difference between the treatments. Phillips and Bartleson (1979) who tried 4 levels in each of P and K (0, 30, 60 and 90 lb/acre of P or K) found that while there was an yield increase for K application, atleast in 2 years out of 5 years, there was no response at all to P application.

Definite yield depressions due to application of P also been reported. Thus Dunphy et al. (1968) found yield all varieties tested to be depressed by the highest level of P application. Similar tendencies of yield decline with applications of P beyond an optimum level have already been pointed out under section (ix) (a) - for e.g., Fauconnier, 1976; Rana and Chand, 1977. Even, the control plot out-yielding the P-applied plot has been reported. Thus, Shahidullah et al. (1979) who tried P+K combination each at 4 levels (0, 30, 40 and 50 lb/acre of  $P_2O_5$  or  $K_2O$ ) over a uniform dose of 40 lb N/acre, reported that the maximum yield of 478 kg/acre was recorded by the control (i.e., no PK) plot.

It is seen from the foregoing that response of soybean to P fertilization has been variable. One possible reason for this could be varietal differences. Remarkable differences in varietal response to applied P have been reported by several workers. Thus, at high doses of P, Howell (1954) found the variety "Chief" to respond favourably well in growth while another variety, "Lincoln" showed definite symptoms of P-toxicity. Howell and Bernard (1961) classified 44 soybean varieties as 'tolerant', 'slightly sensitive', 'intermediate sensitive' and 'very sensitive' according to their response to high concentrations of P. In a further study, Foote and Howell (1964) found increasing the P supply increased the uptake more in sensitive than in the tolerant varieties. They also found that the tolerance in the varieties

was largely due to reduced uptake. With the aid of intercropping, they found the genotypic difference influencing this tolerance behaviour resides in the roots.

Another possible reason for variable response is the level of soil P. From greenhouse tests Kamprath and Miller (1958) concluded that the soil P was the only factor giving indication of the probable yield of soybean. Welch (1963) stated that the native soil P always had a bearing on the response to applied P in many experiments; a yield response in soybean to applied P was obtained when the soil test showed less than 40 lb/acre of available P. In North Carolina Nelson and Hartwig (1948) obtained 6.4 bushels/acre on a low available P-soil as compared to 33.8 bushels/acre with added P. Bray (1961) showed that with 10 and 30 lb/acre of available  $P_2O_5$ , soybean yields would be 75 and 98% of maximum respectively. With the use of tracers, it was demonstrated by Krantz *et al.* (1949) and Welch *et al.* (1950), that in the early stages of growth, 70 to 100% of the plant-P may be derived from the fertilizer. Welch and his co-workers further indicated that the amount of plant-P derived from the fertilizer was inversely correlated with the soil-P level. When radio-active superphosphate was applied by Burrau *et al.* (1953) the plants near maturity had obtained about 25% of their P from the fertilizer in the case of a high-P soil and nearly 60% in the case of a low-P soil. In this case, even though there was response to the P level in the matter of total DM yield - the high P soil giving 38% more total DM than the control while the

low P soil gave an increase of only 9% over the control - there was no difference in the grain yield, it remaining the same at 32 bushels/acre.

(x) Stover yield:

Matrone et al.(1954) reported increase in yield of stover as well as improvement in the quality of its hay to P application. Singh and Singh (1968) found stover yield to increase with applied P. Hampiah and Sinha (1979) reported increasing yield of fresh fodder with P application from 0 to 60 kg  $P_2O_5$ /ha; further yield increase at 90 kg  $P_2O_5$ /ha level was not significant.

## Materials and Methods

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## CHAPTER 3

### MATERIALS AND METHODS

Three field experiments were conducted between August 1979 and July 1980 at the Coimbatore campus of the Tamil Nadu Agricultural University (TNAU). The three experiments were similar in essential features and only the seasons differed.

#### 3.1. Location and climate

The experiments were laid out in two adjacent fields - one (Fd.No. B-1) where the 'bamboo stand' was located and another (Fd.No. B-2) where the 'open field' was sited. The fields were under the control of the Department of Forestry of the TNAU, Coimbatore (11° N and 76° 57' E; 426.7 m altitude above m.s.l., average annual rainfall = 626 mm and mean maximum and minimum temperatures are 31°C and 18°C respectively).

#### 3.2. Soil type

The soil is a brown clay loam typical of the gardenlands of the Coimbatore tract, with moderate drainage. Composite soil samples collected initially from the fields were analysed for mechanical and chemical properties using procedures prescribed by Piper (1966), Subbiah and Asija (1956), Olsen et al. (1954) and Stanford and English (1949). The soil was of medium fertility, low in nitrogen, medium in phosphorus and high in potash. The soil reaction was <sup>slightly alkaline.</sup> The data on the soil are furnished in the table below.

Soil characteristics of the experimental field

## A. Mechanical analysis

Clay	..	30.28%
Silt	..	11.92%
Fine sand	..	30.65%
Coarse sand	..	27.15%

## B. Chemical analysis

Available N (kg/ha)	..	211.6
Available P <sub>2</sub> O <sub>5</sub> (kg/ha)	..	16.4
Available K <sub>2</sub> O (kg/ha)	..	305.2
pH	..	8.1
E.C.(m mhos/cm <sup>2</sup> )	..	0.2

3.3 Season

Three runs of essentially the same experiment were laid out during the periods shown below:

Intercrop (Soybean)

	sown on	harvested on
Experiment 1	18th Aug 1979	24th Nov 1979
Experiment 2	7th Dec 1979	6th March 1980
Experiment 3	18th April 1980	29th July 1980

These periods represent the wet season (August to November, which overlaps the two monsoons viz., Southwest and Northeast) for Experiment 1, the non-rainy Cold weather period (December to early March) for Experiment 2 and the dry hot weather period overlapping the onset of the SW monsoon (April to July) for

Experiment 3, and thus covered more or less a whole year as far as soybean cropping is concerned. Information coverage on bamboo, however, spanned a duration of 1 year and 8 months, starting from the time when the bamboo clumps were about  $\frac{3}{4}$  years of age and ending when they were about 5 years old.

### 3.4 Crops and varieties

The details of the two crops involved in this study, viz., bamboo (=base crop) and soybean (=intercrop) are furnished below.

#### 3.4.1 Bamboo

The species of bamboo used in the investigation was Dendrocalamus strictus Nees, commonly known as 'solid bamboo'. As of date there exist no varieties or improved strains in bamboos of India. Using the classification of Deogun (1937) it may be said that the bamboo used in the present study belongs to the "normal type".

The bamboo stand used in this study was established and formed as detailed below. The seeds were received from the State Silviculturist, Andhra Pradesh Forest Department, Hyderabad (Andhra Pradesh State) and the mother beds were sown on 29<sup>th</sup> April 1975 adopting a seed rate of 100 g/m<sup>2</sup>. The seedlings were outplanted on 19<sup>th</sup> August 1975 at the present experimental site by pricking them into transplant beds at spacings ranging from 30 x 30 cm to 60 x 60 cm where a bamboo nursery experiment involving 3 levels of spacing X 3 levels of N fertilization (0, 50 and 100 kg N/ha) was laid out. The N fertilizer was applied in two split doses, once on 30<sup>th</sup> October 1975 and again

on 8th April 1976. This experiment was partially concluded by mid June 1978 when its venue was shifted to another field.

The left-over bamboo seedlings were then thinned to a uniform spacing of 4.0 x 4.0 m immediately afterwards (in June 1978 itself) and the bamboo stand necessary for the present study was formed. This spacing of 4.0 x 4.0 m though rather close by the existing standards adopted by the Forest Department for bamboo plantations (where it is usually 6.0 x 6.0 cm) in Tamil Nadu, is a very close approximation of the spacings adopted by the farmers, particularly in the Thanjavur district where cultivated land is at a premium. Hence 4.0 x 4.0 m spacing was adopted while forming the stand. At this spacing, the stand finally consisted of 50 young and healthy clumps distributed in 5 rows running N/S of 10 clumps each. Allowing one 'guard row' of clumps all round (i.e., 26 clumps in all), there were available 24 experimental clumps in the centre (3 rows X 8 clumps) which were assigned to 4 replications X 6 treatments, as detailed under sections 3.5.2 and as shown in the layout plan (Fig.1).

During the period November 1978 to February 1979, a pilot experiment on intercropping (which is not discussed in the present report) was conducted at the present experimental site using both the bamboo stand as well as the adjacent open field, to standardise techniques. This experiment involved 2 intercrops

(soybean and cluster onion) X 3 levels of N fertilization (0, 50 or 100 kg N/ha). FYM at 12 1/2 t/ha was also applied uniformly to all the plots of the experiment in November 1978. The experiment, inter alia revealed that soybean is a suitable intercrop for bamboo. Under this experiment, urea was applied according to treatment schedule on 15th December 1978. After the completion of this experiment, the bamboo stand along with the adjacent open field was put under the present investigation.

#### 3.4.2 Soybean

Soybean cv. Co.1 (originally UGM - 20) was used for the intercrop. Breeder's seed of 95% germination was secured for this purpose. This strain was released in January 1980 for general cultivation. It is a selection from Thailand variety, erect in habit, photo-insensitive, resistant to stem fly and pod borer and moderately resistant to yellow mosaic disease. It is suited to both rainfed and irrigated conditions and can be grown throughout the year and thus is capable of being fitted in any crop rotation. It has a duration of 85 days and an average yield potential of 1,640 kg/ha under irrigated conditions and 1,085 kg/ha under rainfed conditions. It has 40-45% protein and 20-25% oil contents (Ayyamperumal et al. (1980).

#### 3.5 Experimental details

All the 3 experiments were similar in treatment details and differed only in the number of parameters studied besides the season.

### 3.5.1. Lay out

The effect of adjacent plot shading cannot be eliminated if bamboo plots were to be located side by side of the 'open' plots which would occur in a conventional layout adopting randomization of plots mixing both the 'bamboo' and 'open' plots. Increasing the plot sizes such that the shading by the tall bamboo clumps is confined to the periphery of an adjacent 'open' plot is also impracticable since the plot size will become prohibitively large. For example, the shade cast by a bamboo clump of 3.5 m height will extend to a horizontal distance of 6.0 m on the ground at 8.00 AM and 4.00 PM, assuming sunrise and sunset at 6.00 AM and PM respectively, since at 8.00 AM and 4.00 PM the solar elevation is  $30^\circ$  and  $\tan 30^\circ = 0.5774$ . This would mean that an 'open' plot surrounded on all sides by 'bamboo' plots (which possibility cannot be ruled out in randomization) will need a border strip 6 m wide all round, over which shading may occur during the early hours of the morning and late hours of the evening. If it is assumed that a shade-free zone (between 8.00 AM and 4.00 PM) of 4 m x 4 m is used for evaluating the performance of the soybean under 'open' conditions, then, the gross plot size will become 16 m x 16 m. With 12 treatments totally and 4 replications, the land requirement for the experimental portion alone will then work out to 1.23 ha. This in its turn will accentuate the natural soil heterogeneity variation as the distances between similarly treated plots increase very much, thereby reducing precision. Considering all these it was



decided, in consultation with the Statistician, to separate the 'bamboo' plots from the 'open' plots and keep all the bamboo plots in one contiguous block (the 'bamboo stand') and similarly have all the 'open' plots in one contiguous block in an immediately adjacent field (the 'open field') with a buffer strip of 6 m between them (vide layout plan in Fig.1). The shade buffer zone comprised an alleyway and one plot deep outskirts of 'open' field.

### 3.5.2. Treatments

The basic aim of the study was to explore the feasibility of raising soybean as an intercrop within a young stand of bamboo clumps; additionally it was aimed to investigate whether the vigour of growth of the bamboo clump exercised any influence on the performance of the intercrop and whether deleterious influence if any, exerted by the bamboo clumps on the intercrop could be ameliorated through phosphorus fertilization since application of phosphorus has been reported to offset some of the adverse effects of low light intensity in cowpea by Tarila *et al.* (1977). Hence the following 3 factors were included in the study. Symbols used for the treatments are furnished within brackets.

(a) Environment (E) - 2 levels;

(i) Within the bamboo stand ( $E_1$ )

(ii) In the open field ( $E_2$ )

(b) Vigour of the bamboo clump (V) - 2 levels;

(i) Low vigour clump, i.e., a clump having 5 or less number of culms at the start of the study (L)

- (ii) High vigour clump, i.e., a clump having 6 or more number of culms at the start of the study (H)
- (c) Phosphorus fertilization (P) - 3 levels:  
 (application done thrice, one for each of the three experiments)
- (i) 0 kg  $P_2O_5$ /ha (i.e., no phosphorus) ( $P_0$ )  
 (ii) 100 kg  $P_2O_5$ /ha ( $P_1$ )  
 (iii) 200 kg  $P_2O_5$ /ha ( $P_2$ )

It must be noted that while a sole crop of soybean (i.e., the 'open field' crop) was included in the study to assess the performance of the intercrop by comparison, there was no sole crop of bamboo since the aim of the study was only to examine the feasibility of 'establishment intercropping' within a bamboo stand through evaluation of the influence of the bamboo clumps on the associated intercrop of soybean and not to investigate the reciprocal relationship. Obviously, a study of the influence of an intercrop, raised even only for a short time in the early years, on the growth and subsequent performance of a very long duration crop like bamboo will have to extend for several years and thus is clearly beyond the scope of the present investigation.

#### 3.5.2.1 Rationale underlying the grouping of bamboo clumps based on the number of culms:

It is well known that in natural stands of bamboos the growth of individual clumps of even age vary much, even within the same locality. This variation is presumably an expression

of the genetic heterogeneity. The variation remarkably manifests through some important parameters such as the height and diameter of individual culms in a clump as well as the number of culms in a clump. The size and spread of the crown as well as the density of foliage also varies depending partly on the above mentioned variables. This in turn will influence the extent and degree of ground shading which eventually will affect the growth and performance of any associated intercrop. Hence, it was decided to study this aspect as well, by classifying the available clumps into two vigour classes - low and high vigour respectively.

For effecting such a classification, the choice of parameters was considered first. For this purpose, a preliminary enumeration of all the clumps was carried out just before the start of the investigation. A scrutiny of the data revealed that the mean height of the 24 experimental clumps (based on the heights of all the individual culms in each clump) was 2.91 m with a C.V. of 22%. However, the variation in heights of individual culms within any one clump fluctuated very much and the C.V. was even as much as 53% in one case. This wide variation evidently is due to the differences in age of individual culms. Hence it was concluded that while the heights of individual culms varies wildly and thus is not a reliable measure of the growth vigour of a clump, the mean heights of clumps (averaging over all the culms within a clump) of similar age does not show so much variation. In other words, while the height of

individual culms is unsuitable as a measure of the vigour of a clump, the stature of a clump as a whole is more or less similar to any other clump belonging to the same population and of similar age, and thus, it also cannot be very useful for classifying bamboo clumps into vigour classes. Hence, height as a parameter of classification was discarded. Similarly, culm diameter also is highly variable within the clump itself, it being essentially a function of the hierarchical position (i.e., the generation to which the rhizome that gives rise to the culm, belongs, which in turn decides the rhizome's and thus the culm's thickness; in general younger the generation, thicker the rhizome and thus the culm) of the culm. Besides, culm diameter per se has not much direct role to play in overhead shading. Hence, this parameter also was discarded.

The number of culms/clump, on the other hand, besides evidently being a measure of the state of vigour of a clump, also has a direct role in competing with an associated plant species. It is obvious that more vigorous is the subterranean rhizome and root system, more number of culms are produced above ground. The presence of more culms with attendant more foliage will evidently produce more photosynthate, upto an optimum level, and thus lead to production of still more culms, which incidentally constitute the major part of the sink. Thus, the number of culms/clump is a logical measure of the vigour of a clump. Besides, it is also a commercial parameter of the value of a clump.

From the point of competitive effect on an associated annual crop also, which alone is of immediate interest to the present study, the 'number of culms/clump' is important. Firstly, a clump with more number of culms occupies a greater land area than one with lesser number of culms, and thus reduces the inter-space available for intercropping, thereby reducing intercrop yields on an unadjusted land area basis, i.e. in absolute terms. Secondly, a larger clump has a longer perimeter and thus any deleterious effect exerted by the clump (for e.g., root competition, allelopathy etc.) will be more severe than that for a clump having lesser number of culms. Thirdly, normally the density of the crown (branches and foliage) will be more for a clump with more number of culms than for one with less number of culms. Hence, shading effect will be more intense. Lastly, a large clump will abstract more nutrients and soil moisture and thus the effect on the associated inter crop will be more intense. On these considerations, the number of living culms/clump was chosen as the parameter for classifying the experimental clumps into two vigour classes.

A scrutiny of the above mentioned data revealed that the mean number of living culms/clump was 7.00 with a C.V. of 55%. A detailed study of the data indicated that it would be best to take 6 living culms/clump as the cut-off point as it involved the least disturbance to the stand while furnishing two equal-sized groups of 12 clumps each and naturally randomized. A few minor adjustments were made in border-line cases, by felling one oldest

culm/clump (3 cases) or replacing a whole clump (2 cases) with a suitable clump as dictated by the randomization plan of the layout, in July 1979. The clumps for whole clump replacement were derived from the outskirts and they were lifted with the greatest care without injuring the underground systems and shifted to their new sites, hardly a few metres away. They established very quickly. Thus, the final stand as per the layout plan was established.

It is to be noted that this classification into 'low' and 'high' vigour clumps, strictly speaking, is applicable only to the initial phases of the study, for it is likely that a particular clump may pass on from one category into another as time passes on. However, as measured over a relatively short period of time, say an year, as in the case of the present study in so far as the intercropping is concerned, the classification is most likely to be stable and thus valid from the standpoint of interpreting the effects on the intercrop.

#### 3.5.2.2 Pre-treatment of crowns of bamboo clumps:

Since in this study the effect of shade cast by the bamboo on the performance of the associated intercrop is an important aspect and wide variation was met with in the heights of individual culms with possible consequent <sup>S</sup>making effects on the study of the effect of the clump's vigour, an initial constantizing of the heights of clumps was carried out. For this, any branch or culm tip projecting beyond 2.5 m was clipped such that the height of all the clumps was 2.5 m only. This eliminates

the effect of 'tall shade' vs 'low shade'.

Similarly, a light pruning of side branches was carried out in the case of a few clumps with very long lateral crown spreads, such that all the experimental clumps were of a comparable size. For this purpose, a rope knotted at a length of 5 m, was circled round the crowns of the clumps at a height of 1.5 m above ground, such that the diameter of the crown was about 1.6 m. Any lateral branch projecting beyond this was clipped off. The result was the crown diameters ranged from a minimum of 0.95 m to 1.6 m and thus the crowns were more or less comparable.

These pre-treatments were carried out only at the start of the first experiment. Subsequently no vertical or lateral pruning was done till the final harvest of the culms.

### 3.5.2.3 Choice of P levels

From the review of the different experiments on P fertilization of soybean (under section 2.5) it is seen that the maximum dose of P fertilizer used by the earlier experimenters had ranged from about 60 kg (Sharma, 1977) to 400 kg (Nogueira et al., 1977) of  $P_2O_5$ /ha. However, the majority had used a maximum dose ranging from 80 kg to 200 kg  $P_2O_5$ /ha. Thus, 80 kg had been used by Jethmalani et al. (1969), Agarwal and Narang (1975) and Ravankar and Badhe (1975), 84 kg by Roy and Mishra (1975), 100 kg by Singh and Saxena (1969), 120 kg by Miyasaka et al. (1966), Tomar and Dev (1973), Rana and Chand (1977)

and Milanez et al. (1978 b), 135 kg by Fellers (1918), 160 kg by Milanez et al. (1978 a) and 200 kg by Thomson and Brown (1967) and Fauconnier (1976).

It is also seen from the foregoing, that all the Indian workers had used a maximum dose ranging from 80 to 120 kg  $P_2O_5$ /ha. Further, decline in soybean yield with P fertilization beyond an optimum dose has also been reported. Thus, Fauconnier (1976) found the yield to decline at 200 kg  $P_2O_5$ /ha and Rana and Chand (1977) working under Indian conditions, found the yield to decline even at 120 kg  $P_2O_5$ /ha. Taking all these into consideration, the maximum dose of P fertilization was fixed in the present study, as 200 kg  $P_2O_5$ /ha adding two lower levels, viz., 100 and 0 kg  $P_2O_5$ /ha. It is to be noted that the P fertilizer application was done to each one of the soybean crops of the three experiments.

#### 3.5.2.4. Treatment combinations

As could be seen, there is a basic difference between the two environments  $E_1$  and  $E_2$ ; in fact, it is the presence of the bamboo clumps on the land, that constitutes the  $E_1$  environment and distinguishes it from  $E_2$ . Hence, the recognition of vigour classes in the bamboo clumps is possible only under  $E_1$ . However, P application is common to both environments. Thus, V X P interaction arises only under  $E_1$ . Hence under environment  $E_1$  alone, the 2 levels of vigour of the bamboo clump (viz., L and H) were combined with the three levels of P application (viz.,  $P_0$ ,  $P_1$  and  $P_2$ ) yielding 6 treatment combinations.

As regards the open field ( $E_2$ ) environment, however, there were only the 3 P levels ( $P_0$ ,  $P_1$  and  $P_2$ ) and since bamboos are absent here, and thus the V factor, no combination arose. Hence there were only 3 treatments. However, for the sake of uniformity, under  $E_2$  environment also 6 plots were formed under each replication, notionally taking the 'vigour' factor also to arrive at the hypothetical 'V' X P combinations and assigning them to corresponding positions in the layout, duplicating the randomization adopted for the bamboo stand ( $E_1$ ) (see the layout plan, Fig.1). While performing statistical analysis, however, this notional distinction into 'L' and 'H' was ignored (in the case of  $E_2$  alone) and corresponding P level treatments were pooled and averaged.

### 3.5.3. Replications and number of plots:

Four replications were used throughout. There were 48 plots in all, 24 for each environment.

### 3.5.4. Designs and statistical analyses.

The designs and structures of analyses of variance were decided in consultation with the Statistician.

#### (a) Data on the intercrop (soybean):

Since there is a variation in the number of factors involved, between the two environments, they were considered as two separate sub-experiments, analysing their data separately using the appropriate analysis of variance. Then, a third analysis of variance was carried out pooling the two environments. This was done for each one of the parameters studied.

In the case of the bamboo stand ( $E_1$ ) environment both the factors, vigour of the bamboo clump (V) and phosphorus application (P) are involved. Hence, in this part of the analysis, not only the main effects V and P were elucidated but also their interaction V X P. The design for this therefore was a factorial RBD.

As for the open field ( $E_2$ ) environment, only one factor viz., phosphorus application (P) was under study. Hence the effect of this alone is deducible and the design was a simple RBD.

Since the principal objective of the present investigation is to compare the performance of soybean under two distinct environments, a pooled analysis was then carried out combining the data from the two environments, the design being a factorial RBD. In this analysis, the main effects of the environment factor (E) as well as that of phosphorus application (P), besides their interaction E X P were elucidated.

The structures of the three analyses of variance are shown below.

(1) Anova for 'within the bamboo stand'

( $E_1$ ) environment:

<u>Source</u>	<u>d.f.</u>
between replications	3
between vigour levels (V)	1
between phosphorus levels (P)	2
Interaction V X P	2
Error	15

(ii) Anova for 'in the open field' ( $E_2$ ) environment:

<u>Source</u>	<u>d.f.</u>
between replications	3
between phosphorus levels (P)	2
Error	18

(iii) Anova for pooled analysis, combining the two environments,  $E_1$  and  $E_2$ :

<u>Source</u>	<u>d.f.</u>
between the environments (E)	1
between phosphorus levels (P)	2
Interaction E X P	2
Error (Pooled)	33

(b) Data on the base crop (bamboo clumps):

The 24 experimental clumps were distributed among the 4 replications and 6 treatment combinations, at the rate of 1 clump/treatment, as mentioned already. The design was a factoria RBD. The structure of the analysis of variance used is shown below:

<u>Source</u>	<u>d.f.</u>
between replications	3
between vigour levels (V)	1
between phosphorus levels (P)	2
Interaction V X P	2
Error	15

(c) Statistical scrutiny:

For soybean crop alone there were 120 sets of observations. At the rate of 3 analyses of variance per set, a total of 360 analysis of variance were performed. For bamboo crop, 55 analyses of variance were performed. Thus, a total of 415 analysis of variance were carried out, the results of which are presented in Tables 1 to 33.

In addition, using the computer facility available in the University, simple correlations were worked out between growth and yield attributes and yield, for the data gathered from the single sample plants. These represent the data for 3 stages of growth, viz., 30, 60 and 90 DAS of the 3 experiments. The two environments ( $E_1$  and  $E_2$ ) were considered separately in working out these correlations. The 346 correlations so calculated are presented in Appendices 4 to 12. Simple correlations were worked out for the soil moisture data also. These relate the grain yield of soybean (single sample plant data) with soil moisture as at 5 different stages of growth, viz., initiation of flowering (33 or 36 DAS), flowering (47/48 and 54/55 DAS), pod formation (68/69 DAS) and early seed formation (76 DAS). These correlations, numbering 20 (correlations between stages themselves being meaningless and thus ignored) are presented in Appendices 13 and 14. Thus, a total of 366 correlation coefficients were worked out.

Besides, two separate multiple linear regression equations, one for the bamboo stand ( $E_1$ ) and another for the open field ( $E_2$ ), were fitted for the soybean single sample plant data of Experiment 3 as on 30 DAS. These related the grain yield of soybean to 8 variables. The prediction equations with the X terms in the original units of measurement, the 'standardised partial regression coefficients' (i.e., Beta values) which are unitless and thus enable a straight-forward evaluation of the magnitude of relative contribution of any one variable towards yield, when the other variables are held constant, the 'multiple coefficient of determination' (i.e.,  $R^2$ ) which is a measure of the total contribution of all the independent variables put together, towards yield, and the R value, which measures the correlation between the predicted yield and actual yield, are presented in Appendix 15.

#### 3.5.4. Plot sizes, spacings and plant populations

##### (i) Plot sizes

	<u>for soybean</u>	<u>for bamboo</u>
Gross	= 3.75 X 3.53 m	4.0 X 4.0 m
Net	= 3.25 X 3.30 m	4.0 X 4.0 m

##### (ii) Spacings

25 x 11.75 cm	4.0 X 4.0 m
---------------	-------------

(vide section 3.6 (iii))

##### (iii) Populations per plot (Experimental) at the start of the study

(a) in $E_1$ = about 358 @	1
(b) in $E_2$ = 364	-

- ⑥ - The reduced population in  $E_1$  is because of the space occupied by the bamboo clump which was located in the centre of the plot. Further, this figure of 358 was true only at the beginning of the study. In the two subsequent experiments the soybean populations in  $E_1$  environment at planting were reduced further because of the progressive expansion of the areas occupied by individual clumps. Care, however, was taken to sow as many seed holes as possible in the  $E_1$  environment and as close as possible to the clumps. Comparability was ensured by final population counts, i.e., at the time of harvest. In both environments each gross plot had 15 sowing lines running E/W, each with 30 seed holes. In both cases, one row of plants all round was excluded treating it as a border row.

### 3.6 Cultural details

The cultural details were essentially similar for all the 3 runs of the experiment.

#### (1) Land preparation:

At the commencement of each experiment the interspaces between the bamboo clumps were manually dug up with manutti, care being taken to avoid any injury to the bamboo rhizomes.

This digging was confined to a depth of 15 cm. However, superficial roots of the bamboo clumps occurring within this depth were severed by the digging, even though such damage was not much as could be judged ocularly. Albeit it was possible to plough the open field ( $E_2$ ), still it was also manually dug to maintain comparability. After the clods were broken and the plots levelled, beds and channels were formed according to the layout plan.

(ii) Fertilizer application:

No organic manure was applied during the tenure of the study to any of the plots. Similarly no nitrogenous or potassic fertilizers were applied. Hence, only phosphatic fertilization through basal application of single superphosphate analysing 16% water soluble  $P_2O_5$  was applied, and that too only to the concerned plots according to the treatment schedule. The superphosphate application was repeated for each one of the 3 experiments, i.e., it was applied first during August 1979, again in December 1979 and again during April 1980. The fertilizer was applied as a pre-plant application, just before sowing the seeds, as basal dressing along the sowing lines at a depth of about 5 cm.

(iii) Seeds and sowing:

Soybean seeds were sown in lines 25 cm apart, and 11.75 cm apart in the line at the rate of 2 seeds per hole and subsequently thinned by about the 15th day to single seedling/hole. The spacing adopted in this study allows 295 sq.cm of land area/plant, which is very close to that obtained under the normally

recommended spacing of 30 x 10 cm (=300 sq.m). The spacing used in this study is more close to a square than that of 30 x 10 cm spacing, besides permitting the sowing lines to approach the centrally located bamboo clump in each plot, thereby increasing land utilization.

(iv) Irrigation

The crops were given weekly irrigations except during rainy season. Irrigation was done to a depth of 5 cm/irrigation.

(v) After cultivation

One hand weeding and another hoeing and weeding during the crop season was given to each soybean crop. Plant protection measures when needed were carried out.

(vi) Cleaning the bamboo clump

As already mentioned the bamboo clumps were given an initial pruning at the start of the study, in August 1979. Subsequently, the bamboo clumps were left untouched excepting for light cleanings near the base, to facilitate sowing at the start of Experiments 2 and 3. Such cleaning involved merely the clipping of projecting side branches from ground level upto a height of 1 m and removal of any dead culm.

(vii) Harvesting:

(a) Soybean:

At the end of each experiment, the border rows in each plot were first harvested and then the net plot was harvested separately. Harvesting was done by pulling out the plants and

then cutting them at the collar. After recording the fresh weights of the roots and aerial parts separately, the pods were separated. After two days of withering the grains were separated by hand thrashing and after further air drying to a constant moisture content of 14%, grain yields/net plot were recorded. Simultaneous with harvest, data on final population/net plot were also recorded.

(b) Bamboo

Normally bamboos are exploitable from the 5th year onwards. The culm yields will, however, be low initially and will increase progressively as years pass, till it stabilizes. In the case of the present study the clumps (planted on 19th August 1975) were subjected to selective felling of culms from 27th June to 23rd July 1981, i.e., about 5 3/4 years after out-planting. Assuming the mean date of harvest as 10th July 1981, the first harvest of culms was carried out 2152 days after planting (DAF) and about an year after the harvest of the soybean crop of Experiment 3.

Harvesting was done by selectively felling the culms in a clump. The felling rules adopted were a felling intensity of 50% (on the number of living culms present in a clump at the time of harvest) and avoiding the felling of culms aged 1-year or less. 'Selective felling' as used in the present study refers to deliberately choosing the culms to be felled in a clump. These

were the larger diameter culms. For this purpose, first, basal diameters of all the living culms of 1-year or more age in a clump, were enumerated. Then the culms were felled in a descending order of culm diameter till half the number of the total number of living culms in that clump was reached. The other half of the living culm population in the clump were left untouched; these culms naturally were the thinner ones and thus older culms. The culms were cut with a sharp cut at a height of about 15 cm from the ground, i.e., above the first visible node. Immediately after harvesting, detailed biometric observations were recorded on the felled culms.

### 3.7 Observations recorded

Data were collected on the following 6 different aspects.

- a) Data on the soybean crop
- b) Data on the bamboo crop
- c) Data on prevailing light intensity
- d) Data on microclimate
- e) Data on soil moisture, and
- f) Data on weed infestation

As regards the data on the soybean crop, information was collected both through sampling as well as on the net plot population as a whole. Sampling was done for recording observations on growth characters, yield characters and yield of single plants. The net plot was considered for recording data on the final plant population, grain yield and biomass (roots +

tops). In the case of Experiments 1 and 2 the same tagged plants were used for biometric data over the entire period of the crop concerned, and were pulled out only at the time of harvest of the entire plot, recording the sample plants' grain yields separately. However, in the case of Experiment 1 alone, in addition to the above, other sets of random plants were used for estimating leaf areas only; these destructive samples were drawn on two occasions (40 and 80 DAS).

In Experiment 3, however, sets of random sample plants were drawn by pulling them out, on 6 different occasions during the crop growth period. However, all the 30 sample plants in each plot which had been selected for pulling out, at the rate of 6 plants/stage over 6 stages, were labelled from the start of the experiment, and observations were recorded at every stage, on all the sample plants standing at that stage including those that were pulled out at that stage, as well as on those that were allowed to remain further. The details of the observations recorded are furnished below.

### 3.7.1 Observations on soybean

#### 3.7.1.1 Data recorded on sample plants

##### A. Growth parameters

1) Height of plant (cm) (base to tip)	Experiments for which data was recorded
a) 30 DAS	1,2,3
b) 40 DAS	3
c) 50 DAS	3
d) 60 DAS	1,2,3
e) 70 DAS	3
f) 90 DAS	1,2,3

	Experiments for which data was recorded
ii) Diameter of stem, at base (mm)	
a) 30 DAS	1,2,3
b) 40 DAS	3
c) 50 DAS	3
d) 60 DAS	1,2,3
e) 70 DAS	3
f) 90 DAS	1,2,3
iii) Number of branches/plant	
a) 40 DAS	3
b) 50 DAS	3
c) 60 DAS	2,3
d) 70 DAS	3
e) 90 DAS	2,3
iv) Number of leaflets (total)/plant	
a) 30 DAS	1,2,3
b) 40 DAS	1, 3
c) 50 DAS	3
d) 60 DAS	1,2,3
e) 70 DAS	3
f) 80 DAS	1
g) 90 DAS	1,2,3
v) Leaf area (total)/plant (cm <sup>2</sup> )	
a) 30 DAS	3
b) 40 DAS	1, 3
c) 50 DAS	3
d) 60 DAS	3
e) 70 DAS	3
f) 80 DAS	1
g) 90 DAS	3

Experiments for  
which data was  
recorded

vi) Length of taproot/plant (cm)

a) 30 DAS	3
b) 40 DAS	3
c) 50 DAS	3
d) 60 DAS	3
e) 70 DAS	3
f) 90 DAS	1,2,3

vii) Number of root nodules/plant

a) 30 DAS	3
b) 40 DAS	3
c) 50 DAS	3
d) 60 DAS	3
e) 70 DAS	3
f) 90 DAS	3

viii) Dry matter production (DMP) (grams/plant)

a) 30 DAS	3
b) 40 DAS	3
c) 50 DAS	3
d) 60 DAS	3
e) 70 DAS	3
f) 90 DAS	3

B. Yield parameters and yield

1) Number of flowers/plant

a) 40 DAS	3
b) 50 DAS	3
c) 60 DAS	3

Experiments for  
which data was recorded

ii) <u>Number of pods/plant</u>	
a) 50 DAS	3
b) 60 DAS	1,2,3
c) 70 DAS	3
d) 90 DAS	1,2,3
iii) Number of grains/plant	1,2,3
iv) 100-grain weight (grams)	1,2
v) Single sample plant grain yield (grams/ plant)	1,2,3

Besides the above, the following derivatives were also  
computed and analysed.

i) <u>Mean leaf area/leaflet (cm<sup>2</sup>)</u>	
a) 30 DAS	3
b) 40 DAS	1, 3
c) 50 DAS	3
d) 60 DAS	3
e) 70 DAS	3
f) 80 DAS	1
g) 90 DAS	3
ii) <u>Root: Shoot ratio</u>	
a) 30 DAS	3
b) 40 DAS	3
c) 50 DAS	3
d) 60 DAS	3
e) 70 DAS	3
f) 90 DAS	1,2,3

iii) Mean grain yield/plant (grams)

(derived from the plant population at harvest and the grain yield/net plot)

1,2,3

3.7.1.2 Data recorded for net plots

i) Plant population/ha (at harvest) 1,2,3

ii) Biomass production (fresh weight) at harvest (kg/ha) 1,2,3

iii) Grain yield (kg/ha) 1,2,3

3.7.1.3 Methods of recording data on soybean

Plant height was measured from base to the growing tip. Diameter of the stem was measured at the base of the stem (just above the collar) using a screw gauge correct to 0.01 mm. The parameters, number of branches, number of leaflets, number of root nodules, number of flowers, number of pods, and number of grains were recorded by counting, on individual sample plants. The 'number of leaflets' refers to individual leaflets being reckoned as the unit of counting and does not refer to compound trifoliolate leaves. This was preferred as it furnishes a more reliable idea about the photosynthetic apparatus; on the other hand, counting based on compound trifoliolate leaves could lead to misleading results by overlooking the possibility of one or more leaflets of a compound trifoliolate leaf being absent due to natural shedding or insect attack.

An approximate idea about the total number of compound trifoliolate leaves/plant is, however, derivable by dividing the 'number of leaflets (total)/plant' by 3. As regards the number

of root nodules, all the identifiable nodules down to the smallest size were counted. For this, the root systems of the pulled out sample plants were washed carefully, including those that got separated in the washing. Leaf area was measured by the punched disc method.

Data on net plot parameters (plant population at harvest, biomass production and grain yield) were recorded after harvesting of the one 'guard row' of plants all round, by pulling out the net plot plants separately. Biomass recorded included all the parts - roots, stem, branches, leaves, flowers if any and pods containing the seeds. While biomass yields were recorded as fresh weight, grain yields are on an air-dry basis.

### 3.7.2. Observations on bamboo clumps

The total experimental population being 24 clumps, each 'plot' (=experimental unit) had only one bamboo clump, distributed over 6 treatments X 4 replications. Hence full enumeration of each clump was carried out. Further, as regards bamboo, the recording of observations were commenced 9 1/2 months before laying out Expt.1, and continued for a period of nearly an year after the harvest of the soybean crop of Expt.3. Thus, observations were recorded on the bamboo clumps over a total period of about 2 years and 8 months which spanned the 3 experiments (Experiments 1,2 and 3).

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The age of the base crop of bamboo at the time of sowing soybean in Experiment 1 was exactly 4 years and it was almost 5 years when the soybean crop of the last experiment (Experiment 3) was harvested. The times of recording the one dozen sets of biometric observations, in terms of days after planting (DAP) the clumps (which were planted on 19.8.1975) and the periods corresponding to the three experiments during which soybean was raised are shown below.

Times recording biometric observations on bamboo clumps		Salient dates in the cropping history of the soybean crop
DAP	Date	Date
1171	2.11.1978	
1355	5.5.1979	
1422	11.7.1979	
1449	7.8.1979	
		<u>Expt. 1</u>
		18.8.1979 sown
1558	24.11.1979	24.11.1979 Harvested
		<u>Expt. 2</u>
		7.12.1979 Sown
		6.3.1980 Harvested
1681	26.3.1980	
		<u>Expt. 3</u>
		18.4.1980 Sown
		29.7.1980 Harvested

1812	4-8-1980
1852	13-9-1980
1960	30-12-1980
2087	6-5-1981
2103	22-5-1981
2152	10-7-1981 - Culms selectively felled.

The following parameters were recorded during the different stages sown under them, on the bamboo clumps.

	recorded at DAP
i) Height of culm (m)	1171, 1355, 1422, 1449, 1558, 1681, 2152
ii) Diameter of culm at base (mm)	1171, 1355, 1422, 1449, 1558, 1681, 1812, 1960, 2087, 2152
iii) Mid-culm diameter (mm)	2152
iv) Number of nodes/culm	1355, 1422, 1449, 1558, 1681, 2152
v) Number of primary branches/culm	1422, 1449, 1558, 1681
vi) Number of living culms/clump (> 1-year old culms)	1171, 1355, 1422, 1449, 1558, 1681, 1812, 1852, 1960, 2087, 2103

recorded at DAP

vii) Number of culms (total)/clump (i.e., all living culms + potential culms)	1171, 1355, 1422, 1449, 1558, 1681, 1812, 1852, 2087, 2103
viii) Number of usable culms harvested/clump	2152
ix) Mean Weight (fresh weight) of individual culms only (kg)	2152
x) Mean Weight (fresh weight) of non-culm aerial vegetative parts (branches + leaves + sheaths)/culm (kg)	2152
xi) Mean Aerial biomass (fresh weight)/culm (i.e., culm + branches + leaves + sheaths) (kg)	2152
xii) Total culm yield by weight (fresh weight)/clump (kg)	2152

### 3.7.2.1 Methods of recording the data on the bamboo clumps

All the one dozen sets of observations on the bamboo clumps were recorded during times when there was no crop of soybean standing in the field, to avoid damage to the latter. Even, the 2 sets of observations, viz., those recorded on 1558 and 1681 DAP (mean age of the bamboo clumps at this stage being about 3 1/2 years), falling within the span of the 3 experiments involving soybean, were recorded during the fallow periods between two crops of soybean. Thus the recording of data on 1558 DAP was made on the same day the soybean crop of Experiment 1 was harvested, after removing the harvested

soybean plants first. The recording of the data of 1681 DAP fell during the interregnum between Experiment 2 and Experiment 3.

As regards height of culm, initially during the first two occasions only (i.e., 1171 and 1355 DAP), it was recorded on only one culm, namely the tallest culm in the clump. Since, rate of growth of individual culms in bamboos is very fast, and thus the heights of new culms in different clumps is highly variable, the recording of the height of 'the tallest culm in the clump' serves only as a rough indication of the average length of a culm in a clump and thus the stature of the clump as a whole, at any given point in time. Hence, during all the subsequent occasions (1422, 1449, 1558, 1681 DAP) heights of all the standing culms in a clump were measured and the Height of culm was measured by using a metallic tape from the first visible node to the tip, taking care to follow the curvature of the culm, if present; hence the measurement is actually the measurement of the length of the culm. In the case of 2152 DAP, the data were recorded not on all the standing culms but on selectively felled culms by laying them flat on the ground.

Diameter of culm was measured at the mid-point of the first visible basal internode, i.e., above the first visible node. For each culm, 2 measurements, one along the perceptible longest diameter and another along the axis perpendicular to it,

were made. The mean of these two readings was taken as the diameter of the culm. This was done to eliminate any ovality of the culm at the point of measurement. This was followed for each and every one of the standing culms in each clump and similarly for all the 24 clumps. In the case of the felled culms, the diameter was measured at the mid-point of the first full internode from the cut end. Mid-culm diameter also was recorded on the selectively felled culms. This parameter does not refer to the mid-point along the length of the culm but refers to the mid-point of that internode along the length of the culm, which divides the total number of internodes in the culm into two equal halves. In the case of culms having an even number of identifiable internodes, this parameter was recorded at the mid-point of the internode immediately below the node that divided the culm into two halves of equal number of internodes. In the case of mid-culm diameter also, the diameter is the mean of two mutually perpendicular measurements. Culm diameters were measured throughout using a vernier callipers to 0.1 mm. accuracy.

Number of nodes/culm, number of primary branches/culm, number of living culms/clump and number of culms (total)/clump were recorded by actual counting. The first two parameters, viz., nodes and primary branches, were counted culm-wise in any one clump and then averaged. However, for these two parameters alone, not all the culms in any particular clump were enumerated because of the difficulty of separating the intertwining culms.

Hence, these data were recorded only for those culms on which the counting could be carried out accurately; generally these were the culms occurring along the periphery of the clumps.

The distinction between 'number of living culms/clump' and 'number of culms (total)/clump' is that the latter parameter includes all the existing culms (i.e., living culms of age 1-year or more) plus all the 'potential' culms (i.e., komalis and 'new recruits' both of which are less than 1-year in age + culms which have been already cut and removed, whose one time existence is indicated by the presence of stumps). Thus, while the 'number of living culms' measures actual productivity at any given point in time, the 'number of culms (total)' furnishes an idea about the potential productivity of a clump, taking into account future culms and lost culms. In the case of the present investigation, very few cut stumps figured in the enumeration of the total number of culms; a few malformed culms, however, had to be felled to avoid clump congestion or facilitate sowing the intercrop. Similarly, not all the komalis that emerge from the ground grow up into culms; many die and dry up. These two kinds of losses are accounted for precisely by the difference between the two parameters 'number of culms (total)/clump' and 'number of living culms'.

While the 'number of living culms' and 'number of total culms' per clump are independent variables, the 'number of usable culms/clump' as referred to in this study, is a dependent variable, since specific felling rules were strictly

enforced. The felling rules observed in this study consisted of (i) avoiding the felling of any culm aged less than 1-year (i.e., komalis and 'new recruits') and (ii) felling of 50% of the remaining culms (i.e., half of all the living culms of age 1-year or more).

As regards the parameters 'mean weight of culm alone', 'mean weight of branches + leaves + sheaths/culm', and 'total culm yield by weight/clump', all these refer to fresh weights as recorded immediately after harvest of the culms on 2152 DAP (mean date of felling). First, the culm along with its branches, leaves and sheaths was weighed. Then, the non-culm aerial vegetative parts (i.e., branches + leaves + sheaths) were separated from the culm and weighed. Finally, the weight of the culm was computed by difference from the above mentioned two parameters. Weighments were made using a spring balance.

### 3.7.3. Light intensity

Light intensity was measured, daily over a period of 11 months from September 1979 to July 1980, covering the period of tenure of the 3 experiments. These measurements were recorded at around 12 noon (local time) daily, both within the bamboo stand ( $E_1$ ) and in the open field ( $E_2$ ) at sites where there was no shading by the soybean. Within each environment, the measurements were recorded at two different spots and in each spot at 3 different points so that the estimate of light intensity for any one stand is the mean of 6 readings.

The light intensity was measured using an 'Aplab' luxmeter. The selenium photocell sensor was covered with two pieces of ND filters and the sensor was placed horizontally on the ground surface with the cell facing the sky. The actual locations where these readings were taken were arranged such that they were at the junctions of 4 plot bunds, and further, were located centrally at each of the 2 locations, in each stand, so as to represent the light climate of the stand more accurately. The same measurement spots were used throughout. At these spots direct shading of the sensor by the soybean plants did not occur.

The total of the 3652 readings recorded over practically a continuous period of 321 days were grouped into standard weeks and the means for the standard weeks were computed, and graphed, and are shown in Fig.2. Appendix 1 furnishes the data for the standard weeks.

#### 3.7.4. Microclimate

The microclimate prevailing within the two environments,  $E_1$  and  $E_2$ , was attempted to be characterized using the two parameters basic to any microclimatic study. These were the ambient temperature and the relative humidity. These were recorded using an Assman psychrometer. There were 12 variables in all, viz., the 2 environments X 3 altitudes (15, 50 and 250 cm above ground level) X 2 times of recording (07.22 hours and 14.22 hours). The observations were recorded over the entire period of experimentation.

The 3 altitudes were chosen such that they represent the 3 distinct layers involved in this study - viz., the near - ground layer, the soybean canopy layer and the bamboo canopy layer. As for earlier work on microclimatic study on this species of bamboo there is only one published work (Dabral et al., 1969). The study referred to, involved besides bamboo, a stand of pine trees also. The authors recorded the microclimatic data at 5 altitudes, viz., ground surface (i.e., zero ft.), 6", 1', 3' and 5' (15, 30, 90, 150 cm). In the present investigation it was felt prudent to avoid ground surface so as to minimize the effect of weeds, and to reckon 15 cm (which corresponds to the 6" of Dabral et al., 1969) as representative of the condition below the soybean canopy. Another difference is that the maximum altitude has been raised still further from 5ft to slightly more than 8 ft (=250 cm) in the present study, so as to secure a truer picture of the condition within the bamboo canopy. This capability of taking a reading at 8 ft (for which, the use of a stool is cumbersome and a ladder is impossible) was achieved by a simple device developed by the author of the present investigation, and is described below:

A casuarina pole, 3 m in length was painted with marks to measure off 15, 50 and 250 cm respectively, from the bottom. A mild steel hook screw was driven into the pole near the top. One end of a nylon chord was tied to the top ring of the Assman psychrometer and the chord was passed through the hook 'pulley', with the other end of the chord being held by the operator.

First, the instrument was raised to the top position such that its shielded bulb section coincided with the 250 cm mark on the pole. The pole was held vertically up and the measurement taken. Immediately after that, the free end of the nylon chord was loosened carefully so as to bring down the instrument quickly to eye level when the reading was noted (vide Plate 1). For the other two altitudes (15 and 50 cm) also, even though the pole was not an absolute necessity, still it was used as a convenient scale.

The observations were recorded at a spot which was the exact centre of the environment concerned so as to represent the environment the most accurately. The daily data so collected over a continuous period of 11 months spanning the 3 experiments were grouped into standard weeks and the means for the standard weeks were computed. The summary of the 8000 readings is presented in Appendix 2 and graphically in Fig. 9 (temperature) and F1.10 (relative humidity).

The weather data as recorded at the Agrimet observatory of the University, located in the same campus, for the corresponding period, were also compiled and are presented in Appendix 3 and graphically in Fig.11, for comparison of the microclimate with the macroclimate.

#### 3.7.5 Data on Soil Moisture

Eventhough this study is an irrigated study, weekly irrigation being provided (excepting during the rainy periods) to

the soybean crop during the period of tenure of the 3 experiments, data on soil moisture status was collected since a relatively large-sized woody perennial crop was involved which could compete effectively for soil moisture with an associated annual crop.

Soil samples were collected at weekly intervals, just before the irrigation was provided, i.e., on the same day on which the crop was irrigated. All the samples were surface samples representing 0 - 15 cm sampling depth and 2 samples (one near the centre and the other near the NE corner of the plot) were collected from each of the 48 plots. Sampling was done using a screw auger. Moisture was determined gravimetrically, separately for each one of the 96 samples at every stage of sampling. Mean soil moisture contents were then calculated separately for each one of the two environments ( $E_1$  and  $E_2$ ). Thus each mean is based on 48 samples.

Soil moisture data was gathered over a continuous period of more than 7 months representing Experiments 1 and 2 only. The summary of the nearly 2500 moisture determinations are furnished in Table 34.

#### 3.7.6. Data on Weed infestation

Data on weed infestation was collected plot-wise, once, at the end of Expt. 3 (as on 30.7.1980, i.e., 1 day after

harvest of the soybean crop). For this purpose a sampling quadrat of 0.5 x 0.5 m sides was used. Four such quadrat samples were used for each plot. The quadrats were positioned along N, E, W and S sections of each plot, 2 samples (N and S) being near the periphery of the plot and 2 other samples (E and W) being near the centre of the plot. The same locations were followed for all the 48 plots.

Weed plants falling within the quadrats were pulled out and their fresh weights were recorded plot-wise. Then, they were enumerated species-wise. The summarized data are presented in Tables 35, 36(a) and 36.

## Results and Discussion

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CHAPTER 4  
RESULTS AND DISCUSSION

The results of the three experiments conducted on soybean and the observations recorded on the other associated aspects, viz., prevailing light intensity, microclimate, soil moisture and weed infestation, and the information collected on the base crop of 'solid' bamboo (Dendrocalamus strictus Nees), with the object of exploring the feasibility of 'establishment intercropping' of soybean within a stand of bamboo during the early stages of the bamboo crop, are presented and discussed in this chapter.

