EFFECT OF DIFFERENT INPUTS ON PRODUCTIVITY AND QUALITY RELATIONS IN NJAVARA (*Oryza sativa*)

BY

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THESIS

submitted in partial fulfilment of the
requirement for the degree

Doctor of Philosophy in Agriculture

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1996

DECLARATION

I hereby declare that the thesis entitled '**Effect of different inputs on productivity and quality relations in *Njavara* (*Oryza sativa*)**' is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship, associateship or other similar title of any other university or society.

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We, the undersigned members of the Advisory Committee of **Smt. Meera V. Menon**, a candidate for the degree of **Doctor of Philosophy in Agriculture**, with major in **Agronomy**, agree that the thesis entitled '**Effect of different inputs on productivity and quality relations in *Njavara* (*Oryza sativa*)**' may be submitted by **Smt. Meera V. Menon**, in partial fulfilment of the requirement for the degree.

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ACKNOWLEDGEMENT

I wish to place on record my deep sense of gratitude and personal obligation to **Dr.N.N.Potty**, Professor of Agronomy and Chairman of my Advisory Committee for his constant inspiration and guidance throughout the course of this work. His vision was the guiding light of this investigation and my thankfulness for having had a such an opportunity to associate with him is too great to be expressed.

I am thankful to **Dr.R.Vikraman Nair**, Professor and Head, Department of Agronomy, **Dr.U.Mohamed Kunju**, Director (Acad. and P.G.Studies), Kerala Agricultural University, **Dr.A.Augustin**, Associate Professor (Biochemistry), College of Horticulture and **Sri.P.V.Prabhakaran**, Professor and Head, Department of Agricultural Statistics, College of Horticulture, for their constructive criticisms and valuable advice during the course of this research work.

I am also grateful to Dr.C.C.Abraham, former Associate Dean, Dr.A.I.Jose, Associate Dean, College of Horticulture, Vellanikkara and Dr.E.Tajuddin, former Director of Extension, Kerala Agricultural University for their help at all stages of this work.

I wish to express my gratitude to Dr.N.Krishnan Nair, Associate Director of Research, R.A.R.S., Pattambi and Dr.P.A.Wahid, Associate Dean, College of Agriculture, Nileshwar, for providing the facilities for conducting part of this study at the Regional Agricultural Research Station, Pilicode. My sincere thanks are also due to the staff of R.A.R.S., Pilicode for their co-operation and help.

CONTENTS

I take this opportunity to express my heartfelt gratitude to Sri.M. Nandakumar, Associate Professor, Department of Animal Nutrition, College of Veterinary and Animal Sciences, Mannuthy, for his tireless help and encouragement for carrying out chemical analyses.

I am greatly indebted to Sri.S.Krishnan, Assistant Professor, Department of Agricultural Statistics for his valuable guidance and unfailing encouragement during the course of this work. I also remember with gratitude the co-operation and assistance I received from Smt.Sreelatha, for statistical analysis of data.

My sincere thanks are also due to Sri.K.A.Joy for the neat typing and prompt service.

The award of the Senior Research Fellowship by the CSIR during the period of this study is gratefully acknowledged.

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Introduction

INTRODUCTION

Njavara is a unique grain plant in the *Oryza* group indigenous to Kerala. It is known as 'Shashtika rice' due to its extra short requirement of 60 days to grow and mature. *Njavara* grain is considered as a curative base of circulatory, respiratory and assimilatory ailments in ayurvedic medicine. Based on glume colour differences, two types of *Njavara* are recognised, the black and golden yellow glumed types. Ecotypes within these two groups have been reported not to differ in growth habits (Menon and Potty, 1996). In spite of a fairly high production potential (Elsy *et al.*, 1992), versatile and curative utility, *Njavara* continues to be confined to expert ayurvedic physicians and is fast shrinking to extinction. Being a rare indigenous genetic resource of high value and unique production and quality characteristics, it is necessary that it is studied thoroughly, conserved, propagated and utilised appropriately. This has been attempted in this research project.