4.1. SOYBEAN

4.1.1 Height of plant (cm)

(Tables 1 and 2, Fig.2(a))

Among the three factors studied only 'environment' (E) and 'vigour of the bamboo clump' exerted any significant influence on the height of the soybean plant. The other factor, viz., 'phosphorus application' (P) did not exercise any significant influence on height. As regards E, soybean height was very highly significantly ( $p = 0.01$ ) taller 'within the bamboo stand' ( $E_1$ ) as compared to the 'open field' ( $E_2$ ), at all stages and significantly so under 70 DAS of Expt.3, excepting at 60 and 90 DAS of Expt.2 and 90 DAS of Expt.3 where the differences were not significant. Even in these cases where statistical significance was not reached, all but one recorded taller plants. Only under 90 DAS of Expt.2, was the height

Table - 1 Height of plant (cm)

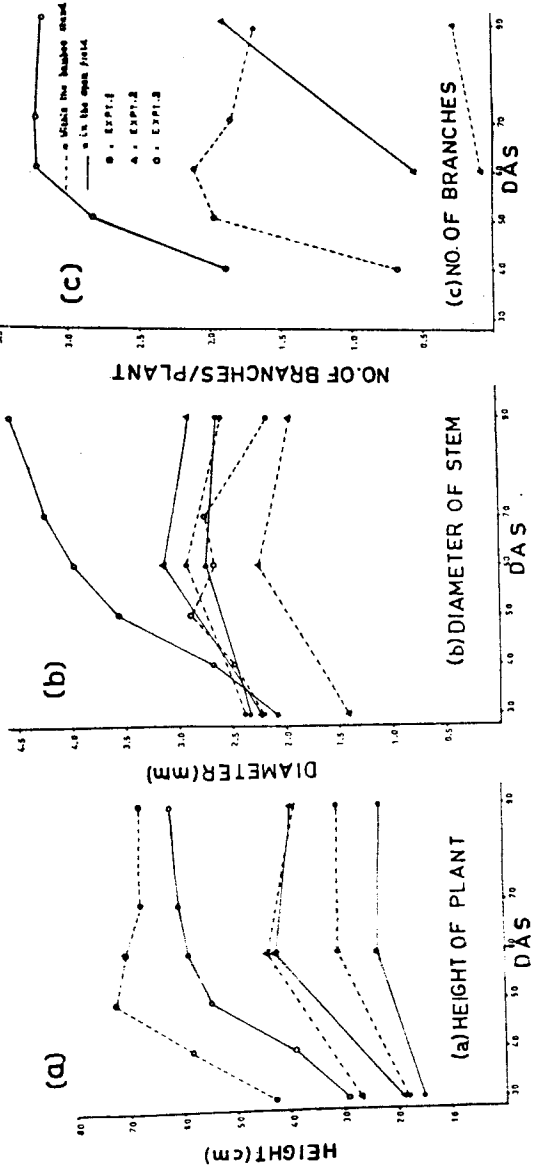
SOYBEAN

	<u>Expt. 1</u>			<u>Expt. 2</u>		
	D A S			D A S		
	30	60	90	30	60	90
<b>1. Within the Bamboo stand (<math>E_1</math>) (a) Influence of Phosphorus levels (P)</b>						
P <sub>0</sub>	17.758	31.404	31.224	26.132	43.244	37.093
P <sub>1</sub>	17.496	29.624	29.543	26.444	43.016	38.735
P <sub>2</sub>	19.473	32.916	33.072	28.105	46.729	41.377
F	NS	NS	NS	NS	NS	NS
SE	0.727	1.296	1.338	0.834	1.379	1.434
CD	-	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>						
L	18.742	31.669	31.490	27.104	45.384	39.801
H	17.743	30.960	31.069	26.683	43.275	38.335
F	NS	NS	NS	NS	NS	NS
SE	0.593	1.058	1.092	0.681	1.126	1.171
CD	-	-	-	-	-	-
<b>2. In the open field (<math>E_2</math>) Influence of phosphorus levels (P)</b>						
P <sub>0</sub>	15.152	23.823	22.923	19.253	42.957	39.785
P <sub>1</sub>	15.021	23.863	23.168	18.367	41.846	37.994
P <sub>2</sub>	15.348	24.601	23.587	18.935	43.691	40.886
F	NS	NS	NS	NS	NS	NS
SE	0.282	0.657	0.666	0.421	1.381	1.340
CD	-	-	-	-	-	-
<b>3. Pooled analysis (a) Influence of Environments (E)</b>						
E <sub>1</sub>	18.242	31.315	31.280	26.894	44.330	39.068
E <sub>2</sub>	15.174	24.096	23.226	18.856	42.831	39.554
F	***	***	***	***	NS	NS
SE	0.307	0.577	0.593	0.371	0.797	0.799
CD	0.885	1.661	1.707	1.070	-	-
<b>(b) Influence of phosphorus levels (P)</b>						
P <sub>0</sub>	16.454	27.614	27.074	22.693	43.101	38.439
P <sub>1</sub>	16.259	26.744	26.356	22.406	42.431	38.365
P <sub>2</sub>	17.410	28.759	28.330	23.530	45.210	41.132
F	NS	NS	NS	NS	NS	NS
SE	0.376	0.707	0.727	0.454	0.976	0.978
CD	-	-	-	-	-	-

**Table - 2** Height of Plant (cm) SOYBEAN

<u>Expt. 3</u>	D A S					
	30	40	50	60	70	90
<b>1. Within the Bamboo stand (E<sub>1</sub>) (a) Influence of Phosphorous Levels (P)</b>						
P <sub>0</sub>	39.700	54.045	67.605	66.155	62.745	64.810
P <sub>1</sub>	44.020	59.900	75.425	72.280	69.015	68.270
P <sub>2</sub>	44.595	61.330	75.220	74.020	72.480	70.415
F	NS	NS	NS	NS	NS	NS
SE	1.470	2.066	2.336	2.777	3.885	4.124
CD	-	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>						
L	40.077	55.840	70.057	69.707	65.440	61.610
H	45.467	61.011	75.443	71.930	70.720	74.053
F	**	*	NS	NS	NS	*
SE	1.200	1.686	1.908	2.268	3.172	3.367
CD	3.616	5.078	-	-	-	10.145
<b>2. In the open field (E<sub>2</sub>) Influence of Phosphorous levels (P)</b>						
P <sub>0</sub>	29.943	38.963	54.495	58.813	61.407	62.104
P <sub>1</sub>	28.723	37.517	53.625	59.096	61.498	62.668
P <sub>2</sub>	29.037	40.427	56.119	59.748	59.859	62.303
F	NS	NS	NS	NS	NS	NS
SE	1.861	3.251	3.677	3.816	4.228	4.183
CD	-	-	-	-	-	-
<b>3. Pooled analysis (a) Influence of Environments (E)</b>						
E <sub>1</sub>	42.772	58.425	72.750	70.818	68.080	67.832
E <sub>2</sub>	29.234	38.969	54.746	59.219	60.921	62.358
F	***	***	***	***	*	NS
SE	0.978	1.602	1.813	1.954	2.353	2.400
CD	2.814	8.239	9.324	10.049	6.788	-
<b>(b) Influence of Phosphorous levels (P)</b>						
P <sub>0</sub>	34.822	46.504	61.050	62.484	62.076	63.437
P <sub>1</sub>	36.372	48.709	64.525	65.688	65.257	65.469
P <sub>2</sub>	36.816	50.879	65.670	66.884	66.170	66.359
F	NS	NS	NS	NS	NS	NS
SE	1.198	1.963	4.928	2.393	2.882	2.938
CD	-	-	-	-	-	-

Fig.2-SOYBEAN - GROWTH ATTRIBUTES - I  
INFLUENCE OF TWO ENVIRONMENTS



slightly shorter under  $E_1$  than under  $E_2$ ; but the difference was very marginal (only 1.2%) and not significant. The increase in height was about 30-40% in most cases. The increased plant height seen under  $E_1$  is clearly ascribable to the reduced light intensity (i.e., shading by the bamboo clumps).

That shading or low light intensity increases the plant height has been reported in groundnut (Cox, 1978), Cotton (Eaton and Ergle, 1954), spinach (Parlevliet, 1967), cowpea (Adedipe and Ormrod, 1974) and in soybean itself (Beuerlein *et al.*, 1971; Wahua and Miller, 1978; Jeyaraman, 1979; Rabie and Kumazawa, 1979; and Prine, 1980). Stem elongation in shade was presumably the result of elongation of component cells as reported by Redington (1929) and internodal elongation as stated by Weaver and Clements (1938).

As regards the influence of the vigour of the bamboo clump (V) an interesting trend was seen. Initially i.e., during the tenure of Experiments 1 and 2, the soybean plants under the 'high' vigour (H) clumps were invariably slightly shorter than those under the 'low' vigour (L) clumps, though the differences were not statistically significant. However, Subsequently, during the tenure of Expt. 3, the trend reversed with the soybean plants under 'H' becoming taller and those under 'L' shorter. Further, the differences were highly significant ( $p = 0.01$ ) at 30 DAS and significant at 40 and 90

DAS under Expt.3, the rest being not significant. Evidently as time passed, the 'high' vigour clumps grew further and put on more foliage as to increase the shading which resulted in increased plant height of soybean.

Phosphorus did not influence the height of the soybean plant significantly, be it under bamboo clumps, or in the open or even in overall terms. This is in contrast to the results reported by several workers, for open field conditions (Howell, 1954; Ferrari et al., 1976; Saleh, 1976; Larence et al., 1977; and Holim et al., 1979). However, it is to be noted that Shahidullah et al. (1979) found soybean plant to increase its height only upto a certain level of P application, beyond which it started to decline. And he had used a maximum dose of only 56 kg  $P_2O_5$ /ha while in the present investigation the maximum dose used was 200 kg  $P_2O_5$ /ha. Further, Kesavan (1970) had reported even a significant negative influence of P on soybean plant height.

Two other salient features common to all the three factors studied (E, V and P) and to all the three experiments, with reference to the passage of time are worthy of note. In almost all cases, there was a steep increase in plant height usually upto 50 or 60 DAS, after which there was a plateausing (i.e., the height remained static) as in the case of the influence of P under  $E_1$  as well as in its overall effect (combining  $E_1$  and  $E_2$ ), or there was a slight reduction in

plant height. This would imply that the height growth of the soybean plant is completed in about 50 - 60 days. The slight reduction in heights beyond 50 - 60 DAS was due to the drying off of the tip. The only exception to this pattern was the behaviour of soybean height in the open field environment ( $E_2$ ) in Expt.3, where the height registered a continuous rise, with passage of time, upto 90 DAS, under all the P levels. Possibly the seasonal conditions that prevailed during the tenure of Expt.3 had a role to play in this. The second feature, is that the plants were the tallest in Experiment 3, followed by those of Experiment 2 and then by those of Experiment 1. Further, these differences got accentuated as time passed, upto 50 - 60 DAS. Presumably this difference in the heights of plants between the 3 experiments is due to the effect of season.

#### 4.1.2 Diameter of stem

(Tables 3, 3(a) 4 and 4(a), Fig. 2(b))

In all the three experiments, significant differences arose only between the two environments, the influences of the other two factors being not significant throughout. In general, the soybean plants growing within the bamboo stand ( $E_1$ ) had thinner stems. However, while in Experiments 2 and 3 this was so, in Expt.1, the plants growing under  $E_1$  had thicker stems initially (30 and 60 DAS) and the difference was highly significant ( $p = 0.01$ ) at 60 DAS. Further, the differences between stem diameters for  $E_1$  and  $E_2$  were very

**Table 3** Diameter of stem at base (mm)

Expt. 1	Expt. 1			Expt. 2		
	D A S			D A S		
	30	60	90	30	60	90
<b>1. Within the bamboo stand (<math>E_1</math>) (a) Influence of Phosphorus levels (P)</b>						
$P_0$	2.432	2.972	2.662	1.461	2.333	2.067
$P_1$	2.357	2.828	2.570	1.408	2.240	1.850
$P_2$	2.389	2.998	2.612	1.379	2.246	1.985
F	NS	NS	NS	NS	NS	NS
SE	0.033	0.087	0.183	0.056	0.117	0.165
CD	-	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>						
L	2.386	2.942	2.573	1.465	2.353	2.038
H	2.398	2.922	2.656	1.366	2.193	1.896
F	NS	NS	NS	NS	NS	NS
SE	0.027	0.072	0.149	0.046	0.095	0.135
CD	-	-	-	-	-	-
<b>2. In the open field (<math>E_2</math>) Influence of phosphorus levels (P)</b>						
$P_0$	2.341	2.699	2.584	2.249	3.241	2.968
$P_1$	2.365	2.814	2.706	2.179	3.002	2.882
$P_2$	2.310	2.752	2.679	2.274	3.210	3.037
F	NS	NS	NS	NS	NS	NS
SE	0.142	0.062	0.066	0.145	0.090	0.096
CD	-	-	-	-	-	-
<b>3. Pooled analysis (a) Influence of Environments (E)</b>						
$E_1$	2.393	2.932	2.615	1.416	2.273	1.967
$E_2$	2.339	2.755	2.656	2.234	3.151	2.962
F	NS	**	NS	***	***	***
SE	0.062	0.043	0.077	0.066	0.059	0.076
CD	-	0.123	-	0.190	0.170	0.219
<b>(b) Influence of phosphorus levels (P)</b>						
$P_0$	2.387	2.836	2.623	1.855	2.787	2.518
$P_1$	2.361	2.821	2.638	1.794	2.621	2.366
$P_2$	2.350	2.874	2.646	1.827	2.728	2.511
F	NS	NS	NS	NS	NS	NS
SE	0.076	0.052	0.094	0.080	0.073	0.093

**Table 3(a) Diameter of stem at base (mm) as on 30 DAS SOYBEAN**

E xpt. 1      Influence of the interaction V X P

P levels	Vigour of the bamboo clump (V)	
	L	H
P <sub>0</sub>	2.456	2.407
P <sub>1</sub>	2.266	2.448
P <sub>2</sub>	2.437	2.340

F test = \*  
SE = 0.046  
CD = 0.139

Conclusions:

a) P over V

$$L = \overline{P_0 P_2 P_1} \quad *$$

$$H = \overline{P_1 P_0 P_2}$$

b) V over P

$$P_0 = \overline{L H}$$

$$P_1 = \overline{H L} \quad *$$

$$P_2 = \overline{L H}$$

**Table 4** Diameter (mm)  
Expt. 3

SOYBEAN

	D A S					
	30	40	50	60	70	90
<b>1. Within the Bamboo stand (E<sub>1</sub>) (a) Influence of Phosphorous levels (P)</b>						
P <sub>0</sub>	2.185	2.415	2.740	2.555	2.670	2.085
P <sub>1</sub>	2.220	2.505	3.170	2.665	2.795	2.100
P <sub>2</sub>	2.265	2.550	2.785	2.805	2.845	2.380
F	NS	NS	NS	NS	NS	NS
SE	0.025	0.043	0.199	0.099	0.177	0.164
CD	-	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>						
L	2.210	2.501	2.797	2.703	2.793	2.267
V	2.237	2.473	3.000	2.647	2.747	2.110
F	NS	NS	NS	NS	NS	NS
SE	0.050	0.035	0.163	0.079	0.144	0.134
CD	-	-	-	-	-	-
<b>2. In the open field (E<sub>2</sub>) Influence of Phosphorous levels (P)</b>						
P <sub>0</sub>	1.992	2.640	3.490	3.857	4.045	4.417
P <sub>1</sub>	2.078	2.700	3.628	4.133	4.464	4.647
P <sub>2</sub>	2.209	2.729	3.593	3.992	4.265	4.707
F	NS	NS	NS	NS	NS	NS
SE	0.075	0.191	0.137	0.132	0.159	0.193
CD	-	-	-	-	-	-
<b>3. Pooled analysis (a) Influence of Environments (E)</b>						
E <sub>1</sub>	2.223	2.490	2.898	2.675	2.770	2.188
E <sub>2</sub>	2.093	2.690	3.570	3.994	4.258	4.590
F	*	NS	***	***	***	***
SE	0.036	0.083	0.097	0.068	0.097	0.104
CD	0.104	-	0.499	0.350	0.499	0.535
<b>(b) Influence of Phosphorous levels (P)</b>						
P <sub>0</sub>	2.089	2.528	3.115	3.206	3.358	3.251
P <sub>1</sub>	2.149	2.603	3.399	3.399	3.630	3.374
P <sub>2</sub>	2.237	2.640	3.189	3.399	3.555	3.544
F	NS	NS	NS	NS	NS	NS
SE	0.044	0.102	0.119	0.084	0.188	0.127

Table 4(a) Diameter of stem at base (mm) as on 40 DAS SOYBEAN  
Expt.3 Influence of the interaction V X P

P levels	Vigour of the bamboo clump (V)	
	L	H
P <sub>0</sub>	2.50	2.33
P <sub>1</sub>	2.43	2.58
P <sub>2</sub>	2.59	2.51

F test = \*  
SE = 0.061  
CD = 0.184

Conclusions:

a) P over V

$$L = \frac{P_2 \quad P_0 \quad P_1}{P_1 \quad \frac{P_2}{P_0} \quad P_0} \quad *$$

b) V over P

$$P_0 = \frac{L \quad H}{P_1 = \frac{H \quad L}{P_2 = \frac{L \quad H}}$$

little under Expt.1 (even on 60 DAS when it was significant) while in the case of Expt.3, though the difference was small initially (30 DAS), with  $E_1$  recording significantly thicker stems than  $E_2$ , not only did the trend reverse after that, with  $E_2$  recording thicker stems, but also the difference between them started to widen and that too at a fast rate. The situation as regards Expt.2 was entirely different with the difference between  $E_1$  and  $E_2$  being large right from the start and being maintained throughout the rest of the crop growth period, at a more or less constant level, the difference being very highly significant ( $p = 0.001$ ) at all the stages (30, 60 and 90 DAS).

The influence of P, however, was strange under the open field environment ( $E_2$ ) when the three experiments are compared, even though under any one experiment P did not exert any significant influence on stem diameter. Thus, while the stem diameter increased, in general (i.e., under all levels of P) upto 60 DAS and thereafter did not increase, the differences between the different stages of crop growth (30, 60 and 90 DAS) were not much under Experiments 1 and 2. On the other hand, in the case of Experiment 3, the stem diameter, under all the 3 levels of P, continued to increase steeply throughout the crop growth period till the end; thus the differences between the diameter at 30 DAS and 90 DAS were very great.

Further, while the main effects of both V and P were not significant throughout, their interaction (VXP) was significant in two instances (Expt.1 and on 30 DAS, and Expt.3 as on 40 DAS).

In general in both cases (Table 3(a) and Table 4(a)) there appears to exist a link between 'high vigour' bamboo clump (H) treatment and application of 100 kg  $P_2O_5$ /ha (i.e.,  $P_1$  level) which acts towards increasing the stem diameter of the soybean plant.

#### 4.1.3 Number of branches/plant

(Tables 5, 6 and 6(a), Fig.2(c))

The soybean plants growing in the open field ( $E_2$ ) had significantly ( $p = 0.001$ ) more number of branches as compared to those growing under bamboo shade ( $E_1$ ), at all stages of growth and under both Expt.2 and Expt.3. The reduction in the number of branches under  $E_1$  is evidently due to the shade cast by the bamboo clumps as shown by the results obtained by earlier workers. Thus, Moursi et al. (1976) observed a reduction in the number of tillers in wheat due to shading. On the other hand, in the case of barley, shading had been observed to increase the number of tillers/plant by Singh (1978); while the evidence as regards the influence of shading on branching is conflicting in the case of cereal crops, the evidence is clear-cut in the case of pulse crops, particularly soybean. Thus, in cowpea higher light intensity improves branching as reported by Tarila et al. (1977). In soybean, Kan and Oshima (1952), Asanuma (1977), Wahua and Miller (1978) and Jeyaraman (1979) have reported the ill effect of shading on branching,

**Table 5** Number of branches/plant SOYBEAN  
Expt. 2 D A S

	60 <sup>g</sup>	90 <sup>g</sup>
<b>1. Within the bamboo stand (E<sub>1</sub>) (a) Influence of phosphorus levels (P)</b>		
P <sub>0</sub>	0.764	0.872
P <sub>1</sub>	0.748	0.766
P <sub>2</sub>	0.744	0.896
F	NS	NS
SE	0.042	0.086
CD	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>		
L	0.745	0.847
H	0.758	0.842
F	NS	NS
SE	0.034	0.070
CD	-	-
<b>2. In the open field (E<sub>2</sub>) Influence of phosphorus levels (P)</b>		
P <sub>0</sub>	0.851	1.530
P <sub>1</sub>	0.989	1.471
P <sub>2</sub>	1.116	1.552
F	*	NS
SE	0.068 @@	0.074
CD	0.202 @@	-
<b>3. Pooled analysis (a) Influence of Environments (E)</b>		
E <sub>1</sub>	0.752	0.846
E <sub>2</sub>	0.985	1.517
F	***	***
SE	0.034 @@	0.046 @@
CD	0.098 @@	0.133 @@
<b>(b) Influence of phosphorus levels (P)</b>		
P <sub>0</sub>	0.808	1.201
P <sub>1</sub>	0.869	1.119
P <sub>2</sub>	0.930	1.224
F	NS	NS
SE	0.041	0.056
CD	0.118	0.162

Table 6 No. of branches/plant

SOYBEAN

Expt. 3

D A S

	40 €	50	60	70	90
1. Within the bamboo stand (E <sub>1</sub> ) (a) Influence of phosphorous levels (P)					
P <sub>0</sub>	0.522	1.905	2.035	1.825	1.710
P <sub>1</sub>	0.804	2.175	2.060	1.685	1.725
P <sub>2</sub>	0.671	1.820	2.255	2.065	1.670
F	NS	NS	NS	NS	NS
SE	0.041 €€	0.198	0.220	0.220	0.241
CD	-	-	-	-	-
(b) Influence of vi our of bamboo clump (V)					
L	0.519	2.093	2.150	1.847	1.513
H	0.812	1.840	2.083	1.870	1.890
F	*	NS	NS	NS	NS
SE	0.033 €€	0.162	0.180	0.180	0.197
CD	0.100 €€	-	-	-	-
2. In the open field Influence of the phosphorus levels (P)					
P <sub>0</sub> <sup>1.164</sup>	3.071	2.551	3.001	2.917	2.750
P <sub>1</sub> <sup>(1.206)</sup>	1.167	3.038	3.479	3.637	3.333
P <sub>2</sub> <sup>(1.232)</sup>	1.446	2.918	3.176	3.137	3.522
F	NS	NS	NS	*	*
SE	0.095 €€	0.185	0.177	0.194	0.211
CD	-	-	-	0.577	0.627
3. Pooled analysis (a) Influence of environments (E)					
E <sub>1</sub>	0.666	1.967	2.117	1.858	1.702
E <sub>2</sub>	1.895	2.836	3.219	3.230	3.202
F	***	***	***	***	***
SE	0.043 €€	0.111	0.114	0.119	0.157
CD	0.221 €€	0.571	0.586	0.612	0.807
(b) Influence of phosphorous levels (P)					
P <sub>0</sub> <sup>1.161</sup>	1.797	2.228	2.518	2.371	2.230
P <sub>1</sub> <sup>(1.206)</sup>	0.986	2.607	2.770	2.661	2.529
P <sub>2</sub> <sup>(1.232)</sup>	1.059	2.369	2.716	2.601	2.596
F	NS	NS	NS	NS	NS
SE	0.053 €€	0.135	0.140	0.146	0.193
CD	-	-	-	-	-

€ = Square root transformation done before analysis

€€ = in square root transformed units

**Table 6 (a) Number of branches/plant as on 70 DAS**      **SOYBEAN**  
Expt. 3      Influence of the interaction E X P

P levels	Environments (E)	
	Within the bamboo (E <sub>1</sub> )	In the open (E <sub>2</sub> )
P <sub>0</sub>	1.825	2.917
P <sub>1</sub>	1.685	3.637
P <sub>2</sub>	2.065	3.137

I test = \*  
 SE = 0.207  
 CD = 0.595

Conclusions:

a) P over E

$$E_1 = \overline{P_2 \quad P_0 \quad P_1}$$

$$E_2 = \overline{P_1 \quad P_2 \quad P_0} \quad *$$

b) E over P

$$P_0 = E_2 \quad E_1 \quad *$$

$$P_1 = E_2 \quad E_1 \quad *$$

$$P_2 = E_2 \quad E_1 \quad *$$

while Johnston et al. (1969) reported increased branching through provision of supplemental light.

As regards the influence of the vigour of the bamboo clump (V), only in one instance (Expt.3, 40 DAS) was the difference significant, with the soybean plants growing under the 'high' vigour clumps (H) recording more number of branches. Barring this single case, the influence of clump vigour was not significant.

Phosphorus exerted a significant influence on branching, only on soybean plants growing in the open field ( $E_2$ ) and that too, in three instances only (Expt.2, 60 DAS; Expt.3, 70 DAS and 90 DAS). Its influence under  $E_1$  or in overall terms was not significant. In the open field condition,  $P_0$  was significantly inferior in all the three instances mentioned above, the other two P treatments being on a par. The inference is application of P increases branching, under open field conditions. As regards interactions, the interaction EXP was significant under Expt.3 as on 70 DAS. Under  $E_2$ ,  $P_1$  was significantly superior to  $P_0$ , with  $P_2$  occupying an intermediate position, itself being on a par with both  $P_1$  and  $P_0$ . Further, under all the three levels of P,  $E_2$  was significantly superior to  $E_1$ , thereby underscoring the importance of light in branching (Table 6(a)).

A comparison of the two experiments (Expt.2 and Expt.3) under which only this parameter was studied, reveals an

interesting trend. Firstly, the number of branches/plant was always but once (i.e., influence of environments under Expt.2, as on 90 DAS), lesser in the case of Expt.2 as compared to Expt.3. It is quite likely that this difference between the two experiments is the effect of season as has already been pointed out while discussing plant height. The more interesting aspect, however, is as regards the pattern of response. While in the case of Expt.3, the number of branches/plant increased steeply upto 60 DAS and thereafter plateaued (under  $E_2$ ) or declined (under  $E_1$ ), the situation under Expt.2 was one of continuous increase from 60 DAS till harvest (90 DAS). Again, this differential behaviour seen under the two experiments is perhaps ascribable to the seasonal effect. One basic difference between the two seasons was in so far as rainfall is concerned - that for Expt.2 being dry while Expt.3 enjoyed some rainfall. However, this could at best be only a surmise.

#### 4.1.4 Number of leaflets (Total)/plant

(Tables 7, 7(a), 8, 8(a), and 9, Fig.3(a))

As in the case of branching, in this attribute also, it was the environmental factor (E) that dominated. The other two factors, V and P, did not exert any significant influence, excepting in one instance (Expt.2, 90 DAS) where V exerted a significant influence.

As regards environment, an interesting feature was observed. In the case of Expt.1, the number of leaflets/plant

**Table 7** Number of Leaflets (Total)/Plant

SOYBEAN

Expt. 1	D A S				
	30	40	60	80	90
<b>1. Within the bamboo stand (<math>E_1</math>) (a) Influence of phosphorus levels (P)</b>					
$P_0$	11.633	15.94	26.926	17.07	7.092
$P_1$	10.949	15.25	22.523	16.10	5.958
$P_2$	11.507	15.07	25.594	14.94	5.359
F	NS	NS	NS	NS	NS
SE	0.352	0.480	1.671	1.142	0.754
CD	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>					
L	11.351	15.61	25.122	15.48	6.195
H	11.374	15.23	24.906	16.58	6.078
F	NS	NS	NS	NS	NS
SE	0.287	0.392	1.365	0.932	0.615
CD	-	-	-	-	-
<b>2. In the open field (<math>E_2</math>) Influence of phosphorus levels (P)</b>					
$P_0$	10.333	15.04	19.528	14.28	4.169
$P_1$	10.436	15.29	21.365	13.72	3.875
$P_2$	10.668	15.04	20.876	13.79	3.036
F	NS	NS	NS	NS	NS
SE	0.243	0.520	1.385	0.905	0.618
CD	-	-	-	-	-
<b>3. Pooled analysis (a) Influence of environments (E)</b>					
$E_1$	11.363	15.42	25.014	16.04	6.136
$E_2$	10.479	15.12	20.590	13.93	3.693
F	***	NS	**	*	***
SE	0.172	0.290	0.879	0.589	0.394
CD	0.494	-	2.529	1.694	1.135
<b>(b) Influence of phosphorus levels (P)</b>					
$P_0$	10.283	15.49	23.227	15.68	5.631
$P_1$	10.693	15.27	21.944	14.91	4.917
$P_2$	11.088	15.06	23.235	14.37	4.198
F	NS	NS	NS	NS	NS
SE	0.210	0.355	1.076	0.721	0.483
CD	-	-	-	-	-

Table 7(a) Number of leaflets (Total)/plant as on 90 DAS  
Influence of the interaction V X P SOYBEAN  
Expt-1

P levels	Vigour of the bamboo clump (V)	
	L	H
P <sub>0</sub>	8.074	6.110
P <sub>1</sub>	4.228	7.688
P <sub>2</sub>	6.282	4.435

F test = \*  
 SE = 1.066  
 CD = 3.209

Conclusions:

- a) P over V  
 L =  $\overline{P_0 P_2}$  P<sub>1</sub> \*  
 H = P<sub>1</sub>  $\overline{P_0 P_2}$  \*
- b) V over P  
 P<sub>0</sub> =  $\overline{L H}$   
 P<sub>1</sub> = H L \*  
 P<sub>2</sub> =  $\overline{H L}$

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**Table 8** Number of leaflets (Total)/plant  
**Expt. 2**

SOYBEAN

	30	60	90 g
<b>1. Within the bamboo stand (E<sub>1</sub>) (a) Influence of phosphorus levels (F)</b>			
P <sub>0</sub>	8.960	21.570	4.291
P <sub>1</sub>	8.496	21.377	5.159
P <sub>2</sub>	9.067	23.313	4.430
F	NS	NS	NS
SE	0.202	1.600	0.172 **
CD	-	-	-
<b>(b) Influence of vigour of bamboo slump (V)</b>			
L	9.033	23.193	3.242
H	8.649	20.979	6.011
F	NS	NS	**
SE	0.165	1.306	0.140 **
CD	-	-	0.423 **
<b>2. In the open field (E<sub>2</sub>) Influence of phosphorus levels (F)</b>			
P <sub>0</sub>	10.741	36.171	7.621 <i>(2.721)</i>
P <sub>1</sub>	10.466	35.786	9.071 <i>(2.850)</i>
P <sub>2</sub>	10.489	36.167	10.745 <i>(3.007)</i>
F	NS	NS	NS
SE	0.272	2.263	0.321 **
CD	-	-	- <i>(0.954)</i>
<b>3. Pooled analysis (a) Influence of environments (E)</b>			
E <sub>1</sub>	8.841	22.086	4.627
E <sub>2</sub>	10.565	36.708	9.146
F	***	***	**
SE	0.140	1.148	0.152 **
CD	0.404	3.311	0.438 **
<b>(b) Influence of phosphorus levels (F)</b>			
P <sub>0</sub>	9.851	28.871	5.956 <i>(2.405)</i>
P <sub>1</sub>	9.481	28.582	7.115 <i>(2.540)</i>
P <sub>2</sub>	9.778	30.740	7.587 <i>(2.597)</i>
F	NS	NS	NS
SE	0.172	1.407	0.187 **
CD	-	-	- <i>(0.539)</i>

\* = Square root transformation done before analysis

\*\* = in square root transformed units

Table 8(a) Number of leaflets (Total)/plant as on SOYBEAN  
90 DAS  
Expt. 2 Influence of the interaction V XP

P levels	Vigour of the bamboo clump (V)			
	L		H	
	<i>N</i> transf.		<i>N</i> transf.	
P <sub>0</sub>	(1.772)	3.066	(2.403)	5.516
P <sub>1</sub>	(1.505)	1.989	(2.954)	6.329
P <sub>2</sub>	(2.237)	4.672	(2.137)	4.187

F test	= *	<i>N</i> transf.	
SE	= } square root transformation	0.242	
CD	= } of the data carried out	0.728	

conclusions:

a) P over V

$$L = \overline{P_2 - P_0 - P_1} \quad *$$

$$H = \overline{P_1 - P_0 - P_2} \quad *$$

b) V over P

$$P_0 = \overline{H - L}$$

$$P_1 = \overline{H - L} \quad *$$

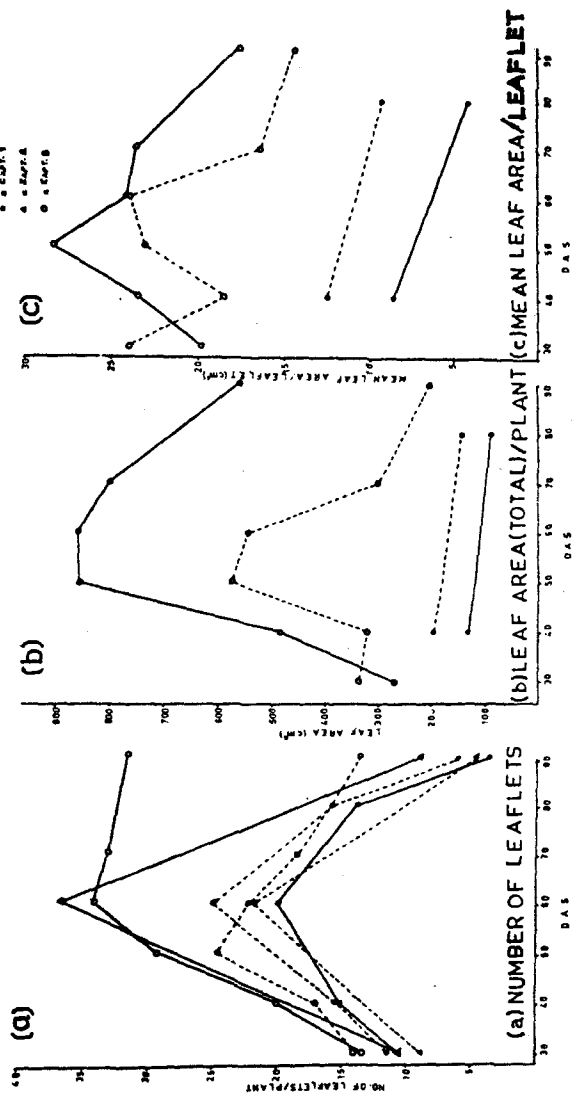
$$P_2 = \overline{L - H}$$

**Table 9** No. of Leaflets (Total)/Plant

SOYBEAN

<u>Expt. 3</u>	D A S					
	30	40	50	60	70	90
<b>1. Within the bamboo stand (E<sub>1</sub>) (a) Influence of Phosphorous levels (P)</b>						
P <sub>0</sub>	13.770	16.165	23.500	21.330	18.940	13.630
P <sub>1</sub>	14.415	16.585	25.665	22.565	17.790	12.770
P <sub>2</sub>	13.895	16.545	24.955	23.375	18.835	15.010
F	NS	NS	NS	NS	NS	NS
SE	0.780	0.752	1.053	1.608	2.525	1.954
CD	-	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>						
L	13.610	16.723	23.957	24.277	19.833	14.187
H	14.443	17.473	25.457	20.570	17.460	13.420
F	NS	NS	NS	NS	NS	NS
SE	0.406	0.614	0.860	1.313	2.061	1.595
CD	-	-	-	-	-	-
<b>2. In the open field (E<sub>2</sub>) influence in the phosphorous levels (P)</b>						
P <sub>0</sub>	13.521	20.355	27.917	31.062	32.875	27.667
P <sub>1</sub>	13.333	18.813	28.229	36.291	36.646	34.146
P <sub>2</sub>	13.396	20.896	31.855	35.833	30.583	33.687
F	NS	NS	NS	NS	NS	NS
SE	0.574	1.436	1.648	2.569	2.888	3.442
CD	-	-	-	-	-	-
<b>3. Pooled analysis (a) Influence of environments (E)</b>						
E <sub>1</sub>	14.027	17.098	24.707	22.423	18.522	13.803
E <sub>2</sub>	13.417	20.021	29.334	34.395	33.368	31.833
F	***	*	***	***	***	***
SE	0.390	0.631	0.761	1.180	1.493	1.540
CD	2.006	2.450	3.914	6.069	7.678	7.920
<b>(b) Influence of Phosphorous levels (P)</b>						
P <sub>0</sub>	13.546	18.260	25.709	26.196	25.908	20.649
P <sub>1</sub>	13.874	17.699	26.947	29.428	27.218	23.458
P <sub>2</sub>	13.645	19.721	28.405	29.604	24.709	24.349
F	NS	NS	NS	NS	NS	NS
SE	0.478	0.773	0.933	1.445	1.829	1.887
CD	-	-	-	-	-	-

FIG. 3 SOYBEAN - GROWTH ATTRIBUTES - 2  
INFLUENCE OF TWO ENVIRONMENTS



was always (30, 40, 60, 80 and 90 DAS) more in the soybean plants growing within the bamboo stand ( $E_1$ ) as compared to those growing in the open field ( $E_2$ ). Further, the differences were statistically significant at all stages of growth but one (40 DAS). On the other hand, the pattern was diametrically opposite under the two experiments which followed. In both Expt.2 and Expt.3, it was the soybean plants growing in the open field ( $E_2$ ) that recorded more number of leaflets/plant as compared to those growing within the bamboo stand ( $E_1$ ) at all stages of crop growth excepting in one instance (Expt.3, 30 DAS) where  $E_1$  was superior to  $E_2$ . And, in all cases (i.e., all the stages and both Expt.2 and Expt.3) the differences were statistically significant.

Other workers have furnished evidence for a lack of response to shading as well as for a negative response, in so far as number of leaves/plant is concerned. Thus, while Murray (1961) stated that shading had no effect on the number of leaves produced in banana, Singh (1978) working on barley reported that shading decreased the number of leaves/plant. In beans, which is a pulse crop, Crookston et al. (1975) observed that shading reduced the number of leaves progressively.

In the present investigation, both an increase (in Expt.1) as well as a decrease (in Expt.2 and Expt.3) in the number of leaflets/plant in the shade environment has been observed. While the reduction in the number of leaflets consequent to shading as seen under Experiments 2 and 3, agrees with the

findings of Singh (1978) and Crookston et al. (1975), the increase in the number of leaflets under shade, seen in Expt.1 is apparently incongruous and needs elucidation.

Two factors, both operating in a parallel manner, appear to have been responsible for this anomalous behaviour. Firstly, it is the result of a progressive increase in the intensity of shade cast on the soybean within the bamboo stand. Initially, at the start of the investigation, the bamboo clumps were relatively younger, their crowns had not developed fully, and the canopy had not closed. Further, a pre-treatment had been given to the crowns just before the start of Expt.1. Hence, during the tenure of Expt.1, the soybean plants grew under a bamboo canopy that was relatively more open. In other words, only a light shade or 'partial shade' was imposed on the soybean plants. However, these conditions changed rapidly, as time passed, with the bamboo canopy developing fast and closing in. Thus, during the subsequent two experiments (Expt.2 and Expt.3) the soybean had to grow under a relatively heavier shade. This reversal in the shade intensities explains in part, the anomaly seen in the number of leaflets/plant under Expt.1 on the one hand and under Experiments 2 and 3, on the other.

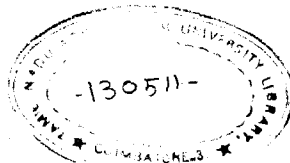
The second factor is the seasonal light climate. A scrutiny of the data on number of leaflets shows that, during the period August 1979 to December 1979, which corresponds to the tenure of Expt.1, the number of leaflets/plant was more in the soybean plants growing within the bamboo stand ( $E_1$ ),

while during the period, 2nd week of January 1980 to the end of July 1980 which corresponds to 30 DAS of Expt.2 to 90 DAS of Expt.3, the number of leaflets/plant was more in the soybean plants growing in the open field ( $E_2$ ), with but one exception (30 DAS of Expt.3). Since light is the factor among the environmental factors that directly influences the photosynthetic apparatus, the ambient light suggests itself as the chief factor that is most likely to influence the number of leaflets/plant.

An examination of the data on the ambient light intensity that prevailed in the open field ( $E_2$ ) reveals certain definite trends over time (Appendix 1 and Fig.2). It is seen that, in general, the light intensity was very high (far more than 100 K lux, as measured at noon) during the period from September 1979 upto the 3rd week of October 1979. This period, particularly September 1979, corresponded to the active vegetative growth phase (i.e., upto 60 DAS) of the soybean crop, of Expt.1. During the same period, the light intensity below the bamboo canopy was generally of the order of about 90 - 99 K lux, excepting for two spells during October 1979, when it reached values as high as 120 and 110 K lux (Appendix 1 and Fig.8). As regards the duration of illumination during this period, the data presented in Appendix 3 and Fig.11 show that the mean hours of bright sunshine/day was generally low during the above mentioned period, being of the order of about 4-6 hours, excepting during a short period of about a week from

15th to 21st October 1979 when the hours of sunshine was longer (10.2 hours). Thus, quantity-wise, the light was not much since the higher intensity of light was offset by shorter duration of illumination. It must, however, be remembered that between the two factors, viz., intensity and time, that determine light quantity, it is the intensity factor that is of greater import from the point of photosynthesis. Light as a production resource is unique in that it cannot be stored but must be used instantaneously.

Against this background of the available light intensity being of a relatively high Order (greater than 100 K lux) during the period when Expt.1 was conducted, let us examine the light utilization capacity of soybean leaves. It is known that the rate of photosynthesis drastically falls beyond certain values of light intensity and plateauing results. In Chapter 2 the light saturation value for soybean was reviewed and it was seen that light saturation occurs at light intensities ranging from 23.68 K lux (Bohning and Burnside, 1956) to about 80 K lux (Boves et al., 1972) in excised soybean leaves. Even if we discount these values as being rather low and as being based on excised leaves, we saw that the light saturation for even field-grown soybean was not very high, light saturation occurs at about 107 K lux light intensity as reported by Beuerlein and Pendleton (1971).



It could therefore be postulated that, during the tenure of Expt.1, the ambient light intensity being very high (an average of 128.1 K lux during the period from sowing upto 60 DAS) and thus far above the saturation light intensity, the soybean plants growing in the open field ( $E_2$ ) produced less number of leaflets so as to be commensurate with the available sink; it was a question of optimisation of the source to match the sink. On the other hand, the light intensity under the bamboo canopy ( $E_1$ ), during the same period, averaged 99.6 K lux only, and thus was well below the light saturation intensity of 107 K lux reported by Beuerlein and Fendleton (1974) for field-grown soybean plants. This would imply that there existed an environmental stimulus within the bamboo stand ( $E_1$ ) for the photosynthetic apparatus to expand so as to capture solar energy more fully. Such an expansion can logically take place through two means - either by increasing the number of leaves or by increasing the surface area per leaf, or by a combination of both. The available data on mean leaf area/leaflet (Tables 10 and 12 and Fig.3(e)) show the interesting phenomenon of the  $E_1$  environment recording larger leaves initially (Expt.1) and smaller leaves later (Expt.3). These results suggest that when there is a slight reduction in light intensity, the area of individual leaflets increases, but when the shade intensifies there is no further area expansion such that if the light intensity in the open is ideal, the open field-grown plants will produce leaves larger in size than those growing in deep

shade. Further, quite apart from increasing the area of individual leaflets, more number of leaflets also were produced during Expt.1, so as to maximise the leaf area (total)/plant as a natural response to the relatively lower light intensities within the bamboo stand ( $E_1$ ).

During the period that followed (i.e., after Expt.1) the ambient light intensity, after having touched the lowest value of 21.9 K lux during the 3rd week of November 1979, started to rise again upto the 2nd week of May 1980, when it reached the maximum value of 115.2 K lux (Appendix 1 and Fig.8). Beyond that, the light intensity started to fall once again touching a value as low as 32.7 K lux during the last week of June 1980, when the soybean crop of Expt.3 was about 70 days old. Taking the averages for the period 'from sowing up to 60 DAS' only, for Expt.2 and Expt.3, we find that the ambient light intensities in the open field ( $E_2$ ) were 71.8 K lux and 88.5 K lux respectively. The corresponding values for the bamboo stand ( $E_1$ ) were, 45.5 K lux and 61.9 K lux for Expt.2 and Expt.3 respectively. It is evident that the light intensities, both in the open as well as inside the bamboo stand, during the tenures of both Expt.2 and Expt.3, were far below the reported light saturation value, though very much higher than the compensation point of 1 to 1.5 K lux reported by Bohning and Burside (1956).

Obviously, this situation was conducive for the soybean plants growing in the open field ( $E_2$ ) to produce more number of leaves in Expt.2 and Expt.3, so as to utilize the available solar energy more fully. It may be thought, that if this were to be true, the same line of reasoning must hold for the bamboo stand also, and since the light intensity inside it being lesser still, the leaf production must be still higher than that for the open-grown soybean. However, it must be remembered that the available assimilates in the soybean plants growing within the bamboo stand ( $E_1$ ) were rather limited, as is evidenced by the data on dry matter production (DMP) to be discussed later in this chapter (section 4.1.12). Hence, the assimilates available being restricted and forced to be shared between purely photosynthetic tissues and non-photosynthetic structural tissues, a constraint would develop sooner or later. Every increase in the number of leaves is attendant with diversion of part of the available assimilates towards the building of non-photosynthetic but essential structural parts like the veins of a leaf. It thus stands to reason that during the periods of Experiments 2 and 3, eventhough there existed a strong environmental stimulus within the bamboo stand ( $E_1$ ) for the soybean plants to put forth more leaves, still the plants did not respond, because of the available assimilates being low and acting as a constraint.

The reversal of the general trend seen in Expt.3 at 30 DAS, with the soybean plants growing within the bamboo stand ( $E_1$ ) recording significantly more number of leaflets/plant than those growing in the open ( $E_2$ ) was perhaps the consequence of a light cleaning given to the bamboo clumps at the commencement of Expt.3, which could have created an optimum environment for soybean leaf production.

As regards the influence of the second factor, viz., vigour of the bamboo clumps (V), there was only one instance of statistical significance. It was seen that the soybean plants growing under 'high vigour' bamboo clumps (H) had significantly more number of leaflets/plant than those growing under 'low vigour' clumps (L) at 90 DAS under Expt.2. This lone exception does not warrant further discussion, particularly since the concerned data had to be square root transformed before statistical analysis.

The third factor, P, did not exercise any significant influence. However, two of its interactions, both involving 'vigour of the bamboo clump' (V), were statistically significant. These pertain to 90 DAS under Expt.1 (Table 7(a)) and 90 DAS under Expt.2 (Table 8(a)). The overall inference that could be deduced from these two interactions, is that P application at 100 kg  $P_2O_5$ /ha (i.e.,  $P_1$ ) significantly increases the number of leaflets/plant in soybean plants growing under 'high vigour' bamboo clumps (H).

Finally, an overall comparison of the three experiments taken together, shows a common feature. It is seen that the number of leaflets/plant initially rises steeply and almost linearly, peaking at 60 DAS, and then registering a sharp fall, the rate of fall being rather slow in Expt.3 only. At 60 DAS, when the peak was reached, the number of leaves/plant ranged from about 19 to about 38 for open field-grown soybean plants ( $E_2$ ). And, in the case of Expt.3 alone, the rate of reduction in the number of leaflets/plant was very slow such that there were 27.67 to 33.69 leaflets/plant in  $E_2$  under the different P levels, even at 90 DAS. The general trend of reduction in leaf number after 60 DAS is ascribable to leaf senescence and fall coupled with progressive cessation of new leaf production.

#### 4.1.5 Leaf area/plant

(Tables 10, 11, 11(a), Fig.3(b))

Only one factor, viz., the environment (E) exerted any influence on the leaf area/plant, the other two factors (V and P) remaining inactive. The influence of the environment was significant throughout, i.e., at all the stages of growth and under both the experiments (Expt.1 and Expt.3) for which leaf area was recorded. The trends, however, were opposite between the two experiments. While in Expt.1 the soybean plants growing within the bamboo stand ( $E_1$ ) recorded a higher leaf area/plant at both 40 and 80 DAS, in Expt.3 the plants growing in the open field ( $E_2$ ) recorded higher leaf area throughout, excepting initially (30 DAS).

**Table 10** Leaf area (total)/plant (cm<sup>2</sup>) Mean leaf area/leaflet (cm

Expt.1	D A S		D A S	
	40	80	40	80
<b>1. Within the bamboo stand (E<sub>1</sub>) (a) Influence of Phosphorus levels</b>				
P <sub>0</sub>	213.002	154.24	13.29	9.11
P <sub>1</sub>	181.969	142.39	11.89	8.99
P <sub>2</sub>	190.911	138.77	12.54	9.54
F	NS	NS	NS	NS
SE	15.654	11.82	0.717	0.611
CD	-	-	-	-
<hr/>				
L	200.520	138.89	12.81	9.18
H	190.066	151.37	12.34	9.24
F	NS	NS	NS	NS
SE	12.782	9.65	0.585	0.499
CD	-	-	-	-
<hr/>				
<b>2. In the open field (E<sub>2</sub>) Influence of phosphorus levels (P)</b>				
P <sub>0</sub>	128.462	95.03	8.53	6.63
P <sub>1</sub>	135.065	81.58	8.72	5.80
P <sub>2</sub>	133.371	81.02	8.71	5.79
F	NS	NS	NS	NS
SE	8.936	6.46	0.440	0.310
CD	-	-	-	-
<hr/>				
<b>3. Pooled analysis (a) Influence of environments (E)</b>				
E <sub>1</sub>	195.294	145.13	12.57	9.21
E <sub>2</sub>	132.299	85.88	8.65	4.14
F	***	***	***	***
SE	7.187	5.36	0.336	0.272
CD	20.680	15.43	0.967	0.784
<hr/>				
<b>(b) Influence of phosphorus levels (P)</b>				
P <sub>0</sub>	170.732	124.64	10.91	7.87
P <sub>1</sub>	158.517	111.99	10.31	7.40
P <sub>2</sub>	162.141	109.90	10.63	7.67
F	NS	NS	NS	NS
SE	8.802	6.57	0.412	0.334
CD	-	-	-	-

Table 11 Leaf Area (Total)/plant (cm<sup>2</sup>)

SOYBEAN

Expt. 3

	D A S					
	30	40	50	60	70	90
<b>1. Within the bamboo stand (E<sub>1</sub>) (a) Influence of phosphorous levels (P)</b>						
P <sub>0</sub>	332.245	300.250	530.405	456.150	318.345	201.760
P <sub>1</sub>	352.900	300.000	589.780	533.410	299.415	168.440
P <sub>2</sub>	326.465	359.145	610.105	646.230	288.205	247.625
F	NS	NS	NS	NS	NS	NS
SE	40.875	22.736	41.825	50.590	55.827	41.206
CD	-	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>						
L	297.797	294.267	529.380	561.283	313.243	207.667
H	376.610	345.330	624.147	509.243	290.733	204.217
F	NS	NS	NS	NS	NS	NS
SE	33.373	18.564	34.148	41.307	45.582	33.644
CD	-	-	-	-	-	-
<b>2. In the open field Influence of the phosphorous levels (P)</b>						
P <sub>0</sub>	253.501	516.345	739.528	830.436	785.767	444.119
P <sub>1</sub>	262.221	441.835	853.288	864.796	898.614	640.963
P <sub>2</sub>	290.132	500.872	976.343	875.027	719.448	608.657
F	NS	NS	NS	NS	NS	NS
SE	30.644	70.200	107.382	93.676	90.372	75.791
CD	-	-	-	-	-	-
<b>3. Pooled analysis (a) Influence of environments (E)</b>						
E <sub>1</sub>	337.203	319.798	576.763	545.263	301.988	205.944
E <sub>2</sub>	268.651	486.351	856.386	856.760	801.276	564.588
F	*	***	**	***	***	***
SE	20.568	30.514	48.596	44.534	44.239	36.08
CD	59.243	156.927	188.678	229.029	227.512	185.55
<b>(b) Influence of Phosphorous levels (P)</b>						
P <sub>0</sub>	292.873	408.298	634.967	643.303	552.056	322.94
P <sub>1</sub>	307.611	370.918	721.534	699.103	599.015	404.70
P <sub>2</sub>	308.299	430.009	793.224	760.629	503.827	428.14
F	NS	NS	NS	NS	NS	NS
SE	25.215	37.371	59.517	54.542	54.182	44.18
CD	-	-	-	-	-	-

Table 11(a) Leaf area (Total)/plant (cm<sup>2</sup>) as on 60 DAS SOYBEAN  
Influence of the interaction V X P  
 Expt. 3

P levels	Vigour of the bamboo clump (V)	
	L	H
P <sub>0</sub>	429.78	483.52
P <sub>1</sub>	500.36	566.46
P <sub>2</sub>	814.71	477.75

F test = \*  
 SE = 71.546  
 CD = 215.568

Conclusions:

- a) P over V  
 L = P<sub>2</sub> P<sub>1</sub> P<sub>0</sub> \*  
 H = P<sub>1</sub> P<sub>0</sub> P<sub>2</sub>
- b) P<sub>0</sub> = H L  
 P<sub>1</sub> = H L  
 P<sub>2</sub> = L H \*

That shading reduces the leaf area has been reported by several workers (Andrew and Burns, 1978 in maize; Palis and Bustrillos, 1976 in sorghum; Crookston et al.; 1975 in beans). Further the complementary phenomenon, viz., increasing light intensity increases the leaf area, has also been demonstrated; for instance, by Adedipe and Ormrod (1974) in cowpea and Tarila et al. (1977), again in cowpea. These evidences clearly establish the deleterious influence of shade on leaf area. The results observed under Expt.3 (excepting at 30 DAS) of the present investigation, is in agreement with the above.

However, lack of influence by shading on leaf area has also been reported by Singh (1978) working on barley. Even, a positive influence of shade on leaf area has also been reported. Thus, Porter (1937) observed in tomatoes leaf area to increase under decreased light intensity and Saxena and Sheldrake (1977) reported that in chickpea, a higher leaf area was retained for a longer time under shading. The results observed under Expt.1 (at both 40 and 80 DAS) of the present investigation corroborate the last two reports.

As regards soybean itself, mutual shading as occurring in normal canopies has been reported to increase the leaf area/plant, as compared to debranched plants which admitted more light through the canopy, by Beuerlein et al. (1971). In contrast to this, Jeyaraman (1979) ascribed the higher leaf area observed by him in the uniform row system as compared to

the paired row system of planting, to more availability of sunlight in the uniform system of planting.

One plausible explanation for these conflicting reports about the influence of shading on leaf area, in different crops including soybean is that, reduction in light intensity initially stimulates the plant to respond to the stress by increasing the total leaf area so as to capture as much light as possible and thus compensate for the partial loss in light intensity. Such increases in total leaf area may be achieved through producing more leaves as well as by increasing the leaf area/leaf. However, this adaptive mechanism may operate only within a range of light intensities (which may vary depending on the plant species concerned) and when the degree of shading intensifies and goes below this range, there simply is not enough assimilate due to the insufficiency of light, that further production of leaf tissue and thus maintenance of a high leaf area becomes impossible. Under still heavier shade, even the number of leaves/plant is reduced for want of assimilates, as compared to the situation in an open field. At this stage, even the leaf area/leaf may suffer.

Thus, a distinction between 'partial shade' and 'deep shade' has to be effected in interpreting the behaviour of total leaf area/plant under reduced light intensity. Whitney (1902) and Hasselbring (1914) reported that partial shade produces large, broad and thin leaves in tobacco. The data

for mean leaf area/leaflet in the present investigation (Table 10 and Table 12) reveal that under Expt.1, during both stages of recording the data (40 and 80 DAS) the mean leaf area/leaflet was higher for soybean plants growing within the bamboo stand ( $E_1$ ) as compared to those growing in the open ( $E_2$ ). Actually, at 40 DAS there was a mean increase of 45% in the area of a single leaflet growing in the shade, and at 80 DAS the increase was still higher (122%), i.e., a shade leaflet was more than double in area than an open-grown leaflet. During the tenure of Expt.2 no observation was recorded on leaf area. As regards Expt.3, the mean leaf area/leaflet was higher for soybean growing within the bamboo stand ( $E_1$ ) only initially (at 30 DAS), the increase being of the order of 21%. Subsequently, however, the trend reversed with the soybean plants growing under shade recording lower values for mean leaf area/leaflet.

As regards the number of leaflets/plant, it has already been pointed out under section 4.1.4 that it was higher in the shade ( $E_1$ ) throughout (30, 40, 60, 80 and 90DAS) in Expt.1, after which it reversed so that there were lesser number of leaflets/plant in the shade ( $E_1$ ) for the rest of the period of the investigation (30, 60 and 90 DAS of Expt.2 and 40, 50, 60, 70 and 90 DAS of Expt.3), the only exception being 30 DAS of Expt.3. Even in this lone exception, the difference was marginal (the shade-grown plants recording only 4.5% more number of leaflets than the open-grown plants) though it was

significant ( $p = 0.01$ ). Setting aside this single exception as a spurious phenomenon, the trend is clear that initially when the bamboo stand cast 'light shade' or 'partial shade' the soybean plants growing under it put on more number of leaflets/plant as compared to the open-grown plants, but subsequently as the bamboo clumps grew and their crowns developed with eventual increasing closure of the canopy, leaflet production in the shade suffered.

Coupling these two factors (i.e., mean leaf area/leaflet and number of leaflets/plant) whose arithmetical product is the leaf area/plant, it is clear that initially when there was only partial shading, both the mean leaf area/leaflet and the number of leaflets/plant increased resulting in increased leaf area (total)/plant, under  $E_1$ . This explains the increased leaf area (total)/plant observed under Expt.1. Subsequent changes followed the pattern indicated earlier so that the leaf area (total)/plant under  $E_1$  was lower than that for  $E_2$ .

As mentioned earlier, neither vigour of the bamboo clump (V) nor phosphorus levels (P) exerted any significant influence on the leaf area (total)/plant. However, there was a long case (60 DAS under Expt.3) of interaction between them. The interaction indicated (Table 11(a)) that application of the highest dose of P, viz., 200 kg  $P_2O_5$ /ha, significantly increased the leaf area (total)/plant in soybean plants growing under 'low vigour' (L) clumps. It is difficult to attempt an explanation

for this interaction as several possibilities suggest themselves, as shown below - (i) the 'L' clump being less vigorous did not compete very much for the added P with the associated soybean plants, which therefore could derive benefit from increased P application; but the observed overall lack of response to P does not lend support to this; (ii) shade cast by a 'L' clump being most probably less intense, P utilization was more efficient by the relatively healthier plants, etc. As regards the main effect of P itself the reports of earlier workers are conflicting. Thus, while Nogueira *et al.* (1977) reported that in soybean the highest leaf area (LA) and LAI were observed under an application level of 400kg as compared to 200 and 100 kg  $P_2O_5$ /ha, Roy and Mishra (1975), under Indian conditions, found LAI to increase only upto 50kg  $P_2O_5$ /ha (i.e., 39 kg P/ha) after which it declined.

Regarding pattern of changes over time (Fig.3(b)) the data for Expt.1 showed the leaf area (total)/plant as at 80 DAS to be uniformly less than that for 40 DAS. The data for Expt.3 is more instructive since there were 6 stages of recording. The general trend was the leaf area (total)/plant steeply increased till about 50-60 DAS, after which it declined. At the peak, the leaf areas were ranging from of 456 to 976  $cm^2$ /plant in Expt.3 and from 128 to 213  $cm^2$ /plant in Expt.2. Curiously in Expt.3, the leaf area initially declined slightly from 30 DAS to 40 DAS, after which it increased, in the case of the soybean plants growing within the bamboo stand ( $E_1$ ) alone; this was not the

case in the open field ( $E_2$ ). This was caused by the reduction in mean leaf area/leaflet within the bamboo stand during this period (Table 12). This may be due to a transient fluctuation.

#### 4.1.6. Mean leaf area/leaflet

(Tables 10 and 12, Fig. 3 (c))

Environment (E) significantly influenced this parameter. In general, leaflets were smaller (4.14 to 13.29  $\text{cm}^2$ ) during the tenure of Expt.1 (August to December season) while they were more than twice as large (16.05 to 30.40  $\text{cm}^2$ ) during the tenure of Expt.3 (April to July season). During both the stages (40 and 80 DAS) of Expt.1 as well as at the beginning (30 DAS) of Expt.3, the soybean plants growing within the bamboo stand ( $E_1$ ) recorded larger leaves, as compared to the plants growing in the open; the increase in the mean leaf area/leaflet being 45%, 122% and 21% for 40 and 80 DAS of Expt.1, and 30 DAS of Expt.3, respectively. Subsequently, the trend reversed and invariably, the leaflets of the open-grown plants ( $E_2$ ) were larger than those of  $E_1$ .

The reason for this has already been pointed out while discussing leaf area (total)/plant (under section 4.1.5) and was ascribed to the phenomenon of the shade cast by the bamboo clumps being light initially (during Expt.1) and subsequently increasing (by the time of Expt.3). The finding of Cooper and Qualls (1967) that the ratio of leaf area to leaf weight

Table 12 Mean leaf area/leaflet (cm<sup>2</sup>)

SOYBEAN

Expt. 3

	D A S					
	30	40	50	60	70	90
<b>1. Within the bamboo stand (E<sub>1</sub>) (a) Influence of Phosphorus levels</b>						
P <sub>0</sub>	23.498	18.355	22.290	20.762	16.089	14.795
P <sub>1</sub>	24.358	17.915	22.795	23.905	17.289	12.690
P <sub>2</sub>	24.060	19.170	24.360	27.185	15.835	15.890
F	NS	NS	NS	**	NS	NS
SE	2.064	0.680	1.032	0.964	2.364	1.693
CD	-	-	-	4.017	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>						
L	21.527	17.443	21.980	23.683	16.753	13.717
H	26.417	19.517	24.317	24.218	16.054	15.200
F	NS	*	NS	NS	NS	NS
SE	1.685	0.556	0.843	0.787	1.930	1.382
CD	-	2.050	-	-	-	-
<b>2. In the open field (E<sub>2</sub>) Influence of Phosphorus levels (P)</b>						
P <sub>0</sub>	18.487	24.074	24.944	24.980	23.120	16.067
P <sub>1</sub>	19.637	23.181	29.795	23.810	24.573	18.839
P <sub>2</sub>	21.471	23.511	30.403	23.861	23.231	18.195
F	NS	NS	NS	NS	NS	**
SE	1.444	2.353	2.725	1.550	1.765	0.582
CD	-	-	-	-	-	2.368
<b>3. Pooled analysis (a) Influence of Environments (E)</b>						
E <sub>1</sub>	23.972	18.480	23.148	23.951	16.404	14.458
E <sub>2</sub>	19.865	23.589	28.381	24.217	23.641	17.700
F	**	**	**	NS	***	**
SE	1.012	1.038	1.230	0.759	1.189	0.704
CD	3.929	4.030	4.776	-	6.115	2.733
<b>(b) Influence of Phosphorus levels (P)</b>						
P <sub>0</sub>	20.993	21.215	23.617	22.871	19.605	15.431
P <sub>1</sub>	21.998	20.548	26.295	23.858	20.931	15.765
P <sub>2</sub>	22.766	21.341	27.382	25.523	19.533	17.043
F	NS	NS	NS	NS	NS	NS
SE	1.537	1.271	1.506	0.930	1.456	0.862
CD	-	-	-	-	-	-

**Table 12 (a) Mean leaf area/leaflet (cm<sup>2</sup>) as on 60 DAS SOYBEAN**  
Influence of the interaction E X P  
 Expt.3

P levels	Environments (E)	
	Within the bamboo (E <sub>1</sub> )	In the open (E <sub>2</sub> )
P <sub>0</sub>	20.762	24.980
P <sub>1</sub>	23.905	23.810
P <sub>2</sub>	27.185	23.861

F test = \*  
 SE = 1.728  
 CD = 4.972

**Conclusions:**

- a) P over E  

$$E_1 = \frac{P_2 \quad P_1 \quad P_0}{*}$$

$$E_2 = \frac{P_0 \quad P_2 \quad P_1}{*}$$
- b) E over P  

$$P_0 = \frac{E_2 \quad E_1}{*}$$

$$P_1 = \frac{E_1 \quad E_2}{*}$$

$$P_2 = \frac{E_1 \quad E_2}{*}$$

Table 12 (b) Mean leaf area/leaflet (cm<sup>2</sup>) as on 60 DAS SOYBEAN  
Influence of the interaction V X P  
 Expt. 3

P levels	Vigour of the bamboo clump (V)	
	L	H
P <sub>0</sub>	20.220	21.304
P <sub>1</sub>	20.080	27.730
P <sub>2</sub>	30.750	23.620

F test = \*\*  
 SE = 1.364  
 CD = 5.684

Conclusions:

- a) P over V  
 L = P<sub>2</sub>  $\frac{P_0}{P_1}$  \*\*  
 H = P<sub>1</sub>  $\frac{P_2}{P_0}$  \*\*
- b) V over P  
 P<sub>0</sub> = H L  
 P<sub>1</sub> = H L \*\*  
 P<sub>2</sub> = L H \*\*

increases under shade as seen in two legumes (alfalfa and birdsfoot trefoil) is of relevance in this context. Thus, in the present investigation, the area/leaflet might have increased without any substantial change in its weight, during the initial phase (Expt.1). Subsequently, the shading having intensified and photosynthesis having been seriously curtailed, there simply might not have been enough assimilate reserves to put forth new leaf tissues, the leaves having become as thin as possible, so that further expansion of leaf area was not possible. In contrast, light being not a constraint in the open field, assimilate availability must have been sufficient enough to make the leaflets attain their optimal size. That shading increases the specific leaf area (SLA) has been reported by other workers also (Blackman and Wilson, 1954, in sunflower; and Santo and Algani, 1976 in the mint plant).

As regards vigour of the bamboo clump (V) there was only one instance (40 DAS under Expt.3) when the difference between L and H reached the level of statistical significance; the leaflets of soybean plants growing under the 'high vigour' clumps were slightly (12% more) larger than those growing under the 'low vigour' (L) clumps. This was a reflection of the trend noticed at all stages excepting 70 DAS, under Expt.3, even though the other differences were not statistically significant. The argument made out for explaining the increase in the mean leaf area/leaflet under shade, applies here also.

In this case, eventhough all bamboo clumps cast shade, presumably an 'L' clump cast light shade and a 'H' clump heavy shade.

Regarding phosphorus, though the overall influence was not significant at any stage under both the experiments, the differences between the levels were significant in the open field ( $E_2$ ) situation, in one single instance, viz., at 90 DAS under Expt.3 (Table 12). The mean leaf area/leaflet under  $P_1$  treatment ( $100 \text{ kg } P_2O_5/\text{ha}$ ) was significantly superior to  $P_0$  (control) treatment, and  $P_2$  occupied an intermediate position, it being on a par with both  $P_1$  and  $P_0$ . This result implies that the mean leaf area/leaflet increases upto an application level of  $100 \text{ kg } P_2O_5/\text{ha}$  after which it declined, a result which is parallel to that observed by Roy and Mishra (1975), for LAI in soybean, though it is not definite that the LAI was chiefly influenced by the mean area/leaflet.

There was also significant interaction between environment and P, under Expt.3 as at 60 DAS (Table 12(a)). The response to P under the environment 'within the bamboo stand' ( $E_1$ ) showed a graded pattern, with  $P_2$  recording the highest mean leaf area, followed by  $P_1$  and then by  $P_0$ .  $P_2$  was significantly superior to  $P_0$  while it was on a par with  $P_1$  which itself was on a par with  $P_0$ . Under the other environment ( $E_2$ ), all the P levels were on a par. Similarly, there was a significant interaction between V and P also (Table 12 (b)) during the same stage (60 DAS of Expt.3). The interaction indicated that the highest level of P (i.e.,  $P_2$ ) in combination with an 'L' clump recorded significantly higher mean leaf area/leaflet, and  $P_1$  and H

interacted similarly.

As regards the pattern of change over time, the general trend under all the factors under both Expt.1 and Expt.3 was a decline in the mean leaf area/leaflet as the crop grew. However, the behaviour was peculiar as shown by the data for Expt.3 (which elucidates the pattern more clearly because of the data being available for 6 stages of crop growth). While the mean leaf area/leaflet of the plants growing 'within the bamboo stand' ( $E_1$ ) showed an initial decline from 30 DAS to 40 DAS (from about  $24 \text{ cm}^2$  to about  $18.5 \text{ cm}^2$ ), the plants growing in the 'open field' environment ( $E_2$ ) did not show any decline but rose steeply from  $19.9 \text{ cm}^2$  to  $23.6 \text{ cm}^2$  during the same period. Between 40 DAS and 50 DAS, the pattern was similar for both the environments - the mean leaf area/leaflet increased. This phase of increase in the area of individual leaflets took place for a duration of 10 days in the case of  $E_2$ , i.e., upto 50 DAS when it attained a value of  $28.4 \text{ cm}^2$ , after which the size of individual leaflets became smaller and smaller till it reached a value of  $17.7 \text{ cm}^2$  at 90 DAS. On the other hand, the increasing trend in the area of individual leaflets, in the case of the shade environment ( $E_1$ ) lasted for a longer period (20 days) from 40 DAS to 60 DAS, even though the rate of leaf area expansion started to show a retardation from 50 DAS. After 60 DAS, the mean leaf area/leaflet started to fall in the case of  $E_1$  also, finally (at 90 DAS) reaching a value of

14.5 cm<sup>2</sup> which was lower than that for E<sub>2</sub>. Further, the mean leaf area/leaflet was lower under E<sub>1</sub>, at all stages of growth excepting initially (30 DAS) when it was significantly higher than that for E<sub>2</sub>. The general pattern of initial increase followed by decrease in mean leaf area/leaflet over time is an expression of the general growth curve for plants.

#### 4.1.7 Length of Tap root

(Tables 13 and 14, Fig. 4(a))

Data on the length of the tap root of individual sample plants were collected for one stage of growth, i.e., at harvest (90 DAS) for Experiments 1 and 2, and over 6 stages (30, 40, 50, 60, 70 and 90 DAS) under Expt.3. The results showed that while under Expt.1 none of the 3 factors exerted any significant influence on tap root's length, and under Expt.2 both the environment (E) and P levels significantly influenced it, under Expt.3, only the environmental factor (E) exerted a significant influence (excepting at 60 DAS), the other two factors remaining inactive.

The influence of the environment (E) was such that the plants growing in the open field (E<sub>2</sub>) in all but one instance (Expt.1, 90 DAS) recorded longer taproots, as compared to those growing within the bamboo stand (E<sub>1</sub>); and the difference was statistically significant in all but two instances (90 DAS of Expt.1 and 60DAS of Expt.3). The lone exception to this trend was seen at 90 DAS under Expt.1 where the plants growing

**Table 13** Length of Tap root/plant (cm) **SOYBEAN**

90 D A S

Expt. 1

Expt. 2

**1. Within the Bamboo stand ( $E_1$ ) (a) Influence of Phosphorus levels (P)**

$P_0$	14.138	6.945
$P_1$	13.685	6.657
$P_2$	13.199	6.935
F	NS	NS
SE	0.743	0.368
CD	-	-

**(b) Influence of vigour of bamboo clump (V)**

L	14.345	7.167
H	13.003	6.524
F	NS	NS
SE	0.607	0.301
CD	-	-

**2. In the open field ( $E_2$ ) Influence of Phosphorus levels (P)**

$P_0$	12.553	12.651
$P_1$	13.219	9.560
$P_2$	13.148	11.212
F	NS	*
SE	0.647	0.763
CD	-	2.267

**3. Pooled analysis (a) Influence of environments (E)**

$E_1$	13.674	6.846
$E_2$	12.973	11.141
F	NS	***
SE	0.400	0.355
CD	-	1.024

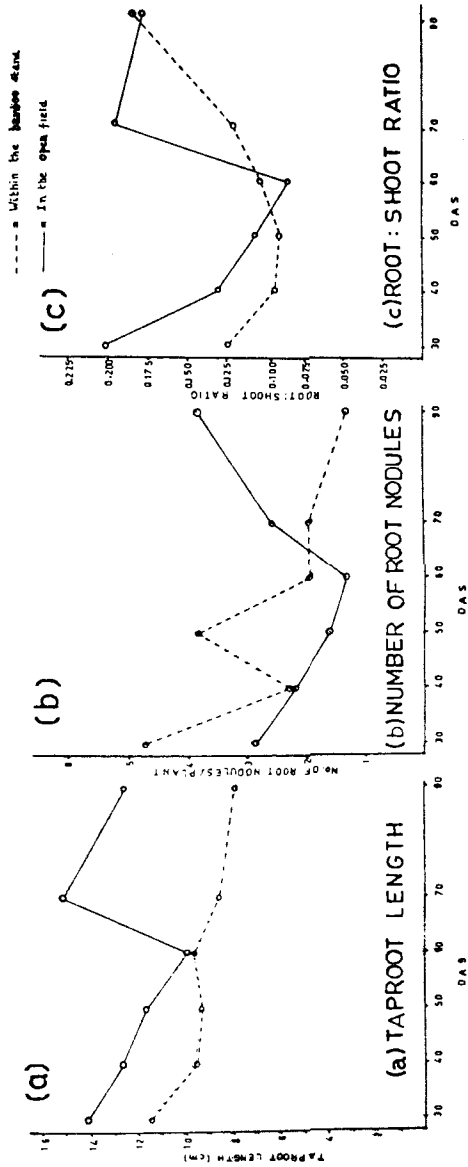
**(b) Influence of Phosphorus levels (P)**

$P_0$	13.346	9.798
$P_1$	13.452	8.109
$P_2$	13.174	9.074
F	NS	*
SE	0.490	0.435
CD	-	1.255

**Table 14 Length of tap root/plant (cm) SOYBEAN**

Expt-3	D A S					
	30	40	50	60	70	90
<b>1. Within the bamboo stand (E<sub>1</sub>) (a) Influence of phosphorous levels (P)</b>						
P <sub>0</sub>	11.160	10.290	10.345	11.160	7.805	7.265
P <sub>1</sub>	11.645	8.790	8.795	8.485	9.415	8.355
P <sub>2</sub>	11.665	9.665	9.040	9.340	8.785	8.360
F	NS	NS	NS	NS	NS	NS
SE	0.705	0.526	0.546	1.289	0.839	0.770
CD	-	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>						
L	11.650	10.147	9.100	9.557	8.933	7.957
H	11.330	9.017	9.687	9.767	8.403	8.030
F	NS	NS	NS	NS	NS	NS
SE	0.576	0.429	0.446	1.052	0.685	0.629
CD	-	-	-	-	-	-
<b>2. In the open field (E<sub>2</sub>) Influence of the phosphorous levels (P)</b>						
P <sub>0</sub>	14.102	12.857	11.445	9.797	15.627	11.578
P <sub>1</sub>	14.192	13.150	11.742	10.372	15.738	13.953
P <sub>2</sub>	14.154	12.071	12.025	9.854	14.187	12.507
F	NS	NS	NS	NS	NS	NS
SE	0.742	1.012	0.762	0.949	1.074	1.103
CD	-	-	-	-	-	-
<b>3. Pooled analysis</b>						
<b>(a) Influence of environments (E)</b>						
E <sub>1</sub>	11.490	9.582	9.393	9.662	8.668	7.993
E <sub>2</sub>	14.149	12.693	11.737	10.008	15.184	12.679
F	***	***	***	NS	***	***
SE	0.419	0.478	0.388	0.645	0.562	0.539
CD	2.155	2.458	1.995	-	2.890	2.772
<b>(b) Influence of phosphorous levels (P)</b>						
P <sub>0</sub>	12.631	11.571	10.895	10.479	11.716	9.422
P <sub>1</sub>	12.919	10.970	10.269	9.429	12.577	11.154
P <sub>2</sub>	12.910	10.868	10.532	9.597	11.486	10.434
F	NS	NS	NS	NS	NS	NS
SE	0.513	0.584	0.475	0.789	0.689	0.660
CD	-	-	-	-	-	-

Fig. 4 SOYBEAN - GROWTH ATTRIBUTES - 3  
 INFLUENCE OF TWO ENVIRONMENTS  
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within the bamboo stand ( $E_1$ ) recorded slightly longer (5% more than that for  $E_2$ ) taproots. However the difference was not statistically significant (Table 13).

As regards the actual lengths of taproots, it ranged from as low as 6.8 cm (90 DAS of Expt.2) under  $E_1$  to as long as 15.2 cm (70 DAS of Expt.3) under  $E_2$ . The implication of the results is clear. Obviously, in the environment  $E_1$ , where another plant species (i.e., the bamboo) with an extensive root spread of fibrous root system, almost near the ground surface, was present, the soybean plants faced stiff competition in root elongation as reflected by the length of the taproot. This competition was entirely absent in the open field ( $E_2$ ) which explains the significantly longer taproots seen under that environment. That there existed a root competition is borne out by the fact that the bamboo roots also occur in more or less the same soil depth zone. Thus Deogun (1937) has reported that the root system of Dendrocalamus strictus is very shallow and does not penetrate more than 60 - 90 cm below ground level. Siva Prasad (1980) reported that the root system of Dendrocalamus strictus extends to a depth of 1' - 2' (30 - 60 cm).

Another feature that strikes the eye in this investigation is the relatively short lengths of the taproot, be it within the bamboo stand or even in the open field. Early workers (Borst and Thatcher, 1934) characterized the soybean plant as having a taproot with many branches which penetrated

to a depth of 150 cm with the major portion occurring in the upper 60 cm. However, subsequent research by other workers (Mitchell and Russell, 1971; Raper and Barber, 1970) demonstrated that field-grown soybean lacked a distinct taproot, with a major portion of the root system consisting of lateral roots arising from the upper 10-15 cm of the primary root; these lateral roots extend outward from the plant nearly horizontally for 40 - 50 cm and then grow downward to depths as great as 180 cm.

Eventhough it has been stated by the workers referred to above that the soybean plant lacks a distinct taproot, the expression 'taproot' has been retained in discussing the present investigation in as much as there is no material difference (anatomically speaking) between a 'primary root' and a 'tap root' in dicot plants. In any case, the length of the tap root also appears to suffer the effects of interspecific root competition, quite apart from any such effects that may be present on lateral and other lower order roots. This is indicated by the depression in the length of the taproot under E<sub>1</sub>.

Vigour of the bamboo clump (V) did not exert any significant influence on the length of the taproot of the soybean, under any one of the three experiments. Similarly the third factor P also failed to exert any significant influence on taproot excepting at 90 DAS of Expt.2. In Expt.2 alone, as at 90 DAS, significant differences arose between the P levels under both 'open field' environment and as regards the overall

effect of P (combining both the environments). In both cases (i.e., influence of P under  $E_2$  and overall influence of P under  $E_1$  and  $E_2$  combined) the same pattern was repeated, with  $P_0$  being significantly superior to  $P_1$  and  $P_2$  occupying an intermediate position, itself being on a par with both  $P_0$  and  $P_1$ . It is however, difficult to explain the superiority of non-application of P on taproot length.

As regards the pattern of change in taproot length over time, the data on Expt.3 revealed (Table 14) a general trend of decline. This means that initially the taproot was relatively longer and progressively shortened as time passed. It is highly probable that as time passed, and the secondary roots took over, the taproot started sloughing off from the tip and at the time of pulling out the plant, despite the care exercised, the sloughed off terminal portion of the tap root was retained in the soil, and since it is equally probable that as time passed and more and more lateral roots took over the functions of the taproot, the decaying of the terminal portion of the tap root extended further up such that samples drawn at successive stages of crop growth recorded lesser and lesser lengths of taproot which would explain the observed decline. There was, however, a spurt of increase in taproot length between 60 DAS and 70 DAS after which it started to decline once again, in the open field environment ( $E_2$ ) under Expt.3. The reason for this is not clear. It is quite possible it is a superious fluctuation.

#### 4.1.8 Number of root nodules/plant

(Table 15, Fig. 4(b))

Before discussing the data under this attribute it must be pointed out that the data had to be subjected to square root transformation before statistical analysis could be carried out, since many zero values were encountered. Such transformation had to be carried out for the data of all the crop growth stages excepting 30 DAS. Hence caution is warranted in interpreting the data.

The results revealed that environment (E) exerted a significant influence. As regards the effect of the environment, the soybean plants growing within the bamboo stand ( $E_1$ ) recorded more number of nodules upto 60 DAS and the differences between  $E_1$  and  $E_2$  were significant throughout except at 40 DAS. From 70 DAS onwards, the trend reversed and the soybean plants growing in the open field ( $E_2$ ) recorded significantly more number of nodules than those growing within the bamboo stand ( $E_1$ ). These results appear to contradict the results reported by several earlier workers (Trang, 1977, Rabie and Kumazawa, 1979; Trang and Giddens, 1980) who found shading to reduce the number of nodules. But, when we consider the fact that the reports of all the earlier workers are based on experiments with artificial, and thus non-living, shades, a plausible argument suggests itself for explaining the apparent contradiction between the results of the present investigation and those reported by earlier workers.

Table 15 No. of root nodules/plant

SOYBEAN

Expt. 3	D A S					
	30	40 <sup>Ⓢ</sup>	50 <sup>Ⓢ</sup>	60 <sup>Ⓢ</sup>	70 <sup>Ⓢ</sup>	90 <sup>Ⓢ</sup>
<b>1. Within the bamboo stand (E<sub>1</sub>) (a) Influence of phosphorous levels (P)</b>						
P <sub>0</sub>	5.375	2.938	4.396	2.021	1.959	1.292 <sup>(P)</sup>
P <sub>1</sub>	4.875	2.042	3.917	1.834	1.668	1.084
P <sub>2</sub>	3.900	1.855	3.209	1.771	1.980	1.583
F	NS	NS	NS	NS	NS	NS
SE	0.576	0.155 <sup>ⓈⓈ</sup>	0.204 <sup>ⓈⓈ</sup>	0.097 <sup>ⓈⓈ</sup>	0.098 <sup>ⓈⓈ</sup>	0.141
CD	-	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>						
L	3.890	2.056	3.084	1.931	1.722	1.264
H	5.543	2.500	4.597	1.820	2.028	1.375
F	*	NS	NS	NS	NS	NS
SE	0.470	0.127 <sup>ⓈⓈ</sup>	0.167 <sup>ⓈⓈ</sup>	0.079 <sup>ⓈⓈ</sup>	0.080 <sup>ⓈⓈ</sup>	0.116 <sup>ⓈⓈ</sup>
CD	1.416	-	-	-	-	-
<b>2. In the open field (E<sub>2</sub>) Influence of the phosphorous levels (P)</b>						
P <sub>0</sub>	3.146	2.146	1.480	1.500	2.375	3.292
P <sub>1</sub>	2.792	2.230	1.875	1.709	2.584	4.126
P <sub>2</sub>	2.667	2.230	1.480	0.834	2.480	4.229
F	NS	NS	NS	NS	NS	NS
SE	0.579	0.174 <sup>ⓈⓈ</sup>	0.143 <sup>ⓈⓈ</sup>	0.152 <sup>ⓈⓈ</sup>	0.091 <sup>ⓈⓈ</sup>	0.150
CD	1.720	-	-	-	-	-
<b>3. Pooled analysis (a) Influence of environments (E)</b>						
E <sub>1</sub>	4.717	2.278	3.841	1.875	1.876	1.320
E <sub>2</sub>	2.868	2.202	1.612	1.348	2.580	3.882
F	***	NS	***	*	*	***
SE	0.324	0.096 <sup>ⓈⓈ</sup>	0.100 <sup>ⓈⓈ</sup>	0.075 <sup>ⓈⓈ</sup>	0.054 <sup>ⓈⓈ</sup>	0.089
CD	1.666	-	0.514 <sup>ⓈⓈ</sup>	0.216 <sup>ⓈⓈ</sup>	0.156 <sup>ⓈⓈ</sup>	0.437
<b>(b) Influence of phosphorous levels (P)</b>						
P <sub>0</sub>	4.751	2.542	2.938	1.761	2.167	2.292
P <sub>1</sub>	3.834	2.136	2.896	1.772	2.136	2.605
P <sub>2</sub>	3.189	2.043	2.345	1.503	2.230	2.906
F	NS	NS	NS	NS	NS	NS
SE	0.397	0.117 <sup>ⓈⓈ</sup>	0.123 <sup>ⓈⓈ</sup>	0.092 <sup>ⓈⓈ</sup>	0.066 <sup>ⓈⓈ</sup>	0.104
CD	-	-	-	-	-	-

Ⓢ - Square root transformation done before analysis

ⓈⓈ - in square root transformed units

It is quite likely that some mechanism similar to allelopathy is involved, but acting synergistically. The possibility of the associated bamboo roots exuding some chemical substance which stimulates nodulation, either through a stimulation of the bacteria or through making the conditions of the soybean rhizosphere more congenial for infection, or a combination of both, cannot be ruled out, albeit evidence for the same is wanting. Another line of reasoning would be from the angle of soil moisture. Sprent (1972) based on extensive investigations in soybean, concluded that water supply is probably the major environmental factor affecting nitrogen fixation, maximum nitrogen fixation occurring with the soil near its field capacity. Though this conclusion applies only to the efficiency of N-fixation by nodules already formed, still it could be argued that increased N-fixation through its beneficial action on the plant will in turn lead to more nodulation. Thus, soil moisture levels get connected with nodule number (or possibly with nodule mass). The soil moisture data of the present investigation (Table 34) reveals that in general the soil moisture was more within the bamboo stand ( $E_1$ ) than in the open field ( $E_2$ ). Eventhough the soil moisture data was collected for Experiments 1 and 2 only, the trend is extrapolable for Expt.3 also.

The foregoing conjectures need further elucidation. Further, it is difficult to explain the reversal of the trend as regards the number of root nodules after 70 DAS. Most probably nodules were sloughed off beyond 70 DAS.

Regarding the influence of the vigour of the bamboo clump (V) significant difference arose only at 30 DAS, with the soybean plants growing under the 'high vigour' clumps (H) recording numerically superior root nodules. Eventhough the differences during the other stages of crop growth were not statistically significant, the general trend was similar, favouring the 'H' clumps, excepting at 60 DAS. These results lend support to the conjecture about the synergistic effect of the bamboo clumps, already discussed. It may be argued that if at all bamboo clumps beneficially influence nodulation in soybean, then such effects must be more pronounced with vigorously growing bamboo clumps than with weaker clumps.

Phosphorus application did not influence nodule number significantly. This is in contrast to the report of De Mooy and Pesek (1966) who brought out the importance of P + K combination for nodulation in soybean. Quite likely, since no K was applied to the crop in the present investigation, P failed to influence nodulation.

4.1.9 Root: Shoot ratio

(Tables 16 and 17, Fig. 4(c))

Data on root: shoot ratio were collected for only one stage, i.e., 90 DAS, for Experiments 1 and 2 while for Expt.3 data is available for all the 6 stages of growth from 30 DAS to 90 DAS. These reveal that environment exerted a significant influence upto 70 DAS, with the lone exception of 60 DAS, under

Table 16 Root/Shoot Ratio

SOYBEAN

Expt. 3

	D A S				
	30	40	50	60	70
<b>1. Within the Bamboo stand (<math>E_1</math>) (a) Influence of Phosphorus level</b>					
$P_0$	0.129	0.103	0.104	0.127	0.143
$P_1$	0.110	0.089	0.093	0.098	0.113
$P_2$	0.136	0.093	0.077	0.086	0.108
F	NS	NS	NS	NS	NS
SE	0.009	0.008	0.010	0.028	0.018
CD	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>					
L	0.130	0.107	0.084	0.092	0.134
H	0.119	0.083	0.098	0.115	0.108
F	NS	*	NS	NS	NS
SE	0.008	0.007	0.008	0.023	0.015
CD	-	0.020	-	-	-
<b>2. In the open field (<math>E_2</math>) Influence of Phosphorus levels (P)</b>					
$P_0$	0.196	0.128	0.108	0.093	0.201
$P_1$	0.209	0.136	0.112	0.064	0.198
$P_2$	0.205	0.126	0.102	0.078	0.188
F	NS	NS	NS	NS	NS
SE	0.011	0.007	0.009	0.006	0.030
CD	-	-	-	-	-
<b>3. Pooled analysis (a) Influence of Environments (E)</b>					
$E_1$	0.125	0.095	0.091	0.104	0.121
$E_2$	0.203	0.130	0.107	0.085	0.196
F	***	***	*	NS	**
SE	0.006	0.004	0.005	0.011	0.015
CD	0.031	0.021	0.014	-	0.058
<b>(b) Influence of Phosphorus levels (P)</b>					
$P_0$	0.163	0.116	0.106	0.110	0.172
$P_1$	0.160	0.113	0.103	0.091	0.156
$P_2$	0.171	0.110	0.090	0.082	0.148
F	NS	NS	NS	NS	NS
SE	0.007	0.005	0.007	0.014	0.018
CD	-	-	-	-	-

Table 17 Root/Shoot Ratio

SOYBEAN

90 D A S

	Expt. 1	Expt. 2	Expt. 3
<b>1. Within the Bamboo stand (<math>E_1</math>) (a) Influence of Phosphorus levels</b>			
$P_0$	0.238	0.239	0.184
$P_1$	0.238	0.264	0.224
$P_2$	0.222	0.257	0.151
F	NS	NS	NS
SE	0.015	0.016	0.031
CD	-	-	-
<b>(b) Influence of vigour of Bamboo clump (V)</b>			
L	0.221	0.254	0.222
H	0.244	0.252	0.151
F	NS	NS	NS
SE	0.012	0.013	0.026
CD	-	-	-
<b>2. In the open field (<math>E_2</math>) Influence of Phosphorus levels (P)</b>			
$P_0$	0.246	0.257	0.184
$P_1$	0.256	0.263	0.179
$P_2$	0.246	0.289	0.178
F	NS	NS	NS
SE	0.026	0.016	0.016
CD	-	-	-
<b>3. Pooled analysis (a) Influence of Environments (E)</b>			
$E_1$	0.233	0.253	0.186
$E_2$	0.249	0.276	0.180
F	NS	NS	NS
SE	0.012	0.009	0.014
CD	-	-	-
<b>(b) Influence of Phosphorus levels (P)</b>			
$P_0$	0.242	0.248	0.184
$P_1$	0.247	0.274	0.202
$P_2$	0.234	0.273	0.165
F	NS	NS	NS
SE	0.015	0.011	0.017
CD	-	-	-

Expt.3. At 90 DAS, the difference was not significant under any one of the three experiments. In all cases of significant difference (30, 40, 50 and 70 DAS of Expt.3) and even when it was not significant, in two instances (90 DAS of Experiments 1 and 2), the open field ( $E_2$ ) recorded a higher root: shoot ratio as compared to the soybean plants growing within the bamboo stand ( $E_4$ ). Similar results have been reported in other crops also. Thus Palis and Eustrillos (1976) working on sorghum and Noguchi et al. (1978) working on lettuce observed the shoot: root ratio to increase under shade, which is the same thing as a decrease in the reciprocal relationship, the 'root: shoot ratio'.

Hicks (1978) stated that eventhough root depth may exceed plant height throughout most of the growing season, the dry weight of the above ground plant parts exceeds the root dry weight throughout the season. The results of the present investigation confirms this as the ratio was always less than unity. As regards the difference in the root: shoot ratio between the two environments, the reduced ratio seen under  $E_4$  ('within the bamboo stand') was obviously the result of severe root competition by the bamboo roots. This clarifies the results secured under the parameter 'length of the taproot' already discussed under section 4.1.7, and strengthens the argument about inter-specific root competition presented therein. It was seen that according to Mitchell and Russell (1971) and

Raper and Barber (1970) the soybean plant lacks a distinct taproot and that the bulk of the root system is represented by the lateral roots. This would imply that the length of the taproot (or primary root) is a poor measure of the situation prevailing below ground. Still, it was also seen that the data on the length of taproot collected in the present investigation brought out a clear trend establishing the fact that root development in terms of taproot length in soybean was poor within the bamboo stand ( $E_1$ ). In contrast, the parameter 'root: shoot ratio' does not suffer this lacuna of non-representativeness, since, for computing this ratio the entire mass of the soybean root system (and not merely the taproot alone) has been taken into consideration. However, since this is a ratio involving another and a totally different component of the plant (i.e., the aerial parts) there is still the likelihood of the ratio being influenced by any change in that component.

Vigour of the bamboo clump (V) failed to exert any significant influence on the root: shoot ratio of soybean, excepting in one instance (40 DAS under Expt.3). At 40 DAS under Expt.3, the root: shoot was higher under the 'low vigour' (L) bamboo clumps than under the 'high vigour' (H) clumps. This result is as could be expected. The severity of root competition offered by a vigorously growing bamboo clump must obviously be more than that by a relatively weaker clump, such that the root development of associated soybean plants suffer much, leading thereby to a lower root: shoot ratio.

Phosphorus application (P) did not influence the roots: shoot ratio significantly in any of the three experiments.

#### 4.1.10 Number of flowers/plant

(Tables 18 and 18(a))

Only the effect of the environment (E) and the overall influence of P were statistically significant. As regards environment, the number of flowers/plant was consistently more in soybean plants growing in the open field ( $E_2$ ) than in those growing within the bamboo stand ( $E_1$ ), at 40, 50 and 60 DAS under Expt.3. Further, the difference was statistically significant at 50 and 60 DAS. These results indicate that flower production in soybean suffers seriously when they grow within a bamboo stand. The reason for this could perhaps be the effect of shading by the bamboo clumps. Thus, Cox (1978) had reported that in groundnut the number of flowers was reduced under low light treatments. Similarly, Tarila et al. (1977) observed that while high light intensity delayed flowering in cowpea, it increased the number of blossoms. In peas, 80% shade considerably reduced flowering as reported by Hedley and Ambrose (1979).

Regarding P, only the overall influence of P (i.e., combining the two environments,  $E_1$  and  $E_2$ ) was significant, and that too only at 60 DAS (Expt.3) P did not exert any influence separately either within the bamboo stand ( $E_1$ ) or in the open field ( $E_2$ ). The overall influence of P at 60 DAS was such that the treatment  $P_1$  recorded the highest number of flowers/plant which was significantly superior to both  $P_0$  and  $P_2$  which themselves were on a par. It must be pointed out

Table 18 No. of Flowers/plant

SOYBEAN

Expt. 3

D A S

	40	50	600	
<b>1. Within the bamboo stand (<math>E_1</math>) (a) Influence of phosphorus levels (P)</b>				
			<i>N. Franck</i>	(P)
P <sub>0</sub>	1.330	5.955	(1.070)	0.834
P <sub>1</sub>	2.080	6.410	(1.425)	2.112
P <sub>2</sub>	1.745	5.700	(1.035)	0.729
F	NS	NS		NS
SE	0.328	1.078		0.129 @@
CD	-	-	(0.389)	-
<b>(b) Influence of vigour of bamboo clump (V)</b>				
L	1.547	6.460	(1.307)	1.662
H	1.890	5.583	(1.047)	0.787
F	NS	NS		NS
SE	0.268	0.880		0.105 @@
CD	-	-	(0.316)	-
<b>2. In the open field Influence of the phosphorus levels (P)</b>				
P <sub>0</sub>	2.682	13.254	(1.644)	2.382
P <sub>1</sub>	1.674	15.632	(1.948)	3.743
P <sub>2</sub>	2.226	14.617	(1.647)	2.323
F	NS	NS		NS
SE	0.406	1.220		0.150 @@
CD	-	-	(0.446)	-
<b>3. Pooled analysis (a) Influence of environments (E)</b>				
E <sub>1</sub>	1.718	6.022	(1.177)	1.225
E <sub>2</sub>	2.261	14.568	(1.746)	2.816
F	NS	***		***
SE	0.215	0.668		0.082 @@
CD	-	3.435		0.422 @@
<b>(b) Influence of phosphorus levels (P)</b>				
P <sub>0</sub>	2.006	9.605	(1.357)	1.608
P <sub>1</sub>	1.977	11.021	(2.928)	2.928
P <sub>2</sub>	1.986	10.259	(4.341)	1.526
F	NS	NS		*
SE	0.264	0.818		0.101 @@
CD	-	-		0.290 @@

\* = Square root transformation done before analysis

@@ = in square root transformed units

Table 18(a) Number of Flowers/plant as on 60 D A S SOYBEAN  
 Expt.3 Influence of the interaction V X P

P levels	Vigour of the bamboo clump (V)			
	$\sqrt{E_{transf.}}$	L	$\sqrt{E_{transf.}}$	H
P <sub>0</sub>	(0.94)	0.515	(1.20)	1.152
P <sub>1</sub>	(1.88)	3.583	(0.97)	0.640
P <sub>2</sub>	(1.10)	0.888	(0.97)	0.570

F test = \*

SE = } Square root transformation of the data  
 CD = } carried out.

Conclusions:

a) F over V

$$L = P_1 \overline{P_2 F_0} \quad *$$

$$H = P_0 \overline{P_1 P_2}$$

b) V over P

$$P_0 = \overline{H L}$$

$$P_1 = L \quad H \quad *$$

$$P_2 = \overline{L H}$$

$$\begin{aligned} & \sqrt{E_{transf.}} \\ SE &= 0.184 \\ CD &= 0.554 \end{aligned}$$

that the concerned data had to be square root transformed before analysis since several zeros were encountered.

Though the factor 'vigour of the bamboo clump' (V) did not exert any significant influence on the number of flowers/plant, the interaction V X P as at 60 DAS was, however, significant (Table 18(a)). The interaction appeared to favour the combination of 'low vigour' clump (L) and the  $F_1$  level of P fertilization. Again, in interpreting this result it must be remembered that these results are based on data subjected to square root transformation.

#### 4.1.11 Number of pods/plant

(Tables 19, 20, 20(a) and 20(b), Fig.5(a))

While under Experiments 1 and 2, only the environmental factor (E) significantly influenced the number of pods/plant, at both the stages (60 and 90 DAS) of recording the data, under Expt.3, besides the significant influence of the environment, P application also significantly affected this attributed.

Regarding the influence of the environment, the trend of results as compared between the three experiments was interesting. In Expt.1, the soybean plants growing within the bamboo stand ( $E_1$ ) recorded significantly more number of pods as compared to those growing in the open field ( $E_2$ ) at both 60 DAS and 90 DAS. And, the differences were statistically significant. But, the trend reversed soon. In Expt.2 as

	Number of pods/plant			
	Expt. 1		Expt. 2	
	60	90	60	90
<b>1. Within the bamboo stand (<math>E_1</math>) (a) Influence of phosphorus levels (P)</b>				
$P_0$	6.809	7.774	7.461	7.300
$P_1$	5.405	6.124	6.087	6.766
$P_2$	7.288	8.082	7.996	7.902
F	NS	NS	NS	NS
SE	0.678	0.834	1.087	1.105
CD	-	-	-	-
<b>(b, Influence of vigour of bamboo clump (V))</b>				
L	6.293	7.374	8.141	8.241
H	6.708	7.278	5.954	6.404
F	NS	NS	NS	NS
SE	0.553	0.681	0.888	0.902
CD	-	-	-	-
<b>2. In the open field (<math>E_2</math>) Influence of phosphorus levels (P)</b>				
$P_0$	4.771	5.108	15.647	19.946
$P_1$	5.491	5.891	16.384	20.938
$P_2$	5.034	6.001	15.866	20.889
F	NS	NS	NS	NS
SE	0.403	0.460	1.161	1.481
CD	-	-	-	-
<b>3. Pooled analysis (a) Influence of environments (E)</b>				
$E_1$	6.501	7.327	7.048	7.323
$E_2$	5.099	5.666	15.966	20.591
F	**	**	***	***
SE	0.315	0.379	0.651	0.764
CD	0.906	1.092	1.877	2.203
<b>(b) Influence of phosphorus levels (P)</b>				
$P_0$	5.790	6.441	11.554	13.623
$P_1$	5.448	6.008	11.236	13.852
$P_2$	6.161	7.042	11.731	14.396
F	NS	NS	NS	NS
SE	0.386	0.465	0.798	0.936
CD	-	-	-	-

Table 20 No. of Pods/plant

SOYBEAN

Expt. 3

D A S

50<sup>0</sup>

60

70

90

1. Within the bamboo stand (E<sub>1</sub>) (a) Influence of Phosphorus levels (P)

P <sub>0</sub>	0.471	2.940	5.450	4.790
P <sub>1</sub>	0.423	3.665	5.430	4.545
P <sub>2</sub>	0.433	4.295	6.730	5.420
F	NS	NS	NS	NS
SE	0.079 <sup>00</sup>	0.584	0.961	0.898
CD	-	-	-	-

(b) Influence of vigour bamboo clump (V)

L	0.508	3.790	6.273	4.943
H	0.576	3.477	5.467	4.893
F	NS	NS	NS	NS
SE	0.064 <sup>00</sup>	0.477	0.785	0.733
CD	-	-	-	-

2. In the open field (E<sub>2</sub>) (Influence of Phosphorus levels (P))

P <sub>0</sub>	0.193	12.169	17.303	20.293
P <sub>1</sub>	0.151	11.703	23.576	30.667
P <sub>2</sub>	0.032	11.213	19.874	23.731
F	NS	NS	*	*
SE	0.051 <sup>00</sup>	1.499	1.430	2.074
CD	-	-	4.401	6.163

3. Pooled analysis (a) Influence of Environments (E)

E <sub>1</sub>	0.442	3.633	5.870	4.918
E <sub>2</sub>	0.125	11.695	20.251	24.897
F	**	***	***	***
SE	0.038 <sup>00</sup>	0.678	0.716	0.951
CD	0.148 <sup>00</sup>	3.487	3.682	4.891

(b) Influence of phosphorus levels (P)

P <sub>0</sub>	0.332	7.555	11.377	12.542
P <sub>1</sub>	0.287	7.684	14.503	17.606
P <sub>2</sub>	0.235	7.754	13.302	14.576
F	NS	NS	NS	*
SE	0.046 <sup>00</sup>	0.831	0.876	1.165
CD	-	-	-	3.352

\* = Square root transformation done before analysis

Table 20(a) Number of pods/plant as on 70 D A S

SOYBEAN

Expt. 3

Influence of the interaction EXP

P levels	Environments (E)	
	within the bamboo (E <sub>1</sub> )	In the open (E <sub>2</sub> )
P <sub>0</sub>	5.450	17.303
P <sub>1</sub>	5.430	23.576
P <sub>2</sub>	6.730	19.874

F test = \*  
 SE = 1.239  
 CD = 3.566

Conclusions:a) P over E

$$E_1 = \frac{P_2 \quad P_0 \quad P_1}{P_2 \quad P_0} *$$

$$E_2 = \frac{P_1 \quad P_2 \quad P_0}{P_2 \quad P_0} *$$

b) E over P

$$P_0 = \frac{E_2 \quad E_1}{E_1} *$$

$$P_1 = \frac{E_2 \quad E_1}{E_1} *$$

$$P_2 = \frac{E_2 \quad E_1}{E_1} *$$

Table 20 (b) Number of pods/plant as on 90 DAS

SOYBEAN

Expt. 3Influence of the interaction EXP

P levels	Environments (E)	
	Within the bamboo (E <sub>1</sub> )	In the open (E <sub>2</sub> )
P <sub>0</sub>	4.790	20.293
P <sub>1</sub>	4.545	30.667
P <sub>2</sub>	5.420	23.731

F test = \*  
 SE = 1.647  
 CD = 4.740

Conclusions:a) P over E

$$E_1 = \frac{P_2 \quad P_0 \quad P_1}{\quad \quad \quad}$$

$$E_2 = \frac{P_1 \quad P_2 \quad P_0}{\quad \quad \quad} \quad *$$

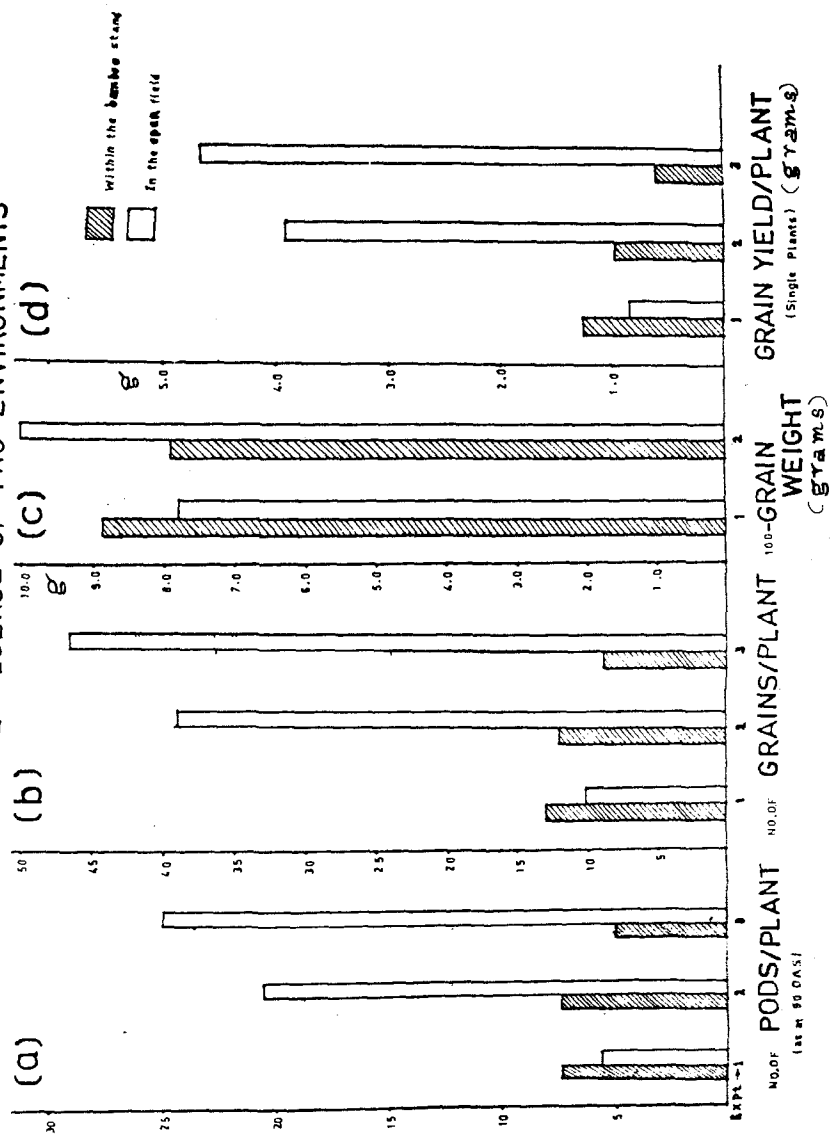
b) E over P

$$P_0 = \frac{E_2 \quad E_1}{\quad \quad} \quad *$$

$$P_1 = \frac{E_2 \quad E_1}{\quad \quad} \quad *$$

$$P_2 = \frac{E_2 \quad E_1}{\quad \quad} \quad *$$

Fig. 5 SOYBEAN YIELD PARAMETERS.  
INFLUENCE OF TWO ENVIRONMENTS



245

well as in Expt.3 (excepting at 50 DAS) it was under the open field environment ( $E_2$ ) that the soybean plants recorded more number of pods as compared to  $E_1$ . Only at 50 DAS under Expt.3, did the soybean plants growing within the bamboo stand ( $E_1$ ) record more number of pods than those of  $E_2$ , and the difference was again significant. But, it must be pointed out that the data for 50 DAS of Expt.3 contained many zeros and had to be square root transformed before statistical analysis could be performed.