The plant is the basic input in agricultural production. It is the medium of production and the seed is the end product of growth and development in the biological cycle. Quantitative and qualitative characteristics of the seed are therefore determined by the growth and development process. Hence, a knowledge about the process of growth and development and its natural yielding ability and quality, is a basic necessity in any effort to understand the plant and evolve management techniques.

Soil and atmospheric environment which constitute the habitat is known to have enormous influence on the quality and quantity components of yield as well as their interrelations. Apart from anchorage, soil provides moisture as well as the essential mineral requirements of the plant, which in turn depend upon content and form of elements as well as their interactions, redox state of the soil etc. Influences of weather variations govern the utilisation of the elements as well as the metabolic processess leading to production. Analysis of the influence of habitat and the component factors will provide basic information on crop response and yield limiting factors, which will have applicability even in the context of general crop production.

Having understood the yield and quality characteristics and adaptability of the biotypes, the next step will be the nutritional management of the better plant type for higher productivity. Evidently, nutritional management is based on the limiting factor concept, conventionally confined to N, P and K. The optimum requirements of nutrients and response pattern shall be worked out through fertilizer trials.

In medicinal plants, the nutritional requirement for quantity and quality are equally important. Accumulated evidences rank the conclusive superiority of nutritional sources in the order: organic, integrated and inorganic in such plants. Thus, the ideal source and optimum source combination will have to be identified.

Information on all the above aspects are necessary for a proper understanding of the *Njavara* plant as well as to formulate scientific recommendations for its cultivation. This project has been designed and conducted to serve these objectives.

Briefly, the specific objectives shall be listed as follows:

i) to characterise the growth and development, yielding ability and quality of two identified types of *Njavara* and to select the better in respect of quality,

ii) to find out the influence of habitat effect on growth, yield and quality of *Njavara* types.

iii) to characterise the response of the plant to changing weather situations and to find out the optimum period of crop commencement

iv) to study the nutritional requirement in the situation best suited to its adaptability in respect of quality, and

v) to find out the influence of different sources so as to fix the ideal source and source combination to ensure good yield.

INTRODUCTION

Njavara is a unique grain plant in the *Oryza* group indigenous to Kerala. It is known as 'Shashtika rice' due to its extra short requirement of 60 days to grow and mature. *Njavara* grain is considered as a curative base of circulatory, respiratory and assimilatory ailments in ayurvedic medicine. Based on glume colour differences, two types of *Njavara* are recognised, the black and golden yellow glumed types. Ecotypes within these two groups have been reported not to differ in growth habits (Menon and Potty, 1996). In spite of a fairly high production potential (Elsy *et al.*, 1992), versatile and curative utility, *Njavara* continues to be confined to expert ayurvedic physicians and is fast shrinking to extinction. Being a rare indigenous genetic resource of high value and unique production and quality characteristics, it is necessary that it is studied thoroughly, conserved, propagated and utilised appropriately. This has been attempted in this research project.

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Review of Literature

2. REVIEW OF LITERATURE

The major inputs of production affecting crop growth and yield are soil and climate. Of these; nutritional factors, viz., nutrient contents and balances play a decisive role in influencing yield expression. In addition to understanding the process determining nutrient availability, arriving at a nutrient management system which integrates organic and inorganic sources at an optimum level is also essential to ensure high crop productivity and ecosystem stability.

Njavara is an extra short duration medicinal rice variety, the special characters of which very little is known. Since it is the medicinal components of *Njavara* which are important, environmental factors affecting the quality aspects as well as quantity aspects are to be understood.

Review of literature covering these subjects are presented below.