Setting aside the results for Expt.1, for the moment, it is clear that the bamboo stand suppresses pod production in the associated soybean plants. The reason for this could be due to two causes - (i) direct effect of shade cast by the bamboo clumps, and (ii) indirect effect of the living shade through root competition. That shading by itself influences fruiting in crop plants is amply demonstrated by the results reported by a number of workers. Thus, Tayo and Morgan (1979) stated that the stress of shading in rape, around the time of anthesis, reduces the number of pods and Eaton and Ergle (1954) working on cotton reported that reduced light intensity reduced the relative fruitfulness.

In pulse crops also, the deleterious influence on fruiting has been reported upon. Thus, in chickpea, Saxena and Sheldrake (1976, 1977) observed a reduction in the number of pods when the plants were grown under thick shade, and Pandey

et al. (1980) reported that the number of pods was drastically reduced when the plants were shaded during the reproductive phase. Leelavathi (1979) observed a decline in the number of pods in blackgram under severe shading. The results of Tarila et al. (1977) on cowpea reveal the same trend though in a different manner; they found that high light intensity increased the number of pods.

In soybean itself, reduction in the number of pods due to shading, has been reported by a number of workers (Catedral and Lantican, 1977; Eriksen and Whitney, 1977; Wahua and Miller, 1978). Reciprocally, an increase in the number of pods through light enrichment has also been reported (Johnston et al., 1969; Schou et al., 1978).

All these evidences which are based on experiments in which artificial shades had been used clearly establish the deleterious influence of pure shade on pod production on soybean.

But, in the present investigation, the shade cast on the soybean plants was not produced by an artificial shade like muslin, cheese or hessian cloths or nylon nett ings but by a living plant, viz., bamboo, and that too a relatively vigorously growing and a larger sized plant at that. Thus, quite apart from the primary effect of pure shading, it is very likely that inter-specific root competition was also involved such that the metabolic vigour of the associated soybean plant was severely sapped which ultimately led to a reduction in the

number of pods. It has already been seen while discussing the other growth attributes, how the growth of the soybean had been curtailed within the bamboo stand as compared to the open field, particularly as reflected in stem diameter, number of branches, number of leaflets, leaf area, length of taproot, and roots: shoot ratio. A scrutiny of the correlation coefficients relating the number of pods with the different growth attributes (Appendices 5, 9, 11 and 12) shows that almost all the correlations were significant. Of particular interest is the diameter of the soybean stem, in this context. For the open field environment ( $E_2$ ) stem diameter was significantly and positively correlated with the number of pods under all the three experiments and for all the stages of growth for which the correlations were studied. Under the 'within the bamboo stand' environment also ( $E_1$ ) positive and significant correlations were noticed at 60 and 90 DAS for Expt.1 and at 90 DAS for Expt.3. While it cannot be argued that the reduction in the vigour of the soybean plant is solely the result of root competition suffered at the hands of bamboo, still this aspect cannot be ruled out.

Now, the apparently conflicting result of more number of pods being recorded by plants growing under  $E_1$ , as seen in Expt.1 could be taken up for discussion. This result implies only that when the shading is mild, relatively speaking, it actually exercises a beneficial influence on pod production.

For, it must be remembered that Expt.1 represents the start of the investigation and at this stage, the bamboo clumps were younger and thus smaller and above all a pre-treatment of crown pruning had been given, such that the canopy was more open, all of which conjointly resulted in the creation of only a 'partial shade'. This is clearly brought out by the data on the light intensity prevailing within the bamboo stand expressed as a fraction of that for the open field (Appendix 1 and Fig.2). It is seen that the light intensity within the bamboo stand were as much as about 82% to about 91% of that of the open field, till the end of the 3rd week of September 1979, which were the highest values for light intensity within the bamboo stand, ever recorded during the course of the present investigation. And this period corresponded to the early growth phase, i.e., upto about 35 DAS, of the soybean crop of Expt.1.

Such a beneficial influence of light shading on pod production, has also been actually observed in other crops. Thus Saxena and Sheldrake (1976) reported that thin shade (50% transmission) significantly increased the number of pods per unit area in chickpea, while thick shade considerably reduced the same. Leelavathi (1979) who studied the effect of graded levels of shading on blackgram, observed that upto 25% shading (i.e., 75% transmission) the number of pods improved. Hedley and Ambrose (1979) observed an improvement in the number of pods in peas with thin shade, i.e., 30% shade (i.e., 70% transmission). It could be conjectured that the mechanism of this beneficial influence of light shade relates to optimisation of light intensity such that light saturation does not occur.

It is known that pulse crops have the  $C_3$  pathway and thus their light saturation intensities are relatively lower than the full sunlight. All the three examples cited above to demonstrate the beneficial effect of a slight reduction in the light intensity, as also soybean, are pulse crops.

Vigour of the bamboo clump (V) did not exert any significant influence on the number of pods/plant. The third factor, P, however, significantly affected the number of pods as at 70 DAS and 90 DAS under Expt.3 only, there being no significant effect as in Expt.1 and Expt.2. In Expt.3, at both 70 and 90 DAS, significant differences arose between the P levels in the open field environment ( $E_2$ ) while within the bamboo stand ( $E_1$ ) the differences were not significant. Similarly, at 90 DAS, the overall influence (i.e., combining the two environments,  $E_1$  and  $E_2$ ) was significant. In all these three cases the pattern of ranking of the three P levels was identical, with  $P_1$  coming first, followed by  $P_2$  and then by  $P_0$ . This means that the number of pods/plant increases very steeply with the application of the first level of P, i.e., 100 kg  $P_2O_5$ /ha as compared to no P application, but further addition of P at the dose tried in this investigation, instead of increasing the number of pods, reduces it, though at a slower rate than the initial rate of increase which was steep. It would therefore appear that a dose of 100 kg  $P_2O_5$ /ha is the optimum level from the point of pod production, at Coimbatore, particularly under open field conditions. Regarding statistical significances,  $P_1$  was distinctly superior to  $P_0$  in all the three instances; however, only

under the open field environment and that too only at the terminal stage of the soybean crop (i.e., 90 DAS)  $P_1$  was significantly superior not only to  $P_0$  but even to  $P_2$ , the two latter levels being on a par. In both the remaining two instances (i.e., at 70 DAS under open field environment and 90 DAS under the overall influence of P, combining  $E_1$  and  $E_2$ ) the significances were such that  $P_1$  was superior  $\lambda$  to  $P_0$  with  $P_2$  occupying an intermediate position, itself being on a par with both  $P_1$  and  $P_0$ . The positive influence of P application on the number of pods/plant has been reported by several workers (Lixandrou et al., 1976; Mahatanya, 1976; Saleh, 1976; and Shahidullah et al., 1979) with which the above mentioned results agree.

Regarding interactions, only E X P interaction was significant, and that too at both 70 and 90 DAS (Tables 20(a) and 20(b)). Further, in both cases, the pattern was identical in so far as the influence of E is concerned. The treatment  $P_1$  was significantly superior to both the other P levels in the open field while within the bamboo stand all the three P levels were on a par. As regards the comparison between the two environments, the open field-grown soybean was significantly superior to that grown within the bamboo stand under  $\lambda$  all the three levels of P. Since the bamboo is relatively a very large plant as compared to soybean, its P needs are likely to be more and because bamboo has an extensive root system as compared to soybean, it would confer a competitive edge on bamboo. In other words, a stress for P in so far as soybean

is concerned, would arise within the bamboo stand which explains the tie-up between the environment and P levels. It remains now to explain why the highest dose of P, viz., P<sub>2</sub> failed to significantly interact with V, if response to P arises differentially according to the environment. It is most probable that at the very high level of 200 kg P<sub>2</sub>O<sub>5</sub>/ha (i.e., the P<sub>2</sub> level), P toxicity of soybean set in or a nutrient imbalance arose, so that the beneficial influence of P was lost.

#### 4.1.12 Dry Matter Production

(Table 21)

As regards dry matter production (DMP), only one of the three factors, viz., the environment (E) exerted any significant influence as revealed by the data for Expt.3. Significantly more dry matter (DM) was recorded by the soybean plants growing in the open field (E<sub>2</sub>) as compared to those growing within the bamboo stand (E<sub>1</sub>), from 40 DAS onwards upto harvest (90 DAS); only at 30 DAS was there no significant difference and the DMPs of E<sub>1</sub> and E<sub>2</sub> were almost similar.

The reduction seen in the DMP of the soybean plants growing within the bamboo stand (E<sub>1</sub>) is clearly the result of the reduced light intensity prevailing under the bamboo canopy because of the direct effect of light on photosynthesis. Reduction of ambient light below an optimum level (which itself may be less than full sunshine) is bound to lead to a reduction in the amounts of photosynthates available for incorporation

Table 21 Dry matter production/plant (grams)

SOYBEAN

Expt. 3	D A S					
	30	40	50	60	70	90
<b>1. Within the Bamboo stand (<math>E_1</math>) (a) Influence of Phosphorus level</b>						
$P_0$	1.037	1.412	2.060	2.462	2.394	2.247
$P_1$	1.044	1.438	2.562	2.533	1.988	2.035
$P_2$	0.900	1.737	2.426	3.002	2.153	2.708
F	NS	NS	NS	NS	NS	NS
SE	0.128	0.133	0.194	0.272	0.416	0.311
CD	-	-	-	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>						
L	0.952	1.455	2.178	2.843	2.253	2.305
H	1.036	1.603	2.521	2.489	2.094	2.356
F	NS	NS	NS	NS	NS	NS
SE	0.104	0.109	0.158	0.222	0.340	0.254
CD	-	-	-	-	-	-
<b>2. In the open field (<math>E_2</math>) Influence of Phosphorus levels (P)</b>						
$P_0$	1.009	2.333	4.375	6.466	6.981	7.240
$P_1$	0.957	2.149	4.298	6.466	8.294	8.890
$P_2$	1.004	2.287	5.121	6.773	6.946	10.142
F	NS	NS	NS	NS	NS	NS
SE	0.089	0.283	0.516	0.677	0.935	1.109
CD	-	-	-	-	-	-
<b>3. Pooled analysis (a) Influence of Environments (E)</b>						
$E_1$	0.994	1.529	2.349	2.666	2.178	2.330
$E_2$	0.990	2.256	4.598	6.568	7.407	8.757
F	NS	***	***	***	***	***
SE	0.063	0.131	0.233	0.308	0.431	0.488
CD	-	0.674	1.198	1.584	2.217	2.510
<b>(b) Influence of Phosphorus levels (P)</b>						
$P_0$	1.023	1.873	3.218	4.464	4.688	4.744
$P_1$	1.001	1.794	3.430	4.500	5.141	5.463
$P_2$	0.952	2.012	3.774	4.888	4.550	6.425
F	NS	NS	NS	NS	NS	NS
SE	0.077	0.161	0.285	0.377	0.527	0.598
CD	-	-	-	-	-	-

into structural parts which represent the DM of a plant. The effect of pure shade created by non-living and thus other-wise non-competing shades towards reduction of DMP in plants has been amply demonstrated by the studies of many workers. Thus, Pendleton and Weibel (1965) reported that the dry weight of wheat plants was decreased by shading. Singh (1978) observed leaf DM and plant DM to decrease with increasing shading in barley. In sorghum Falis and Lustrillos (1976) observed a reduction in total DM with increasing shade. Eaton and Ergle (1954) reported that the fresh weight of leaves + stems in cotton was reduced by shading. Leelavathi (1979) reported shading adversely affected the DMP in black gram. Hedley and Ambrose (1979) reported that 80% shade significantly reduced DMP in peas. Evidence through a reciprocal study is also available. Thus, Adedipe and Ormrod (1974) found higher light intensity to produce higher DMP in cowpea.

In soybean itself numerous reports are available to show that the DMP suffers under shade (Popescu and Axinte, 1977; Asanuma, 1977 and Wahua and Miller, 1978). Reciprocally, evidence exists to show that light enrichment increases total DM accumulation, as shown by the work of Schweitzer and Harper (1980).

As regards the pattern of change in DMP with reference to time, there was a general trend of increasing DMP with passage of time, for all the factors. This trend is common to all plant species. However, the patterns for the different factors

exhibited interesting differences. Taking P first, its effect is brought out if we examine the data for the open field environment ( $E_2$ ). The pattern of DM accumulation for P application (as seen in  $E_2$ ) revealed a sigmoidal trend. The accumulated DM initially increased at a rather steep rate between 30 DAS and 40 DAS, then inflected upwards and continued to increase at a still steeper rate (with a slope of about  $65^\circ$ ) upto 60 or 70 DAS and then showed a declining rate. Between the P levels themselves, at 90 DAS,  $P_2$  recorded the maximum DM followed by  $P_1$  and then by  $P_0$ , indicating a positive trend of response to applied P, eventhough the differences were not statistically significant. As regards the overall influence of P (i.e., evaluating its influence combining both  $E_1$  and  $E_2$ ) also a similar pattern was seen for DM accumulation. Further, yet another trend was clearly discernible. While initially (at 30 DAS) there was practically no difference in DM accumulation between the three P levels, subsequently differences started to appear as time passed, with the curves for the three P levels fanning out such that at harvest time they were well spread out (though the differences did not reach levels of statistical significance) in a graded fashion with  $P_2$  ranking first followed by  $P_1$  and then  $P_0$ .

As regards environment (E), there was a marked difference in the curve shapes for  $E_1$  and  $E_2$ . While in  $E_2$ , there was a steep, continuous and practically a linear (the curve shape was an elongated sigmoid) increase as regards DM accumulation,

under  $E_1$ , DM accumulation increased at a rather slow rate between 30 DAS and 60 DAS after which, the rate not only declined but showed a negative trend with the accumulated DM decreasing between 60 DAS and 70 DAS, after which it stabilized and recorded more or less the same DM accumulation between 70 and 90 DAS. Thus while there was a peak for DM accumulation, which was at 60 DAS, for the  $E_1$  environment, there was no peaking in the curve for  $E_2$ , which showed a continuously increasing trend up to harvest of the soybean (90 DAS). As a consequence, the two curves starting at the same point (the DM at 30 DAS being 0.994 g/plant for  $E_1$  and 0.990 g/plant for  $E_2$ ) started to diverge right from the start and got separated very widely at the end. As a result of this, the DM accumulation at 90 DAS for the soybean plants growing in the open field ( $E_2$ ) was nearly four-folds that for the plants growing within the bamboo stand ( $E_1$ ). The slight reduction in the DM accumulation seen between 60 and 70 DAS for the  $E_1$  curve is because of profuse leaf shedding. Hanway and Weber (1971) have furnished separate curves for cumulated dry weights of soybean plant parts during different stages of growth, separately for data (i) without including the fallen petioles and leaves and (ii) total, including the fallen petioles and leaves. While the curves for (i) show only slight declines after reaching a maximum, and thus more or less sigmoidal in shape, those for (ii) exhibit a peak after which there is a steep fall.

These observations about (ii) apply to all plant parts - stem, petioles, leaves, pods, and beans, without exception. The present findings agree with these observations.

As regards the pattern of influence of the vigour of the bamboo clumps (V) over time, it was seen that it was essentially the same for both the 'low vigour' clumps (L) and 'high vigour' clumps (H) and they resembled the general curve for the 'within the bamboo stand' ( $E_1$ ) environment, very closely. The depressing effect of the bamboo stand on soybean was seen in the curves for  $P_0$ ,  $P_1$  and  $P_2$  as a function of time; all were more or less flattened curves.

#### 4.1.13 Biomass production

(Table 22)

The biomass yield/net plot was recorded at the time of harvest, for all the three experiments. This represented the fresh weight of the roots, stem, branches, leaves, flowers if any and the pods containing the seeds, i.e., the whole plant. This, however, does not take into account shed leaves and flowers.

Among the three factors studied, only environment (E) exerted any significant influence, and that too, only in Experiments 2 and 3. In Expt.1, the biomass yield of soybean growing within the bamboo stand ( $E_1$ ) was 19% more than that for the open field ( $E_2$ ), but the difference was not statistically significant. But subsequently (Experiments 2 and 3)

Table 22 Biomass Production (Fresh Weight) at harvest (t/ha)

	Expt.1	Expt.2	Expt.3
1. Within the Bamboo stand ( $E_1$ ) (a) Influence of Phosphorus levels (P)			
$P_0$	0.727	0.462	1.235
$P_1$	0.530	0.457	1.244
$P_2$	0.731	0.495	1.531
F	NS	NS	NS
SE	0.076	0.064	0.272
CD	-	-	-
(b) Influence of vigour of bamboo clump (V)			
L	0.688	0.504	1.454
H	0.637	0.439	1.220
F	NS	NS	NS
SE	0.062	0.052	0.222
CD	-	-	-
2. In the Open field ( $E_2$ ) Influence of Phosphorus levels (P)			
$P_0$	0.505	2.960	6.326
$P_1$	0.610	2.614	7.252
$P_2$	0.559	2.757	7.489
F	NS	NS	NS
SE	0.052	0.138	0.653
CD	-	-	-
3. Pooled analysis (a) Influence of Environments (E)			
$E_1$	0.662	0.471	1.337
$E_2$	0.558	2.777	7.022
F	NS	***	***
SE	0.037	0.064	0.298
CD	-	0.184	1.532
(b) Influence of Phosphorus levels (P)			
$P_0$	0.616	1.711	3.781
$P_1$	0.570	1.535	4.248
$P_2$	0.645	1.626	4.510
F	NS	NS	NS
SE	0.045	0.078	0.365
CD	-	-	-

this advantage vanished and the soybean plants growing in the open ( $E_2$ ) recorded more biomass yields than those for  $E_1$ , and the differences, were statistically very highly significant ( $p=0.001$ ). The differences were of a very high magnitude; soybean plants growing in the open ( $E_2$ ) recorded, 489% in Expt.2 and 425% in Expt.3, biomass yield as compared to those growing within the bamboo stand ( $E_1$ ).

It is obvious that the bamboo stand seriously affects the growth and thus final biomass production of the associated soybean plants. It is true that leaves and aborted flowers were shed during the crop growth period and the weight of such losses are not accounted for by the biomass yield as recorded at harvest. And, that extensive flower abortion (20 - 80%) can occur at any stage of development from the time of bud initiation to seed development, in soybean, has also been reported (Hardman, 1970; Van Schrik and Frobst, 1958). The quantities of such shed plant parts could be substantial. Hicks (1978) stated that, at maturity, above ground dry matter in soybean, consists of approximately 28% leaves (fallen), 15% petioles (fallen), 17% stems, 11% pods and 29% seed. Further, it is possible that the amounts of leaves and flowers so shed may differ between the two environments,  $E_1$  and  $E_2$ . In the absence of data on this aspect it is difficult to draw any definite conclusion on the comparative biomass productivities of the two environments; the data gathered in this investigation permits the drawal of conclusions only on biomass production

as actually seen at harvest and not on biomass productivity. However, since biomass is intimately related to DMF/plant, and since it was seen in the discussion under the preceding section (i.e., 4.1.12) that the DMF of soybean is very seriously curtailed within the bamboo stand ( $E_1$ ), the data on the final biomass production can be relied upon to interpret the differential influences of the two environments.

Wahua and Miller (1976) reported highly significant negative correlation between fresh weight of the soybean plant and shading. The results of the present investigation are in agreement with the above mentioned finding. The superiority of  $E_1$  over  $E_2$ , eventhough not significant, seen in Expt.1 is evidently due to the beneficial effect of partial shade already discussed extensively under leaf area/plant (section 4.1.5) and number of pods/plant (section 4.1.11). Wahua and Miller (1978) found that a slightly sub-normal light intensity was beneficial as regards soybean DMF.

A comparison of the results of the three experiments, reveals that while the biomass yield of soybean under  $E_1$  was 0.662 t/ha, it was reduced to 0.471 t/ha under Expt.2 and again increased to reach 1.337 t/ha under Expt.3. The initial higher yield of Expt.1 as compared to Expt.2 is easily explained in terms of the beneficial effect of 'partial shade' already mentioned. But the second increase seen under Expt.3 appears to be strange. If the closing of the bamboo canopy and expansion of the root system of the bamboo clumps led to a

reduction in the biomass yield of soybean in Expt.2, such an effect must then have been still more pronounced under Expt.3. But, the biomass yield of Expt.3 instead of decreasing, registered an increase as compared to that for Expt.2. Perhaps, this arose because of seasonal differences between Expt.2 and Expt.3, and possibly also because of an interaction of such seasonal conditions with the shading and other microclimatic effects caused by the bamboo stand. This needs further elucidation.

#### 4.1.14 Number of grains/plant

(Table 23(a), 23(c), Fig.5(b))

The data on the number of grains/plant was recorded on single sample plants at harvest. The results show that environment (E) exerted a significant influence in all the three experiments. But, while in Expt.1, the soybean plants growing within the bamboo stand ( $E_1$ ) recorded significantly more number of grains, (29% more), the trend reversed after that, and in Experiments 2 and 3 the open field environment ( $E_2$ ) was significantly superior to  $E_1$ . This initial superiority of  $E_1$ , may be expected because of such a trend having been seen in a number of growth attributes (number of leaflets, leaf area, mean leaf area/leaflet, length of taproot, biomass production) and in the yield attribute, number of pods/plant. It is very likely that the same causes which led to a superiority in all these attributes in Expt.1, which conjointly have been called as the 'beneficial effect of partial shading', must have been responsib

Table 23 Grain parameters

SOYBEAN

	(a) Number of grains/plant			(b) 100-grain weight (grams)	
	Expt.1	Expt.2	Expt.3	Expt. 1	Expt.2
1. Within the Bamboo stand (E <sub>1</sub> ) (a) Influence of Phosphorus levels					
P <sub>0</sub>	13.289	12.259	8.185	8.464	7.899
P <sub>1</sub>	11.099	10.687	7.085	8.501	7.632
P <sub>2</sub>	14.674	13.344	10.920	9.572	8.066
F	NS	NS	NS	*	NS
SE	1.491	1.950	1.746	0.272	0.280
CD	-	-	-	0.819	-
(b) Influence of vigour of bamboo clumps (V)					
L	13.056	13.396	8.723	9.039	8.083
H	12.986	10.797	8.737	8.652	7.648
F	NS	NS	NS	NS	NS
SE	1.217	1.592	1.426	0.222	0.228
CD	-	-	-	-	-
2. In the open field (E <sub>2</sub> ) Influence of Phosphorus levels (P)					
P <sub>0</sub>	8.748	37.030	38.938	7.697	10.086
P <sub>1</sub>	10.944	41.249	54.250	6.091	10.125
P <sub>2</sub>	10.696	38.889	46.125	7.536	9.836
F	NS	NS	*	NS	NS
SE	0.916	3.039	3.394	0.352	0.133
CD	-	-	10.084	-	-
3. Pooled analysis (a) Influence of Environments (E)					
E <sub>1</sub>	13.021	12.097	8.729	8.846	7.866
E <sub>2</sub>	10.129	39.056	46.438	7.774	10.015
F	**	***	***	***	***
SE	0.700	1.502	1.621	0.184	0.123
CD	2.013	4.332	8.337	0.528	0.355
(b) Influence of Phosphorus levels (P)					
P <sub>0</sub>	11.019	24.645	23.563	8.081	8.993
P <sub>1</sub>	11.022	25.968	30.667	8.296	8.879
P <sub>2</sub>	12.685	26.117	28.521	8.554	8.951
F	NS	NS	NS	NS	NS
SE	0.857	1.839	1.986	0.225	0.150
CD	-	-	-	-	-

Table 23(c)

Number of grains/plant

SOYBEAN

Expt. 3

Influence of the interaction E X P

P levels	Environments (E)	
	Within the bamboo (E <sub>1</sub> )	In the open (E <sub>2</sub> )
P <sub>0</sub>	8.187	38.937
P <sub>1</sub>	7.084	54.250
P <sub>2</sub>	10.917	46.125

F test = \*

SE = 2.808

CD = 8.099

Conclusions:a) P over EE<sub>1</sub> =  $\frac{F_2 \quad P_0 \quad P_1}{F_2 \quad P_0}$ E<sub>2</sub> =  $\frac{P_1 \quad F_2 \quad P_0}{F_2 \quad P_0}$  \*b) E over PP<sub>0</sub> = E<sub>2</sub> E<sub>1</sub> \*P<sub>1</sub> = E<sub>2</sub> E<sub>1</sub> \*P<sub>2</sub> = E<sub>2</sub> E<sub>1</sub> \*

Table 23 (d) 100-grain weight (grams)  
Expt.1 Influence of the interaction E X P

SOYBEAN

P levels	Environments (E)	
	within bamboo (E <sub>1</sub> )	In the open (E <sub>2</sub> )
P <sub>0</sub>	8.464	7.697
P <sub>1</sub>	8.501	8.091
P <sub>2</sub>	9.572	7.536

F test = \*  
 SE = 0.318  
 CV = 0.915

Conclusions:a) P over E

$$E_1 = \frac{P_1 \quad P_0}{P_2} \quad *$$

$$E_2 = \frac{P_0 \quad P_2}{P_1}$$

b) E over P

$$P_0 = \frac{E_1 \quad E_2}{P_1} \quad *$$

$$P_1 = \frac{E_1 \quad E_2}{P_2}$$

$$P_2 = \frac{E_1 \quad E_2}{P_0}$$

for the significantly more number of grains also. That shading adversely affects the number of grains has been reported by the other workers also - in wheat by Pendleton and Weibel (1965) and in pearl millet by Rao and Singh (1980). But, in soybean Duffy et al. (1981) found neither pre-anthesis shading nor shading during seed filling period to affect the number of seeds.

A more important feature was the behaviour of this attribute under the two environments over time. Under  $E_1$  a declining trend in the number of grains was seen between the three experiments, it being highest in Expt.1, followed by Expt.2 and least in Expt.3 which recorded a mean 8.73 grains/plant. In contrast, under  $E_2$ , an increasing trend was seen, with the number of grains being least in Expt.1, more in Expt.2, and being the maximum in Expt.3 (46.44 grains/plant). Thus, the two environments showed diametrically opposite trends. While the variation between the three experiments, in so far as the open field ( $E_2$ ) is concerned, may be the effect of season, the variation noticed in the behaviour of soybean within the bamboo stand ( $E_1$ ) is clearly ascribable to the deleterious influence of the bamboo clumps acting through increasing closure of the canopy and expanding root system.

The factor vigour of the bamboo clump (V) did not exert any significant influence on the number of grains/plant, even though a general trend of reduced number of grains was

noticed under the 'high vigour' (H) bamboo clumps, in Experiments 1 and 2.

As regards the third factor, viz., P, significant differences between the three levels were observed only under the open field ( $E_2$ ) environment, and that too only in one (Expt.3) out of the three experiments. The level, 100 kg  $P_2O_5$ /ha (i.e.,  $P_1$ ) recorded significantly more number of grains/plant than the control ( $P_0$ ); while the 200 kg  $P_2O_5$ /ha level (i.e.,  $P_2$ ) occupied an intermediate position, itself being on a par with  $P_1$  and  $P_0$ . Thus the curve of the response to added P initially rose upto  $P_1$  level and then fell. This trend of initial rise and subsequent fall, as seen in Expt.3, was noticed even in the other two experiments (Expt.1 and Expt.2) also, eventhough the differences did not reach levels of statistical significance. In fact, this pattern of response to added P in the open field environment ( $E_2$ ), viz., an initial rise from  $P_0$  to  $P_1$  and a subsequent fall from  $P_1$  to  $P_2$ , is seen under a number of parameters in the present investigation, eventhough in most cases the differences between the three P levels were not significant. Thus, such a trend was noticed under, (i) height of plant (70 and 90 DAS of Expt.3), (ii) diameter of stem (30, 60 and 90 DAS of Expt.1, and 50, 60 and 70 DAS of Expt.3), (iii) number of branches (50, 60, 70 and 90 DAS of Expt.3), (iv) number of leaflets (40 and 60 DAS of Expt.1, and 60, 70 and 90 DAS of Expt.3), (v) leaf area (total)/plant (40 DAS of Expt.1, and 70 and 90 DAS of Expt.3), (vi) mean leaf area/leaflet (70 and 90 DAS of Expt.3), (vii) length of taproot (90 DAS of Expt.1, and

30, 40, 60, 70 and 90 DAS of Expt.3), (viii) number of root nodules (40, 50, 60 and 70 DAS of Expt.3), (ix) root: shoot ratio (30, 40 and 50 DAS of Expt.3), (x) number of flowers (50 and 60 DAS of Expt.3), (xi) number of pods (60 DAS of Expt.1, 60 and 90 DAS of Expt.2, and 70 and 90 DAS of Expt.3), and (xii) DMP (70 DAS of Expt.3). All these clearly indicate that the response of soybean to added P in the open field ( $E_2$ ), under Coimbatore conditions, can be expected to occur up to a maximum level of around 100 kg  $F_2O_5$ /ha.

While P exerted a significant influence under open field conditions ( $E_2$ ) atleast in one experiment, it failed to evoke any significant response in soybean, within the bamboo stand ( $E_1$ ), in any one of the three experiments. Further, the overall influence of P (i.e., pooling the two environments,  $E_1$  and  $E_2$ , together) was also not significant in any of the three experiments.

As regards interactions, only one, viz., E X P in Expt.3, was significant. While within the bamboo stand ( $E_1$ ) all the three P levels were on a par, in the open field ( $E_2$ ),  $P_1$  was significantly superior to both  $F_2$  and  $P_0$ , which were themselves on a par (Table 23(c)). This implies that the effect of P is suppressed within the bamboo stand. The physical explanation for this is, perhaps under the overwhelming competitive influence of the bamboo clumps, the P that became actually available to the soybean intercrop was very much reduced thereby evoking very little response. As regards the behaviour

of the two environments under the different P levels,  $E_2$  was significantly superior to  $E_1$ , throughout. The disadvantages suffered by the soybean plants within the bamboo stand ( $E_1$ ) have already been explained in details as to need elaboration, which explains the superiority of the soybean plants growing in the open field ( $E_2$ ).

#### 4.1.15 100-grain weight

(Tables 23(b), 23(d), Fig.5(c))

The available results (Expt.1 and Expt.2) reveal an interesting feature in so far <sup>as</sup> the environment factor (E) is concerned. While in Expt.1, the soybean plants growing within the bamboo stand ( $E_1$ ) recorded a significantly higher seed weight, in Expt.2, it was the open field-grown soybean plants ( $E_2$ ) that recorded significantly heavier seeds.

That shade depresses the grain weight has been reported in wheat by Moursi et al. (1976). In soybean itself, Catedral and Lentican (1977) observed the depressing influence on 100-grain weight by 50% shading and Wahua and Miller (1978) found that 100-grain weight was highly significantly and negatively correlated with shade. Evidence is to hand that the reciprocal effect does not take place. Thus, Johnston et al. (1969) observed that the 100-grain weight of light-enriched soybean plants to be lower than that for normal untreated plants. This would imply that there appears to exist an optimum light intensity, any intensity above or below which will act to

reduce the 100-seed weight. Most likely this phenomenon of optimum light intensity was responsible for the heavier seeds observed under  $E_1$  in Expt.1 of this investigation. In soybean, seeds are physiologically mature in about 65 - 75 days (Hicks, 1978) and the linear seed-filling phase starts from about 50 DAS. An examination of the light intensities prevailing during the period 50 DAS to 70 DAS for Expt.1 (Appendix 1 and Fig.2) reveals that the light intensity within the bamboo stand fluctuated between about 95 K lux and about 55 K lux while the ambient light (as measured under  $E_2$ ) between about 132 K lux and about 115 K lux at 50 DAS and 70 DAS respectively. In sharp contrast, the light intensities during Expt.2 were 50 K lux within the bamboo stand and 77 K lux in the open field at 50 DAS, and about 55 K lux for  $E_1$  and 79 K lux for  $E_2$  at 70 DAS. It would therefore appear that approximately the range 80 to 95 K lux is ideal from the point of weight of grain in soybean.

Further, the stage of crop growth at which shading occurs has also been reported to be important in determining grain weight. Prine (1980) noted the criticality of shading during the seed-filling stage in soybean. In the present investigation, however, the question of shading at selected stages of crop growth does not arise; it was a case of continuous shading right from seed emergence. Still, there is a difference in the degree of shading suffered by the soybean plants during the seed-filling phase, between Expt.1 on the one hand and Expt.2 on the other because of differences in (1) the extent

of closure of the overhead soybean canopy and (ii) the prevailing ambient light as determined by seasonal conditions. As a consequence of these variations, even in continuous shading, variations would arise in the amount of light reaching the soybean canopy. Such differences explain the difference seen in the 100-grain weight for Expt.1 and that for Expt.2.

Another feature worthy of note is the disparity between the two parameters, 100-grain weight and number of seeds/plant, as regards their response to shade. While the differences between  $E_1$  and  $E_2$  were of the order of 14% (in Expt.1) and 21% (in Expt.2) as regards 100-grain weight, vaster differences were noticed under the number of grains/plant, which were as much as 29% in Expt.1, 69% in Expt.2, and 89% in Expt.3. Some workers have stated that shading affects the number of grains much more than it affects the 100-grain weight (in wheat, by Pendleton and Weibel, 1965; in maize, by Early *et al.*, 1967). Based on studies on chickpea, Saxena and Sheldrake (1976, 1977) concluded that over the shading range of 16-77% transmission there was no significant effect on the 100-seed weight, by shading. It would therefore appear that the attribute 100-grain weight is much more plastic in its response to shading which explains the differences in the magnitudes of influence of shading on 100-grain weight as compared to the number of grains/plant.

Vigour of the bamboo clump (V) did not exercise any significant influence on the seed weight. As regards, P, its

effect was significant, only within the bamboo stand ( $E_1$ ) and that too only in Expt.1. In Expt.1, it was seen that the pattern of response was graded, with  $P_2$  recording the heaviest grains, followed by  $P_1$  and then by  $P_0$ ;  $P_2$  was significantly superior to the other two levels, which themselves were on a par. On the other hand, the differences were not significant in Expt.2. As regards the response to P in the open field ( $E_2$ ), the differences were not significant under both the experiments. However, a trend showing the grain weight, to increase between  $P_0$  and  $P_1$  and then decreasing between  $P_2$  and  $P_1$  was seen under both the experiments, suggesting the existence of an optimum level for P within the range of doses tried in this investigation. Now we may consider an explanation for the significant response to P seen in Expt.1 under  $E_1$ . If the existence of an optimum for P application is assumed and if it is further assumed that such optimum, in the present investigation, was somewhere around 100 kg  $P_2O_5$ /ha (i.e.,  $P_1$  level) as suggested by the results for the open field ( $E_2$ ), then it stands to reason that within the bamboo stand ( $E_1$ ), because of competition for soil and/or added P, the P available to the associated soybean crop was reduced to such a level as to evoke a sustained response to added P, over both the levels  $P_1$  and  $P_2$ . It could then be postulated that the observed significant response was the result of this initial mild competition. Subsequently, with the further growth of the bamboo clumps and aggravated competition, this moderating influence vanished and there was no response to added P which apparently supplied P to the soybean, but which in reality was perhaps unavailable to the soybean.

The overall influence of P (over both  $E_1$  and  $E_2$  put together) was not significant. However, the interaction E X P under Expt.1 was significant (Table 23(d)). While within the bamboo stand ( $E_1$ ) P showed a graded pattern of response with  $P_2$  being significantly superior to the other two levels of P which themselves were on a par, in the open field ( $E_2$ ) all the three P levels were on a par. Regarding the performance of the two environments over the three P levels,  $E_1$  was significantly superior to  $E_2$ , under the  $P_2$  level only. The possible reason for these results has already been discussed in the preceding paragraph.

#### 4.1.16 Single sample plant grain yield.

(Table 24, Fig.5(d))

Among the three factors, only environment (E) exerted any significant influence. This was so in all the three experiments. However, the trend of results among the experiments was different. In Expt.1, the soybean plants growing within the bamboo stand ( $E_1$ ) registered significantly higher grain yield/plant (44% more) than that for those growing in the open field ( $E_2$ ). But this reversed and in Expt.2, the soybean plants growing in the open ( $E_2$ ) out yielded those of  $E_1$ , registering a 300% increase. In Expt.3 also  $E_2$  out yielded  $E_1$ , but the disparity became much more (692% increase).

Table 24 Single Sample Plant Grain Yield (grams/plant) SOYBEAN

Expt.1
Expt.2
Expt.3

1. Within the Bamboo stand ( $E_1$ ) (a) Influence of Phosphorus levels

$P_0$	1.139	0.998	0.548
$P_1$	0.945	0.831	0.500
$P_2$	1.437	1.111	0.724
F	NS	NS	NS
SE	0.150	0.199	0.145
CD	-	-	-

(b) Influence of vigour of bamboo clump (V)

L	1.216	1.098	0.577
H	1.131	0.562	0.604
F	NS	NS	NS
SE	0.123	0.162	0.118
CD	-	-	-

2. In the open field ( $E_2$ ) Influence of Phosphorus levels (P)

$P_0$	0.691	3.740	4.000
$P_1$	0.922	4.186	5.310
$P_2$	0.828	3.831	4.734
F	NS	NS	NS
SE	0.097	0.310	0.393
CD	-	-	-

3. pooled analysis (a) Influence of Environments (E)

$E_1$	1.174	0.980	0.591
$E_2$	0.813	3.919	4.681
F	**	***	***
SE	0.072	0.153	0.306
CD	0.206	0.441	1.576

(b) Influence of Phosphorus levels (P)

$P_0$	0.915	2.369	2.274
$P_1$	0.934	2.509	2.905
$P_2$	1.933	2.471	2.729
F	NS	NS	NS
SE	0.068	0.168	0.250
CD	-	-	-

Considering the trend of results seen uptill now under the different attributes, it is not difficult to see the reason for this pattern. Particularly under the three parameters influencing grain yield, viz., number of pods/plant, number of grains/plant and 100-grain weight, it was seen that while in Expt.1, soybean plants growing within the bamboo shade ( $E_1$ ) consistently and significantly outperformed those growing in the open field ( $E_2$ ), the situation was exactly the reverse in Expt.2 with  $E_2$  outperforming  $E_1$ , consistently and significantly under all the three attributes, and this was repeated in Expt.3 (for number of pods and number of grains).

A scrutiny of the correlations presented in Appendices 6,9 and 12 reveals that the number of pods/plant was very highly significantly ( $p = 0.001$ ) and positively correlated with the grain yield/plant, in the case of Expt.1 and Expt.3 in the bamboo stand environment ( $E_1$ ), and in all the three experiments under the open field environment ( $E_2$ ); only in the case of  $E_1$  of Expt.2 was the correlation not significant. As regards the other parameter, number of grains/plant, which was computed for Experiments 1 and 2 only, all the four correlations (2 environments under each of 2 experiments) were very highly significant ( $p = 0.001$ ) and positive and tight, the correlation coefficients in all the four cases being 0.96. These results suggest the high degree of importance of these attributes in deciding the grain yield/plant in the present studies.

The equations for the 'predicted yield/plant' separately for each of the two environments, based on the multiple regression analysis carried out, are furnished in Appendix 15. The striking difference between the two equations is in the magnitudes of the intercept, it being a mere 0.8091 for  $E_1$  while it is as high as 14.6055 for  $E_2$  (18-folds higher) which vividly portrays the deleterious influence of the bamboo stand on soybean grain yield. An examination of the beta values for the two environment reveals that while in the open field situation leaf area acts positively and contributes the maximum towards soybean grain yield, within the bamboo stand it is the weight of the soybean roots, followed by the length of the taproot and then by the number of leaflets/plant that contribute positively towards grain yield. These results therefore suggest that the roots of soybean suffer a serious setback within the bamboo stand and thus perhaps also imply that the soybean plants growing below the bamboo clumps are able to adapt to the reduced light intensity, though to a certain extent only, through modifications in leaf area. Regarding LMP, it is seen that under both the environments it makes a negative contribution. However, it must be borne in mind all these predictions are based on the data for 30 DAS only, a period far removed in time from the harvest stage.

Regarding  $P$ , though it exerted no significant influence, it is worth pointing out a trend seen in the open field environment ( $E_2$ ). The pattern of rise between  $P_0$  and  $P_1$  and

the fall between  $P_1$  and  $P_2$ , as seen under many attributes in this investigation was repeated as regards grain yield/plant also, thereby suggesting the existence of an optimum dose for P lying somewhere around 100 kg  $P_2O_5$ /ha.

#### 4.1.17 Plant population at harvest

(Table 25)

Among the three factors studied, only environment (E) exerted a significant influence on the final plant population of soybean. In all the three experiments, the open field environment ( $E_2$ ) recorded significantly more number of soybean plants/ha at harvest, than within the bamboo stand ( $E_1$ ). It is to be remembered that even at the start of each one of the three experiments, the soybean population under  $E_1$  was always lesser than that for  $E_2$ , because of the space occupied by the bamboo clump. Further, only at the commencement of the series of the three experiments, could a uniform population be maintained within  $E_1$ . Thus, at the time of sowing the soybean in Expt.1, a uniform number of 364 seed holes/net plot in all the plots in  $E_2$  and 358 seed holes/net plot in all the plots in  $E_1$  could be established. Therefore, even at the commencement of Expt.1, the soybean population within the bamboo stand ( $E_1$ ) was only 98.4% of that for  $E_2$ . In other words, the bamboo clumps occupied 1.6% of the land area. Subsequently, by the time Expt.2 commenced, the bamboo clumps had expanded and occupied larger ground spaces, though such expansions varied with individual bamboo clumps, thereby reducing the area available for sowing the soybean crop.

Table 25 Plant Population/ha (at harvest)

SOYBEAN

	<u>Expt.1</u>	<u>Expt.2</u>	<u>Expt.3</u>
<b>1. Within the Bamboo stand (<math>E_1</math>) Influence of Phosphorus levels</b>			
P <sub>0</sub>	2,55,711	2,11,310	1,78,205
P <sub>1</sub>	2,65,501	2,19,002	1,92,774
P <sub>2</sub>	2,46,387	1,92,662	1,97,436
F	NS	NS	NS
SE	8,116	9,942	10,136
CD	-	-	-
<b>(b) Influence of vigour of bamboo clump (V)</b>			
L	2,55,869	2,15,384	1,95,722
H	2,55,869	1,99,925	1,83,217
F	NS	NS	NS
SE	6,627	8,117	8,276
CD	-	-	-
<b>2. In the Open field (<math>E_2</math>) Influence of Phosphorus levels (P)</b>			
F <sub>0</sub>	2,73,426	2,86,601	2,38,112
P <sub>1</sub>	2,91,142	2,91,030	2,33,333
P <sub>2</sub>	2,76,345	2,90,676	2,60,722
F	NS	NS	NS
SE	10,472	4,335	10,570
CD	-	-	-
<b>3. Pooled analysis (a) Influence of Environments (E)</b>			
E <sub>1</sub>	2,55,869	2,07,655	1,89,471
E <sub>2</sub>	2,80,307	2,89,436	2,44,056
F	**	***	***
SE	5,473	4,289	5,990
CD	15,739	12,369	30,804
<b>(b) Influence of Phosphorus levels (F)</b>			
P <sub>0</sub>	2,64,568	2,48,960	2,08,158
P <sub>1</sub>	2,78,321	2,55,021	2,13,053
P <sub>2</sub>	2,61,370	2,41,669	2,29,079
F	NS	NS	NS
SE	6,704	5,249	7,336
CD	-	-	-

It is therefore pertinent to examine the data on rate of expansion of the bamboo clumps. It was pointed out under section 3.7.2 that a round of biometric observations was recorded on the bamboo clumps on 1449 DAP (i.e., when they were nearly 4 years of age) and 9 days after that (i.e., when the bamboo clumps were exactly 4 years old) the first soybean crop (i.e., of Expt.1) was sown both between the bamboo clumps as well as in the adjacent open field. The data on the bamboo clumps themselves, presented in Table 32 indicates that, on 1449 DAP, the total number of culms/clump ranged from 7.333 for 'low vigour' (L) clumps and 11.833 for 'high vigour' (H) clumps. Therefore, the average total number of culms/clump works out to 9.583. As regards the land space occupied by the clump, even though the absolute spacing between bamboo clumps in this study was 4.0 x 4.0 m and thus a land area of 16 sq.m, it has to be noted that the bamboo clumps were separated by bunds because of the P treatments, and by irrigation channels. Hence the net plot area as applicable to the soybean crop, viz., 3.25 x 3.30 m, i.e., 10.725 sq.m (=1/932.4 ha), must alone be reckoned for purposes of comparisons. Thus, on 1449 DAP, i.e., immediately before the start of Expt.1, there were, on an average, 9.583 bamboo culms/net plot, occupying 1.6% of ground space. Converting the total number of culms to a per hectare basis, there were a total of  $9.583 \times 932.4 = 8935$  culms/ha. Even though from the point of crown spread, the bamboo clumps may be covering almost the entire area of land, the ground

space actually occupied is very small, and at 1449 DAP, a total of 8935 bamboo culms occupied only 1.6% of land area, or just 160 sq.m. Therefore, the average ground space occupied by a single culm works out to  $160 \text{ sq.m.} \div 8935 \text{ culms} = 0.01791 \text{ sq.m./culm.}$

The average ground space/culm as computed above may be used for arriving at the approximate ground spaces occupied by the bamboo clumps as on 1558 DAP and 1681 DAP which dates represent the starts of Expt.2 and Expt.3, respectively. On 1558 DAP there were an average of 13.167 number of total culms/bamboo clump (the L clumps recording 10.167 and the H clumps recording 16.167 culms/clump) or 12.277 culms/ha. Similarly, on 1681 DAP there were on an average of 16.666 number of total culms/bamboo clump (the L clumps recording 13.000 and H clumps 20.333 culms/clump) or 15,539 culms/ha.

It must also be borne in mind that the ground space occupied/culm is not a stable factor as time passes, in the case of young bamboo clumps which are rapidly expanding. The reasons for these are two. Firstly, the diameters of the successive culms that are produced are not the same but progressively increase, eventhough at some point in time it stabilizes. This aspect has already been reviewed under section 2.1.5.B. The second reason is due to a geometric property of enclosed bidimensional spaces. If the basal area of a bamboo clump is circular in shape and continues to be so,

over a period of time, as new culms are added on along the periphery of the clump, the diameter increases at a steady rate while the circumference of the bamboo clump's base increases at a rapid rate and its area at a very rapid rate. bamboo clumps in general have a circular configuration for basal ground area occupied by them. As regards the spacing between individual culms within a clump, it is more or less constant in adult clumps, it being decided by the elongation and curvature of the rhizomes that give rise to the culm.

Ignoring the effect of geometric configuration of the basal area of a bamboo clump on the number of culms that could be packed within such an area, and taking into account only the basal diameter of single culms, the need now arises to make adjustments in the average ground area occupied by a single culm, at 1558 DAP and 1681 DAP with reference to that for 1449 DAP. Data on the mean basal diameters of an individual culm presented in Table 28 show that it was 22.731 mm for a 'low vigour' (L) clump and 22.414 mm for a 'high vigour' (H) clump as on 1558 DAP, with the average being 22.572 mm/culm. This means that the culm diameter had increased by 2.786 mm or 14% by 1558 DAP as compared to 1449 DAP. But, comparing the average cross sectional areas of culms based on basal diameters, we find that it was 307.472 sq.mm on 1449 DAP, 400.157 sq.mm on 1558 DAP, and 451.711 sq.mm on 1681 DAP. This means that the average cross sectional area/culm increased by about 30% on 1558 DAP and by about 47% on 1681 DAP as compared to 1449 DAP.

If we consider only the average cross sectional areas of culms, the ground spaces occupied by bamboo clumps must be  $0.000307472 \text{ sq.m} \times 8935 \text{ culms} = 2.7475 \text{ sq.m/ha}$  on 1449 DAP,  $0.000400157 \text{ sq.m} \times 12.277 \text{ culms} = 4.9130 \text{ sq.m/ha}$  on 1558 DAP, and  $0.000451711 \text{ sq.m} \times 15.539 \text{ culms} = 7.0190 \text{ sq.m/ha}$ . These areas are the irreducible minimum ground spaces for accommodating the total culms in a hectare and assumes perfect packing of culms without any interspace. However, since the culms in a clump are produced with sufficient interspaces between them, the actual ground space occupied will be much more than the figures shown above. Thus, while the absolute minimum ground space required for accommodating the 8,935 culms/ha as on 1449 DAP, as calculated above, works out to only 2.7475 sq.m, the actual ground area, as measured by the area left over after accommodating the soybean plants, works out to 160 sq.m. Eventhough this 160 sq.m. is very small in comparison to a hectare, still it is 58.23 times of the total area occupied by the same number of culms on a cross sectional basis. Hence, logically, this multiplying factor of 58.23 must be applied to the total cross sectional areas of culms for 1558 and 1681 DAP also. Though it is possible that the magnitude of this correction factor may not remain constant at 58.23, but may change as time passes and the bamboo clumps expand, still, within a short period of less than an year i.e., the period during which the three experiments were run, there may not be much change in its magnitude and is valid as a correction factor.

Applying the above correction, we get  $4.913 \text{ sq.m} \times 58.23 = 286.08 \text{ sq.m/ha}$  and  $7.019 \times 58.23 = 408.72 \text{ sq.m/ha}$  for 1558 and 1681 DAP respectively. Hence the proportions of actual ground space occupied by the bamboo clumps, intercropped with soybean, works out to 1.60%, 2.86% and 4.09% on 1449 DAP, 1558 DAP and 1681 DAP respectively. This would in turn imply that the land area available for and thus the population, at sowing, of the soybean plants must have been 98.40%, 97.14% and 95.91% at the starts of Expt.1, Expt.2 and Expt.3 respectively. Assuming no mortality, the final soybean populations also must have been the same at harvest.

But the actual soybean populations as recorded at the time of harvest were as shown in Table 25. It is seen that the soybean population even in the open field was not the same under the three experiments. Further, they were far below the theoretically calculated soybean population of 3,39,394 plants/ha, based on the spacing of 25 X 11.75 cm - (i.e., 364 plants/net plot) for the open field ( $E_2$ ). The actual soybean populations as recorded at harvest, for the open field were, 82.6%, 85.3% and 71.9% for Expt.1, Expt.2 and Expt.3, respectively. These deviations from the calculated full stocking is the result of natural causes other than the factors of study, and most probably the effect of the seasonal conditions.

As regards the soybean populations within the bamboo stand ( $E_1$ ), they were 75.5%, 61.2% and 55.8% of the theoretically calculated 100% population for the open field ( $E_2$ ). Assuming

that the influence of the season acted uniformly for  $E_1$  and  $E_2$  we must expect the same pattern of change in the soybean populations for  $E_1$  also, as seen under  $E_2$ , among the three experiments, of course proportionately reducing the populations allowing for the expansion of the bamboo clumps as mentioned already. In other words, we must expect for  $E_1$ , the following populations: for Expt.1, 98.40% of 82.6% = 81.3%, for Expt.2, 97.14% of 85.3% = 82.9%, and for Expt.3, 95.91% of 71.9% = 69.0%, assuming no mortality during crop growth.

But, it is seen that the soybean populations for  $E_1$ , had been much reduced than the above shown calculated values. Thus, at the end Expt.1, there were only 75.5% plants as against the expected 81.3%, and at the end of Expt.2, there were only 61.2% instead of the expected 82.9%, and finally, at the end of Expt.3, there were only 55.8% instead of the expected 69.0%. The shortfalls were, thus 5.8% for Expt.1, 21.7% for Expt.2, and 13.2% for Expt.3.

In terms of a direct comparison of populations under  $E_1$  with those under  $E_2$ , they were (Table 25), 91.3%, 71.7% and 77.6% for Experiments 1, 2 and 3 respectively. In other words, the differences were 8.7%, 28.3%, and 23.0% for Experiments 1, 2 and 3 respectively. These actual differences do not differ very much from the theoretically calculated differences mentioned under the preceding paragraph; and anyway, they show a similar pattern of change among the three experiments.

The reduced soybean population observed within the bamboo stand ( $E_1$ ) is ascribable to mortality of soybean plants caused by the root competition and shading effect of the associated bamboo clumps. In Expt.1, there was only an actual reduction 8.7% in soybean population under  $E_1$  as compared to  $E_2$  which is not substantial. This was evidently because, during the tenure Expt.1, the bamboo canopy was very open and the bamboo root development was not complete. But, at the end of Expt.2, the reduction in the soybean population reached a value as high as 28.3% under  $E_1$  as compared to  $E_2$ . This is obviously due to the root competition from bamboo and its shade effect which had intensified by then. At the end of Expt.3 also, the soybean population was reduced drastically in  $E_1$  as compared to  $E_2$ . However, the reduction was only 23.0% and thus lesser than that for Expt.2. This difference between Expt.2 and Expt.3 is perhaps due to the seasonal differences. The season during Expt.2 was conspicuously dry while that during Expt.3 was relatively wetter.

#### 4.1.18 Grain yield

(Tables 26, 26(a) and Fig.6)

Among the three factors studied, environment (E) alone exerted any significant influence on the grain yield of soybean, and that too, only in the case of Expt.2 and Expt.3. The other two factors, V and P did not exert any significant influence on grain yield.

The influence of the environment, however, presented an

**Table 26** Grain yield SOYBEAN  
Yield/unit area (kg/ha) Mean Grain Yield/plant (grams)  
Expt.1 Expt.2 Expt.3 Expt.1 Expt.2 Expt.3  
1. Within the bamboo stand (E<sub>1</sub>) (a) Influence of Phosphorus levels (P)

P <sub>0</sub>	259.8	182.0	174.8	0.995	0.850	0.908
P <sub>1</sub>	201.8	158.1	183.1	0.766	0.724	0.932
P <sub>2</sub>	285.4	190.1	213.0	1.159	0.960	1.098
F	NS	NS	NS	NS	NS	NS
SE	31.37	29.59	44.82	0.115	0.124	0.211
CD	-	-	-	-	-	-

(b) Influence of vigour of Bamboo clump (V)

L	260.5	191.7	212.7	1.016	0.891	1.071
H	237.4	161.7	168.0	0.930	0.797	0.887
F	NS	NS	NS	NS	NS	NS
SE	25.61	24.16	36.60	0.094	0.101	0.173
CD	-	-	-	-	-	-

2. In the open field (E<sub>2</sub>) Influence of Phosphorus levels (P)

P <sub>0</sub>	166.4	1,074.0	1,266.3	0.607	3.725	5.406
P <sub>1</sub>	242.0	1,080.1	1,504.7	0.835	3.753	6.443
P <sub>2</sub>	194.1	1,061.2	1,641.0	0.706	3.627	6.323
F	NS	NS	NS	NS	NS	NS
SE	27.51	55.82	122.86	0.088	0.211	0.512
CD	-	-	-	-	-	-

3. Pooled analysis (a) Influence of Environments (E)

E <sub>1</sub>	248.9	176.7	190.3	0.973	0.844	0.979
E <sub>2</sub>	200.8	1,071.8	1,470.7	0.716	3.701	6.057
F	NS	***	***	*	***	***
SE	16.9	26.44	55.22	0.059	0.102	0.233
CD	-	76.26	283.97	0.168	0.294	1.200

(b) Influence of phosphorus levels (P)

P <sub>0</sub>	213.1	628.0	720.6	0.801	2.288	3.157
P <sub>1</sub>	221.9	619.1	843.9	0.801	2.239	3.688
P <sub>2</sub>	239.8	625.7	927.0	0.933	2.294	3.710
F	NS	NS	NS	NS	NS	NS
SE	20.74	32.38	67.63	0.072	0.125	0.286
CD	-	-	-	-	-	-

Table 26(a)  
Expt. 1

Grain yield (kg/ha)  
Influence of the interaction E X P

SOYBEAN

P levels	Environments (E)	
	Within the bamboo (E <sub>1</sub> )	In the open (E <sub>2</sub> )
P <sub>0</sub>	259.8	166.4
P <sub>1</sub>	201.8	242.1
P <sub>2</sub>	285.4	194.1

F test = \*  
SE = 29.33  
CD = 84.39

Conclusions:

a) P over E

$$E_1 = \frac{P_2 \quad F_0 \quad P_1}{F_2 \quad P_0}$$

b) E over P

$$P_0 = \frac{E_1 \quad E_2}{E_1} \quad *$$

$$P_1 = \frac{E_2 \quad E_1}{E_1} \quad *$$

$$P_2 = \frac{E_1 \quad E_2}{E_2} \quad *$$

Table 26 (b)      Mean Grain Yield/Plant (grams)  
Expt.1              Influence of the interaction E X P

SOYBEAN

P levels	Environments (E)	
	Within the bamboo (E <sub>1</sub> )	In the open (E <sub>2</sub> )
P <sub>0</sub>	0.995	0.607
P <sub>1</sub>	0.766	0.835
P <sub>2</sub>	1.159	0.706

F test    = \*SE        = 0.101  
CD        = 0.291

Conclusions:

a) P over E

$$E_1 = \frac{P_2 P_0 + P_1}{P_2 P_0} \quad *$$

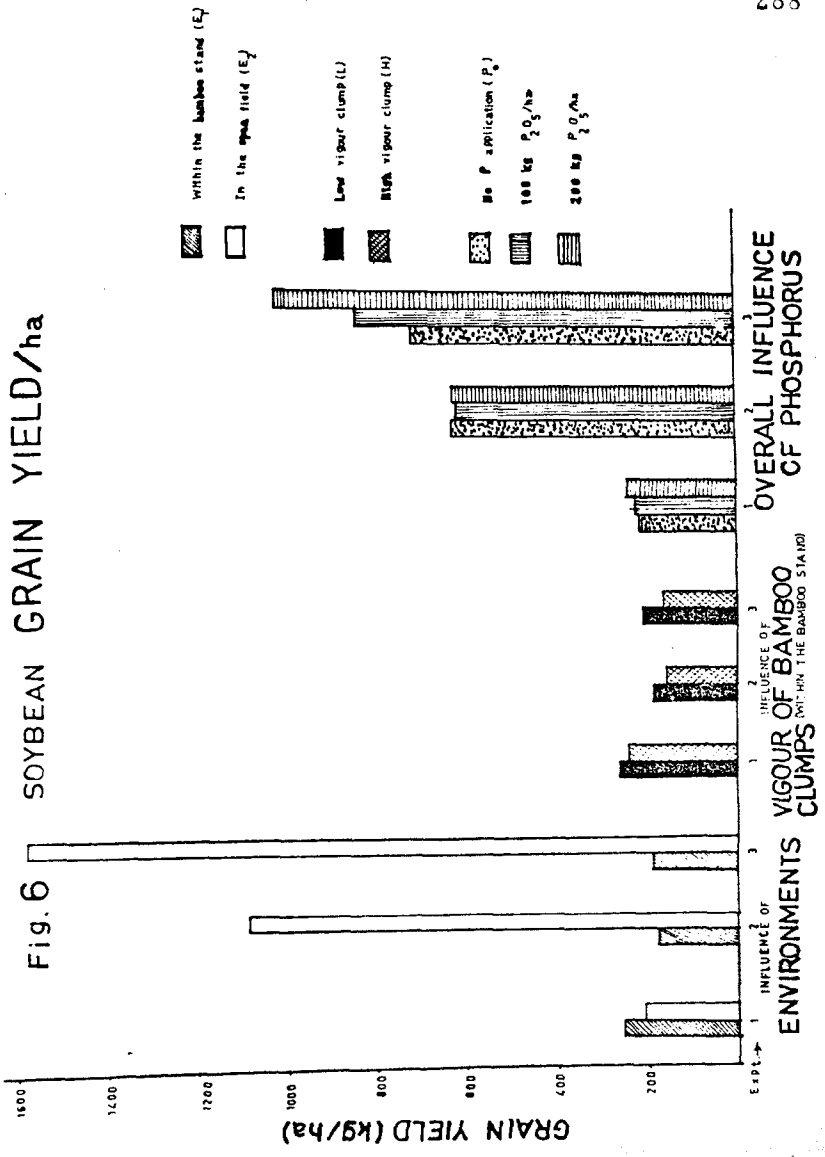
$$E_2 = \frac{P_1 P_2 + P_0}{P_1 P_2 P_0}$$

b) E over P

$$P_0 = \frac{E_1 E_2}{E_1} \quad *$$

$$P_1 = \frac{E_2 E_1}{E_1}$$

$$P_2 = \frac{E_1 E_2}{E_2} \quad *$$



interesting feature. In Expt.1, the soybean intercrop grown within the bamboo stand ( $E_1$ ) outyielded the sole crop grown in the open field ( $E_2$ ), by nearly 24%. However, this difference was not statistically significant. Subsequently, this superiority of  $E_1$  over  $E_2$  reversed, the sole crop of soybean growing under  $E_2$  out-yielding those growing under  $E_1$ , under both Experiments 2 and 3; and in both cases the differences were statistically very highly significant ( $p=0.001$ ). In Expt.2, the soybean growing under  $E_1$  recorded only about 16.5% of the yield under  $E_2$ , and in Expt.3, it was still lower, being only about 13.0% of that for  $E_2$ . In other words, the sole crop yields were 607% and 773% as compared to the intercrops yield, under Expt.2 and Expt.3 respectively.

These results indicate an apparent conflict between the experiments in the same study. Thus, while Expt.1 suggests that soybean cannot only be successfully intercropped within a bamboo stand, but also with, sometimes, a slight yield advantage, the results of Expt.2 and Expt.3 negate it and suggest severe yield reductions to the tune of about 83.5% and 87.0%, respectively. Evidences are available to show that soybean can be successfully intercropped between different tree species. Thus, soybean is being grown in between trees, chiefly teak (Tectona grandis) during the initial phases of the tree crop, under the taungya system (FAO, 1978). Liyanage et al. (1984) reported that soybean is one of the intercrops commonly grown in coconut gardens in Sri Lanka. Soybean has

been raised as an intercrop, for the first two years, between oil palm (Elaeis guineensis) trees in Malaysia (Cheu Poh Soon and Koo Kay Thye, 1976). According to Couto et al. (1982), soybean intercropped between seedlings of Eucalyptus grandis trees, in the initial phases, yielded the same as normally obtained for a sole crop of soybean in the region.

The successful intercropping of soybean in Expt.1 in the present investigation, agrees with similar experiences reported by the different workers mentioned above. The subsequent change towards yield depression noted in the present investigation is clearly the consequence of increased shading by the bamboo canopy and root competition by bamboo roots. The non-significant yield increase seen under Expt.1, was most likely due to the beneficial effect of 'partial shade', already touched upon. It was seen that a number of attributes were beneficially influenced by the bamboo stand in so far as Expt.1 is concerned. Thus, in Expt.1, the soybean plants growing within the bamboo stand ( $E_1$ ), had more number of leaflets, more leaf area, longer taproots and greater biomass production, and more number of grains per plant, besides heavier seeds, as compared to the soybean plants growing in the open field ( $E_2$ ). And, in almost all these attributes the differences between  $E_1$  and  $E_2$  were statistically significant. All these advantages naturally led to single plant grain yields recording a significantly higher yield (by 44% extra yield) under  $E_1$ . And, when we consider the fact that the

final soybean population within the bamboo stand ( $E_1$ ) was not materially lower than that for  $E_2$ , the reduction being to the tune of only 8.7%, it is not surprising that the soybean plants growing within the bamboo stand ( $E_1$ ) outyielded those growing in the open field ( $E_2$ ), though not significantly so.

The benefits of 'partial shade' mainly arise from a slightly reduced light intensity. Several workers have reported that slight shading either does not depress yield or actually increases it, in the case of different crops. Further, there are reports also as regards the influence of the time of shading with reference to the stage of growth of the crop, which, in the temporal sense could be considered as partial shading. Thus, Stansel et al. (1965) found that shading during the vegetative stage of growth had little effect on the yield of rice, though significant yield reduction happened if the shading was applied during heading. In tomatoes, Edmond et al. (1964) reported that the maximum yield was obtained only when the light intensity was reduced to 45% of full sunlight. Saxena and Sheldrake (1976) reported that in chickpea, thin shade not only did not exert any influence on one variety, but actually increased the yield in another variety. In these examples artificial shading with inanimate shades had been experimented with. Hence, the non-reduction in yield or even a slight increase in yield in the different crops when the light intensity is reduced upto certain levels, point to the advantage of partial shading. Further, during the tenure of Expt.1, the bamboo clumps were relatively younger and thus

smaller, possessing a less extensively developed root system. Hence root competition must have been minimal and this also must have contributed in not reducing soybean grain yield.

The situation during Expt.2 changed with the rapid expansion of the root systems of the bamboo clumps and more particularly of the bamboo canopy. The average light intensity within the bamboo stand ( $E_4$ ) never fell below 75% of the full sunshine, upto about 40 DAS, and averaged 67.7% for the entire crop growth period in the case of Expt.1 (Fig.2). On the other hand, in the case of Expt.2 the average for the entire crop growth period was about 63.5% only of full sunshine, while during Expt.3, it was about 64.5% of full sunshine. This relatively heavier shading coupled with increasing root competition as it must have increased by then, led to the severe yield reduction in soybean seen under Experiments 2 and 3.

Evidences are not wanting to prove the deleterious influence of shade, particularly heavy shade, on the yield of different crops (Rai and Murty, 1977, in rice; Pendleton and Weibel, 1965, in wheat; Early *et al.*, 1966, in maize; Pepper and Prine, 1972; and Falis and Eustrillos, 1976, in sorghum; Eaton and Ergle, 1954, in cotton; Fandey *et al.*, 1980, in chickpea; and Hedley and Ambrose, 1979, in peas). In soybean itself yield reductions with shading, often in a graded manner, have been reported. Thus, under 50% intensity of sunlight, while Catedral and Lantican (1977) observed an yield reduction of 30%, Wien (1977) reported a reduction as high as 50%.

Asanuma (1977) reported that the effect of shading in reducing grain yields were more pronounced with higher degree and earlier application of shading. Eriksen and Whitney (1977) and Eriksen (1978) reported yield decrease as the light intensity decreased. The results of Wahua and Miller (1976) who tried 5 different levels of shading, vividly bring out the progressive reduction in yield. At 47% shade (which approximately corresponds to the level used by Cathedral and Lantican, 1977; and Wien, 1977) the yield reduction was 25%, and at 93% shading, the yield reduction was as severe as 98%. The average ambient illumination in their study having been 124.2 K lux, the light intensity under the 47% shading (i.e. the light intensity reduced to 47% of full sunshine intensity) treatment, must have been 58.3 K lux. Thus, if even at a low level of light intensity of 58.3 K lux the yield reduction was only 25%, we must expect still less yield depressions for the 6% and 64% light intensities of Expt.2 and Expt.3 of the present investigation. But the yield depressions were severer in the present study which is ascribable to the root competition from bamboo clumps.

In the present investigation, the intensity of shading was not controlled and held constant, as no artificial shade was used. The intensity of shade continuously varied with changes in the development of the bamboo canopy over a period of time. The light intensity at ground level within the bamboo stand ( $E_1$ ) during Expt.2 ranged from 57.8% to 69.2% that of

full sunlight. During Expt.3, it ranged from 53.8% to 78.2%. The average values for light intensities that prevailed within the bamboo stand, are therefore 63.5% for Expt.2 and 64.5% for Expt.3. The nearest values of light intensities to those values, used by other workers are, 68 - 75% by Popescu and Axinte (1977), 50% by Catedral and Lantican (1977) and Wien (1977), and 47% by Wahua and Miller (1978). Comparing the yield reductions reported by these workers, it is seen that Popescu and Axinte (1977) found yield depressions ranging between 6.9% to 13.5% depending on the time of application, and Catedral and Lantican (1977) reported a 30% yield reduction while Wien (1977) observed a 50% reduction. Wahua and Miller (1978) reported an yield depression of 25%. Thus, it is seen that pure shade by itself can reduce soybean grain yield as much as by 50% when light intensity is reduced to half of full sunlight, and at a light intensity ranging between 68 - 75% of full sunlight the yield reduction is about 7 to 14%. Extrapolating on these values, we may expect an yield reduction of about 37% for an average light intensity of 63% of full sunshine. Such extrapolation may not be valid, particularly since Singh (1978) working on barley, has reported that decreases in growth of the plant were not linearly related to decreases in light intensity; still, in the absence of any other yardstick, the extrapolated value of 37% may be taken for evaluating the results of the present investigation.

Yield data for Expt.2 shows that the yield reduction was as severe as 83.5%, far in excess of the 37% depression suggested in the preceding paragraph. In the case of Expt.3, the yield reduction was severer still, it being 87.1%. The reason for this deviation is traceable, again to the nature of the shade. All the experimenters mentioned above had used only artificial shades wherein root competition was absent. But in the present investigation root competition was present and which involved a large net work of relatively shallow roots growing in more or less the same soil depth zone as that of the soybean roots. Evidently the serious yield depressions seen in this study were a consequence of not only overhead shading but also of root competition, perhaps possibly also with the two factors interacting in some complex way. Partitioning the root effect and shade effect of living and growing shade like the bamboo clumps, is rather difficult. This aspect needs further elucidation.

The contributory factors which led to yield reductions seen in Expt.2 and Expt.3 are not far to seek. A perusal of all the discussions so far made under the various growth and yield attributes would reveal, how the open field-grown soybean plants have been superior to those grown with <sup>in</sup> the bamboo stand, consistently and often statistically significantly so. A brief summary of the results, in notation, for certain select stages of crop growth, are furnished below, to explain this point.

Parameter	Conclusion and level of statistical significance			
	Expt.2		Expt.3	
1. Diameter of stem	30 DAS	E <sub>2</sub> E <sub>1</sub> * * *	E <sub>1</sub> E <sub>2</sub> *	
	60 DAS	E <sub>2</sub> E <sub>1</sub> * * *	E <sub>2</sub> E <sub>1</sub> * * *	
	90 DAS	E <sub>2</sub> E <sub>1</sub> * * *	E <sub>2</sub> E <sub>1</sub> * * *	
2. Number branches	60 DAS	E <sub>2</sub> E <sub>1</sub> * * *	E <sub>2</sub> E <sub>1</sub> * * *	
	90 DAS	E <sub>2</sub> E <sub>1</sub> * * *	E <sub>2</sub> E <sub>1</sub> * * *	
3. Number of leaflets	30 DAS	E <sub>2</sub> E <sub>1</sub> * * *	E <sub>1</sub> E <sub>2</sub> * * *	
	60 DAS	E <sub>2</sub> E <sub>1</sub> * * *	E <sub>2</sub> E <sub>1</sub> * * *	
	90 DAS	E <sub>2</sub> E <sub>1</sub> * * *	E <sub>2</sub> E <sub>1</sub> * * *	
4. Leaf area	30 DAS	-	E <sub>1</sub> E <sub>2</sub> *	
	40 DAS	-	E <sub>2</sub> E <sub>1</sub> * * *	
	50 DAS	-	E <sub>2</sub> E <sub>1</sub> * * *	
	60 DAS	-	E <sub>2</sub> E <sub>1</sub> * * *	

Parameter	Conclusion and level of statistical significance			
	Expt.2	Expt.3		
5. Mean leaf area/leaflet	70 DAS	-	E <sub>2</sub> E <sub>1</sub> * * *	
	90 DAS	-	E <sub>2</sub> E <sub>1</sub> * * *	
	30 DAS	-	E <sub>1</sub> E <sub>2</sub> * *	
	40 DAS	-	E <sub>2</sub> E <sub>1</sub> * *	
	50 DAS	-	E <sub>2</sub> E <sub>1</sub> * *	
	60 DAS	-	E <sub>2</sub> E <sub>1</sub> N.S.	
	70 DAS	-	E <sub>2</sub> E <sub>1</sub> * * *	
	90 DAS	-	E <sub>2</sub> E <sub>1</sub> * *	
	6. Length of tap root	30 DAS	-	E <sub>2</sub> E <sub>1</sub> * * *
		40 DAS	-	E <sub>2</sub> E <sub>1</sub> * * *
50 DAS		-	E <sub>2</sub> E <sub>1</sub> * * *	
60 DAS		-	E <sub>2</sub> E <sub>1</sub> N.S.	
70 DAS		-	E <sub>2</sub> E <sub>1</sub>	

Parameter	Conclusion and level of statistical significance				
	Expt.2		Expt.3		
	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>	
7. Number of pods	90 DAS	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>
		*	*	*	*
8. Biomass (final)	60 DAS	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>
		*	*	*	*
	70 DAS		-	E <sub>2</sub>	E <sub>1</sub>
9. Number of grains				*	*
				*	*
10. Seed weight	90 DAS	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>
		*	*	*	*
		E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>
		*	*	*	*
		E <sub>2</sub>	E <sub>1</sub>		-
		*	*	*	

It is seen from the above table that in almost all instances, E<sub>2</sub> was statistically very highly significantly (p=0.001) superior to E<sub>1</sub>. Out of a total of 45 conclusions presented above there are only 4 instances wherein E<sub>1</sub> has come out superior to E<sub>2</sub>. The overwhelming superiority of E<sub>2</sub> is clear. It is then not surprising that all these got reflected in the grain yield of single sample plants whose

results were, as could be expected,  $E_2 E_1$ , \*\*\*, in both Expt.2 and Expt.3 (Table 24). Soybean plant population also repeated an identical pattern which finally led to the significantly superior grain yield of  $E_2$ , seen under both Expt.2 and Expt.3.

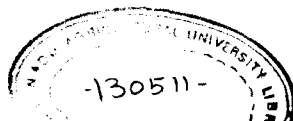
In this connection it would be fruitful to examine the correlations between the different plant attributes and grain yield, presented in Appendices 4 to 14. The implications of these have already been discussed under 'single sample plant grain yield' (section 4.1.16).

As regards the next factor, the vigour of the bamboo clumps (V), it is seen that eventhough it did not exert any significant influence on the grain yield of soybean, still a definite trend is patent. In all the three experiments, the soybean plants growing under the 'low vigour' (L) bamboo clumps recorded numerically higher yields than those growing under the 'high vigour' (H) clumps, the increase ranging from 9.7% in Expt.1 to 18.5% in Expt.2, and 26.6% in Expt.3. This trend is explainable in the same manner as was done while comparing  $E_1$  and  $E_2$ . Evidently the 'L' clump with lesser crown development and thus lesser shading and with a less extensive root system resembled the open field environment in so far as its influence on soybean grain yields are concerned. Hence its superiority.

Finally, the third factor, F, also did not exercise any significant influence, either within the bamboo stand ( $E_1$ ) or in the open field ( $E_2$ ) or even in its overall effect, combining

the two environments. This is not surprising since absence of response to P application in soybean has been reported by several workers (Patrascoiu et al., 1976; Lawrence et al. 1977; Phillips and Bartleson, 1979). In the present study, the response to P application showed erratic trends, though the differences were not significant, in so far as its influence within the bamboo stand as well in its overall effect (pooling  $E_1$  and  $E_2$ ) are concerned. However, a definite trend, though the differences were not statistically significant, manifested itself in so far as the response to P in the open field ( $E_2$ ) is concerned. It was seen that in Experiments 1 and 2, the  $P_1$  level of application gave numerically higher grain yield than both  $P_0$  and  $P_2$ , thereby showing a response pattern of rise from  $P_0$  upto  $P_1$  and then a fall upto  $P_2$ . It is pertinent to point out here that a similar rise and fall pattern was observed under several attributes in this study, but more particularly under the number of grains/plant, 100-grain weight and single sample plant grain yield. In the case of Expt.3, on the other hand, the pattern of response was one of continuous increase with  $P_2$  recording numerically higher grain yield, followed by  $P_1$  and then by  $P_0$ .

While no reliance can be placed on these non-significant results, still they are indicative of the presence of a pattern of response. It is likely that the effect of added P could not be seen in the same year of application. Thompson and Brown (1967) reported that the high level fertilizer mixture



containing P and K applied by them did not increase soybean yields during the treatment years but generally increased it in the subsequent years. The trend of a rise in grain yield upto  $P_1$  (i.e., 100 kg  $P_2O_5$ /ha) and thereafter a fall as seen in the first two experiments (Expt.1 and Expt.2) which subsequently changed to one continuous rise in grain yield upto the  $P_2$  level as seen in Expt.3, is suggestive that the delayed response to added P is quite plausible as reported by Thompson and Brown (1967). Similarly, the trend of an initial rise in the grain yield upto the  $P_1$  level and a subsequent fall as seen in Experiments 1 and 2 would suggest the existence of a peak for the response. It was already pointed out under section 4.1.15 '100-grain weight' about the possibility for the existence of such an optimum, centred around 100 kg  $P_2O_5$ /ha in the present investigation. In this context it must be remembered that most of the Indian workers had secured the highest grain yield at around, or recommended a dose of 80 to 120 kg  $P_2O_5$ /ha; for example, Singh and Singh, (1968); Jethmalani et al. (1969); Singh and Saxena (1969); Tomar and Dev (1973); Kavankar and Badhe (1975); Agarwal and Narang (1975); Rana and Chand (1977); and Hampaih and Sinha (1979). Further, Fauconnier, (1976) had reported that the yield increased only upto 100 kg  $P_2O_5$ /ha after which it decreased. Based on all these evidences and the trend of results seen in the present investigation, it may be safely concluded that an application level of about 100 kg  $P_2O_5$ /ha seems to be the optimum for open field-grown soybean under Coimbatore conditions.

As regards soybean grown inside a bamboo stand no definite conclusion is possible to be drawn with the results secured in this investigation. However, a general trend favouring the  $P_2$  level is visible when the trends of yields for all the three experiments are examined. In fact, in Expt.3, a continuously increasing trend in grain yield was seen, with  $P_1$  recording a numerically superior yield to  $P_0$ , and  $P_2$  in turn outyielding  $P_1$ , though the differences did not reach levels of statistical significance. These trends would then suggest that an application level of 200 kg  $P_2O_5$ /ha (i.e.,  $P_2$ ) is more beneficial to a soybean crop when intercropped within bamboo clumps. It is thus seen that while a relatively lower level of 100 kg  $P_2O_5$ /ha appears to be the optimum for open field-grown soybean (as mentioned earlier), a still higher level, viz., 200 kg  $P_2O_5$ /ha appears to be beneficial to a soybean crop grown within a bamboo stand. This means that the response of soybean grain yield to added P is extended to higher levels of application when the soybean is grown within a bamboo stand, though the rate of response may be much lower than that for an open field-grown soybean crop. Putting it in another manner, it may be argued that the deleterious influence of the base crop of bamboo on an intercrop of soybean, appears to be mitigated, atleast partially, through P fertilization. This inference is strengthened by the conclusions of Tarila *et al.* (1977) who studied the interaction between light intensity and P nutrition in cowpea and reported that P could be used to offset some of the adverse effects of low light intensity as well as to hasten growth and maturation.

As regards interactions, only the  $EXP$  interaction was statistically significant in Expt.1 (Table 26(a)). While under both the environments,  $E_1$  and  $E_2$ , all the three  $P$  levels were statistically on a par, the situation was different when the two levels were compared under each one of the three  $P$  levels. The soybean plants growing within the bamboo stand ( $E_1$ ) were significantly superior in grain yield to those growing in the open field ( $E_2$ ) under  $P_0$  and  $P_2$  levels, while under  $P_1$ ,  $E_2$  recorded a non-significant numerically superior grain yield. These results lend partial support to the inference about the beneficial influence of  $P$  application to soybean intercropped within a bamboo stand, already discussed in the previous paragraph. But, it must be noted that under  $P_0$  (i.e. non-application of  $P$ ) also,  $E_1$  was significantly superior. Further, only in one out of the three experiments, and that too only in the experiment representing the initial stages of the present investigation, viz. Expt.1, has this interaction been observed. The available results do not warrant further inferences.

In conclusion, the foregoing discussion could be summarised as below:

- 1) It is agronomically possible to raise a successful intercrop of soybean within a bamboo stand of Dendrocalamus strictus, with the bamboo clumps spaced at 4 X 4 m, provided the bamboo clumps are young, i.e., upto an age of 4 years and 3 months (i.e. 'Establishment intercropping') and further provided that the bamboo

canopy has not closed completely but casts only a partial shade;

ii) Serious yield depression in intercropped soybean will occur if such intercropping within a bamboo stand is carried on beyond the above mentioned age of 4 years and 3 months. The causes for such reduction appear in one part due to the primary effect of the shade cast by the bamboo canopy and on the other part through intense competition from the bamboo roots of relatively older bamboo clumps. It therefore appears, that 'establishment intercropping' of soybean and possibly other annuals also, within a bamboo stand, atleast for another period of about 4 to 5 years beyond the first 4 1/4 years mentioned above, (i.e., upto an age of 8 to 9 years) is possible, provided the bamboo canopy is suitably manipulated through crown trimming and through partial pruning of bamboo roots judiciously, through digging the soil. However, the results of the present investigation do not permit of any forecast as regards the immediate and long-range consequences on the yield of bamboo culms of such manipulations. This aspect needs further study;

iii) The influences of vigorously growing bamboo clumps vis-a-vis less vigorously growing bamboo clumps on the performance of an intercrop of soybean, do not appear to be substantial. However, there appears to be a trend favouring the less vigorously growing bamboo

clumps from the point of soybean's performance, while more vigorously growing bamboo clumps are to be logically preferred from the angle of maximizing bamboo culm yields. This conflict may perhaps be resolved through adoption of a wider spacing of the bamboo clumps, say at about 6 X 6 m or more when the severity of competition between the vigorously growing bamboo clumps and the intercrop of soybean could be expected to be minimized

iv) Though P application has not generally exerted any significant influence in this study, there appears to exist a trend favouring its application at a rate of about 100 kg P<sub>2</sub>O<sub>5</sub>/ha for open field-grown soybean and at a rate of about 200 kg P<sub>2</sub>O<sub>5</sub>/ha for soybean intercropped within a bamboo stand.

#### 4.1.15 Mean grain yield/plant

(Tables 26 and 26(b))

This is a parameter derived from the data on grain yield/net plot, and the soybean plant population/net plot at the time of harvest. This parameter was calculated so as to serve as a cross-check on the single sample plants grain yield data (already discussed under 4.1.16) which was collected independently, and presented in Table 24. While both the parameters measure the same attribute, viz., the grain yield produced by a single plant of soybean, they are of independent origins and thus distinct. It must be remembered that the 'single sample

plant grain yield' represents the actual grain yield measured on single sample plants while the 'mean grain yield/plant' is an estimate of the same quantity based on all the soybean plants of a net plot. Theoretically, there must be very close, if not perfect, agreement between the two parameters. However, in practice, this may not be obtained. Large deviations between the two parameters, if seen, would imply the existence of wide variations in the grain yields of single plants, i.e., random errors, and thus help in evaluating the results.

Before proceeding to discuss the influence of the three factors on the mean grain yield/plant, as has been done for all the parameters uptill now, it would be fruitful to first of all compare the results secured under the two parameters, 'single sample plant grain yield' and 'mean grain yield/plant'. A comparison of the data for the above two parameters reveals that there was a fair degree of agreement between them, not only in so far as patterns of response, but even as regards the magnitudes of grain yields in absolute terms. Further, as regards statistical significances, the concordance was perfect.

Examining the pattern of response (Tables 24 and 26) first, we find that out of the 15 pairs of comparisons (i.e., 5 comparisons - viz., F under  $E_1$ , V under  $E_1$ , P under  $E_2$ ,  $E_1$  vs  $E_2$ , F under both  $E_1$  and  $E_2$  - X 3 experiments) there were only two instances (viz., influence of F under  $E_1$  in Expt.3,

and overall influence of P in Expt.2) where the pattern of response to the applied levels of the factor concerned was different between 'single sample plant grain yield' on the one hand and 'mean grain yield/plant' on the other. In all the other cases the pattern of responses were identical.

As regards the agreement in the values between the two parameters, however, the differences ranged from as low as 0.4% (in  $P_0$  under  $E_2$  of Expt.2) and as high as 86.4% (in  $P_1$  under  $E_1$  of Expt.3). Yet, as far as Expt.1 and Expt.2 are concerned, the difference never exceeded 24.0% and in many instances were far less. Only in Expt.3, large differences were met with, and that too only under the bamboo stand environment ( $E_1$ ). These results indicate that by and large the grain yield of a single sample plant reflects the grain yield that could be expected/plant; though the concordance between the actually observed value and the estimate was of a fairly high order under Expt.1 and Expt.2, it was poor under Expt.3. One reason for this poor concordance seen under Expt.3 could be due to an unknown interaction between the seasonal conditions and the bamboo stand environment ( $E_1$ ) which might have led to wide variations in the yields of individual plants. It is pertinent to point out here that the microclimate within the bamboo stand, particularly the light regimen, must have been vastly changed during the tenure of Expt.3 as compared to the conditions that must have prevailed during the course of Expt.1. As regards the third aspect, viz., concordance in statistical significances, it has already been pointed out that both the

parameters were identical.

Now, we may take up the examination of the influence of the three factors studied, on the mean grain yield/plant. Table 26 shows that only the environment factor (E) exerted any significant influence, the effects of the other two factors, V and P being not significant. Regarding the influence of the environment, it is seen that while in Expt.1, the soybean plants growing within the bamboo stand ( $E_1$ ) recorded a significantly superior mean grain yield/plant, the trend reversed subsequently such that under both Expt.2 and Expt.3, it was the open field-grown soybean ( $E_2$ ) that recorded very highly significantly ( $p=0.001$ ) superior mean grain yield/plant. As regards differences in the mean grain yield/plant between  $E_1$  and  $E_2$ , they were about 36%, 77% and 84% for Expt.1, Expt.2 and Expt.3 respectively. This pattern of  $E_1$  being superior to  $E_2$  under Expt.1 and later on  $E_2$  becoming superior to  $E_1$  is an exact repetition of the trend seen under single sample plant grain yield (Table 24), eventhough the magnitudes of differences between  $E_1$  and  $E_2$  were much more under single sample plant grain yield, where they were 44%, 300% and 692% under Expt.1, Expt.2 and Expt.3 respectively. The progressive increase in the magnitude of the difference between  $E_1$  and  $E_2$ , as time passed on, is indicative of the divergence in the conditions that prevailed, both aerially and underground, between the two environments.

The arguments presented under section 4.1.16 'Single sample plant grain yield' apply in entirety here also, for explaining the observed responses under the two environments. Similarly, the arguments made under the discussion on the lack of influence for applied P, hold good for this parameter also.

Significant interaction arose in one instance only (Expt.1). The interaction E X P (Table 26(b)) repeated an almost similar pattern seen under grain yield (Table 26(a)), the only difference being that in the case of mean grain yield/plant, the differences between the three P levels under E<sub>1</sub>, reached levels of statistical significance ( $p = 0.05$ ), such that P<sub>2</sub> was superior to P<sub>1</sub>, with P<sub>0</sub> occupying an intermediate position and being on a par with both P<sub>2</sub> and P<sub>1</sub>. This similarity is expectable since grain yield/net plot was one of the components in the computation of the mean grain yield. Hence the explanations furnished under grain yield hold good in this case also.

## 4.2. BAMBOO

### 4.2.1 Height of culm

(Table 27)

The vigour of the clump did not exert any significant effect on the height of the culm at any one of the 7 stages of growth for which measurements were recorded - be it for the tallest culm in the clump (1171 and 1355 DAP) or the mean height of culm (based on all the culms in the clump) recorded on 1422, 1449, 1558, 1681 and 2152 DAPs. Further the height of culms ranged from 2.811 m (for 'high vigour', i.e., H-clump as at 1422 DAP) to 3.977 m (for H-clump as at 1558 DAP).

The reports of several workers indicate that the height of culms in Dendrocalamus strictus varies within wide limits, depending on the locality. For example, 4.57 to 18.29 m by Deogun (1977) 6.0 - 7.5 to 13-15 m by Dutta and Tomar, (1964), 6 to 16 m by Aslam (1971) and 6.1 to 15.2 m by Wint (1978). But then, all these estimates pertain to culms produced by fully grown adult clumps. At Coimbatore itself, 16-year old clumps of D. strictus have been reported to have culm lengths ranging from 5.30 to 7.35 m by Shanmuganathan et al. (1980). However, Deogun (1937) reporting a 1927 experiment stated that culm height ranged between 4.02 m to 5.09 m for 5-year old clumps and from 4.91 m to 6.10 m for 6-year old clumps. The height of culms in the present investigation (in which, the age of the bamboo clumps during the period of observation, ranged

**Table 27**                      **Height of Culm (m)**                      **BAMBOO CLUMPS**

of the tallest culm	Mean height over all the culms in the clump						
	Days after planting out						
	1171	1355	1422	1449	1558	1687	2132
<b>1. Influence of Vigour of the Clump (V)</b>							
L	3.314	3.391	2.913	2.898	3.859	3.060	3.221
H	3.248	3.479	2.811	2.924	3.977	2.980	3.147
F	NS	NS	NS	NS	NS	NS	NS
SE	0.230	0.226	0.189	0.204	0.213	0.112	0.154
CD	-	-	-	-	-	-	-
<b>2. Influence of Phosphorus levels (P)</b>							
P <sub>0</sub>	3.261	3.342	2.674	2.748	3.781	3.094	3.259
P <sub>1</sub>	3.520	3.682	3.120	3.147	4.156	3.038	3.269
P <sub>2</sub>	3.063	3.282	2.792	2.839	3.818	2.928	3.024
F	NS	NS	NS	NS	NS	NS	NS
SE	0.282	0.276	0.231	0.250	0.261	0.137	0.189
CD	-	-	-	-	-	-	-
<b>3. Inter action V X P</b>							
F	NS	NS	NS	NS	NS	NS	NS

between 3 1/4 years to almost 6 years) though slightly lower, agree closely with these values.

Scrutiny of the data reveals that the height of culms over the period of observation (2 3/4 years) was almost constant with an overall average of 3.23 m. The reductions in the height, seen at 1422 and 1449 DAPs as compared with 1171 and 1355 DAPs is explained by the fact that, while the former two (1422 and 1449 DAPs) pertain to 'mean' culm heights which were based on all the culms in each clump, the latter two figures represent the height of only the tallest culm in the clump. As regards mean heights, while the data for 1422, 1449 and 2152 DAPs are practically similar in magnitude, those for 1558 DAP show relatively taller culms (a difference of about a metre). The reason for this is that bamboo culms grow rapidly and a few culms in a clump may attain relatively great heights so that, even if a few such tall culms are produced at about the same time, the average culm height for that clump at that stage will be boosted up substantially. Another reason is that the 1558 DAP measurements were made during late November which is precisely the season when new culms can be expected to have attained their maximum height.

Phosphorus application did not exert any significant influence on culm height, at any stage during the period of observation. But a general trend of initial increase in culm height from the  $P_0$  upto the  $P_1$  level and then a fall in height from the  $P_1$  to the  $P_2$  level was noticeable.

#### 4.2.2. Basal diameter of culm

(Table 28)

The vigour of the bamboo clump did not exert any significant influence on the basal diameter of the culm. The diameters ranged from a minimum of 17.673 mm (H-clump, 1171 DAP) to a maximum of 27.554 mm (L-clump, 1960 DAP). Culm diameter steadily increased over time, at a slow rate though. Taking the average of L-and H-clumps, it is seen that the average diameter was 18.102 mm at 1171 DAP, and 26.956 mm at 2087 DAP. Thus over a span of 2 years and 5 months the culm diameter had increased by about 50%. This would mean an increase of 222% in cross sectional area of culms. Since the culm of D. strictu is practically solid, and also since it was already seen under section 4.2.1 that the height of the culm remained practically unchanged over the period of observations, it is to be surmised that during the said period of nearly 2 3/4 years the valuable pulpwood which is the most important economic product of bamboos, more than doubled.

The range of culm diameters as observed in this study agrees very closely with those for clumps of similar age reported by Deogun (1937). The slight reduction in culm diameter seen under L-clumps at 1422 DAP in this study is explained by the fact that the diameters for 1422 DAP is a mean value based on all the culms of a clump and hence is susceptible to suffer changes if a few dead culms are felled in clumps as was done immediately prior to 1422 DAP. Evidence



for such reductions in culm diameters over a time span when means are considered and when fellings of culms takes place during the intervening period is provided when we compare the data of Deogun (1937) when the clumps concerned were of 5 years age, and that of Kadambi and Rawat (1949) for the same clumps when they were of 10 years age. Comparing the two sets of data we find that a reduction in the mean culm diameter to the tune of 10% (in the case of clumps developed from rhizome transplants) resulted over a period of 5 years, i.e., between 5-year age to 10-year age.

Phosphorus application failed to exert any significant influence on culm diameter, throughout the period of observation. Ueda (1960) who tried the application of NK, PK, NP and NPK combinations on seedlings of Pleioblastus pubescens bamboo, observed that though the fertilizer treatments failed to influence culm diameter the control treatment recorded the least diameter. Numata and Ogawa (1959) who tried N, P and K singly and as NPK combination along with Ca, on Phyllostachys bambusoides bamboo, in a field experiment, found while N induced fast growth, P and K fertilizers failed to give a notable positive effect even though they promoted good quality in the timber. Ueda (1960) who studied the influence of NK, PK, NP and NPK treatments along with an unfertilized control, on the bamboo Phyllostachys reticulata in a field experiment found that all the fertilizer treatments were almost similar in their response though recording a slightly higher diameter

than the control. All these reports indicate that the culm diameter is not much influenced by fertilization, even though a slight increase occurs as compared to the unfertilized control. However, Fatil (1980) working on Dendrocalamus strictus itself, reported that the application of fertilizers (NPK in combination) increased the mean diameter of culms, but it is to be noted these results are based on bamboo seedlings of less than 2-year age. It may therefore be concluded that P by itself does not materially influence culm diameter in bamboo as seen from the results of the present investigation which agree with the earlier reports.

#### 4.2.3 Mid-culm diameter

(Table 33)

The diameter of the middle-most internode in the culm was recorded on the culms that were selectively felled on 2152 DAF, i.e., when the clumps were almost 6 years of age. The results showed that neither the vigour of the clump nor P application exerted any significant influence on the mid-culm diameter. The mid-culm diameter ranged from 14.855 mm for 'low vigour' (L) clumps to 14.307 mm for 'high vigour' (H) clumps, the average being 14.581. mm.

The absence of response in the mid-culm diameter to either the vigour of the clump or P application is a repetition of the results seen under 'basal diameter of culm' (section 4.2.2). Further, even the patterns of differences,

which were, however, not significant, between the different levels under each one of the factors, V and P, were also similar to that observed under 'basal diameter of culm'. Thus in both the parameters, it was the culm from 'low vigour' (L) clumps that recorded a slightly larger diameter (with but one exception in basal diameter). Under P, the P<sub>0</sub> level recorded the largest mid-culm diameter followed by P<sub>1</sub> and then P<sub>2</sub>.

That the mid-culm diameter should reflect the basal diameter of the culm is to be expected since the 'form factor' (i.e., the quantity which gives an idea about the taper along the length of the main stem of a tree) for any particular species of tree or bamboo is more or less constant. From Table 28 it is seen that the basal diameters of the usable culms felled at 2152 DAP were 22.459 mm and 21.802 mm for the L- and H- clumps respectively. The average therefore, works out to 22.130 mm for basal diameter. Comparing the average mid-culm diameter with the average basal diameter, it is seen that the former was 66% of the latter.

#### 4.2.4. Number of nodes/culm

(Table 29 and 25(a))

The number of nodes/culm (for the period upto 1681 DAP i.e., on standing culms) ranged from 20.997 (H-clump, 1422 DAP) to 28.123 (L-clump, 1558 DAP). For 16-year old clumps of Dendrocalamus strictus. Shanmuganathan et al. (1980) had reported that the number of internodes ranged from 26 to 45.

**Table 29**                      Number of Nodes/culm                      **LAMBOO CLUMPS**  
**In the tallest culm**                      **Mean over all the culms in the clump**  
**Days after planting out**

	1355	1422	1449	1558 <sup>⊙</sup>	1681	2152
<b>1. Influence of Vigour of the Clump (V)</b>						
L	25.917	21.792	23.257	28.123	24.592	18.980
H	23.583	20.997	22.579	24.630	26.115	17.630
F	NS	NS	NS	NS	NS	NS
SE	1.530	1.079	1.248	-	1.187	0.854
CD	-	-	-	-	-	-

<b>2. Influence of phosphorus levels (P)</b>						
P <sub>0</sub>	23.875	20.532	21.554	22.444	25.083	17.712
P <sub>1</sub>	26.750	24.043	25.393	29.209	27.577	19.704
P <sub>2</sub>	23.625	19.609	21.808	27.477	23.401	17.501
F	NS	NS	NS	NS	NS	NS
SE	1.874	1.322	1.528	-	1.453	1.046
CD	-	-	-	-	-	-

<b>3. Interaction VXP</b>						
F	NS	NS	NS	NS	*	NS

⊙ = Square root transformation done before analysis

BAMBOO CLUMPS

Table 29 (a) Mean Number of Nodes/culm as on 1681 DAP

<u>P levels</u>	<u>Influence of the Interaction VXP</u>	
	<u>Vigour of the clump (V)</u>	
	L	H
P <sub>0</sub>	27.808	22.358
P <sub>1</sub>	23.955	31.198
P <sub>2</sub>	22.013	24.788

F test = \*  
SE = 2.056  
CD = 6.194

Conclusions:

a) P over V

$$L = \overline{P_0 P_1 P_2}$$

$$H = P_1 \overline{P_2 P_0} *$$

b) V over P

$$P_0 = \overline{L H}$$

$$P_1 = H \overline{L} *$$

$$P_2 = \overline{H L}$$

The data for the present investigation fall near the lower limit of the above range, obviously because the clumps were three times younger than those of Shanmuganathan et al. (1980).

Neither the vigour of the clump nor P application exerted any significant influence at any of the stages during the period of observation. However, the interaction V X P was significant at 168 $\frac{1}{2}$  DAP (Table 29(a)). It was seen that while under the 'low vigour' (L) clumps all the three levels were on a par, under the 'high vigour' (H) clumps, the level P<sub>1</sub> recorded significantly more number of nodes/culm as compared to P<sub>2</sub> which was itself on a par with P<sub>0</sub> (control). Comparing the two vigour levels under each one of the three P levels, the H-clumps were significantly superior to the L-clumps under the P<sub>1</sub> level, there being no significant difference under the other two P levels. While it must be admitted that it appears that the number of nodes/culm is pre-fixed by genetic factors for any particular species of bamboo, and while it is also true that only the visible nodes are counted in culm enumerations, it is also likely that the number of such visible nodes to be influenced within certain limits, by the manipulation of the environmental factors such as application of chemical fertilizers.

It must be borne in mind that this interaction was observed at 168 $\frac{1}{2}$  DAP which fell in between Expt.2 and Expt.3

of the soybean experiments, which implies that by then P fertilizer had been applied twice, i.e., after application of a total quantity of 200 kg and 400 kg  $P_2O_5$ /ha, to the  $P_1$  and  $P_2$  treatments respectively. Viewed against this background of heavy and continuous application of P, it is clear that there is a response to added P, though the response is delayed because of a necessity for the pre-accumulation of available P in the soil before a response could be evoked. The reason for this is perhaps that all the applied P cannot be utilized by the bamboo clumps immediately; it had to wait for the root system of the bamboo clumps to progressively expand in space, over a span of time. The residual effect of applied P fertilizers is well known in other crops. Also, the 'high vigour' (H) clumps appear to be more responsive to the added fertilizer.

#### 4.2.5 Number of primary branches/culm

(Tables 30 and 30(a))

The vigour of the bamboo clumps did not exercise any significant influence on branching. The number of primary branches/culm ranged from 21.943 (H-clump, 1684 DAP) to 61.348 (L-clump, 1558 DAP). Since branches arise only at nodes there is a relationship between the number of nodes in a culm and the number of branches borne by it. The expression 'primary branch' as used in the present investigation, refers to any lateral branch arising from a culm node. One or more such branches may arise from the same node depending on the cutting treatments given to culms or the first formed branch as reported

**Table 30** Mean Number of Primary Branches/culm BAMBOO CLUMPS  
Days after Planting out

	1422	1449	1558 e	1681
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**1. Influence of Vigour of the clump (V)**

L	28.813	44.350	61.348	19.568
H	34.010	44.943	56.244	21.943
F	NS	NS	NS	NS
SE	4.391	3.162	-	1.284
CD	-	-	-	-

**2. Influence of Phosphorus levels (P)**

P <sub>0</sub>	32.488	45.988	57.685	20.127
P <sub>1</sub>	33.105	47.604	67.862	23.106
P <sub>2</sub>	28.642	40.348	50.841	19.034
F	NS	NS	NS	NS
SE	5.378	3.873	-	1.573
CD	-	-	-	-

**3. Interaction VXP**

F	NS	NS	NS	*
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e = square root transformation done before analysis

Table 30(a) Mean Number of Primary Branches/culm BAMBOO CLUMPS  
As on 1681 DAP

Influence of the interaction VXP

P levels	Vigour of the clump (V)	
P <sub>0</sub>	22.613	17.640
P <sub>1</sub>	19.048	27.163
P <sub>2</sub>	17.043	21.025

F test = \*  
SE = 2.225  
CD = 6.704

Conclusions:

a) P over V

L =  $\frac{P_0 \quad P_1 \quad P_2}{P_1 \quad P_2 \quad P_0}$  \*

b) V over P

P<sub>0</sub> =  $\frac{L \quad H}{H \quad L}$  \*  
P<sub>1</sub> = H L  
P<sub>2</sub> =  $\frac{H \quad L}{L \quad H}$

by Kadambi (1949). Taking the data on the number of nodes/  
culm already discussed and the number of primary branches/culm  
for corresponding times of observation and the vigour class of  
the clump, it is seen that the average number of branches/node  
works out to from as low as 1.322 for an L-clump as at 1422 DAP  
to as much as 2.283 for a H-clump as at 1558 DAP. It is seen  
that the H-clumps always had more number of primary branches/  
node than the L-clumps. In other words, the density of branch-  
ing was more in H-clumps than in L-clumps. It is quite likely  
that such differences arise due to differences in the genetic  
make-up of the different clumps. Hence the idea emerges that  
even though all the clumps included in the present study  
phenotypically belong to one and the same category, viz., the  
'normal type' as defined by Deogun (1937), the possibility for  
the existence of genotypic differences cannot be ruled out,  
with resultant expressions in branchiness. Hence, the classi-  
fication of the clumps into two vigour classes seems to be  
appropriate and valid.

A lot of thought has been bestowed by earlier workers on  
congestion in bamboo clumps as related to branching. Rao (1975)  
observed that in Dendrocalamus strictus the clumps look much  
congested with a lot of dry thin culms by the 4th year of  
planting seedlings. Clump congestion is an aspect of economic  
importance since it inter<sup>e</sup>fer<sup>s</sup> with the ease of felling culms  
and thus affects labour costs which in turn influences the  
cost of exploitation and therefore ultimately the cost of  
production of culms. Of course, branchiness is only one of

the two factors of clump congestion, the other being the 'density ratio' (i.e., number of culms/circumference of the clump) as suggested by Chakravarti (1949). Still, branchiness counts.

In the present investigation there was a spurt in the number of primary branches on 1558 DAP as compared to the periods of observation immediately preceding it (1449 and 1422 DAPs) as well immediately after it (1681 DAP). Thus, if the average number of primary branches/culm (44.646) for 1449 DAP is considered as 100%, then the number of branches/culm at 1558 DAP rose to 132% and then fell to 46% at 1681 DAP. Two entirely different reasons were responsible for these shifts.

It must be remembered that immediately after 1449 DAP and just before the commencement of Expt.1 on soybean, the lower branches occurring upto a height of 1.5 m from ground level were cut off as part of the pre-treatment given to the bamboo crowns, so as to facilitate the sowing of the soybean intercrop. The immediate consequence of this was the production of more number of fresh branches, eventhough they did not seriously interfere with the subsequent cultural operations on the soybean intercrop. Kadambi (1949) has drawn attention to the reaction of bamboo clumps and specifically Dendrocalamus strictus, to cutting heights of culms. Eventhough he has not adduced any physiological reason for the production of side branches when

a culm is cut upto the 2nd year of its emergence, it may be inferred that this is a natural reaction caused by the diversion of the immediately available assimilates to branch production instead of to new culm production, since new culm production is relatively a long-drawn out proposition which involves the production of a new rhizome first. In other words, there is an acute need for creating sufficient sink immediately after culm cutting, and the immediate solution is the production of new branches. It then stands to reason that a similar mechanism must operate if branches also are removed which would explain the spurt in the number of branches seen immediately after branch removal and trimming of tops of a few culms, in the present investigation.

As regards the sharp fall in the mean number of primary branches/culm at 1681 DAP, this resulted from the fact that between 1558 DAP and 1681 DAP, the number of living culms/clump had increased by an average of 3.583 (i.e., difference between 1558 and 1681 DAPs averaged for L- and H-clumps) as seen from Table 31. This increase represents the new culms produced and their maximum age at 1681 DAP must therefore have been hardly 3 months (i.e.,  $1681 - 1558 = 123$  days). Since Kadambi (1949) has reported that in the dry plains the season of emergence of new culms is any time between July to October, for Dendrocalamus strictus, and Dutta and Tomar (1964) had reported maximum emergence during August, for the same species,

it could safely be presumed that these new culms that were recorded between 1558 and 1681 DAPs, must have emerged between August - October 1979. Late emergence also is quite possible since the bulk of the annual rainfall received at Coimbatore is only during the NE monsoon and the peak rainfall usually occurs during November only. In fact, it was during the period 12th to 25th November 1979, which corresponds to the period immediately preceding 1558 DAP of the present investigation, that the maximum amount of rainfall, viz., 577.2 mm was received in just 9 rainy days (Appendix 3 and Fig.5). This quantity of rainfall represents 92% of the average annual rainfall of 676 mm for Coimbatore. Hence the new culms observed at 1681 DAP must have emerged late in the season, around October-November 1979.

Elongation of the new culms is completed in 2-3 months (Deogun, 1937; Kadambi, 1949) during which phase, it is leafless and branches. Varmah and Bahadur (1980) have stated that branches develop only after growth in height is complete. Hence the newly emerged culms observed at 1681<sup>DAP</sup> were branchless and while other culms which had emerged much earlier, contributed to an increase in the number of culms/clump, the recent culms that had emerged during October-November 1979 did not contribute to the total number of branches/clump and thus the mean number of primary branches/culm, whose computation is based on both the total number of culms as well as the total number of branches in the clump, was decreased.

Phosphorus application also failed to influence the number of primary branches significantly. However, the interaction V X P was significant. The pattern of interaction was almost identical to the one seen under the number of nodes/culm, the only difference being, under H-clumps the P<sub>1</sub> level while still being numerically superior to both P<sub>2</sub> and P<sub>0</sub>, was on a par with the P<sub>2</sub> level. The arguments put forward while discussing the number of nodes/culm hold good for the number of primary branches as well.

4.2.6 Number of living culms/clump

(Table 31 and Fig.7(a))

All the living culms of age 1 year or more were enumerated on 11 different occasions encompassing a total period of about 2 1/2 years, starting from the time when the clumps were 3 1/4 years of age to 5 3/4 years of age. It must be noted that changes in the number of living culms/clump truly reflect the rate of production of new culms since only the living culms that have existed atleast for 12 months after emergence are included in this parameter. All komalis and culms of less than 1-year age which are generally leafless and are usually designated as 'new recruits', both of which sometimes may perish at any stage after emergence and thus whose enumeration as a measure of new culm production is very unreliable, have been excluded from this parameter. Newly produced culms which have successfully crossed the age of 1-year have a fair degree of probability of continuing to live and grow into mature culms.



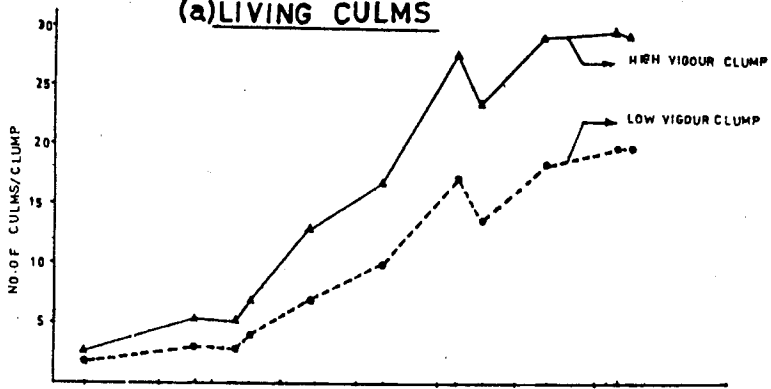
Table 31(a) Number of living Culms/clump (1-year and more age culms)

BAMBOO CLUMPS

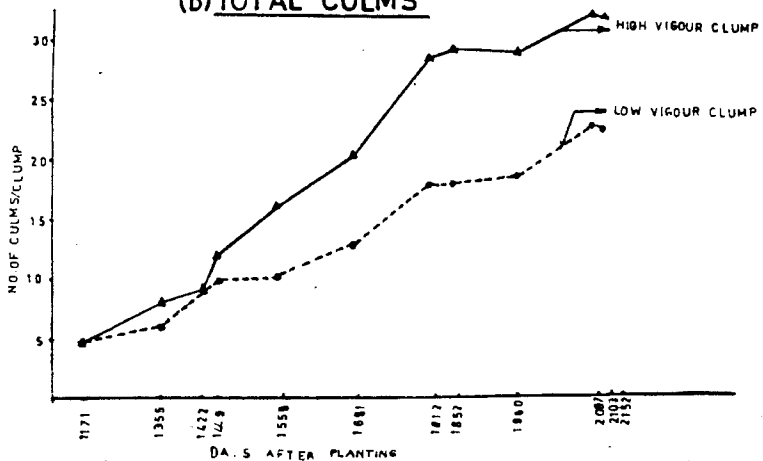
Influence of Clump Size on New Culm Production  
Days after Planting out

	1171	1355	1422	1449	1558	1681	1812	1852	1960	2087	2103
1. L-clump	2.083	3.083	2.833	3.833	7.083	10.000	17.417	13.667	18.667	19.167	19.167
Change (%)		48%	-8%	35%	85%	41%	74%	-22%	37%	3%	0%
2. H-clump	2.667	5.417	5.250	7.083	12.833	17.083	27.917	23.667	29.250	29.197	29.667
Change (%)		3%	-3%	35%	81%	33%	63%	-15%	24%	0%	2%

BAMBOO  
Fig.7. INFLUENCE OF VIGOUR OF CLUMPS  
(a) LIVING CULMS



(b) TOTAL CULMS



It is proposed to discuss the number of living culms/clump under the following headings and in that order - 1. changes in the number of living culms/clump averaged over both the 'low vigour' (L) and 'high vigour' (H) clumps, over the span of time during which the observations were recorded, 2. influence of the vigour of the clumps, and 3. response to P application.

4.2.6.1 Changes in the average number of living culms/clump over time:

It may be noted that <sup>the</sup> 10 intervals of time between the successive pairs of stages of observation, were not of a uniform length. Starting with the period from 1171 DAP to 1355 DAP when the interval was 184 days, the other intervals in strict order were 67, 7, 109, 123, 131, 40, 108, 127 and 16 days. This means that a straightforward comparison of the number of living culms recorded at different times will be misleading, if we consider only the number of living culms in absolute terms. While percentage differences between two stages of observation may help in comparison, still they do not take into account the variability in the time intervals. Hence the quantity the 'average number of living culms present/day/clump' was calculated which is the equivalent of 'per day production' used in annual crops research.

It is seen that, comparing the average number of living culms/clump as at 1171 DAP with that for 2103 DAP, there was an increase of 1028% over a period of about 2 1/2 years. This

steep increase indicates the rapidity of clump expansion in this investigation, while it may not be so under forest conditions. Deogun (1937) has stated that, in artificially raised Dendrocalamus strictus plants which are regularly watered and weeded, the time required for the formation is about after 3 seasons and that the clumps may be workable after 6 seasons, while natural seedlings develop much more slowly.

The data presented in Table 31 reveals that though in general the average number of living culms/clump continued to increase throughout, there were three occasions when there were decreases as compared to the immediately preceding stage of observation. Thus there were reductions of 5%, 18% and 0.5% at 1355 - 1422 DAPs, 1812 - 1852 DAPs, and 2087 - 2103 DAPs respectively. These reductions were caused by the removal of dead and malformed culms as part of the cleaning of the clumps during the above mentioned periods.

As regards the increases in the average number of living culms/clump between successive stages of observation, they were 179%, 135%, 182%, 136%, 167%, 128%, and 102% during the time intervals 1171 - 1355 DAPs, 1422 - 1449 DAPs, 1449 - 1558 DAPs, 1558 - 1681 DAPs, 1681 - 1812 DAPs, 1852 - 1960 DAPs, and 1960 - 2087 DAPs. It is seen that the increases varied from as low as 2% (1960 - 2087 DAPs) to as high as 82% (1449 - 1558 DAPs). The data on per day production of living culms show that it ranged from as low as 0.0031 for the interval 1355 - 1422 DAPs, to as high as 0.2024 for the interval 1422 - 1449 DAPs. Apart

from the high rate of production just mentioned, there were 4 other intervals also wherein the rates of production of living culms were of a relatively high order. Thus, rates of 0.0697, 0.0490, 0.0413, 0.0291 living culms/day were produced during the time intervals 1681 - 1812 DAPs, 1852 - 1960 DAPs, 1449 - 1558 DAPs, and 1558 - 1681 DAPs respectively.

Earlier workers have reported variable numbers for new culm production. These have always been in terms of number of new culms produced/clump/annum. So as to facilitate the comparison of these figures with those of the present investigation, the figures of the earlier workers, besides being reproduced here as reported by them, have also been converted to 'number of culms produced/day' which is shown within parentheses. Kadambi and Rawat (1949) reviewing an early experiment on Dendrocalamus strictus conducted at the Forest Research Institute, Dehra Dun, reported that clumps established by three different methods, 7 years after planting produced an average of 2.9 new culms/clump/annum (i.e., 0.0079 culms/day). Rao (1975) reported that in artificially raised plantations of Dendrocalamus strictus, clumps of 5 or more years of age produced 5-6 new culms/clump/annum (0.0137 - 0.01644 culms/day). These figures agree in general with the results observed in the present investigation.

The increases mentioned already resulted from different causes. Taking the highest rate of increase of 0.2024 living culms/day observed during the time interval 1422-1449 DAPs

first, we note that this occurred just before the starting of the series of the three soybean experiments. It is significant that this period corresponded to the later two-thirds of July and the first week of August 1979 during which the SW monsoon rains were received. Deogun (1937) reported that rainfall is an important factor in culm production. Besides, a general cleaning of the clumps was carried out during this period, and dead culms were removed as part of the pre-treatment given to the clumps before starting the soybean experiments. It is clear that these two factors, viz., rainfall and clump cleaning, were responsible for the steep increase in the rate of production of living culms. That, years of plentiful rainfall generally produces a larger number of culms than those with scanty or deficient rainfall, has been reported by Kadambi (1949); he had also reported that the mere cleaning of the clumps (i.e., cutting away all dry culms) results in an increased production of culms in the years following this treatment.

It was during the succeeding periods, viz., 1449 - 1558 DAPs, 1558 - 1681 DAPs, and 1681 - 1812 DAPs, that Expt.1, Expt.2, and Expt.3 on soybean, respectively were conducted. The corresponding rates of living culms produced/day were 0.0413, 0.0291 and 0.0697. During the period 1852 - 1960 DAPs the rate was 0.0490. Subsequently, the rate tapered off to very low rates of 0.0046 and 0.0078. These rates if expressed for an year, reveal that for the lowest rate of increase, seen during the soybean experiments, viz., 0.0291,

the annual addition of living culms works out to 10.63 culms/year/clump. Similarly, <sup>at</sup> the maximum rate of 0.0697 the annual rate works out to 25.43 culms/year/clump.

It is evident that these high daily rates of production of living culms resulted from the agronomic manipulations carried out within the bamboo stand on the soybean intercrop, which incidentally benefited the associated bamboo clumps. The agronomic manipulations were, soil digging thrice in the interspaces between the clumps for sowing the soybean, hoeing thrice, provision of irrigations almost every week over a continuous period of one year, and systematic weeding. Besides, the possible contribution of the intercrop of soybean by way of the fixation of atmospheric nitrogen has also to be taken into account.

The subsequent reductions in the rates of per day living culm number from 1960 DAP onwards lends support to the foregoing arguments. It may therefore be concluded that better management of a stand of Dendrocalamus strictus (soil working, provision of periodical irrigations and systematic weeding) conduces to increased production of survivable culms, besides the known fact of higher rates of production of new culms during the wet season. However, nothing can be said about the advantage or otherwise of raising an intercrop, particularly a legume crop like soybean, in as much there was no provision for comparison with a sole crop stand of Dendrocalamus strictus bamboo in the present investigation.

#### 4.2.6.2 Influence of the vigour of the clumps

Vigour of the bamboo clump significantly influenced the number of culms/clump at all stages of observation excepting only at 1171 DAP. Thus, initially, when the clumps were about 3 1/4 years of age (1171 DAP), the clumps did not differ much in the number of living culms they had. But, soon the situation changed, and by 1355 DAP differences in the number of living culms/clump started appearing and they were significant, even though the clumps had not been classified into the two vigour classes at that time. These differences were significant at  $p = 0.05$  level.

At 1422 DAP the differences got accentuated and were highly significant ( $p = 0.01$ ). Similarly, the differences as at 1449 DAP were highly significant ( $p = 0.01$ ) with the 'low vigour' (L) clumps recording a mean number of living culms/clump of 3.833 while the 'high vigour' (H) clumps recorded a mean of 7.083. It was only after this enumeration that the classification of the 24 experimental clumps into the two vigour classes was actually effected, with 5 or lesser number of living culms/clump as the dividing line.

During all the subsequent successive stages of observation, the differences between the L- and H-clumps were statistically significant. Besides, the differences between the two classes of clumps progressively increased such that at the time of the last observation (2103 DAP), while the low 'vigour clump' (L) clumps had a mean number of living culms of only 19.167,

the 'high vigour' (H) clumps recorded a mean of as high as 29.667 living culms/clump, thereby showing a difference of 55%.

That, 'clump size', i.e., the number of culms present already in a clump, influences the rate of production of new culms has been pointed out by earlier workers. This in essence is the 'initial capital' phenomenon. Thus, Deogun (1937) studied the pattern of new culm production by individual clumps as related to 'clump size', basing his study on a very large population of 2,650 clumps of Dendrocalamus strictus bamboo spread over 5 states. For the then Madras province (presently Tamil Nadu) he found that a clump having 10 culms already, produced 1.7 new culms/annum (i.e., 0.0047 culms/day), a clump of 15 culms produced 1.9 new culms/annum (i.e., 0.0052 culms/day) etc., upto a clump size of 50 culms which produced 3.0 new culms/annum (i.e., 0.0082 culms/day). Evidently the clumps included in this study were not of identical ages and hence comparability must suffer. He concluded that although bigger clumps (i.e., the ones having a large number of existing culms) produce more new culms and the ratio between the new and old culms in bigger clumps falls off with increasing size of clump so that two small clumps produce more new culms than one big clump of the size of the two combined. He further concluded that clumps of 20-40 culms should be the ideal from the management point of view. Kadambi (1949) reported that in Dendrocalamus strictus, with increasing size of clump, upto a certain upper size limit, the production of new culms also increases; thus for a clump size of 5 culms; new culms produced ranged

from 1.0 - 2.5/annum (i.e., 0.0027 to 0.0068 culms/day), for a size of 10 culms it ranged from 2.25 - 4.00 new culms/annum (i.e., 0.0062 to 0.0199 culms/day) etc., upto a size of 75 culms which produced 9.0 - 12.5 new culms/annum (i.e., 0.0247 to 0.0342 culms/day). Dutta and Tomar (1964) who studied 88 clumps of Dendrocalamus strictus concluded similarly and stated that the percentage of new culm production is higher for small clumps as compared to the large ones. He added that, the yield of culms will be more from an area containing smaller clumps than from an area having larger clumps.

In the present investigation also, it was the 'low vigour' (L) clumps, i.e., clumps of a smaller size, that recorded a slightly higher rate of production of new culms as compared to the 'high vigour' (H), i.e., larger clumps. Dutta and Tomar (1964) suggested that the reason for the percentage of new culm production being higher for small clumps as compared to the large ones, was probably due to the fact that the majority of the new culms are contributed mainly by rhizomes of 1-2 year-old culms; further, a small clump consists mostly of culms 1-2 year-old, as compared to a large clump where there is comparatively a higher proportion of more than 2-year-old culms, which are not probably very effective so far as new culm production is concerned. They also suggested that the higher percentage of new culm production in smaller clumps may also be due to more clump-periphery area as well as more utilisable area/culm being available. It is very likely

that these were the causative mechanisms for the slightly increased percentage of production of new culms by the 'low vigour' (L) clumps seen in the present investigation. The initial spurt in one group of clumps (the H-clumps) might have originated from a genetic superiority.

#### 4.2.6.3 Response to P application:

Phosphorus application did not exert any significant influence on the number of living culms/clump, throughout and more specifically during the period following its application, viz., after 1449 DAP. Watanabe (1972) who tried different doses of a fertilizer mixture consisting of N, P, K, Mg and Si, on young seedlings of Thyrsostachys siamensis bamboo, concluded that the new culms produced were more in the fertilized pots. Ueda (1960) who tried the combinations NK, PK, NP and NPK in a field experiment on Phyllostachys reticulata bamboo, concluded application of NPK combination was the best from the point of new culm production. While these reports indicate a general response in new culm production to application of chemical fertilizers they do not provide evidence specifically bearing on P fertilization.

The absence of response to the added P observed in the present investigation, perhaps emphasizes the fact that some other plant nutrient is more important in the nutrition of bamboos. It is most likely that nitrogen is the element that plays a vital role in culm production in bamboos, particularly

so when we consider the facts that culms represent the major aerial vegetative parts and constitute the major portion of the dry matter of bamboos, and that it is well established that the influence of nitrogen is the greatest on the vegetative parts of plants in general. Ueda (1960) from a pot experiment on seedlings of the bamboo species Pleioblastus pubescens concluded that N is the element most required by bamboos, followed by K and then by P. Thus it may be inferred that application phosphatic fertilizers alone without any addition of N or K, to clumps of Dendrocalamus strictus bamboo is not advantageous from the point of new culm production.

#### 4.2.7 Number of culms (total)/clump

(Table 32, Fig.7(b))

As already explained under section 3.7.2.4, the distinction between the parameter 'number of living culms/clump' and the parameter now taken up for discussion, viz., 'number of culms (total)/clump' is that the latter parameter includes all the existing culms (i.e., living culms of age 1-year or more) plus all the 'potential' culms (i.e., komalis and 'new recruits, both of which are less than 1-year in age + culms which have already been cut and removed)). Thus, this parameter measures the potential productivity of the clumps, i.e., how many culms would have been produced had all the komalis and 'new recruits' that emerged from the ground survived and grew to maturity, besides taking into account the culms that dried up, died and removed. In other words, this measures the theoretical production.



A scrutiny of the data for the total culms shows that though the figures were higher than that for the 'number of living culms/clump' at all stages, as it should be, the patterns of changes over time were similar. Hence, all the discussions made under section 4.2.6 will hold good for this parameter also, and it is not proposed to discuss this aspect further.

The total number of culms/clump increased from an average of 4.667 at 1171 DAP to an average of 27.458 at 2103 DAP. The difference between the average (mean of 'L' and 'H' clumps) number of total culms/clump and the average number of living culms/clump, ranged from as low as 0.666 culms/clump at 1812 DAP to as high as 5.166 culms/clump at 1852 DAP, in terms of number of culms. A more meaningful method of comparison would be to express these differences as percentages of the total number of culms/clump. The percentage differences between the total number of culms/clump and the number of living culms/clump, were 49%, 39%, 47%, 43%, 24%, 19%, 3%, 22%, 11% and 11%, at 1171, 1355, 1422, 1449, 1558, 1681, 1812, 1852, 2087, and 2103 DAPs respectively. This means that the 'would-be culms' that were lost, ranged from as low as 3% to as high as 49%. The data also reveals that initially upto and inclusive of 1449 DAP, the lost culms ranged between 39 to 49% which subsequently reduced progressively, though slightly erratically, and reached a value of 11% finally. This is not surprising, since during the initial stages of clump development when there were

only a few culms/clump, the loss of even a single 'would-be-culm' through the death of a Komali or drying of one culm would represent a substantial percentage of the total. Subsequently when the clump had developed almost to its full size and the rate of production of new culms and rate of loss of culms stabilize, the loss of a single culm would represent only a small percentage of the total. In conclusion, it may be inferred that, by the time the clumps attain the age of about 6 years, a total of only 11% of the total of all the culms or culm precursors like komalis or 'new recruits' are lost, upto that point in time. It therefore implies that if care is exercised to make all the komalis and 'new recruits' to survive and to prevent early death of culms, an additional yield of culms of about 10% could be expected.

Regarding the influence of the two factors of study, the arguments presented under 'number of living culms/clump' (sections 4.2.6.2 and 4.2.6.3) apply for the total number of culms/clump also. Hence these are not discussed here. However, it must be pointed out that while under the 'number of living culms', the differences between the 'low vigour' (L) and 'high vigour' (H) clumps were statistically significant at all stages excepting 1171 EAP, as regards the 'total culms/clump', the differences did not reach levels of statistical significance during 4 stages, viz., 1171, 1355, 1422 and 2087 DAPs. Further, in general, the level at which the differences were

significant was  $p = 0.05$  under 'total number of culms/clump'. This difference between the two parameters as regards the sensitivity to the F-test, arose because of differences in the percentage losses between the two vigour classes. While initially (when clumps were  $3 \frac{1}{4}$  years of age) both the L- and H-clumps had identical number of total culms/clump, viz., 4.667, they differed very much at 2403 DAP, with the L-clumps recording 22.750 and the H-clumps recording 32.167 number of total culms/clump. Phosphorus application also failed to exert any significant influence on the total number of culms/clump.

#### 4.2.8 Number of usable culms harvested (i.e., culm yield)

(Table 33)

As already mentioned in section 3.7.2.1, culms were selectively harvested following certain specific felling rules, when the clumps had attained an age of almost 6 years.

The vigour of the clump exerted a significant influence on the number of usable culms harvested. While the yield of usable culms/clump was as low as 9.500 in the 'low vigour' (L) clumps, it was 16.917 for the 'high vigour' (H) clumps, and the difference was highly significant ( $p=0.01$ ). This clearly demonstrates the superior culm productivity of vigorously growing clumps of bamboo.

**Table 33 Final harvest data on selectively felled culms  
(as on 2152 DAP)**

## BAMBOO CLUMPS

	Number of usable culms harvested/ clump	Mean Mid-culm Diameter (mm)	Mean Fresh Weight/ culm (alone) (kg)	Fresh weight of bran- ches + leaves + sheaths/ culm (kg)	Aerial Biomass/ culm (Fresh weight) (kg)	Total culm yield/ clump (Fresh wt.) (kg)
<b>1. Influence of Vigour of the clump (V)</b>						
L	9.500	14.855	0.965	1.080	2.029	9.821
H	16.917	14.307	0.895	0.903	1.792	14.746
F	**	NS	NS	NS	NS	NS
SE	1.727	0.784	0.096	0.136	0.217	1.927
CD	7.197	-	-	-	-	-
<b>2. Influence of Phosphorus levels (P)</b>						
P <sub>0</sub>	14.000	15.020	1.007	0.996	1.998	13.388
P <sub>1</sub>	13.500	15.008	0.983	1.126	2.099	13.351
P <sub>2</sub>	12.125	13.716	0.802	0.853	1.634	10.113
F	NS	NS	NS	NS	NS	NS
SE	2.115	0.960	0.117	0.161	0.266	2.360
CD	-	-	-	-	-	-
<b>3. Interaction V X P</b>						
F	NS	NS	NS	NS	NS	NS

The average number of usable culms harvested (i.e., averaged over the L- and H-clumps) works out to 13.2085 culms/clump. At the planting spacing of 4 x 4 m, the population works out to 625 clumps/ha. Assuming a 100% stocking, and taking the average of 13.2085 culms/clump, a total yield of 8,255 culms/ha could be expected when the clumps reach 6-years of age.

From Table 33 it is seen that these usable culms that were harvested, had mid-culm diameters of 14.855 mm and 14.307 mm, for the L- and H-clumps respectively, the average working out <sup>to</sup> 14.581 mm. Similarly, the average height works out to 3.184 m (Table 27). These sizes are not the lengths and diameters of the culms of commerce where still larger culm diameters and longer lengths are expected. Thus, if these small-sized culms harvested when the clumps are 6-years old, though saleable, will fetch relatively low prices only. Still they are usable and thus saleable, because of the solidity of the culms. It thus appears that since most of the culms harvested must have been of more than 1-year age, and perhaps upto about 3 years of age, if the next harvest is carried out after another 3 years, i.e., when the clumps attain the age of 9 years, commercial sized culms may be expected to be yielded, as sufficient time would then have become available for the culms to reach maturity.

Phosphorus application did not exert any significant influence on the number of usable culms harvested. The

consistent failure of P to influence the number of culms, be it the number of living culms or the total culms or the usable culms harvested, indicates that it is not advantageous to apply P singly, from the point of culm yields in terms of number.

#### 4.2.9 Weight of individual culms

(Table 33)

The mean fresh weight of a single culm (without branches, leaves and sheaths) ranged from 0.895 kg for the 'high vigour' (H) clumps to 0.965 kg for the 'low vigour' (L) clumps the average working out to 0.930 kg. The difference, however, was not significant. That the culm weight is slightly higher under the L-clumps could be expected from the fact that these culms in general were slightly longer (Table 27) and thicker (mid-culm diameter under Table 33) at 2152 DAF, as compared to the culms harvested from the 'high vigour' (H) clumps.

While mature culms may weigh several kilograms, generally 3.0 to 3.5 kg/culm at exploitable age, it is not surprising that the culm weight in the present investigation is far less, when we consider the fact that the clumps were very young.

Phosphorus application did not exert any significant influence on the fresh weight of individual culms.

#### 4.2.10 Weight of branches, leaves, and sheaths/culm

(Table 33)

While the non-culm aerial vegetative parts, viz., the

branches, leaves, and culm sheaths have no commercial value, still, an idea about their relative proportions to the economically valuable culm proper, will help to assess the efficiency of conversion of solar energy into saleable produce.

The fresh weight of the non-culm aerial vegetative parts was 1.080 kg/culm for the L-clumps, and 0.903 kg/culm for the H-clumps, the average therefore working out to 0.991 kg/culm. If the weight of a single culm as seen under section 4.2.10, viz., 0.930 kg, is compared with the weight of the non-culm parts associated with the culm, viz., 0.991 kg, it is seen that the ratio works out to 1:1.067. If differences in the moisture contents of the different plant parts are ignored, this ratio of almost unity would imply that approximately half the dry matter (DM) produced by the bamboo clump is tied up in non-saleable plant parts. Eventhough this inference is based on 6-year old clumps of Dendrocalamus strictus, it is very likely that this may be valid for still older clumps also, and perhaps to the other species of tropical bamboos also. Incidentally, the ratio of unity for culm; non-culm aerial vegetative parts, observed in this investigation bears a strong resemblance to the grain:straw ratio of most high-yielding varieties of annual cereal crops also being about unity.

Neither the vigour of the clump nor P application affected the fresh weight of the non-culm aerial vegetative

parts significantly.

#### 4.2.11 Aerial biomass

(Table 33)

The aerial biomass represents the fresh weight of all the aerial plant parts, viz., culms + branches + leaves + culm sheaths. In the present investigation, the average fresh weight aerial biomass worked out to 1.910 kg/culm (average of L- and H- clumps), when the clumps were about 6-year old. This data is based only on the selectively felled culms and thus, strictly speaking, is not applicable to the remaining culms leftover in the clump itself, since selection had been exercised in choosing the culms to be felled. However, if it is assumed that (i) the aerial biomass of culms is the same for different culms in a clump, and further that (ii) substantial changes in aerial biomass could not have occurred within a short period of about 50 days (i.e., 2103 DAF to 2152 DAF), then we can use the above average of 1.910 kg/culm and the average of 24.417 number of living culms/clump recorded at 2103 DAF (Table 31), for arriving at a rough estimate of the total aerial biomass/hectare. Multiplying the above two figures together, and then by the population of 625 clumps/ha (at the spacing of 4 X 4 m) assuming a 100% stocking, we get the estimated aerial biomass yield of 29.148 tonnes/ha at the end of 6 years after planting Dendrocalamus strictus bamboo seedlings. Even though this means that the average annual production of aerial biomass was only of the order of about 5 tonnes/ha/year, which is far less than that for a common seasonal tuber crop, it must be

borne in mind that these data pertain to bamboo clumps which were in their formative stage.

Neither the vigour of the clumps nor P application significantly influenced the aerial biomass. This pattern of results is a repetition of those seen under the components constituting the aerial biomass, viz., fresh weight of culm and fresh weight of the non-culm aerial vegetative parts. The lack of response of the aerial biomass to P application seen in the present investigation is in contrast with the results of Patil (1980) for the same species of bamboo, of course, as reported for dry matter (DM) accumulation. He observed the DM accumulation to increase with application of N,P,K in combination. The absence of response noticed in the present investigation is perhaps ascribable to the application of only P, instead of N, P, and K, together.

#### 4.2.12 Total culm yield/clump (fresh weight)

(Table 33)

It was already pointed out under section 2.1.7 that the yield of the economic product from bamboos, viz. the culms, is often expressed on a weight basis also. The data reveal that the total fresh weight of all the extracted culms/clump, i.e., the 'usable culms'/clump, was 9.821 kg for the 'low vigour' (L) clumps, and 14.746 kg for the 'high vigour' (H) clumps; the average of the two being 12.2835 kg. The spacing between the bamboo clumps in this investigation being 4 X 4 m, the calculated bamboo population works out to 625 clumps/hectare.

Assuming 100% stocking (which is possible under farm conditions in contradistinction to forest conditions) and using the average yield of 12.2835 kg of culms/clump calculated above, the theoretically projected yield works out to 7.677 tonnes of green culms/hectare at the first harvest, from 6-year old clumps of Dendrocalamus strictus raised partly under irrigation, under Coimbatore conditions.

While the estimates as regards culm yields expressed on a weight basis, for Dendrocalamus strictus bamboo, by the earlier workers (Osmaston, F.C., as reported by Deogun, 1937, Chaudhari, 1966, Seth and Kharbada, 1972, Watanabe, 1972, Seth, 1978; and Varmah and Bahadur, 1980) are very low, ranging from 0.173 t/ha/year to 4.45 t/ha/year, it must be remembered that these estimates were based on bamboo clumps growing naturally in forests, and further that, these are estimates of sustained annual yields, after the clumps had grown to their full size and the yields had stabilized. On the other hand, the high yields of culms secured in the present investigation are ascribable to (i) the artificial conditions of raising the clumps under farm situations, and (ii) the accumulation of culms over a period of about 6 years from planting the seedlings. It is quite likely, that in subsequent harvests, the annual yields may not be the same 7.68 tonnes of green culms/hectare, but may be lower. Rao (1975) had predicted that in artificially-raised plantations of Dendrocalamus strictus bamboo, an

optimistic culm yield of 4 t/ha for the first cut can be expected. He had also forecasted that, over a life cycle of 32 years, a total yield of 74 t/ha, which works out to a mean annual yield of 2.3 t/ha. The results of the present investigation lend support to the above view.

The vigour of the clump did not exert any significant influence on culm yield. This is contrast to the significant difference seen under the mean number of usable culms harvested/clump, i.e., culm yield expressed in terms of number. In this context, it must be remembered that the selectively felled culms from the 'low vigour' (L) clumps were slightly longer and thicker and thus slightly heavier (0.965 kg/culm) as compared to the culms felled from the 'high vigour' (H) clumps, as was pointed out under section 4.2.9. Thus, eventhough the mean number of usable culms harvested were significantly lower for the L-clumps (9.500 culms/clump) as compared to the culm yield from H-clumps (16.917 culms/clump), the slightly heavier weight of individual culms of the L-clumps, compensated for the reduction in the number of culms/clump, such that the difference in the total weight of harvested culms/clump from the L-and H-clumps narrowed down to such a level that the difference was not statistically significant.

Phosphorus application also did not evoke any significant response. It may therefore be concluded that neither the vigour of the clump nor P application influences the yield of culms on a weight basis, and that an yield of about 7.7 tonnes of green culms/ha could be expected during the first harvest, i.e., at

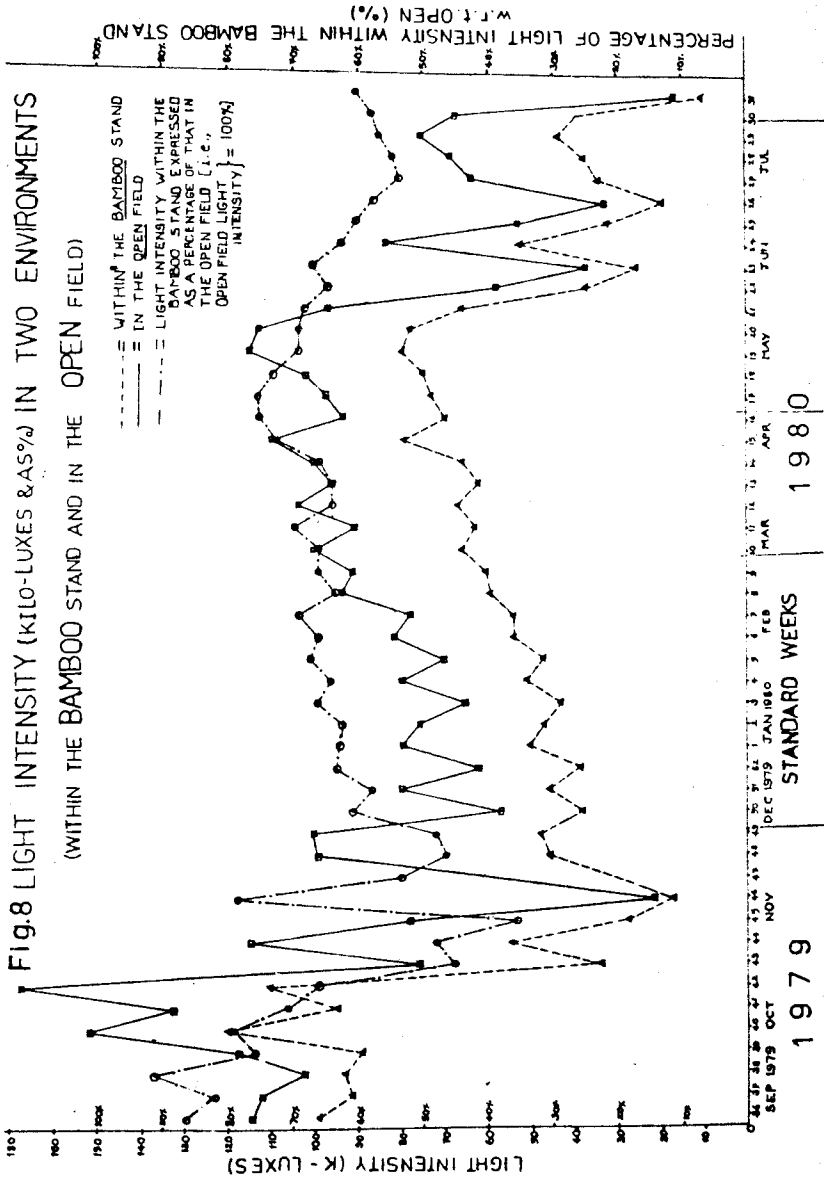
the end of 6 years after planting Dendrocalamus strictus seedlings.

#### 4.3. LIGHT INTENSITY (Appendix 1 and Fig.8)

The data on daily light intensities as recorded both within the bamboo stand and in the open field, at 12 noon local time, and at ground level, were summarised by computing the weekly means for standard weeks and are presented in Appendix 1. The data reveals that the light intensities in the open were generally very high during the first three weeks of October 1979 (Standard weeks 40 - 43), ranging from 132.1 to 167.1 K Lux (which was the highest value recorded during the observation period of 11 months). The lowest value of 21.9 K lux was recorded during the period 12th - 18th November 1979 (Standard week 46).

##### 4.3.1 Light intensities in the opens

As regards the pattern of changes of ambient light, the intensity which was very high, though fluctuating rather widely, during the months of September and October 1979, fell sharply to low levels during the first week of November 1979 and reached the lowest value of 21.9 K lux during the third week of November 1979 (Standard week 46). Thereafter the light intensity progressively increased and reached the peak of 115.2 K lux during the second week of May 1980 (Standard week 19). After this, the light intensity fell very sharply and touched the low



value of 37.1 K lux during the period 3rd - 9th June 1980 (Standard week 23), followed by a spurt of increase to 84.3 K lux during the next week, and then a fall to 32.7 K lux during the last week of June 1980. Thereafter the light intensity started to increase once again.

In the above pattern of changes, if we ignore the sudden spurts and falls noticed as random fluctuations, a clear trend of movement of ambient light intensity emerges, which may be stated as follows. The march of ambient light intensity over an year shows two peaks and two troughs. The first peak occurs during the third week of October and the second peak which is smaller, occurs during the second week of May. The troughs which are more or less similar in magnitude occur during the third week of November and the last week of June. Further, the rate of rise of light intensity from the trough of November to the peak of May, is very slow.

The high light intensity during the month of May is to be expected as it is the peak of summer when clear skies and bright sunshine prevail. But it is seen from the data that the light intensity was still higher during the first three weeks of October. The reason for this is that this period corresponds to the lull between the two monsoons viz., SW and NE, and while the rainfall during this inter-monsoon break is relatively less, the sky is generally dominated by large cloud masses. The weather data for the period 1-21 October 1979

(Appendix 3) reveals that during this period a total quantity of 69.4 mm of rainfall was received in 4 days. Thus, there were 17 non-rainy days during this period, which were cloudy but not overcast. The reflection of sunlight by the clouds increased the diffuse skylight component which accounts for the very high light intensities recorded during this period. The subsequent sharp fall in light intensities was due to heavily overcast skies.

#### 4.3.2 Light intensities within the bamboo stand:

As could be expected, the light intensities within the bamboo stand were always lower than that in the open. But the differences between the two varied, though in general the light intensity within the bamboo stand followed closely that in the open. The highest light intensity of 120.0 K lux for the bamboo stand was recorded during the first week of October 1979, and the lowest of 17.2 K lux during about the third week of November 1979 (Standard week 46). In terms of percentage fractions of the light intensity in the open, it ranged from as high as 91.2% (Appendix 1) (Standard week 38) to as low as 35.3% during the period 5 - 11 November 1979 (Standard week 45).

In general, the relative percentage light intensity within the bamboo stand as compared to the open was high during September and the first week of November 1979. There were two reasons for this. Firstly, the bamboo canopy was relatively more open at that stage because the clumps were

comparatively younger and their crowns had been trimmed as part of a pre-treatment carried out during August 1979. Hence more light reached the ground. Secondly, the bamboo clumps being relatively younger possessed less foliage and thus contributed more as reflectors of light than as screens for shutting out light. Saeki (1963) has reported that when direct sunlight is blanked off from the measuring instruments, the direct sunlight is diffused by foliage and branches within a wooded area and thus light is incident on the measuring instrument from a much wider angle thereby resulting in an increase in the relative light intensity accompanied by a shift in the spectral composition of the shade light in the wood.

From the last week of October 1979 onwards upto the end of the third week of December 1979, the percentage light intensity within the bamboo stand was relatively very low, barring one exception (Standard week 46). This, it would appear, is because light attenuation within the bamboo canopy follows the exponential model proposed by Davidson and Philip (1958). However, the high relative percentage value of 78.5% recorded during Standard week 46 is difficult to explain.

In general, the light intensity within the bamboo stand was in the range of 60% to 75% of the ambient light. It may therefore be concluded that, about a quarter to one-third of the ambient light is cut out by the bamboo canopy when the clumps are about 4-5 years of age and spaced 4 X 4 m apart.

This is in contrast to light transmission values of 50 - 55% for coconut stands reported by Litscher and Whiteman (1982) and very sharply so with the 28 - 5% relative light intensity for forest floors reported by Monsi and Saeki (1953).

#### 4.4. MICROCLIMATE

##### 4.4.1 Air temperature

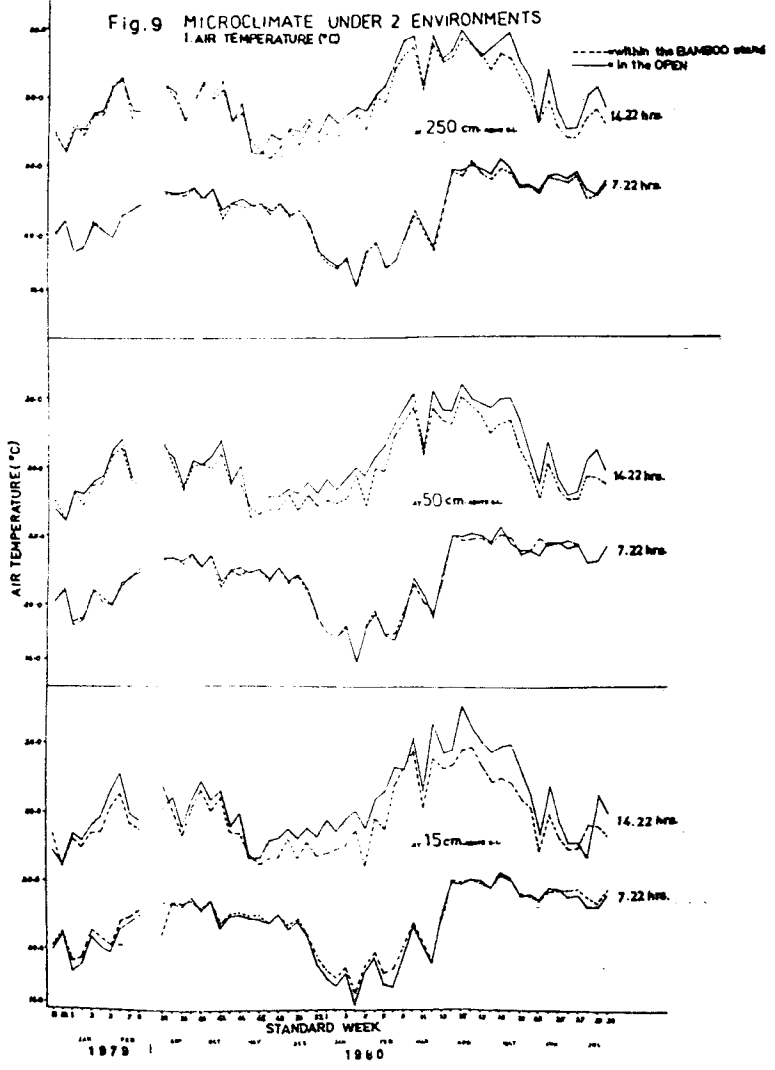
(Appendix 2.1(a) and (b), Fig.9)

##### 4.4.1.1 Seasonal changes:

The overall behaviour of temperature showed that it was very low during the months of December 1979 - January 1980 and started rising to reach the highest values for the year as a whole, sometime during the months of April 1980 - May 1980, after which it started to fall. Thus, there was a peak of high temperature during summer and a trough of low temperature during the cold weather period (Appendix 2.1 (a) and (b)).

Though the march of temperature as described above was similar for both the X-epoch (i.e., morning, 7.22 hours) and the N-epoch (i.e., afternoon, 14.22 hours), the periods of occurrences of the annual maximum and minimum temperatures for the two epochs were not coincidental.

Thus while for the X-epoch, the lowest temperature for the year was recorded during the last week of January (Standard week 4) at all the 3 altitudes (15,50, and 250 cm above ground level), and under both the environments (bamboo stand and open),



for the N-epoch, it was during the period 5th November to 25th November (Standard weeks 45- 47) that the lowest temperatures were recorded. Similarly, the highest temperatures of the year, were generally recorded during the period 6th - 12th May (Standard week 19) for the X-epoch, at all the 3 altitudes for the open field environment and at 15 and 50 cm altitudes for the bamboo stand, while for the 250 cm altitude the maximum temperature for the bamboo stand was recorded during 15th - 21st April 1980 (Standard week 16). In addition, there was another peak of the same magnitude during the first week of April 1980 (Standard week 14) for the 50 cm altitude within the bamboo stand.

As regards the N-epoch, the lowest temperatures were recorded during 5th-25th November 1979 (Standard weeks 45-47) for both the environments and at all the 3 altitudes, while the highest temperatures were recorded during the period 8th-21st April 1980 (Standard weeks 15 and 16) for both the environments and at the 3 altitudes.

Thus, it is seen that while for the X-epoch, the lowest temperatures were reached during the typical cold weather season, viz., the last week of January (Standard week 4), for the N-epoch, the lowest temperatures were reached much earlier and recorded during the last phase of the NE monsoon, viz., major part of November (Standard weeks 45-47). Similarly, as regards the highest temperatures also there was no coincidence. For the X-epoch, the maximum temperatures were

reached, in general, during the second week of May, while for the N-epoch, it was one month ahead of it, viz., the second week of April, in all cases excepting the 15 cm altitude of the bamboo stand, whose highest temperature also was reached in the immediately following week, i.e., 15th - 21st April (Standard week 16). It may therefore be concluded that there exists a precession phenomenon as regards temperature behaviour in the N-epoch. The coldest period of N-epoch appears to precede that for the X-epoch by nearly 2 1/4 months and the warmest period by about a month. The reasons for such non-coincidence between the two epochs are traceable to macro-climatological changes in weather elements and hence are not discussed here.

As regards actual temperatures, the lowest temperature recorded during the period of observation, was 15.8°C for the open field environment at 15 cm altitude for the X-epoch during 22nd-28th January 1980 (Standard week 4). The highest temperature of 37.7°C was also recorded by the open field environment at 15 cm altitude, but during the N-epoch, during 8th-14th April 1960 (Standard week 15). The range in temperature between the highest and lowest was more (11.4°C) during the N-epoch than during the X-epoch (9.9°C).

#### 4.4.1.2. Diurnal variations:

The greatest differences in temperature between the two epochs (X-i.e., morning, and N-i.e., afternoon) occurred during the third week of March (Standard week 12) and was in the range of 14.8 - 16.5°C for the three different altitudes. The minimum differences between the two epochs (X- and N-) temperatures, on the other hand were recorded during two

periods, viz., the period of 12th-25th November (Standard weeks 46 and 47) when the differences ranged between 3.6-6.0°C, depending on the environment and the altitude, and again during the period 1st - 14th July (Standard weeks 27 and 28) when the differences ranged between 2.8 - 7.4°C depending on the environment and altitude.

It is apparent that; while the maximum diurnal difference between N- and X-epochs occurred only at one time, viz., during the third week of March and further that the differences between the different environments and altitudes was within a very narrow range <sup>of</sup> 1.7°C, the minimum diurnal difference occurred during two periods, once during November, when the differences, between the different environments and altitudes were only 2.4°C and thus narrow, and again during July, when the differences between the different environments and altitudes were a bit wider, to the extent of 4.6°C.

These diurnal variations also being macroclimatological phenomena, they are not discussed here any further. It is sufficient to note that these data bring out the point that heat stress is likely to be experienced by annual crops during the month of March, particularly during the third week, under Coimbatore conditions.

#### 4.4.1.3 Comparison of temperatures within the two environments:

From Appendix 2.1(a) it is seen that the temperatures in the open field, for the X-epoch, ranged between 15.8-25.6, 15.9-

25.6, and 16.3-25.7°C, for the altitudes 15, 50, and 250 cm respectively. It is seen from the data that, while at the two higher altitudes (50 and 250 cm) the temperatures in the two environments did not differ much, near the ground surface (15 cm altitude), the bamboo stand temperatures were generally higher, to the tune of even 1.2°C during the cool season (viz., the third week of February 1980) as compared to the open field. Thus, in general, the air layer near the ground surface was slightly warmer within the bamboo stand as compared to the open field. This agrees with the findings of Dabral et al. (1969) who studied the microclimate within a 14-year old stand of the same species of bamboo used in the present investigation, viz., Dendrocalamus strictus, and planted at almost the same spacing, viz., 12 ft. X 12 ft. (i.e., 3.66 X 3.66 m). They also reported that the ground surface remained warmer inside the bamboo (as well as chir pine) plantations, as compared to the open field, and the effect was more pronounced during the cool season.

This effect of the air layer near the ground being warmer within a bamboo stand was attributed by Dabral et al. (1969) to the sheltering and blanketing effects of the bamboo cover, which effectively checked the outflow of heat. From the view-point of raising intercrops of annuals within a bamboo stand, this implies that the growth conditions for annuals, whose statures are not very high and thus lie within the air layer near the ground, are more favourable within a bamboo stand than in the open, particularly during the cool season, when

the rate of growth of the annual intercrops is bound to be rather slow. Thus, while a bamboo stand may impose a stress on an associated annual intercrop by way of shading and root competition, it also confers a benefit by keeping the zone near the ground warmer, during the chilly morning hours.

As regards the N-epoch (i.e., afternoon) the pattern was different, the temperature difference between the two environments being very much accentuated, with the bamboo stand almost invariably recording a lower temperature as compared to the open field, at all the three altitudes. From Appendix 2.1(b) it is seen that the bamboo stand temperatures ranged within the limits of 26.1-34.7, 26.4-35.1, and 25.7-34.5°C, for 15, 50, and 250 cm altitudes respectively, while the corresponding temperatures in the open field were 26.5-37.7, 26.2-35.9, and 26.0-35.2°C. This clearly shows the cooler temperatures that prevailed within the bamboo stand, the ranges in the limits of the temperature depression being 0.4-3.0, 0.1-0.8, and 0.3 - 0.7°C for 15, 50, and 250 cm altitudes respectively. These differences are, of course, between the extremes which naturally were recorded during entirely different periods. But, still they serve to highlight the cooling effect of the bamboo stand.

Restricting the consideration only to particular periods of the N- epoch, the maximum differences in temperature between the two environments (bamboo stand always being cooler) were 3.2°C during the second week of April 1980 (Standard week 15) for the 15 cm altitude, 2.3°C during the third week of July 1980

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(Standard week 29) for the 15 cm and 30 cm altitudes. Thus, the maximum cooling by the bamboo stand to the tune of 3.2°C occurred around mid-April very near the ground surface (15 cm above ground level), precisely the zone where any low-statured annual intercrop will be growing. Radke and Hagstrom (1973) also had observed an air temperature difference of 1.5°C between an unsheltered stand of soybean and a soybean stand sheltered by a windbreak.

That the cooling effect of the bamboo stand should be maximum during the hot weather period of the year (April and July), which incidentally is the period when dissipation of heat is most needed, is not surprising. During the wet season, the high latent heat of the water comes into play and the temperature difference between the two environments is not much, while during the hot weather period which is usually dry, this factor does not operate and the cooling effect of the shade cast by the bamboo canopy manifests itself in a pronounced manner.

From the point of intercropping within a bamboo stand this cooling effect, particularly during the hot weather period of the year, is a welcome feature. Summing up, it is seen that the air layer very near the ground within the bamboo stand, while being warmer during the cool period of the year, is cooler during the hot weather period, thus moderating the microclimate in favour of any associated annual intercrop.

The results of the present investigation, in so far as the air being cooler within the bamboo stand near ground surface, is in conflict with those of Dabral et al. (1969) who recorded higher temperatures within the bamboo stand as compared to the open, during the hot seasons. They explained the higher temperature in terms of the bamboo defoliating itself during the hot season thus allowing more heat to reach the ground, while the culms continued to prevent the free movement of air. The anomaly between these findings is due to the fact that while under the conditions of Dehra Dun, which is in the extreme north of India, Dendrocalamus strictus bamboo may defoliate itself during hot seasons, it is not so under the conditions of Coimbatore, which is far down south. At Coimbatore, during the hot weather period Dendrocalamus strictus bamboo, while drying up its leaves with accompanied colour change, does not shed its leaves, thereby shading the ground substantially. It must be remembered that as far as ground shading is concerned, it is immaterial whether the shade is dead or living.

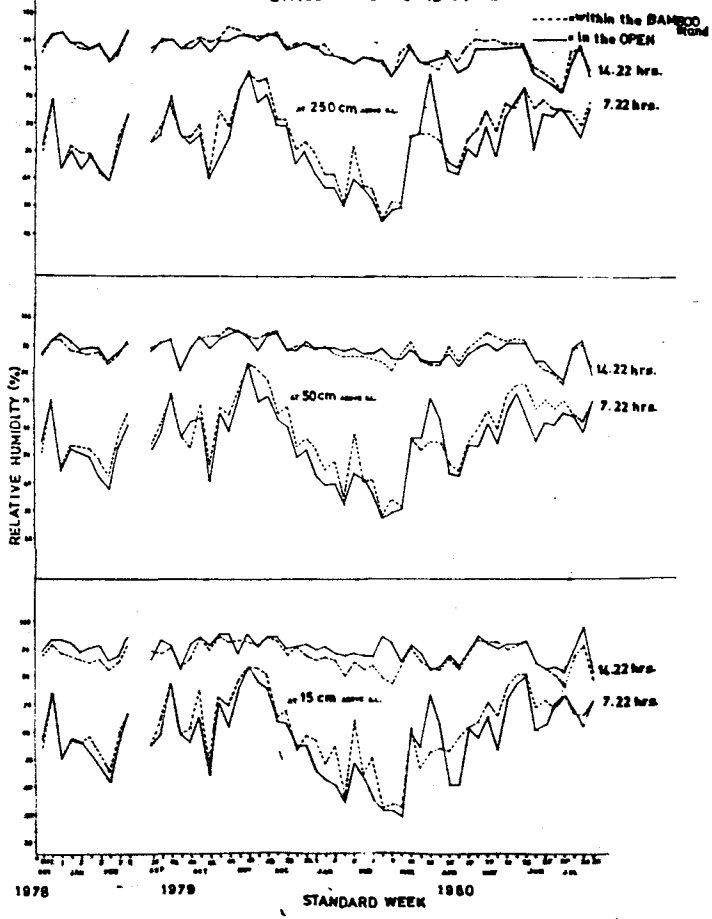
#### 4.4.2. Relative Humidity

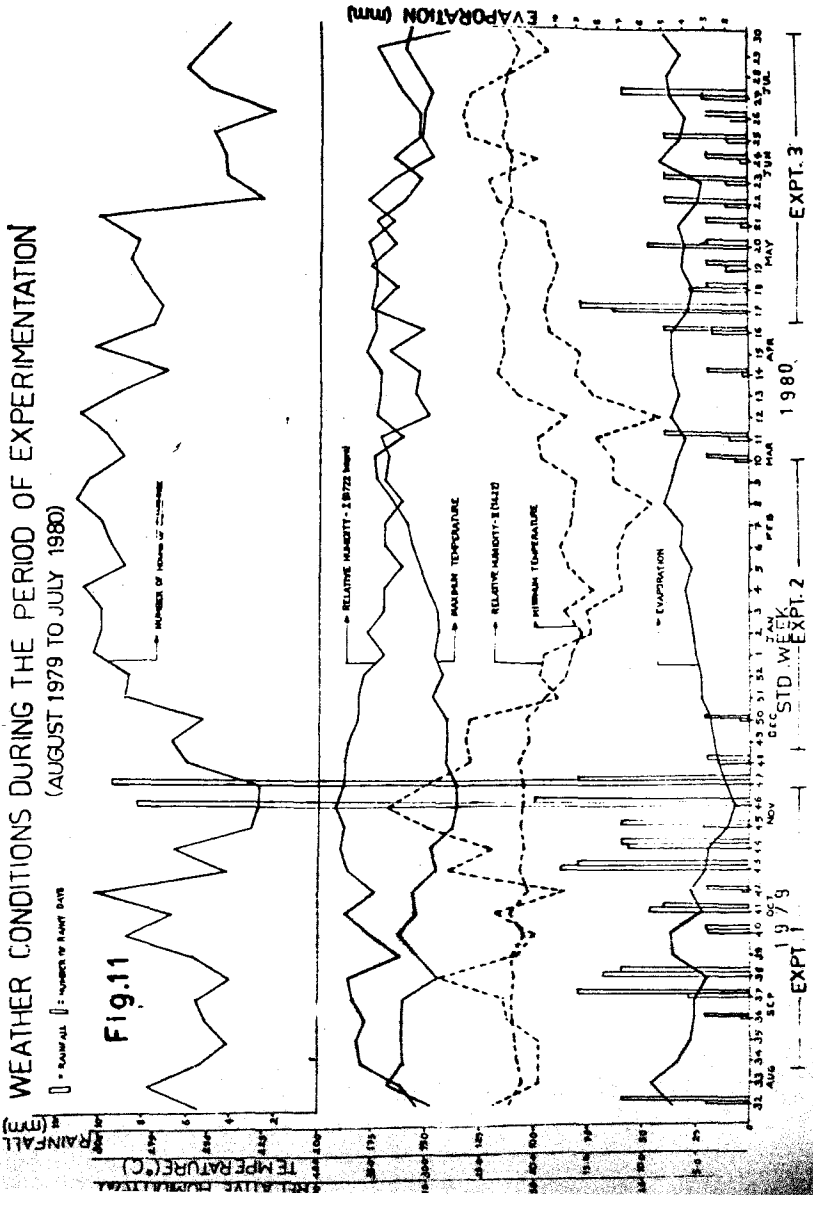
(Appendix 2.2(a) and (b), Fig. 10)

##### 4.4.2.1 Seasonal changes:

The march of relative humidity showed the usual interesting feature of differential patterns of change between the two epochs. While the X-epoch (morning) relative humidity was

Fig. 10 MICROCLIMATE UNDER 2 ENVIRONMENTS  
2. RELATIVE HUMIDITY (%)





more or less constant and at a high level, almost throughout the year, the N-epoch (afternoon) relative humidity showed two peaks and two troughs, thereby fluctuating within wide limits. This was the general pattern for all the three altitudes (Appendix 2.2(a) and (b)). As regards the N-epoch, the first peak which was more pronounced and rather sharp, occurred during the period 12th-18th November 1979 (Standard week 46) when the relative humidity ranged between 70.0% to 83.3% depending on the environment and altitude. The second peak, whose amplitude was lesser as compared with the first peak, occurred during the period 3rd-9th June, the relative humidity ranging between 74.7% and 80.1%. The troughs intervened between the two peaks.

As regards absolute values, invariably the relative humidity was higher during the mornings (X-epoch) as compared to the afternoons (N-epoch). During the X-epoch, the maximum values for relative humidity, which ranged between 93.9% and 96.1% depending on the environment and the altitude, were recorded during the period 22nd October to 2nd December 1979 (Standard weeks 43-48), which corresponded to the wettest part of the year, i.e., the NE monsoon rains, which thus explains the very high relative humidities. The lowest values of relative humidity for X-epoch, occurred during the first week of July 1980 (Standard week 27) and ranged between 73.2% and 81.1%. It can be seen that the maximum difference in relative humidity between the extremes was only 22.9% which indicates that the fluctuation was not very much during the X-epoch.

During the N-epoch, the highest ever relative humidities, which ranged between 79.0% and 83.3%, occurred during 12th-18th November 1979 (Standard week 46), while the lowest values, which ranged between 24.6% and 31.9% depending on the environment and the altitude, occurred during 19th February to 10th March 1980. Thus, the maximum difference between the extremes was 58.7% which shows the higher magnitude of swing in relative humidities during different seasons.

This pattern of the morning relative humidity being higher and more or less constant, and the afternoon relative humidity being lower in value and fluctuating widely over time is well known, as to need an explanation. Further such differences are due to macroclimatological phenomena.

#### 4.4.2.2 Diurnal variations:

The diurnal difference between the X- and N-epochs was the maximum during the period 19th-25th February 1980 (Standard week 8). The differences, i.e., the swings in the relative humidity between the X- and N-epoch, were 58.1%, 61.9%, and 59.1% at 15, 50, and 250 cm altitudes respectively, for the open field, while, for the bamboo stand, the corresponding values were 47.2%, 56.6%, and 56.7%. These show that the diurnal fluctuations in relative humidity were more wild in the open, as compared to within the bamboo stand. The buffering effect of the bamboo stand on the daily fluctuations of relative humidity, is ascribable principally to its shading effect which reduces the ambient temperature slightly (as was seen under

section 4.4.1.3) thereby suppressing evapotranspirational losses to the atmosphere besides preventing advection by its blanketing effect.

The altitudinal differences in relative humidity were very insignificant, be it the X-epoch or the N-epoch.

#### 4.4.2.3 Comparison of relative humidities within the two environments:

The differences in the relative humidities between the open field and the bamboo stand were fluctuating widely; though certain definite trends were discernible. In general, the differences in the relative humidities between the two environments were not very much during the X-epoch; they were more or less the same for the two environments at all the 3 altitudes. But, during the N-epoch, the bamboo stand generally recorded a higher relative humidity than in the open field, at all the 3 altitudes, with one notable exception during the period 18th March to 7th April 1980 (Standard weeks 12- 14) when the open field recorded a higher relative humidity than within the bamboo stand. The differences were most pronounced during the last week of March 1980 (Standard week 13).

The maximum differences in the relative humidities, at all the 3 altitudes, between the bamboo stand and the open field occurred during the period 29th January - 4th February, 1980 (Standard week 5). The actual differences were 15.9%, 15.0%, and 11.3% for 15, 50 and 250 cm altitudes respectively.

In all cases, it was the bamboo stand that recorded the higher humidity and these maximum differences between the two environments arose only during the hottest part of the day, viz., the N-epoch.

Though the maximum difference occurred during January - February which are the cooler parts of the year, still, the same trend of the bamboo stand recording a higher humidity even during the hot weather period (later part of April through July) is seen, which will be beneficial to any associated annual crop raised as an intercrop within the bamboo stand. The higher humidity observed within the bamboo stand is due both to the shading effect by the canopy which reduces evaporational losses, and to the blanketing effect of the culms which effectively reduce the advectational losses of moisture in the air.

The singular exception of the period 16th March to 7th April 1980 when the open field recorded higher relative humidities as compared to the bamboo stand - to the extent of even 23.1% at 250 cm altitude during the period 25th - 31st March 1980 - was caused by a unique combination of circumstances. It must be remembered that soybean was intercropped during the period when microclimatic observations were recorded and the soybean crop was provided with weekly irrigations excepting during periods of rainy weather and during the last stages of maturity of the crop. The soybean intercrop of Expt.2 was harvested on 6th March 1980, and the next soybean crop (Expt.3)

was not sown until 18th April 1980. Thus, during the interval between the last irrigation for the soybean crop of Expt.2, which was given in February 1980 and the sprout irrigation given to the soybean crop of Expt.3 on 18th April 1980, the soil was not wetted. During this interval (26th February to 14th April 1980), a total quantity of only 28.2 mm of rainfall was received in 4 rainy days, while the pan evaporation during this period amounted to as much as 49.2 mm (Appendix 3 and Fig.11). Under these conditions of evaporation exceeding very much the precipitation, with no irrigation to supplement the soil moisture, the residual soil moisture must have been depleted at a very fast rate by the large bamboo clumps with their extensive root systems, which soon led to a relatively drier soil within the bamboo stand as compared to the open. With no soil moisture for evaporation, the relative humidity within the bamboo stand fell to values lower than that for open field.

#### 4.4.3 Overall conclusions about microclimate.

The bamboo stand ameliorates both the air temperature (by reducing it) and the relative humidity (by increasing it) thereby reducing the heat load on an associated annual intercrop and reducing evaporational loss of soil moisture, both of which will benefit an associated annual intercrop. On the other hand the bamboo stand deleteriously influences the annual intercrop through reducing the light intensity available for photosynthesis and through root competition.

#### 4.5 SOIL MOISTURE

(Table 34)

The significant fact that strikes the eye when the data on the fluctuations in the soil moisture status of the two environments is examined, is that the soil moisture content was thought <sup>to</sup> be higher within the bamboo stand as compared to the open, excepting on three occasions (Table 34).

Reckoning the soil moisture in the open field as the standard, it is seen that the increase within the bamboo stand ranged from 9.7% at 47 DAS to 30.1% at 26 DAS, for Expt.1, the range thus being 20.4%. Expt.1 was conducted during the months of August to mid-November, 1979. During this period, there was one occasion (68 DAS, i.e., 25th October 1979) when the pattern was inverted, and the bamboo stand recorded a lower moisture content, the depression being - 15.4%.

As regards Expt.2, the increased soil moisture within the bamboo stand as compared to the open, ranged from as low as 31.0% to as much as 162.9%, the range thus being 131.9%. Expt.2 was conducted during the months of December 1979 to early March 1980. In this case also, there were two occasions, when the bamboo stand recorded lower soil moisture contents as compared to the open field, in the first instance (76 DAS, i.e., 21st February 1980) to the tune of - 15.1%, and in the second instance (83 DAS, i.e., 28th February 1980) to a still greater extent, viz., -32.3%.

Table 34 Weekly Soil Moisture fluctuations under two Environments

E<sub>1</sub> = Within the bamboo stand; E<sub>2</sub> = In the open field

Experiment	Stage of sampling		Soil moisture (%) under		Difference as a % over E <sub>2</sub>
	w.r.t. the soybean crop	Date	E <sub>1</sub>	E <sub>2</sub>	
Expt.1	12 DAS	30 Aug 1979	12.48	9.96	25.7
	19 DAS	6 Sep 79	13.08	10.23	27.8
	26 "	13 Sep 79	18.65	14.41	30.1
	33 "	20 Sep 79	17.70	15.74	12.4
	40 "	27 Sep 79	12.51	10.53	18.8
	47 "	4 Oct 79	8.03	7.32	9.7
	54 "	11 Oct 79	21.63	19.36	11.7
	68 "	25 Oct 79	18.63	18.67	(-)15.4
	76 "	2 Nov 79	15.60	13.42	16.2
	83 "	9 Nov 79	20.66	18.45	12.1
fallow	31 "	17 Nov 79	23.20	19.73	17.6
	6 DAS	30 Nov 79	19.08	19.01	0.4
	1 DAS	6 Dec 79	16.09	13.40	20.0
	6 DAS	13 Dec 79	21.86	16.69	31.0
	14 "	21 Dec 79	21.75	16.21	34.2
	20 "	27 Dec 79	18.85	12.31	36.9
	27 "	3 Jan 1980	22.06	12.77	72.7
	30 "	6 Jan 80	12.39	6.61	87.4
	36 "	12 Jan 80	17.67	6.72	162.9
	46 "	24 Jan 80	8.35	3.65	128.8
Expt.2	55 "	31 Jan 80	22.10	13.75	60.7
	62 "	7 Feb 80	14.32	10.42	37.4
	69 "	14 Feb 80	21.46	9.59	123.8
	76 "	21 Feb 80	12.89	15.19	(-)15.1
	83 "	28 Feb 80	7.93	10.39	(-)32.3
	fallow	1 DAS	7 Mar 80	7.23	6.74

The higher soil moisture noticed within the bamboo stand was the direct consequence of reduced evapotranspiration due to the shading effect of the bamboo canopy and the wind-break effect. Aase and Siddoway (1976) had shown that wind-breaks of tall wheat grass (Agropyron elongatum) reduce evaporation from the soil surface.

Yadav et al. (1963) studied the pattern of changes in the soil moisture contents at 4 different depths (0-1', 1'-2', 2'-3', and 3'-4') within a 16-year old stand of Dendrocalamus strictus, spaced 12' x 12', and compared it with an adjacent grass plot. This study is comparable with the present investigation in certain aspects - the 'grass plot' would correspond to the 'open field', the 0-1' depth roughly corresponds to the 0-15 cm soil depth of sampling of the present investigation, the species of the bamboo used is the same and the spacing between the clumps are almost same. However, the ages of the bamboo clumps differ very much and while in the study of Yadav et al. (1963) the bamboo stand was entirely rainfed, in the present investigation, the bamboo clumps received the benefit of weekly irrigations made to the soybean intercrop. Above all, in the former study there was no intercrop to complicate interpretations. Yadav et al. (1963) also reported that the soil moisture content was generally of a higher order under bamboo than under grass due largely to less evaporational losses and higher water ret lining power of the soil under the former.

The instances where the soil moisture content of the bamboo stand were lower than that of the open field may now be examined. In Expt.1, when the soybean crop was 68 DAS old (i.e., on 25th October 1979) the bamboo stand recorded 15.4% less moisture than the open field. An examination of the weather data (Appendix 3 and Fig.11) reveals that during the period 22nd-28th October 1979, a total rainfall of 88.3 mm was received in 4 rainy days. While this represented the highest ever received upto that stage of soybean growth, and thus sufficiently soaked up the soil in the open field (with only the soybean cover), it was not high enough to penetrate the bamboo canopy sufficiently as to add a similar quantity of water through drip. Bulk of the rainfall was intercepted by the bamboo canopy. Hence the soil within the bamboo stand while being wet was not as wet as in the open field, which explains the anomaly. Subsequently (12th-18th November 1979) when a very heavy rainfall of 263.6 mm was received in 5 rainy days, the rainfall was far in excess of the infiltration rate for the soil and the run off loss was high, while the bamboo canopy moderated this and prolonged (through leaf drip) the period of addition of rain water such that the soil moisture content within the bamboo stand was once again higher than that for the open field.

In Expt.2, the two consecutive occasions when the soil moisture within the bamboo stand was less than that for the open field, occurred during the last phase of crop growth of

the soybean crop (76 - 83 DAS), when irrigations had been cut out. These two periods of sampling, viz., 21st February and 28th February 1980, corresponded with the rainless period of the year (Appendix 3). With no irrigation to supplement the soil moisture, and the weather being dry, the root competition for soil moisture from the bamboo clump must have been so intense that <sup>the</sup> soil moisture reserve was quickly depleted within the bamboo stand such that it recorded a lower soil moisture as compared to the open field.

The differences during the fallow periods were relatively not much and hence lend support to the inferences drawn above. however, it must be pointed out that further work is indicated for resolving the complex inter-relations between weather, the sheltering effect of the bamboo canopy, root competition for soil moisture between bamboo and an associated intercrop, and above all the effect of super-imposition of irrigation.

As regards absolute moisture contents, it ranged from 8.03% to 23.20% for the bamboo stand and from 7.32% to 19.73% for the open field, during Expt.1. In this experiment, the times of occurrence of the lowest soil moisture content (4th October 1979) and the highest soil moisture content (17th November 1979) were the same for both the environments.

During Expt.2 the soil moisture contents ranged from 7.03% (on 28th February 1980) to 22.10% (on 31st January 1980) for the bamboo stand and from 3.65% (on 24th January 1980) to 16.69% (on 13th December 1979) for the open field. Thus, unlike

in Expt.1, the times of occurrence of the lowest as well as the highest soil moisture contents were not coincidental in Expt.2. The reason for this was that while Expt.1 was conducted during the wet season, Expt.2 was conducted during the cool dry season, so that a time lag developed between the two environments as far as soil moisture charging and depletion are concerned, due to the presence of the bamboo canopy chiefly and the consequent difference introduced. Yadav et al. (1963) observed a similar phenomenon in their study which was conducted under entirely rainfed conditions. They found that while the minimum soil moisture values were reached simultaneously or a little later in the grass plot as compared to the bamboo stand in 0-1' soil layer, they were recorded much earlier in the deeper layers of soil under grass plot. The time lag observed in the present investigation may be due to a thermal lag within the bamboo stand caused by an inertia of the air mass within the bamboo stand to respond quickly to temperature changes in the atmosphere.

Comparing the two experiments (Expt.1 and Expt.2) it is seen that the soil moisture differences between the two environments were more pronounced in Expt.2 than in Expt.1. The reason for this is that while Expt.1 was conducted during the wettest part of the year, Expt.2 was run during the dry, though cool season. It is obvious the heavy rainfall during Expt.1 marked the protective mulch effect of the bamboo stand and thus reduced the differences between the two environments.

It may therefore be concluded that from the point of soil moisture conservation, under irrigated conditions, the bamboo stand is superior to the open field, acting similar to a mulch, by reducing evapotranspirational losses. This advantage may be useful in reducing the irrigation water demand, and possibly also in increasing the water use efficiency (WUE) as reported by Radke and Burrows (1970) for sheltered soybean.

#### 4.6 WEED INFESTATION

(Table 35, 35(a) and 36)

Though hoeing and weeding was carried out once, when the soybean crop was young, subsequently the weeds were not removed, in the case of Expt.3, so as to observe the pattern of weed infestation, as judged after the harvest of the soybean.

From Table 35 it is seen certain clear-cut differences emerge between the two environments. Firstly, the weed population was substantially lower within the bamboo stand (mean incidence of 24.4 weed plants/m<sup>2</sup>) as compared to the open field (mean incidence of 34.3 weed plants/m<sup>2</sup>). Secondly, while monocot weeds were very abundant in the open field (48.64% incidence) as compared with the bamboo stand, (14.05% incidence), the reverse was the case with the bamboo stand, where dicot weeds dominated (85.95% incidence) as compared to the open field (51.36% incidence). Thirdly, there were differences in the floristic compositions of the weed populations, between the two environments. Thus, while certain species like Corchorus olitorius and Euphorbia hirta were very abundant and more or

Table 35 Species-wise distribution of weed flora occurring in two environments  
Expt. 2

WEEDS

S.No.	Weed species	Natural order	Within the bamboo strand (E <sub>1</sub> )		In the open field (E <sub>2</sub> )	
			Number/ sq.m	% of total	Number/ sq.m	% of total
DICOTS						
1	<i>Acalypha</i> sp.	Euphorbiaceae	26	3.58	18	1.75
2	<i>Acanthospermum hispidum</i>	Compositae	2	0.28	-	0.00
3	<i>Amaranthus diandrus</i>	Amaranthaceae	-	0.00	2	0.19
4	<i>Amaranthus</i> sp.	-do-	34	4.68	12	1.17
5	<i>Alysicarpus rugosus</i>	Papilionaceae	2	0.28	2	0.19
6	<i>Boerhavia diffusa</i>	Myctaginaceae	12	1.65	18	1.75
7	<i>Corchorus olitorius</i>	Tiliaceae	98	13.50	140	13.62
8	<i>Corchorus</i> sp.	-do-	14	1.93	6	0.58
9	<i>Euphorbia hirta</i>	Euphorbiaceae	92	12.67	98	9.53
10	<i>Evolvulus alsinoides</i>	Corvolvulaceae	8	1.10	2	0.19
11	<i>Indigofera</i> sp.	Papilionaceae	14	1.93	18	1.75
12	<i>Lagaceae mollis</i>	Compositae	48	6.61	18	1.75
13	<i>Lantana camara</i>	Verbenaceae	2	0.28	-	0.00
14	<i>Leucas aspera</i>	Labiatae	26	3.58	2	0.19
15	<i>Oldenlandia aspera</i>	Rubiaceae	30	4.13	8	0.78
16	<i>Oldenlandia stylosa</i>	-do-	-	0.00	6	0.58
17	<i>Parthenium hysterophorus</i>	Compositae	-	0.00	4	0.39
18	<i>Phyllanthus madraspatensis</i>	Euphorbiaceae	46	6.34	68	6.61
19	<i>Phyllanthus nerurii</i>	-do-	4	0.55	-	0.00

Contd.

Table 25 (Contd.) Species-wise distribution of weed flora occurring in two environments WEEDS  
Expt. 2

S.No.	Weed species	Natural order	Within the bamboo stand (F <sub>1</sub> )		In the open field (F <sub>2</sub> )	
			Number/ sq.m	% of total	Number/ sq.m	% of total
20	<i>Friva leptostachya</i>	Verbenaceae	6	0.82	2	0.19
21	<i>Rhynchosia minima</i>	Labiataceae	14	1.93	4	0.35
22	<i>Sida cordifolia</i>	Malvaceae	12	1.65	10	0.97
23	<i>Trianthema portulacastrum</i>	Aizoaceae	2	0.28	2	0.19
24	<i>Tridax procumbens</i>	Compositae	88	12.12	74	7.20
25	<i>Vernonia cinera</i>	-do-	32	4.41	4	0.39
26	<i>Vicoa indica</i>	-do-	12	1.65	10	0.97
Sub-total for dicots			624	85.95	528	51.36
MONOCOTS						
1	<i>Chloris barbata</i>	Graminae	44	6.06	116	11.28
2	<i>Commelina</i> sp.	Commelinaceae	38	5.23	-	0.00
3	<i>Dactyloctenium aegyptium</i>	Urticinae	16	2.20	364	35.41
4	<i>Panicum</i> sp.	-do-	4	0.55	20	1.95
Sub-total for monocots			102	14.05	500	48.64
Grand Total for 30 sq.m. area			726	100.00	1,028	100.00
Mean incidence of weeds/sq.m.			24.2		34.3	

Table 35(a) Natural-order wise distribution of Weed flora WEEDS  
in two environments  
Expt.3

S.No.	Natural order	Within the bamboo stand (E <sub>1</sub> )		In the open field (E <sub>2</sub> )	
		Number	% of total	Number	% of total
<u>DICOTS</u>					
1	Aizoaceae	2	0.28	2	0.19
2	Amaranthaceae	34	4.68	14	1.36
3	Compositae	182	25.07	116	10.70
4	Convolvulaceae	8	1.10	2	0.19
5	Euphorbiaceae	168	23.14	184	17.90
6	Labiataeae	26	3.58	2	0.19
7	Malvaceae	12	1.65	10	0.97
8	Nyctaginaceae	12	1.65	18	1.75
9	Papilionaceae	30	4.13	24	2.33
10	Rubiaceae	30	4.13	14	1.36
11	Tiliaceae	112	15.43	146	14.20
12	Verbenaceae	8	1.10	2	0.19
<u>MONOCOTS</u>					
1	Commelinaceae	38	5.23	-	0.00
2	Craminae	64	8.81	500	48.64
Total		725	100.00	1,028	100.00

## WEEDS

Table 36 Biomass (fresh weight) of weeds under two environments  
 Expt. 3 at harvest of soybean crop (kg/ha)

F levels	within the bamboo stand (E <sub>1</sub> )		In the open	Mean
	Vigour of bamboo clump (V)		field	
	L	H	(E <sub>2</sub> )	
P <sub>0</sub>	107.5	122.5	536.2	255.4
P <sub>1</sub>	150.0	72.5	460.0	227.5
P <sub>2</sub>	270.0	85.0	493.7	282.9
Mean	175.8	93.3		
Overall Mean		134.6	496.7	

less similar in incidence under both environments, species like Amaranthus sp., L. asca mollis, Leucas aspera, Rhynchosia minima, etc., were more abundant within the bamboo stand than in the open, the maximum difference being seen in the case of Leucas aspera which recorded a 19-fold increase within the bamboo stand.

That the weed population within the bamboo stand is lesser could be expected, since it was seen that the intercrop of soybean, particularly in Expt.3, was deleteriously influenced by the bamboo shade and root competition. It stands to reason that the weed plants also must have been similarly affected. Taking the mean weed incidence for the open field ( $34.3/m^2$ ) as the standard, it is seen that there was a reduction in weed population within the bamboo stand, to the tune of 30%. This bears a very close resemblance to the reduction in soybean population, where it was 22% (Table 25) at the end of Expt.3. The weed population having suffered wanton removal once (i.e., hoeing and weeding) unlike the soybean, can naturally be expected to show a population reduction higher (30%) than that for soybean (22%).

Viewed from an entirely different angle, the presence of a substantial number of weeds (2,42,000 population/ha) within the bamboo stand is indicative of the fact that inspite of the adverse conditions for plant growth within the bamboo stand, still, many annual green plants appear to thrive. This conclusively establishes the feasibility of raising some

economically useful annual crop within a bamboo stand of similar age (upto about 5 years), the only lacuna being the identification of the ideal crop species which will effectively compete with the bamboo roots, adapt itself to the reduced light conditions, and thrive to maturity. Though soybean perhaps may not be the ideal intercrop within a bamboo stand, there may exist other crops adapted to the conditions prevailing within the bamboo stand.

The predominance of dicot weeds within the bamboo stand suggests a superior adaptation on their part. It is known that there are distinct differences between monocot and dicot plants in so far as sorption of mineral nutrients is concerned. Thus dicot plants sorb cations much more than anions. As a corollary, in a mixed stand of both monocots and dicots, there may not be competition for the same nutrient element. Thus, bamboo being a monocot must differ from the dicot weeds in its nutritional preferences, which would explain the predominance of dicot weeds and the suppression if not total exclusion of monocot weeds. This, differential behaviour, incidentally, would simplify choice of weedicides in chemical weed killing because of the disparity between bamboo, a monocot, and the dicot weeds, which is a practical advantage.

If we examine the composition of weeds in terms of the natural orders to which they belong (Table 35(a)) it is seen that it is Euphorbiaceae that dominates both the environments

followed by *Tiliceae*. But *compositae*, while being dominant within the bamboo stand was not so in the open field.

This line of discussion cannot, however, be extended to the monocot weeds, since there are not many natural orders in monocots as compared to dicots, as to effect any meaningful comparison at the natural order level.

While discussing natural orders of the weeds, it is interesting to note that *Papilionaceae*, to which soybean also belongs, accounts for only 4.13% in the bamboo stand and 2.33% in the open field. Perhaps these low percentages are the result of less abundance of <sup>P</sup>~~P~~apilionaceous weeds, as a whole, in the ecological environment of the present investigation. However, the higher percentage of <sup>P</sup>~~P~~apilionaceous weeds seen within the bamboo stand would perhaps suggest their natural adaptation to low light intensities. More particularly, the 11-fold abundance of the Papilionaceous weed *Rhynchosia minima* within the bamboo stand lends support to this line of reasoning.

As regards individual species, as already mentioned some weed species like *Corchorus olitorius* which recorded the highest abundance (about 13.55% of the total weed population) for any one weed species, in this investigation, occurred equally abundantly in both environments. It is very likely that this species is shade tolerant and adapts itself to the reduced light conditions prevailing within the bamboo stand. That such adaptations on the part of one and the same species in

both open and shady habitats exists, has been reported by Grime (1968) as seen in Acer rubrum. In contrast the 19-fold abundance of the Labiateae weed Leucas aspera within the bamboo stand suggests that it is a shade plant rather than a sun-plant.

Table 36 presents data on the biomass of weeds. It is seen that the fresh weights of whole weed plants were 496.7 kg/ha in the open field while it was as low as 134.6 kg/ha within the bamboo stand. This drastic reduction in weed biomass within the bamboo stand to the extent of 73% highlights the adverse conditions prevailing therein. Comparing this with the soybean biomass yields (Table 22) for Expt.3, it is seen that soybean biomass was depressed much more, to the extent of 81%, within the bamboo stand. These reductions within the bamboo stand were caused by the shade effect of the bamboo which must have seriously curtailed the photosynthesis of the weed plants and the root competition from the bamboo clumps. This is further highlighted by the differential behaviour among bamboo clumps themselves. Thus, while the weed biomass was 175.8 kg/ha under 'low vigour' (L) clumps, it was as low as 93.3 kg/ha under the 'high vigour' (H) clumps. On the other hand, P levels did not influence the weed infestation materially.

It may be summed up that, like the intercrop, the weed flora also suffer serious setbacks in growth, within the bamboo stand. This setback manifests itself as reductions in weed population and weed biomass. Such a setback while focussing attention on the adverse conditions for green plant growth within the bamboo stand, is a welcome feature in so far as

weed suppression is concerned. Some species of weeds thrive equally well in both environments while yet others thrive better within the bamboo stand which points to their shade adaptation. Between monocot and dicot weeds, the latter preponderate within the bamboo stand, which may be taken advantage of in chemical weed control in sole crop bamboo plantations since bamboos are monocots and thus selectivity is ensured.

#### 4.7 ECONOMICS OF INTERCROPPING BAMBOO STANDS AND ASPECTS OF PRACTICAL MANAGEMENT

In evaluating the cost: benefit ratio of raising annual intercrops between woody perennial crops, like bamboos, certain constraints as listed below, need consideration.

1. The woody perennial crop which is the base crop, is of relatively very long duration and its yield is realisable only terminally at the end of several years after planting. However, in the case of bamboos the wood yield is repetitively realisable, usually once in three years. Still, even in bamboos it takes more than a decade before the felling cycle yields stabilize. Hence, judging bamboo culm yields based on a young crop of about 6 years will not be realistic but only indicative.
2. Further, the culms harvested from a young crop will be smaller in size to that obtained from full-grown and yield-stabilized clumps and hence will fetch very low prices in the market.

3. During the first 5 to 6 years of establishment of a sole crop of bamboo, no return is realisable. On the other hand expenditure is involved in establishing the crop.
4. The costs of establishing bamboo plantations have been estimated by several forest officials. Unfortunately these estimates are not directly applicable to farm situations because,
  - i) the estimates pertain to large-scale plantations of several hundreds of hectares with attendant economies of scale;
  - ii) they pertain to Government-owned lands and hence include charges for supervision, protection, and interest on capital etc.,
  - iii) they pertain to forest situations where certain unavoidable expenditures like scaring away of wild life, cost of transport over long leads and difficult terrain etc., arise, which are absent under farm situations; on the other hand, the plantation once established is invariably rainfed and practically unweeded which in turn reduce the cost of maintenance of the crop., and
  - iv) they usually assume pro-rata costs for exploitation, the harvesting being usually carried out by contractors supplying paper mills.

5. Regarding costs of cultivation of intercrops between tree crops also, practically no published information is available as of date since this agroforestry practice is yet to gain momentum as many of the problems of such a system remain unsolved. Even if the cost of cultivation under kumri cultivation conditions for annual intercrops raised between young trees are gathered through any survey, they can at best be only indicative for the following reasons -

- i) the kumridhar uses only family labour since he lives inside the forest;
- ii) the forest soil is more fertile, being richer in humus, and hence cannot be compared with the farm soil;
- iii) all operations are manually carried out since no bullock power is available within the forest;
- iv) maintenance of soil fertility and sustained levels of production of annual crop yields are not faced by the Kumridhar, who is only a shifting cultivator;
- v) Commonly no fertilizers or agrochemicals are applied by him and hence the costs are reduced;
- vi) institutional finance is not needed by him, for he produces the crops generally for his own consumption rather than for the distant market;

vii) part of the cost of raising the base crop (seedling production and transport to site) as well as maintenance of established tree crop are borne by the forest departments; and

viii) his annual crops are generally rainfed, the forest climate being vastly different from that of the plains.

6. Even during the initial phases of growth of the base crop, when 'establishment intercropping' is practicable, bullock or mechanical power may not be usable unless the spacing between the tree crop is very wide; hence manual labour costs will be increased as compared sole crops of the annual crops concerned.

#### 4.7.1 Cost estimates by earlier workers:

With these constraints regarding arriving at an accurate estimate of costs of cultivation in mind, the situation may now be examined. Andiyappan and Wilson (1963) reported that the cost of raising a bamboo plantation in Tamil Nadu, even on a large scale, will be not less than Rs.500 per hectare, under reserved forest conditions. Neelay (1972) estimated the cost of establishment of bamboos under Madhya Pradesh reserved forest conditions at Rs.243.90 and 349.50 per hectare for 6.0 x 6.0 m and 4.5 x 4.5 spacings respectively, for the first year alone; subsequent maintenance costs were Rs.100 and Rs.200 per hectare for the above two spacings, and for the second and third years.

Venkatakrishnan (1972) who studied departmental exploitation of bamboo plantations in certain reserved forests of Tamil Nadu, reported that the cost of raising a bamboo plantation and maintaining it upto 10 years (1960-1970) worked out to only Rs.1,844 for 16.6 hectares, which is Rs.111 per hectare. On the other hand, the expenditure incurred on extraction, conversion (i.e., cleaning and trimming to size) and transport of the culms to the nearest depot was Rs.15,620.50, which works out Rs.941 per hectare, while the total revenue realised by sale of the extracted bamboos was Rs.34,670, which works out to Rs.2,089 per hectare. Thus, based on the total expenditure of Rs.1,052 per hectare, the cost:benefit ratio works out to 1.99.

The experience gained in establishing commercial plantations of bamboos by the West Coast Paper Mills Ltd., at Dandell (Karnataka State) has been reported by Chaudhari (1966). He has furnished the cost of raising plantations of Bambusa arundinacea bamboo; this cost does not include cost of raising the seedlings since they were obtained from naturally regenerated seedlings. However, costs of fertilizers, their application and manual weeding are included, though certain costs like supervision, fire protection, inspection roads, and watch and ward are also included, which do not normally arise under farm situations. He reported per hectare (converted from the per acre figures) expenditures of Rs.247, Rs.74, Rs.12.35, and

Rs.99 for the 1st, 2nd, 3rd and 6th years of establishment respectively, no expenditure being incurred during the 4th and 5th years. The total expenditure thus worked out to Rs.432.35 per hectare.

Siva Prasad (1980) from Andhra Pradesh, reported that Dendrocalamus strictus plantations with clump spacings of 5 X 6 m having a stocking of around 140 clumps/acre (346 clumps/ha) will come for first felling on the 7th year when 20 culms/clump (i.e., 2,800 culms/acre) will be ready for extraction, out of which only 2000 culms will be exploitable to maintain the life cycle. He assumed a rate of Rs.2/culm for the 7th year felling and thus calculated that a total return of Rs.4,000/acre (i.e., Rs.9,880/ha) will result, while, according to him the cost of developing and maintaining such a plantation will not exceed Rs.500/acre (i.e., Rs.1235/ha). And, in another 2 years, the same plantation will yield another Rs.5000-6000 (i.e., Rs.12,350 - Rs.14,820/ha). He also stated that intercropping of dry land vegetable, pulse or coarse grain crops with the bamboo, is also possible upto 3 to 4 years.

Nathan (1980) countered these estimates and based on the experience of cultivation of Dendrocalamus strictus on the alluvial soils of the Thanjavur delta (Tamil Nadu State) under farm situations, stated that the culms attain their maximum size only by about the 12th-15th year after planting after which it stabilizes. Thus, though the first felling can be done after

7 years, fair-sized culms can be had by the 12th year only. He further stated that even if 140 clumps are planted to an acre, through a process of natural selection, only 40 clumps/acre (i.e., 99 culms/ha) will survive 10 years after planting. He recommended that it is better to limit the clump size to about 40-50 culms/clump and stated that every year new culms will be added at the rate of 1/4th of the clump size, while every alternate year 1/3rd of the culms can be cut away. He reported that the then (1980) prevailing market rate for a culm of 40' (i.e., 12.2 m) length and 5" (i.e., 127 mm) diameter, was Rs.10, and added that Rs.4,000/acre (Rs.9,860/ha) can be realised every alternate year.

A survey conducted by the staff of the Department of Forestry of the Tamil Nadu Agricultural University, Coimbatore (Anonymous, 1975) in the Thanjavur district (Tamil Nadu State) showed that the revenue realisable by sale of the harvested culms (1975 figures) ranged from Rs.34,580/ha for 5-year old clumps (at an average of 40 culms/clump out of which 50% are felled, and at 432 clumps/ha) at the time of the first harvest, to Rs.29,640/ha, after the yield had stabilized, for 20-year old clumps. Seshadri *et al.* (1977b), based on the experience of raising bamboos under farm conditions and under scientific methods of management, furnished a detailed package of practices for bamboo cultivation. They stated that an yield of 2,500 culms/ha can be expected from middle-aged clumps, and that each culm will fetch Rs.3-5 in the retail market.

From the foregoing discussion it is seen that the cost of establishment of bamboo stands and their maintenance upto the first felling, as reported by different workers, varies from Rs.111 - 500/ha under reserved forest conditions and about Rs.432 for commercial plantations. Nathan (1980) reported that the annual expenditure on intercultivation, trashing, fencing and some propping and culling is fully met by the price obtained for the bamboo 'thorns' (i.e., the branches) that are trashed and sold, under farm situations.

It may therefore be safely assumed that under farm conditions and at present day (1985) costs, the cost of establishment and maintenance of a stand of Dendrocalamus strictus bamboo, upto the 6th year would work out to about Rs.750 per hectare. In addition, the cost of felling, cleaning and transporting of culms from 6 year old bamboo clumps could be safely assumed at Rs.1000 per hectare. Similarly, the culms as harvested at the end of the 6th year, being small, could be assumed to fetch only Rs.6/culm, which is a conservative estimate. Taking the average yield of 8,255 culms/ha, which is based on the data from actual harvests made in the present investigation (discussed under section 4.2.8), the revenue realisable by sale of harvested culms works out to Rs.49,530/ha at the time of the first harvest (i.e., 6 years after planting).

Regarding the soybean crop used in the present investigation, the cultural details were identical both for the sole

crop grown in the open field as well as for the intercrop grown within the bamboo stand. Hence, the costs of cultivation were the same. Any difference in labour costs on weeding that could have arisen due to the reduced soybean population within the bamboo stand was offset by the increased difficulty of moving about within the stand, such that weeding costs were the same. The cost of cultivation of sole crop of soybean raised under irrigation, works out to about Rs.750/hectare, at the present time (1985) costs.

#### 4.7.2. Economics of intercropping in bamboo

Based on the above figures for bamboo and soybean, and restricting the yields of both the bamboo and soybean to the actual figures observed in the present investigation, the following balance sheet is worked out.

##### (a) Economics of cultivating a sole crop of soybean over 1 hectare and over a 6-year period

(vide Table 26)

i) Cost of cultivation for 18		
crops, at the rate of 3 crops/		
year $\times$ 6 years $\times$ Rs.750 per hectare		Rs.13,500
ii) Yield of grain/year		
1st crop	= 201 kg	
2nd crop	= 1,072 kg	
3rd crop	= 1,401 kg	
Total	= <u>2,674 kg</u>	

iii) Total return by sale of grain at the rate of 2,674 kg/year X 6 years X Rs.3/kg		Rs.48,132
iv) Net profit for 6 years	=	Rs.34,632
v) Cost: Benefit ratio	=	3.56

(b) Economics of cultivating a base crop of bamboo, inter-cropped with soybean, over 1 hectare and over a 6 year period.

1. Base crop - Bamboo

i) Cost of cultivation of bamboo up to the 6th year		Rs. 750
ii) Cost of harvesting culms at the end of the 6th year		Rs. 1,000

2. Intercrop - Soybean

iii) Cost of cultivation for 18 crops, at Rs.750 per crop per hectare		Rs.13,500
iv) Total expenditure for 6 years		Rs.15,250

3. Returns

v) Total return from bamboo by sale of 8,255 culms (Table 33) at Rs.6/culm, at the end of 6 years		Rs.49,530
vi) Yield of grain of soybean/year (Table 26)		
1st crop	=	249 kg
2nd crop	=	177 kg
3rd crop	=	190 kg
Total	=	616 kg

vii) Total return by sale of grain at the rate of 616 kg/year X 6 years X Rs.3/kg	Rs.11,088
viii) Grand total return	= Rs.60,618
ix) Net profit for 6 years	Rs.45,368
x) Cost: benefit ratio	= 3.97

(c) Comparison of systems (a) and (b)

	<u>Net profit for 6 years</u>
i) Intercropping system of bamboo + soybean	Rs.45,368
ii) Sole crop system of only soybean	<u>Rs.34,632</u>
Difference in profit over a 6-year period	= <u>Rs.10,736</u>

Therefore,

Average annual difference = Rs.1,789/ha

It is evident from the above calculations that the intercropping system is more profitable (11.5% higher cost: benefit ratio) than raising a sole crop of either soybean or bamboo, as judged over a 6-year period. For periods less than this, the returns from the intercropping system will obviously be lower than those from sole crop soybean. Undoubtedly, the return from the soybean component in the intercropping system will be very poor as compared to that from a sole crop soybean, due to severe yield reduction. But the average extra income of Rs.1,789/ha/year derivable from the intercropping system more than offset this disadvantage.

#### 4.7.3 Validity of assumptions and alternative balance sheets

In the foregoing calculations certain assumptions, as regards rates have been made though actually observed yields have been used. While cultivation costs, for both bamboo and soybean, have been estimated rather accurately and the prevailing market rate for soybean grain has been used, the sale price for the produce from the base crop (i.e., Rs.6/culm) assumed is a very conservative estimate. In the retail markets, the price for a well-sized culm ranges from Rs.15-20. These prices are, of course for bamboo used as timber. However, when bamboo culms are sold as pulpwood raw material to paper mills, the price offered will be very low. Taking the average yield of culms of 7.677 tonnes/ha (as discussed under section 4.2.12) and the current (1985) price of Rs.350/tonne of bamboo offered by the paper mills in the State (their actual buying rate from the government forests being much lower than this), the total return from bamboo, if sold on a weight basis, will work out to only Rs.2,687/ha at the end of the 6th year of planting. Even though, this level of return would still give a profit, since the cost of cultivation of bamboo is just Rs.1,750/ha over a 6-year period, it cannot compete with the profit realisable through sale of bamboo culms as timber.

Another assumption made is the uniform rate of annual yield of 616 kg grain/hectare for the soybean when grown as

intercrop. This is based on the actual yields secured during the period 5th - 6th year after planting the bamboo, by which time bamboo clumps had grown very much as to seriously curtail soybean yields. It stands to reason that during the earlier years (i.e., upto the 5th year) still higher yields could be expected for the soybean, since the bamboo plants would not have even developed into clumps. Hence, the actual profits from the bamboo + soybean intercropping system will, in practice be much more than shown under section 4.7.2.

Further, the soybean as well as bamboo yields used in these calculations have been secured under conditions of non-application of N and K fertilizers. In actual practice, when these fertilizers also will be applied, the yields are bound to increase further and thus increase the profits.

Moreover, the yield for bamboo in these calculations pertains to that obtainable at the first harvest. Subsequent harvests must yield much more than this yield and thus increase the net profits. Simultaneously soybean yields are bound to decrease further as the shading and root effects of the bamboos increase, and intercropping may become impossible, at the existing spacing of 4 X 4 m between the bamboo clumps. Thus, the need for further research work on optimising the spacing between the bamboo clumps, and canopy manipulation through trimming of the bamboo crowns, such that bamboo yields will not suffer while the yield of the intercrop will be maximised,

is brought out. While such research will be a long drawn-out one spread perhaps over a continuous period of a decade from the time of planting the bamboo, the results secured in the present investigation have brought out the fact that economically profitable intercropping within bamboo stands is a practical proposition.

#### 4.8 ADVANTAGES OF INTERCROPPING IN BAMBOO

Quite apart from the monetary advantage of the bamboo + soybean intercropping system, already discussed under section 4.7, there are certain other advantages also, as shown below.

1. The interspaces between the bamboo clumps are utilised more efficiently. As was indicated under section 4.1.17, the actual ground space occupied by the clumps was estimated to be just about 409 sq.m in a hectare by about 4 1/2 years, which implies that nearly 96% of the land area is locked up in the interspaces, when the clumps are planted at a spacing of 4 X 4 m.
2. The mixing of two entirely different crops on the same land confers the advantage of insurance against risks, particularly weather hazards. Bamboo being a hardy crop and Dendrocalamus strictus in particular being so, return from the land is assured, though after a few years wait, while the annual intercrop earns money during the intervening period.

3. The mixing of two different crops with entirely different end uses - food and wood, offers a sound combination from the marketing point of view, in contrast to the conventional mixtures of annual food crops with other annual food crops.
4. Weed suppression, soil conservation and moisture utilisation will be more effective if intercrops are raised within bamboo stands.

It may therefore be concluded that a system of bamboo + annual intercrop cultivation offers many advantages as compared to sole crops of either bamboo or annual crop.

## Summary and Conclusions

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## CHAPTER 5

### SUMMARY AND CONCLUSIONS

Three field experiments during three different seasons (August - November, December - March, and April - July) were conducted in the fields of the Department of Forestry of the Tamil Nadu Agricultural University campus during 1979 - 80, to explore the feasibility of raising soybean (Glycine max) as an intercrop within a stand of 4-5 year old clumps of 'solid' bamboo (Dendrocalamus strictus Nees) planted at a spacing of 4 m either way. The intercrop was raised under irrigation. A sole crop of soybean was raised in an adjacent open field for comparison. Besides a comparison of the performance of the soybean under these two environments ('within the bamboo stand' and 'in the open field'), the influence of the vigour of the bamboo clumps on, as well as the response to three levels of P application (0, 100 and 200 kg  $P_2O_5$ /ha) by the soybean were also evaluated. Additionally, the growth of the bamboo clumps over a period of 32-months (from age 3 years and 3 months to 5 years and 11 months) as well as their culm yields at the end of this period were evaluated in terms of the effect of the vigour of the clump and response to the aforementioned three levels of P application through data collected on 12 occasions. Besides, data were collected on light intensity, microclimate, soil moisture and weed infestation. The conclusions based on these studies are presented below.

### A. Soybean

1. Plant height was significantly influenced by the environment. Soybean plants growing within the bamboo stand were taller as compared to the open field, and significantly so in many instances.
2. Stem diameter, in general, was thinner in soybean plants growing within the bamboo stand, as compared to those growing in the open field.
3. The number of branches were significantly more in the soybean plants growing in the open field.
4. The number of leaflets/plant was significantly influenced by the environment. While in Experiment 1 the soybean plants growing within the bamboo stand always recorded more number of leaflets, the opposite was true during the subsequent two experiments with the open field-grown soybean plants recording more leaflets.
5. The total leaf area/plant was significantly influenced throughout. Initially (Experiment 1) the soybean plants growing within the bamboo stand had higher leaf areas. But later on (Experiment 3) the open field-grown soybean plants recorded higher leaf areas.
6. Mean leaf area/leaflet was significantly influenced by the environment. Initially (Experiment 1) the soybean plants growing within the bamboo stand had larger leaves, but later on (Experiment 3), those growing in the open field had larger leaves. This was explained in terms of the shade being only

partial initially and thus optimising the light intensity, and the shade deepening subsequently.

7. The length of the taproot was initially (Experiment 1) not influenced by any of the three factors studied, but later on (Experiment 2) was influenced by both environment as well as by phosphorus application, and finally (Experiment 3) by only the environment. In general, the soybean plants growing in the open field had longer taproots.

8. The number of root nodules/plant was more in the soybean plants growing within the bamboo stand upto 60 DAS, but subsequently it was the open field-grown plants that recorded more number of nodules.

9. Root: shoot ratio was generally influenced significantly by the environment upto about 70 DAS. Higher root: shoot ratio was recorded by soybean plants growing in the open field, throughout.

10. The number of flowers were consistently more in the plants growing in the open field.

11. The number of pods/plant was significantly influenced by environment. While initially (Experiment 1) the plants growing within the bamboo stand had significantly more number of pods, subsequently (Experiments 2 and 3), it was the plants growing in the open field environment that had more pods.

12. Dry matter production (DMP) was significantly influenced only by environment. Open field-grown soybean recorded more

DM than those growing within the bamboo stand.

13. Biomass yield was influenced significantly only by environment, and that too in Experiments 2 and 3 only. Initially (Experiment 1) the plants growing within the bamboo stand recorded a non-significant increase of 19% more biomass. But subsequently the plants growing in the open field recorded significantly higher biomass (489% in Experiment 2 and 425% in Experiment 3).

14. The number of grains was significantly influenced by environment. Initially (Experiment 1) the soybean plants growing within the bamboo stand had significantly more number of grains than those growing in the open field. But later on, in both Experiments 2 and 3, the open field-grown plants were significantly superior to those growing within the bamboo stand.

15. The 100-grain weight was significantly influenced by the environment. While initially (Experiment 1) the plants growing within the bamboo stand had significantly heavier grains subsequently (Experiment 2) it was the open field-grown soybean that recorded significantly heavier grains.

16. Grain yield/plant (sample plant) was influenced significantly only by environment. Initially (Experiment 1) the soybean plants growing within the bamboo stand registered a significantly higher (44% more) grain yield as compared to those growing in the open field. But later on, the plants

growing in the open field outyielded (by 300% in Experiment 2 and 692% in Experiment 3) those growing within the bamboo stand, and the differences were significant. This pattern of results was the result of the beneficial influence of initial 'partial shade' that prevailed during Experiment 1, which subsequently changed to heavy shading, and which, along with possible root competition, led to the yield reduction observed within the bamboo stand during the subsequent experiments.

17. The number of pods/plant was very highly significantly ( $p=0.001$ ) and positively correlated with grain yield/plant, throughout (in all the three experiments) in the case of the open field-grown soybean plants, and in Experiments 1 and 3 in the case of the soybean plants growing within the bamboo stand. The number of grains/plant also, was very highly significantly ( $p=0.001$ ), positively and closely ( $r=0.96$ ) correlated with grain yield/plant, under both the environments.

18. Multiple regression analysis brought out the disparity in the values of the intercept, which was 18-folds higher for the open field environment as compared to the bamboo stand environment. While in the open field situation leaf area appeared to positively contribute the maximum towards grain yield/plant, it was the weight of the soybean roots, followed by the length of the taproot, and then by the number of leaflets/plant that contributed positively towards grain yield/plant, within the bamboo stand.

19. Neither the vigour of the bamboo clumps nor phosphorus application exerted any significant influence on single sample plant grain yield.
20. The soybean plant population at harvest stage significantly differed between the environments, with the open field environment always recording a higher population than the bamboo environment. While even at the start of the investigations (i.e., at sowing of Experiment 1) the population within the bamboo stand was only 98.4% of that for the open field, due to the ground space occupied by the bamboo clumps, the final (at harvest) populations were 91.3%, 71.7% and 77.6% for Experiments 1, 2 and 3 respectively.
21. The grain yield/ha was significantly influenced only by the environment factor and that <sup>too</sup> only in the later two experiments. While initially (Experiment 1) the soybean intercrop raised within the bamboo stand outyielded by 24% the sole crop grown in the open field, the difference not being significant, in the two subsequent experiments, it was the sole crop that outyielded the intercrop, and very highly significantly ( $p=0.001$ ) so. The sole crop grain yield was 607% and 773% compared to the yield of the intercrop, in Experiments 2 and 3 respectively.
22. The initial (Experiment 1) non-significant yield increase observed, was due to the beneficial influence of 'partial shade' which led to a 44% (significant) increase in single plant grain yield while at the same time reducing the final soybean population only a little (to the tune of 8.7%) as compared to the sole crop.

Subsequent severe reductions in grain yield/ha of the intercrop (to the extent of 83.5% and 87.0% in Experiments 2 and 3 respectively) were the result of heavier shading coupled with possible increasing root competition offered by the bamboo clumps.

23. The grain yields were 249,177 and 190 kg/ha for the intercrop grown within the bamboo stand, and 201, 1072 and 1471 kg/ha for the sole crop grown in the open field, in Experiments 1, 2 and 3 respectively.

24. Eventhough the vigour of the bamboo clump did not exercise any significant influence on the grain yield of the associated intercrop or soybean, a trend of the grain yield being slightly higher under the 'low vigour' bamboo clumps was noticeable.

25. Phosphorus application also failed to evoke any significant response, either within the bamboo stand or in the open field or even in terms of its overall effect pooling both the environments. However, based on the trends it appears that an application level of 100 kg  $F_2O_5$ /ha appears to be the optimum dose for a sole crop of soybean grown in the open field. Similarly, a trend favouring the application of 200 kg  $F_2O_5$ /ha for soybean grown as an intercrop between bamboos, was noticeable, which indicates that the deleterious influence exerted by the bamboo clumps on the associated intercrop of soybean

could be mitigated, atleast partially, through phosphorus fertilization at higher levels.

26. Based on all the foregoing results, it was concluded that it is agronomically possible to practice "establishment intercropping". Within a young stand of Dendrocalamus strictus bamboo, and raise a successful intercrop of soybean, when the bamboo clumps are spaced 4 x 4 m, and upto the age of about 4 1/4 years for the bamboo, provided the bamboo canopy has not closed completely but casts only partial shade. Summing up, the study demonstrates the feasibility of intercropping of annual crop within a bamboo stand.

27. Serious yield depression in soybean will result if intercropping of soybean is attempted inside a more older bamboo stand.

28. If intercropping of soybean, and possibly also other annual crops, is aimed at within still older stands of bamboo, it is evident that the bamboo canopy has to be suitably manipulated (through crown trimming) to open it up so as to increase the light intensity reaching the ground, besides partial pruning of the bamboo roots through judicious digging of the soil. Under such conditions, it may then be possible to practise intercropping within a bamboo stand beyond even 4 1/4 years of age, perhaps upto about 9 years of age.

However, the information collected in the present investigation does not permit of any forecast as regards the immediate

and long range consequences on the yield of bamboo culms by such manipulations. This needs further study.

29. While vigorously growing bamboo clumps adversely affect an associated soybean crop than less vigorous clumps, the former ('high vigour' clumps) are logically to be preferred from the angle of maximizing the yield of bamboo culms. This conflict may perhaps be resolved by increasing the spacing between the bamboo clumps from the 4 X 4 m used in the present investigation to about 6 X 6 m or a still wider spacing, if intercropping is contemplated.

#### E. Bamboo

30. The height of culms was not influenced by either the vigour of the clump or by phosphorus application. The mean height of culms over the period of observation (i.e., about 2 3/4 years) remained constant at an average of 3.23 m.

31. The basal diameters of culms ranged from an average of 18.102 mm (3 1/4 years age) to 26.956 mm (5 3/4 years age). But, while the basal diameter of the culms progressively increased as time passed, at no stage were the differences between the 'high vigour' and 'low vigour' clumps, significant. Phosphorus application also failed to evoke any significant response in the basal diameter of the culm throughout. Similarly, the mid-culm diameter, as measured on culms felled when

clump age was almost 6 years, was not significantly influenced either by the vigour of the clump or by phosphorus application. The average mid-culm diameter was 14.581 mm, i.e., 66% of the basal diameter.

32. The number of nodes/culm ranged from about 21.0 to about 28.1. Neither the vigour of the clump nor phosphorus application exerted any significant influence.

33. The number of primary branches/culm ranged from 21.9 to 61.3. The quantity 'average number of primary branches/node' was computed which ranged from 1.322 to 2.263. The vigour of the clump did not exert any significant influence on the number of primary branches/culm at any stage. Similarly phosphorus application also failed to evoke any response. Clump cleaning through removal of a few branches resulted in increased branchiness.

34. The number of living culms of age 1-year or more/clump, progressively increased from an average of 2.375 (at 3 1/4 years clump age) to 24.417 (at 5 3/4 years clump age) an increase of 1,028%. The data converted into the quantity, 'average number of living culms present/day/clump' brought out the beneficial influences of (a) monsoon rains, (b) clump cleaning, and (c) agronomic manipulations in the interspaces between the bamboo clumps, on new culm production.

35. The increases in new culm production ranged between 0.0291 culms/day/clump (i.e., 10.63 culms/year/clump) to

0.0697 culms/day/clump (i.e., 25.43 culms/year/clump) when the clumps were between the ages of 4 - 5 years. The agronomic manipulations were, digging the soil for sowing the intercrop, soil stirring through hoeing, periodical irrigations, and weeding, besides the raising of the legume intercrop itself which possibly conduced to addition of nitrogen.

36. The vigour of the bamboo clump significantly influenced the economic attribute, the 'number of living culms/clump'. The 'high vigour' clumps recorded significantly more number of living culms, throughout (excepting initially, at 3 1/4 years age), as compared to the 'low vigour' clumps. The difference in the number of culms, which was initially small, increased progressively as time passed, such that when the clumps were about 5 3/4 years of age, the 'high vigour' clumps had 55% more number of living culms as compared to the 'low vigour' clumps. This divergence and disparity was ascribed to the influence of the 'clump size'.

37. Phosphorus application did not significantly affect the number of living culms/clump. It was inferred that application of phosphatic fertilizers alone, without any addition of other primary nutrients (N or K or both) is not advantageous from the point of new culm production.

38. The 'total number of culms/clump' (i.e., all living culms of age 1-year and more + all komalis and 'new recruits', both of which, are living but not fully formed culms and are of age less than 1 year + all cut and removed culms, either because

they died or were malformed), like the number of living culms/<sup>415</sup> clumps, continuously increased from an average of 4.667 culms/clump (at 3 1/4 years clump age) to an average of 27.458 culms/clump (at 5 3/4 years clump age). At 5 3/4 years of age, 32.167 and 22.750 total culms/clump were recorded by the 'high' and 'low' vigour clumps respectively.

39. Vigour of the bamboo clump, though initially did not influence the total number of culms/clump, started to influence it significantly from the time when the clumps were 4-years old. Phosphorus application failed to exert any significant influence on the total number of culms/clump.

40. The 'number of usable culms/clump' that were selectively harvested when the clumps were 6 years old, were 9.500 for the 'low vigour' clumps and 16.917 for the 'high vigour' clumps. The difference was highly significant ( $p = 0.01$ ).

41. At an average of 13.2085 usable culms/clump, and assuming a 100% stocking for the 625 bamboo clumps/ha (at 4 X 4 m spacing), a total yield of 8,255 usable culms/hectare is theoretically possible when the clumps attain the age of about 6 years. Though such culms may not fetch a high price in the market, they being relatively slender (an average mid-culm diameter of 14.6 mm) and shorter (average length of 3.18 m) as compared to the bamboos of commerce, still they are saleable because of the solidity of the culms.

42. The fresh weight of a cleaned culm (i.e., without branches, leaves, and sheaths) ranged from 0.895 kg for the

'high vigour' clumps to 0.965 kg for the 'low vigour' clumps, the average working out to 0.930 kg. The difference, however, was not significant. Phosphorus application did not influence the fresh weight of the culm.

43. The ratio between the fresh weights of the non-culm aerial vegetative parts (i.e., branches + leaves + sheaths) and the culm proper, was 1.067:1. The average fresh weight of the aerial biomass (i.e., culm + branches + leaves + sheaths) was 1.910 kg/culm, and it was estimated that the standing aerial biomass was 29 tonnes/ha when the clumps were about 6 years of age.

44. Culm yields, expressed in terms of weight, for the usable culms selectively felled, were 9.821 kg/clump for the 'low vigour' and 14.746 kg/clump for the 'high vigour' clumps, the average being 12.283 kg/clump. With a population of 625 clumps/ha (at the spacing of 4 X 4 m and assuming 100% stocking) this implies that the total yield of cleaned green culms will be 7.677 tonnes/ha for a Dendrocalamus strictus plantation of 6-years age, raised partly under irrigation, on a brown clay loam soil of pH 6.1 with a rainfall of about 600-700 mm, and under farm conditions of management.

#### C. Environmental aspects

45. During the period of observation (i.e., over about 1 year), the ambient light intensity fluctuated between 21.9 K lux and 167.1 K lux, while within the bamboo stand it ranged

between 17.2 K lux and 120.0 K lux. In general, the light intensity within the bamboo stand was 60-75% of that for the open field. Light intensity within the bamboo stand was high during September and November 1979 since the bamboo clumps were younger then, and since a partial pruning of the bamboo crowns was carried out during August 1979. Under such conditions, the bamboo leaves acted more as reflectors than as screens, leading to an increase in the diffuse light component within the bamboo stand.

46. The relatively very high ambient light intensities observed during the wet month of October 1979 was because of the increased skylight component due to the reflection of sunlight by the huge cloud masses of October, as compared to the dry and cloudless month of May 1980.

47. As regards microclimate, air temperatures within the bamboo stand were generally lower as compared to the open field, the maximum depression being 3.2°C recorded near the ground level (15 cm above) during mid-April 1980. The cooling effect of the bamboo stand was therefore, more pronounced during the hot weather period. It was therefore concluded that this is a positive advantage from the point of raising a low-statured annual intercrop within a bamboo stand, since the heat load on the annual crop is reduced by the bamboo canopy.

48. The relative humidity did not differ much between the

two environments in the morning, but showed wide differences in the afternoon, with the bamboo stand, generally recording a higher humidity than the open field, excepting during March - April 1980 when the reverse was true.

49. The higher relative humidity observed almost throughout the year within the bamboo stand resulted from the shading effect of the bamboo canopy which reduced evaporational losses, and due to the blanketing effect of the culms which reduced advectational losses.

50. Soil moisture content was almost invariably higher within the bamboo stand as compared to the open. This was due to the shading by the bamboo canopy and the windbreak effect of the bamboo culms which reduced evaporational loss of soil moisture. The difference between the bamboo stand and the open field, as regards soil moisture contents ranged from 9.7-30.1% during the wet season, and from 31.0-162.9% during the dry season, the soil moisture within the bamboo stand being almost always higher. Thus, the differences between the two environments were more pronounced during the drier part of the year when the masking influence of rains was absent.

51. Weed infestation was less within the bamboo stand (mean incidence of 24.2 weed plants/m<sup>2</sup>) as compared to the open field (mean incidence of 34.3 weed plants/m<sup>2</sup>). While monocot weeds were very abundant (48.64% incidence) in the open field, dicot weeds dominated (85.95% incidence) within the bamboo

stand. Weeds of the natural orders Euphorbiaceae followed by Tiliaceae, dominated in both environments. But Compositae, while being dominant within the bamboo stand, was not so in the open field.

52. While some species of weeds occurred equally abundantly in both the environments, some others appeared to prefer a particular environment: Thus, while Corchorus olitorius, which recorded the highest abundance (13.55%) for any weed species, occurred equally abundantly in both the environments, the <sup>p</sup>olygonaceous weed Rhynchosia minima was 11-fold more abundant within the bamboo stand, and the Labiateae weed Leucas aspera recorded the maximum difference between the two environments, it being 19-fold more abundant within the bamboo stand.

53. Weed biomass was drastically reduced within the bamboo stand (134.6 kg/ha) as compared to the open field (496.7 kg/ha). Further, among the bamboo clumps themselves, the weed biomass was severely curtailed by the 'high vigour' clumps (93.3 kg/ha) as compared to the 'low vigour' clumps (175.8 kg/ha). The reduction in weed biomass seen within the bamboo stand was the direct consequence of the shade-and root-effects of the bamboo clumps. Phosphorus application did not exert any material influence on weed infestation.

54. Comparing the economics of cultivation of sole crops of soybean over a period of 6 years, and a crop of bamboo inter-cropped with soybean, over the same period of 6 years, it was

seen that an extra profit of Rs.10,736/ha over a period of 6 years (or an average extra profit of Rs.1,789/ha/year) is obtainable. The cost: benefit ratio, computed for the entire period of 6 years, worked out to 3.56 and 3.97 for the sole crop soybean and bamboo + soybean intercropping system respectively. In these estimates, the actual yields of the intercrop of soybean when the bamboo clumps were 4-5 years old, have been used. Since intercrop yield of soybean raised during the still earlier years of the bamboo clumps will be much more than this, the actual monetary benefit from the bamboo + soybean intercropping system during the first 6 years after planting the bamboo will be still higher than the estimated Rs.10,736/ha. Hence it was concluded that the bamboo + soybean intercropping system is more profitable than raising a sole crop of soybean.

55. Besides the monetary advantage, certain other advantages like increased land utilization in bamboo plantations (the inter-spaces between the bamboo clumps accounting for about 96% of the land area), insurance against risks, particularly weather hazards, advantages in marketing through mixing of two crops with entirely different end uses (food and wood), better weed suppression, better soil conservation and better utilization of soil moisture also accrue from intercropping a bamboo stand with annual intercrops.

56. Hence, the raising of an intercrop of soybean between clumps of Dendrocalamus strictus bamboo, upto the first 6 years of planting the bamboo, is an economically viable system and thus may be recommended to the farmers for wider adoption.

#### D. Future lines of research

57. All valuable annual crop species will have to be screened for their compatibility as intercrops between bamboo clumps.

58. The full economics of the first phase the initial 6 years after planting the bamboo clumps must be studied to arrive at an accurate estimate of the monetary benefits. Further, a sole crop of bamboo also may be included, along with a sole crop of the annual crop concerned, besides the bamboo + annual crop intercropping system, in such studies.

59. The influence of different levels and methods of manipulation of the bamboo clumps on the yields of, not only the associated annual intercrop, but also the bamboo clumps themselves, will have to be studied in depth. Such manipulations may involve trying different wider spacings and different planting geometries between the bamboo clumps, thinning/peripheral pruning of the bamboo crowns, different levels of pruning the roots of the bamboo clumps etc. The long-range effects of such manipulations on the bamboo clumps themselves will have to be studied.

60. The beneficial influence of 'partial shade' must be investigated further and the light intensity for different annual intercrops will have to be optimised.
61. The study of the effect of light enrichment through reflectors at the (a) crown level of the bamboo clumps, and (b) ground level, on the annual intercrop yield holds promise.
62. The influence of other fertilizer elements like N and K also will have to be studied on the yields of the bamboo clumps as well as any associated annual intercropping system.
63. The beneficial influence of a bamboo stand on the microclimate and soil moisture in so far as an annual intercrop is concerned, must be investigated in detail, and irrigation scheduling of the bamboo + annual crop system must be precisely restructured. Such studies may be conducted under purely rainfed conditions also, to assess the benefits of the altered microclimate.
64. Similar studies on the other important species of bamboo, viz., Bambusa arundinacea also will have to be initiated.

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# Plates

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Plate 1 Visit of Dr.M.S.Swaminathan, then Director-General, ICAR and Secretary (Agriculture) to the Government of India, and now Director-General, International Rice Research Institute, The Philippines, to the experimental field, on 30th October 1979, when Expt.1 was in progress. The author of the present investigation (to the left) explains the work to Dr.Swaminathan (to the right). The Chairman of the Advisory Committee, Dr.Y.B.Morachan is at the extreme left.



Plate 2 Another view of the above.



Plate 3 Method of recording  
Assman psychrometer readings  
using the pole device devel-  
oped by the author.  
( 'within the bamboo stand'  
environment)

Plate 4 Pre-treatment (cont-  
rolled pruning) being given  
to the bamboo (Dendrocalamus  
crispus) crowns before the  
start of the investigations.





Plate 5 Pre-treated bamboo (Dendrocalamus strictus) clumps, at the start of Expt.1. Note the shade buffer strip at left bottom corner. (soybean intercrop not sown).



Plate 7 A close-up view of the soybean intercrop struggling to grow, very close to a bamboo (Dendrocalamus strictus) clump. Photo taken during the experiment about 5 years of age.



Plate 6 Within the bamboo (*Dendrocalamus strictus*) stand. Start of Expt.2 (sowing of the soybean intercrop, in progress). Note that the bamboo canopy has started closing in.



Plate 8 A general view of the two environments, taken immediately after completion of Expt.3. Note the complete closure of the bamboo (*Dendrocalamus strictus*) canopy ('bamboo stand' is in the background and 'open field' is in the foreground).

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## Appendices

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## APPENDIX 1

## LIGHT INTENSITIES PREVAILING AT NOON IN TWO ENVIRONMENTS

Standard week	Period	Light intensity		
		(in kilo lux) with the bamboo stand (E <sub>1</sub> )	In the open field (E <sub>2</sub> )	E <sub>1</sub> as a percentage over E <sub>2</sub> (%)
<u>1979</u>				
36	Sep 5 -- 9	99.0	114.3	86.6
37	10 --16	91.4	111.9	81.7
38	17 --23	92.9	101.9	91.2
39	24 --30	89.0	117.6	75.7
40	Oct 1 -- 7	120.0	151.8	79.1
41	8 --14	94.3	132.1	71.4
42	15 --21	110.5	167.1	66.1
43	22 --28	54.2	75.8	45.1
44	29 -- 4 Nov	55.0	114.5	48.0
45	Nov 5 --11	27.6	78.1	35.3
46	12 --18	17.2	21.9	78.5
47	19 --25	30.6	57.2	53.5
48	26 -- 2 Dec	46.1	99.7	46.2
49	Dec 3 -- 9	48.2	100.3	48.2
50	10 --16	37.9	61.9	61.2
51	17 --23	46.4	80.3	57.8
52	24 --31	38.7	61.4	63.3
<u>1980</u>				
1	Jan 1 -- 7	50.5	80.0	63.1
2	8 - 14	47.4	75.7	62.6
3	15 --21	43.2	65.0	66.5
4	22 --28	51.4	80.0	64.3
5	29 -- 4 Feb	47.1	70.0	67.3

Appendix 1 (Contd.)

Standard week	Period	Light intensity		E <sub>1</sub> as a percentage over E <sub>2</sub> (%)
		(in kilo lux) With the bamboo stand (E <sub>1</sub> )	In the open field (E <sub>2</sub> )	
6	Feb 5 -- 11	54.3	82.1	66.1
7	12 -- 18	54.2	78.3	69.2
8	19 -- 25	59.5	93.8	63.4
9	26 -- 3 Mar	60.5	91.4	66.2
10	Mar 4 -- 10	66.2	100.0	66.2
11	11 -- 17	63.1	90.5	69.7
12	18 -- 24	66.9	104.3	64.1
13	25 -- 31	62.4	96.4	64.7
14	Apr 1 -- 7	65.9	100.0	65.9
15	8 -- 14	79.5	109.8	72.4
16	15 -- 21	69.8	93.2	74.9
17	22 -- 28	73.1	97.1	75.2
18	29 -- 5 May	74.7	102.1	73.2
19	May 6 -- 12	80.0	115.2	69.4
20	13 -- 19	78.1	112.9	69.2
21	20 -- 26	66.4	97.1	68.4
22	27 -- 2 Jun	37.4	57.9	64.5
23	Jun 3 -- 9	24.8	37.1	66.9
24	10 -- 16	52.7	84.3	62.5
25	17 -- 23	32.1	53.2	60.3
26	24 -- 30	18.9	32.7	57.8
27	Jul 1 -- 7	34.4	64.0	53.8
28	8 -- 14	37.5	68.6	54.7
29	15 -- 21	43.9	76.9	57.1
30	22 -- 28	39.5	67.9	58.1

Appendix 2

MICROCLIMATIC DATA FOR TWO ENVIRONMENTS

1. TEMPERATURE (°C)

(a) at 07.22 hours (X - epoch)

E<sub>1</sub> = Within the bamboo stand; E<sub>2</sub> = In the open field

Stand- ard week	Period	Altitude above ground					
		15 cm		50 cm		250 cm	
		E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>
	<u>1979</u>						
36	Sep 4 - 9	21.1	23.3	23.2	23.3	23.0	23.2
37	10 - 16	23.3	23.2	23.3	23.3	23.0	23.1
38	17 - 23	23.2	23.0	22.9	23.1	22.9	23.1
39	24 - 30	23.4	23.6	23.5	23.6	23.4	23.5
40	Oct 1 - 7	22.9	22.7	22.6	22.7	22.5	22.7
41	8 - 14	23.4	23.4	23.5	23.5	23.3	23.4
42	15 - 21	21.7	21.5	21.2	21.6	21.2	21.9
43	22 - 28	22.6	22.4	22.4	22.5	22.4	22.5
44	29 - 4 Nov	22.7	22.5	22.1	22.6	22.1	22.7
45	Nov 5 - 11	22.5	22.3	22.4	22.3	22.1	22.3
46	12 - 18	22.5	22.2	22.5	22.5	22.4	22.4
47	19 - 25	21.9	21.9	21.7	21.8	21.8	21.7
48	26 - 2 Dec	22.5	22.5	22.5	22.6	22.5	22.4
49	Dec 3 - 9	21.8	21.5	21.5	21.6	21.4	21.6
50	10 - 16	22.2	22.0	22.0	22.1	21.9	21.9
51	17 - 23	21.1	21.0	20.9	21.1	20.8	21.0
52	24 - 31	19.5	18.9	18.9	19.0	18.8	19.0
	<u>1980</u>						
1	Jan 1 - 7	18.5	17.9	18.0	18.0	18.0	18.3
2	8 - 14	17.9	17.3	17.6	17.6	17.6	17.9
3	15 - 21	18.7	18.2	18.5	18.3	18.5	18.3
4	22--28	16.8	15.8	15.9	15.9	16.2	16.3
5	29 - 4 Feb	18.8	18.2	18.5	18.4	18.7	18.9

Appendix 2 (Contd.) 1-a

Stand- ard week	Period	Altitude above ground					
		E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>		
<u>1979</u>							
6	Feb 5 - 11	19.9	19.4	19.5	19.3	19.5	19.6
7	12 - 18	18.2	17.4	17.8	17.7	17.8	17.7
8	19 - 25	18.6	17.2	17.9	17.4	18.0	18.1
9	26 - 3 Mar	20.2	19.2	19.5	19.2	19.8	19.9
10	Mar 4 - 10	21.9	21.7	21.5	22.0	21.5	22.0
11	11 - 17	20.6	20.4	20.2	20.7	20.3	20.6
12	18 - 24	19.1	18.9	19.5	19.1	18.8	19.2
13	25 - 31	22.2	22.3	21.9	22.2	21.8	22.2
14	Apr 1 - 7	25.1	24.9	25.0	25.0	24.7	24.9
15	8 - 14	25.0	24.8	24.6	24.9	24.4	24.8
16	15 - 21	25.1	25.1	24.7	25.1	25.6	25.2
17	22 - 28	24.8	25.0	24.7	25.0	24.6	25.0
18	29 - 5 May	24.4	24.4	24.3	24.5	24.2	24.6
19	May 6 - 12	25.4	25.6	25.0	25.6	25.0	25.7
20	13 - 19	25.0	25.2	24.8	25.4	24.7	25.1
21	20 - 26	24.0	23.8	23.6	23.9	23.6	23.8
22	27 - 2 Jun	23.8	23.9	23.8	23.9	23.7	23.8
23	Jun 3 - 9	23.4	23.5	24.7	23.5	23.2	23.4
24	10 - 16	24.1	24.4	24.2	24.5	24.3	24.5
25	17 - 23	24.2	24.3	24.4	24.4	24.2	24.6
26	24 - 30	24.2	23.7	24.6	24.0	24.0	24.3
27	Jul 1 - 7	24.3	23.9	24.4	24.3	24.5	24.8
28	8 - 14	23.7	23.0	23.1	23.0	22.8	23.5
29	15 - 21	23.3	23.0	23.2	23.1	23.0	23.2
30	22 - 28	24.2	23.9	24.1	24.2	23.8	24.2

Appendix 2 (Contd.)

1. TEMPERATURE (°C)

(b) at 14.22 hours (N - epoch)

$E_1$  = within the bamboo stand;       $E_2$  = In the open field

Stand- ard week	Period	Altitude above ground					
		15 cm		50 cm		250 cm	
		$E_1$	$E_2$	$E_1$	$E_2$	$E_1$	$E_2$
<u>1979</u>							
36	Sep 4 - 9	31.8	30.1	31.7	31.5	30.9	30.9
37	10 - 16	29.9	31.0	30.1	30.6	29.9	30.4
38	17 - 23	28.1	28.8	28.3	28.5	28.3	28.3
39	24 - 30	30.0	30.9	30.0	30.4	29.7	29.7
40	Oct 1 - 7	31.5	32.2	30.1	30.1	31.0	31.2
41	8 - 14	29.9	30.7	29.8	30.7	29.9	30.3
42	15 - 21	30.9	31.4	30.8	31.8	30.7	31.2
43	22 - 28	28.4	28.8	28.5	28.7	28.3	28.3
44	29 - 4 Nov	28.3	29.8	28.7	30.0	28.9	29.7
45	Nov 5 - 11	26.7	26.5	26.9	26.2	26.9	26.0
46	12 - 18	26.1	26.6	26.4	26.5	26.2	26.0
47	19 - 25	26.5	27.8	26.8	27.8	25.7	27.5
48	26 - 2 Dec	26.6	28.0	26.8	27.8	26.5	27.1
49	Dec 3 - 9	28.0	28.7	27.9	28.3	27.8	27.9
50	10 - 16	26.6	28.0	26.7	28.0	26.6	27.7
51	17 - 23	27.8	28.8	27.9	28.8	28.2	28.7
52	24 - 31	26.8	28.1	27.1	28.0	26.9	27.6
<u>1980</u>							
1	Jan 1 - 7	27.0	29.4	27.5	29.0	27.6	29.0
2	8 - 14	27.3	28.6	27.3	28.3	27.4	28.3
3	15 - 21	27.6	29.5	27.6	29.1	27.8	29.0
4	22 - 28	28.7	30.1	29.3	29.9	29.0	29.5
5	29 - 4 Feb	26.2	28.8	27.0	29.3	27.8	29.2

Contd.

Appendix 2 - 2(a) Continued

Stand- ard week	Period	Altitude above ground					
		15 cm		50 cm		250 cm	
		E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>
6	Feb 5 - 11	82.0	87.0	86.0	86.6	85.4	85.4
7	12 - 18	83.5	86.5	84.8	86.8	85.0	84.4
8	19 - 25	79.1	89.0	84.3	89.0	82.6	83.7
9	26 - 3 Mar	76.9	87.3	80.6	85.3	78.3	77.6
10	Mar 4 - 10	84.6	84.9	87.6	84.7	87.6	83.7
11	11 - 17	90.0	90.8	91.5	88.7	89.8	88.8
12	18 - 24	84.9	88.0	84.1	84.9	84.3	84.3
13	25 - 31	82.7	81.6	83.4	83.7	83.3	83.9
14	Apr 1 - 7	81.7	83.1	82.6	83.7	81.0	84.6
15	8 - 14	86.3	87.1	89.6	86.7	88.4	86.0
16	15 - 21	82.4	83.4	84.3	82.0	84.1	80.0
17	22 - 28	88.3	87.9	89.0	87.0	89.5	81.9
18	29 - 5 May	92.6	94.4	91.9	89.6	92.7	88.6
19	May 6 - 12	91.8	90.8	95.3	91.3	92.3	89.0
20	13 - 19	92.1	89.6	93.3	88.6	92.7	88.7
21	20 - 26	89.3	91.4	92.1	90.6	90.9	89.6
22	27 - 2 Jun	90.6	91.1	92.7	90.7	91.3	89.2
23	Jun 3 - 9	92.3	92.3	91.7	91.1	91.1	90.4
24	10 - 16	84.0	84.1	83.9	83.6	82.6	80.2
25	17 - 23	81.9	82.0	80.8	83.7	80.3	78.1
26	24 - 30	80.0	82.6	79.7	80.1	78.3	75.9
27	Jul 1 - 7	75.7	81.1	75.6	77.4	73.9	73.2
28	8 - 14	86.6	88.7	88.4	88.9	88.6	84.1
29	15 - 21	90.7	97.8	90.3	92.4	89.4	90.6
30	22 - 28	77.6	81.1	82.3	79.4	81.0	78.6

Appendix 2 (Continued)

2. RELATIVE HUMIDITY (%)

(b) at 14.22 hours (N - epoch)

$E_1$  = Within the bamboo stand;

$E_2$  = In the open field

Stand- ard week	Period	Altitude above ground					
		15 cm		50 cm		250 cm	
		$E_1$	$E_2$	$E_1$	$E_2$	$E_1$	$E_2$
<u>1979</u>							
36	Sep 4 - 9	55.8	54.7	53.5	51.8	53.8	53.0
37	10 - 16	64.4	59.1	61.6	57.9	58.9	56.0
38	17 - 23	77.1	77.1	71.6	72.1	68.4	70.0
39	24 - 30	58.9	58.9	56.3	56.3	55.7	55.7
40	Oct 1 - 7	60.7	56.2	52.3	61.7	55.1	53.1
41	8 - 14	75.0	65.3	68.6	58.4	60.4	56.3
42	15 - 21	46.2	44.4	45.4	40.1	41.1	40.3
43	22 - 28	72.9	69.9	67.4	64.7	65.0	64.7
44	29 - 4 Nov	68.7	60.9	63.9	58.0	59.1	53.3
45	Nov 5 - 11	77.7	75.3	74.2	72.3	72.5	72.0
46	12 - 18	83.3	82.7	83.0	83.0	79.0	80.3
47	19 - 25	82.7	77.8	81.0	69.0	76.2	68.6
48	26 - 2 Dec	80.4	75.4	77.1	70.7	76.9	71.3
49	Dec 3 - 9	64.8	63.0	64.6	62.8	62.4	60.0
50	10 - 16	67.4	62.5	66.9	60.0	62.4	59.6
51	17 - 23	53.0	53.9	53.0	49.0	51.2	46.4
52	24 -- 31	58.0	54.4	55.6	51.6	53.8	50.2
<u>1980</u>							
1	Jan 1 - 7	56.6	44.9	52.3	42.7	49.6	42.1
2	8 - 14	47.4	42.1	44.1	39.4	42.0	37.4
3	15 - 21	54.0	39.7	47.3	39.6	41.7	37.1
4	22 - 28	36.0	34.0	33.6	32.1	31.4	30.0
5	29 - 4 Feb	64.3	48.4	58.3	43.3	52.0	40.7

## Appendix 2 - 2(b) (Continued)

Stand- ard week	Period	Altitude above ground					
		15 cm		50 cm		250 cm	
		E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>
6	Feb 5 - 11	43.7	42.4	40.0	41.1	38.4	36.9
7	12 - 18	49.8	34.8	41.2	35.7	36.8	32.8
8	19 - 25	31.9	30.9	27.7	27.1	25.9	24.6
9	26 - 3 Mar	33.1	30.9	34.1	29.0	32.7	28.9
10	Mar 4 - 10	31.9	29.0	31.7	29.9	32.4	29.9
11	11 - 17	60.4	59.3	55.9	56.3	56.6	55.6
12	18 - 24	46.0	54.0	52.0	56.4	56.8	57.6
13	25 - 31	51.9	73.0	55.3	70.6	57.0	80.1
14	Apr 1 - 7	53.1	61.6	54.6	63.0	54.9	63.3
15	8 - 14	51.7	40.4	46.7	43.1	47.1	44.4
16	15 - 21	57.3	39.9	44.0	42.3	45.0	42.7
17	22 - 28	60.7	60.4	54.6	53.7	55.7	52.0
18	29 - 5 May	62.9	57.9	60.0	53.0	59.3	49.0
19	May 6 - 12	69.9	64.7	66.1	61.0	65.9	60.7
20	13 - 19	65.1	53.3	59.0	53.9	58.7	49.0
21	20 - 26	76.4	70.0	72.4	56.0	69.0	63.7
22	27 - 2 Jun	79.9	76.6	75.7	72.9	67.1	69.0
23	Jun 3 - 9	80.1	79.6	76.0	74.7	73.3	75.0
24	10 - 16	67.9	60.1	66.6	55.4	66.6	51.7
25	17 - 23	70.8	71.8	70.3	67.3	70.2	64.7
26	24 - 30	67.6	69.4	66.7	66.0	67.3	63.9
27	Jul 1 - 7	72.6	75.4	69.7	69.8	66.7	67.1
28	8 - 14	66.6	67.4	65.3	63.9	66.1	62.1
29	15 - 21	65.7	61.0	62.3	57.8	61.0	56.1
30	22 - 28	70.6	70.6	69.0	69.1	69.9	67.7

APPENDIX 3  
 WEATHER DATA FOR TNAU, COIMBATORE  
 (for the period of experimentation)

Stan- dard week	Period	Rain- fall (mm)	No. of rainy days	Temperature (°c)		Relative Humidity (%)		Hours of bri- ght sun- shine (hrs.)	Eva- pora- tion (mm)
				Max.	Min.	07.22 hrs.	14.22 hrs.		
<u>1979</u>									
32	Aug 6-12	19.7	5	29.5	22.2	77	59	5.5	7.3
33	13-19	-	-	35.6	21.1	81	49	7.8	9.2
34	20-26	0.8	-	32.1	21.5	90	49	5.4	6.8
35	27-2Sep.	1.0	-	32.2	21.7	91	49	4.1	5.6
36	Sep 3 -9	4.3	1	32.2	22.0	89	56	5.1	5.2
37	10-16	28.6	4	32.1	22.1	92	57	5.5	5.1
38	17-23	68.4	3	28.9	21.9	93	72	4.0	3.8
39	24-30	-	-	30.7	22.1	81	54	5.7	7.2
40	Oct 1-7	19.8	1	32.5	20.9	88	50	8.8	7.3
41	8-14	46.2	2	30.9	22.3	94	59	6.7	4.3
42	15-21	3.4	1	31.2	20.5	87	43	10.2	5.4
43	22-28	88.3	4	29.1	21.3	93	70	4.1	4.0
44	29-4Nov	56.4	3	29.6	21.0	95	60	6.6	3.7
45	Nov 5-11	21.7	3	27.7	21.3	94	75	3.0	2.0
46	12-18	283.6	5	27.3	21.2	96	84	2.7	1.3
47	19-25	293.6	4	27.4	21.1	94	75	2.7	2.1
48	26 -2Dec	15.2	1	28.3	21.6	94	65	6.0	3.0
49	Dec 3-9	0.7	-	28.2	20.5	93	61	6.7	3.3
50	10-16	3.7	1	28.2	20.8	91	60	5.2	3.6
51	17-23	-	-	29.5	19.1	91	45	8.9	4.5
52	24-31	0.4	-	28.5	17.2	90	49	8.7	4.5
<u>1980</u>									
1	Jan 1-7	-	-	29.4	16.6	85	43	10.3	5.0
2	8-14	-	-	29.0	15.7	89	37	10.0	5.3
3	15-21	-	-	29.1	17.4	85	38	10.0	5.6
4	22-28	-	-	30.0	14.7	85	30	10.8	6.1
5	29- 4Feb	-	-	30.8	17.1	81	31	8.9	5.5
6	Feb 5-11	-	-	31.5	17.8	85	31	9.6	6.6
7	12-18	-	-	32.0	16.8	85	29	10.0	6.4

Contd.

Appendix 3 (Contd.)

Standard week	Period	Rain-fall (mm)	No. of rainy days	Temperature (°c)		Relative Humidity (%)		Hours of bright sun-shine (hrs.)	Eva por tie (mm)
				Max.	Min.	07.22 hrs.	14.22 hrs.		
8	Feb 19-25	-	-	33.3	16.5	81	23	11.2	8.0
9	26-3 Mar	-	-	34.7	16.3	85	32	10.6	7.3
10	Mar 4-10	5.9	1	34.9	19.5	84	32	9.0	6.9
11	11-17	19.0	2	32.3	19.9	86	36	9.8	6.1
12	18-24	-	-	34.9	17.2	75	21	11.1	7.5
13	25-31	-	-	34.4	21.9	78	37	9.2	6.7
14	Apr 1-7	3.3	1	34.3	23.6	77	41	7.0	7.3
15	8-14	-	-	35.7	23.1	84	40	10.4	7.4
16	15-21	16.9	2	34.8	23.2	76	47	7.7	7.3
17	22-28	63.9	4	34.8	22.5	88	48	7.2	5.9
18	29-5 May	20.1	1	32.8	23.3	87	47	8.1	5.3
19	May 6-12	10.7	1	35.4	23.5	87	45	8.7	6.2
20	13-19	47.3	1	33.1	22.9	89	47	8.4	6.1
21	20-26	3.3	1	34.8	23.3	83	48	10.2	6.7
22	27-2 Jun	13.3	2	32.1	22.3	89	59	2.6	5.0
23	Jan 3-9	11.2	2	30.6	22.5	83	62	4.3	4.5
24	10-16	2.6	1	33.1	22.2	74	50	4.4	8.4
25	17-23	9.7	2	30.5	23.2	77	66	5.0	6.5
26	24-30	8.1	1	30.4	22.8	77	67	2.1	6.0
27	Jul 1-7	21.5	3	29.7	23.1	81	65	5.1	7.3
28	8-14	1.0	-	30.9	22.6	84	56	6.2	7.7
29	15-21	1.7	-	32.1	21.6	87	47	5.2	6.3
30	22-28	1.0	-	31.5	22.5	70	52	4.2	7.9

Expt.1

Appendix 4  
Correlation Coefficients

SOYBEAN

Single Sample Plants Data as on 30 DAS

Y = Grain yield/plant

 $X_1$  = height of plant $X_2$  = Diameter of stem at base $X_3$  = Number of leaflets (Total)/plant $X_4$  = Leaf area (Total)/plant (as on 40 DAS)

	$X_1$	$X_2$	$X_3$	$X_4$	Y
(a) <u>Within the bamboo stand (<math>E_1</math>)</u>					
		NS	NS	NS	NS
$X_1$	1	0.2231	0.2582	0.0016	0.1808
$X_2$		1	**	NS	*
			0.5347	0.3150	1.5066
$X_3$			1	NS	***
				0.0669	0.6547
$X_4$				1	NS
					-0.0368
Y					1
(b) <u>In the open field (<math>E_2</math>)</u>					
		*	**	**	NS
$X_1$	1	0.4138	0.5448	0.5662	0.3781
$X_2$		1	**	**	***
			0.6240	0.6000	0.6500
$X_3$			1	***	***
				0.7379	0.8448
$X_4$				1	***
					0.6788
Y					1

Correlation CoefficientsSingle Sample Plants Data as on 60 DAS

Y = Grain yield/plant

X<sub>1</sub> = Height of plantX<sub>2</sub> = Diameter of stem at baseX<sub>3</sub> = Number of leaflets (Total)/plantX<sub>4</sub> = Leaf area (Total)/plant (as on 80 DAS)X<sub>5</sub> = Number of pods/plant

	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	Y
<u>(a) Within the bamboo stand (E<sub>1</sub>)</u>						
X <sub>1</sub>	1	* 0.4851	** 0.5390	** 0.6169	** 0.5262	** 0.5405
X <sub>2</sub>		1	*** 0.7479	** 0.6147	*** 0.6939	*** 0.7374
X <sub>3</sub>			1	*** 0.6920	** 0.7610	*** 0.7394
X <sub>4</sub>				1	** 0.5592	** 0.5537
X <sub>5</sub>					1	*** 0.7513
Y						1
<u>(b) In the open field (E<sub>2</sub>)</u>						
X <sub>1</sub>	1	*** 0.7279	*** 0.8219	NS -0.1741	*** 0.8240	*** 0.8016
X <sub>2</sub>		1	*** 0.6470	* -0.5142	*** 0.7293	*** 0.7452
X <sub>3</sub>			1	NS -0.0762	*** 0.6465	*** 0.8143
X <sub>4</sub>				1	NS -0.3056	NS -0.2866
X <sub>5</sub>					1	*** 0.8602
Y						1

Correlation CoefficientsSingle Sample Plants Data as on 90 DAS

Y = Grain yield/plant

X<sub>1</sub> = Height of plantX<sub>2</sub> = Diameter of stem at baseX<sub>3</sub> = Number of leaflets (Total)/plantX<sub>4</sub> = Leaf area (Total)/plant (as on 80 DAS)X<sub>5</sub> = Number of pods/plantX<sub>6</sub> = Number of grains/plant

	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	XY
(a) Within the bamboo stand (E <sub>1</sub> )							
X <sub>1</sub>	1	* 0.4934	NS -0.0738	*** 0.6335	* 0.5009	*** 0.6588	** 0.6069
X <sub>2</sub>		1	** 0.5171	* 0.4775	*** 0.6723	*** 0.8321	*** 0.7576
X <sub>3</sub>			1	NS 0.2045	NS 0.3398	* 0.4098	NS 0.3235
X <sub>4</sub>				1	** 0.6051	** 0.6203	** 0.5534
X <sub>5</sub>					1	*** 0.6901	*** 0.6393
X <sub>6</sub>						1	*** 0.9637
Y							1
(b) In the open field (E <sub>2</sub> )							
X <sub>1</sub>	1	** 0.6199	* 0.4580	NS -0.1710	*** 0.8433	** 0.8501	*** 0.7505
X <sub>2</sub>		1	NS 0.3761	*** -0.7412	*** 0.6895	*** 0.6972	** 0.6063
X <sub>3</sub>			1	NS -0.1311	* 0.4882	* 0.4352	* 0.4321
X <sub>4</sub>				1	NS -0.3495	NS -0.3382	NS -0.2866
X <sub>5</sub>					1	*** 0.9826	*** 0.9346
X <sub>6</sub>						1	*** 0.9614
Y							1

Expt.2

Appendix 7

SOYBEAN

Correlation Coefficients

Single Sample Plants Data as on 30 DAS

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Y = Grain yield/plant  
X<sub>1</sub> = Height of plant  
X<sub>2</sub> = Diameter of stem at base  
X<sub>3</sub> = Number of leaflets (Total)/plant

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	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	Y
(a) <u>within bamboo stand (E<sub>1</sub>)</u>				
		NS	NS	NS
X <sub>1</sub>	1	0.0772	-0.1992	-0.3096
			NS	NS
X <sub>2</sub>		1	-0.0649	0.0402
				NS
X <sub>3</sub>			1	0.1896
Y				1

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(b) <u>In the open field (E<sub>2</sub>)</u>				
		NS	NS	**
X <sub>1</sub>	1	0.0764	-0.0275	-0.5596
			*	NS
X <sub>2</sub>		1	0.4527	0.0519
				NS
X <sub>3</sub>			1	0.3552
Y				1

---

Expt.2

Appendix B

SOYBEAN

Correlation CoefficientsSingle Sample Plants Data as on 60 DAS

Y = Grain yield/plant

X<sub>1</sub> = Height of plantX<sub>2</sub> = Diameter of stem at baseX<sub>3</sub> = Number of leaflets (Total)/plant

	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	Y
(a) <u>within the bamboo stand (E<sub>1</sub>)</u>				
X <sub>1</sub>	1	NS -0.1097	NS 0.1730	* 0.4570
X <sub>2</sub>		1	NS -0.2267	NS 0.2289
X <sub>3</sub>			1	NS 0.1120
Y				1
(b) <u>In the open field (E<sub>2</sub>)</u>				
X <sub>1</sub>	1	NS 0.0603	NS 0.3439	NS 0.1812
X <sub>2</sub>		1	NS 0.2141	NS 0.0164
X <sub>3</sub>			1	* 0.5155
Y				1

Correlation CoefficientsSingle Sample Plants Data as on 90 DAS

Y = Grain yield/plant

X<sub>1</sub> = Height of plantX<sub>2</sub> = Diameter of stem at baseX<sub>3</sub> = Number of leaflets (Total)/plantX<sub>4</sub> = Number of pods/plantX<sub>5</sub> = Number of grains/plant

	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	Y
(a) Within the bamboo stand (E <sub>1</sub> )						
		NS	NS	NS	NS	NS
X <sub>1</sub>	1	0.1638	0.0755	0.2543	0.3262	0.4014
			NS	NS	NS	NS
X <sub>2</sub>		1	-0.2510	0.3888	0.0726	0.0764
				NS	NS	NS
X <sub>3</sub>			1	-0.3316	0.2260	0.2018
					*	NS
X <sub>4</sub>				1	0.4071	0.3403
						***
X <sub>5</sub>					1	0.9615
						***
Y						1
(b) In the open field (E <sub>2</sub> )						
		NS	NS	NS	NS	NS
X <sub>1</sub>	1	0.1581	-0.0216	-0.2625	-0.2468	-0.2421
			*	**	NS	NS
X <sub>2</sub>		1	0.4863	0.6055	0.3229	0.2413
				**	**	NS
X <sub>3</sub>			1	0.5907	0.5467	0.3932
					***	***
X <sub>4</sub>				1	0.7583	0.7255
						***
X <sub>5</sub>					1	0.9626
						***
Y						1













Expt.1      Appendix 13 Correlation Coefficients      SOIL MOISTURE

Soil moisture during different stages of crop growth and grain yield of soybean

Y = Grain yield/plant (single sample plant)

X<sub>1</sub> = Soil moisture as on 33 DAS

X<sub>2</sub> =                   "           47 DAS

X<sub>3</sub> =                   "           54 DAS

X<sub>4</sub> =                   "           68 DAS

X<sub>5</sub> =                   "           76 DAS

	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	Y
<u>(a) Within the bamboo stand (E<sub>1</sub>)</u>						
X <sub>1</sub>	1	NS 0.2809	NS 0.0101	NS 0.0317	NS 0.0315	NS -0.2112
X <sub>2</sub>		1	NS 0.2221	NS 0.0582	NS 0.3064	NS 0.1336
X <sub>3</sub>			1	NS 0.0018	*** 0.6440	NS 0.0209
X <sub>4</sub>				1	NS 0.1428	NS -0.0658
X <sub>5</sub>					1	NS -0.0392
Y						1
<u>(b) In the open field (E<sub>2</sub>)</u>						
X <sub>1</sub>	1	NS -0.2675	NS -0.1333	NS -0.2230	NS -0.0417	NS -0.3400
X <sub>2</sub>		1	NS 0.2977	NS 0.1116	NS 0.4265	NS -0.0589
X <sub>3</sub>			1	NS 0.0631	* 0.5126	NS 0.3135
X <sub>4</sub>				1	NS 0.2580	NS -0.1875
X <sub>5</sub>					1	NS 0.3487
Y						1

Expt.2

Appendix 14 Correlation Coefficients

SOIL MOIST

Soil moisture during different stages of crop growth and grain yield of soybean

Y = Grain yield/plant (single sample plants)

X<sub>1</sub> = Soil moisture as on 36 DAS

X<sub>2</sub> = " 48 DAS

X<sub>3</sub> = " 55 DAS

X<sub>4</sub> = " 69 DAS

X<sub>5</sub> = " 76 DAS

	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	Y
(a) Within the bamboo stand (E <sub>1</sub> )						
X <sub>1</sub>	1	NS 0.4042	NS -0.1098	NS -0.0188	NS 0.0126	NS -0.1096
X <sub>2</sub>		1	NS 0.1298	NS 0.3290	NS 0.1715	NS -0.2584
X <sub>3</sub>			1	NS 0.2711	NS 0.3346	NS 0.2352
X <sub>4</sub>				1	NS 0.2230	* 0.4126
X <sub>5</sub>					1	NS 0.2452
Y						1

(b) In the open field (E <sub>2</sub> )						
X <sub>1</sub>	1	*** 0.6726	** 0.5998	NS 0.3721	NS -0.3161	** 0.5988
X <sub>2</sub>		1	NS 0.3869	NS 0.3228	** -0.5281	NS 0.4004
X <sub>3</sub>			1	NS 0.2230	NS 0.0231	** 0.5434
X <sub>4</sub>				1	** -0.5891	* 0.4446
X <sub>5</sub>					1	NS -0.1838
Y						1

Multiple linear regression equation fitted

(attributes as on 30 DAS)

Y = Predicted grain yield of soybean (grams/plant)

X<sub>1</sub> = Height of plant (cm)X<sub>2</sub> = Diameter of stem at base (mm)X<sub>3</sub> = Number of leaflets /plantX<sub>4</sub> = Leaf area (Total)/plant (cm<sup>2</sup>)X<sub>5</sub> = Length of taproot (cm)X<sub>6</sub> = Number of root nodules/plantX<sub>7</sub> = O.D. weight of roots/plant (grams)X<sub>8</sub> = Dry matter production (DMF) (grams/plant)(a) For the environment 'within the bamboo stand' (E<sub>1</sub>)i) Predicted yield

$$\hat{Y} = 0.8091 - 3.0712 X_1 - 0.1308 X_2 + 0.0239 X_3 \\ + 1.5030 X_4 + 0.0266 X_5 - 0.1191 X_6 \\ + 4.5440 X_7 - 0.2061 X_8$$

ii) Standardised partial Regression Coefficients

Beta X 1 = -0.1664

Beta X 2 = -0.0860

Beta X 3 = 0.2538

Beta X 4 = 0.0093

Beta X 5 = 0.2785

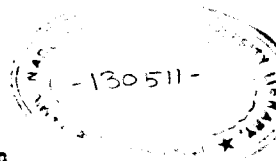
Beta X 6 = -0.3445

Beta X 7 = 0.5240

Beta X 8 = -0.3593

111) Multiple Coefficient of Determination

$$R^2 = 0.5096$$



Appendix 15 (Continued)

iv) Correlation between the predicted and actual yields

$$R = 0.7138$$

(b) For the environment 'open field' (E<sub>2</sub>)

i) Predicted Yield

$$\begin{aligned}\hat{Y} = & 14.6053 - 0.0486 X 1 - 0.5672 X 2 - 0.6050 X 3 \\ & + 0.0295 X 4 - 0.3147 X 5 - 1.0086 X 6 \\ & - 6.6814 X 7 - 1.8499 X 8\end{aligned}$$

ii) Standardised partial Regression Coefficients

Beta X 1	= -0.1212
Beta X 2	= -0.0832
beta X 3	= -0.4576
Beta X 4	= 1.0207
beta X 5	= -0.2889
Beta X 6	= -0.2175
Beta X 7	= -0.2057
Beta X 8	= -0.2074

iii) Multiple Coefficient of Determination

$$R^2 = 0.4195$$

iv) Correlation between the predicted and actual yields

$$R = 0.6477$$