2.1 *Njavara* - The plant

Njavara, a medicinal rice type, is one of the native genetic resources of Kerala, famed for its use in Ayurveda. As it seems to have originated in a limited area and did not spread appreciably (as its cultivation and use is confined to Kerala), it can be considered an endemic crop (Harlan, 1975). The evolution of such a cultigen could be the result of folk domestication and, as in the case of many such crops, there is danger of its being wiped out by large scale expansion of high yielding rice cultivars, and the impact of modern agriculture (Arora, 1983).

The famed 'Ashtanga Hridaya', the literal condensation of all that is known in Ayurveda, and the living text for the Ayurveda physician, lists *Njavara* as 'Shashtika' rice as it is supposed to mature in 60 days, and also records the occurrence of two types of *Njavara*, black and white glumed of which the latter is superior. However, the yield and quality of *Njavara* varies with the location. Corroborating the 'Ashtanga Hridaya', the 'Susrutha Samhitha' cites *Njavara* as a special cereal, having properties to rectify the basic ills affecting the circulatory, respiratory as well as the digestive systems. However, it describes black glumed *Njavara* as being best.

Elsy *et al.* (1992) have described the morpho-physiological characteristics of *Njavara* and have reported that it yielded an average of 2.5 t ha^{-1} in wetland conditions.

An attempt to morphologically evaluate medicinal rice, *Njavara* by Menon and Potty (1996) positively identified two distinct biotypes, viz. black and golden, based on plant growth and glume colour and suggested the possibility of qualitative variations existing between the two types.

A very early report on the medicinal use of rice was made by Watt (1891) who records the use of rice poultice as a substitute for that of linseed meal. The possibility of the medicinal uses of rice was also made in a recent study by Fu *et al.* (1991) on the medicinally active constituents of black glutinous rice.

2.2 Weather influences on rice growth

Rice is cultivated under diverse climatic, hydrological and edaphic conditions, at latitudes extending from 35° S to 53° N, at elevations ranging from below sea level to more than 2000 M, at water regimes ranging from upland conditions with no accumulated surface water to low conditions with 5 M deep water and under a wide range of temperatures and humidity. The wide range of cultivation of rice denotes its wide adaptability to varied agroecological situations. However as more than 50 per cent of the yield expression of a crop is governed by climatic factors, the importance of location specific weather conditons on crop growth and development cannot be overemphasized.

Weather conditions play a direct role by their effect on dry matter accumulation and yield. However, the effects may be favourable or unfavourable. For example, dry matter accumulation may be reduced, but grain yield may be enhanced. Other than these direct effects, weather conditions may have indirect effects as on nutrient absorption and metabolism.

Crop-weather studies conducted by Alexander *et al.* (1990) showed that realizable yield of rice was profoundly affected by weather situations prevailing during the growth phases of the crop. The influence of weather components was manifested more in the number of productive tillers per unit area, number of filled grains per panicle, and sterility as well as weight of grains.

As most of the world's rice is grown in the tropics, the determining factor for growing rice appears to be temperature. Lin (1976) reported that high temperatures led to increased production of ineffective tillers and also resulted in dwarf plants with small leaves. Suzuki (1983) reported a significant positive correlation between the mean temperature and cumulative growth rate at the initial growth stage. However, with the advancement of growth, the correlation was lowered and it turned to significantly negative for the period from 3 to 6 weeks after heading. A similar shift in optimum temperature for rice from high to low as growth advanced from vegetative to productive stages was observed by Yoshida (1973). The rice plant was very sensitive to low temperature about 9 days before flowering (Satake, 1976) and high temperature at flowering (Satake and Yoshida, 1978). Goswami and Murty (1995) reported that increase of temperature by more than 4°C over the ambient adversely affected the photosynthetic activity.

Chaudhary and Sodhi (1979) observed that in the flowering period, sterility was minimum (12-18%) when the mean temperature was 27-28°C, whereas it was maximum (36%) when the mean temperature was above 36°C. However, very low temperature is also harmful as is seen from experimental evidence that the ripening period was negatively correlated with minimum temperature of that period (Krishnakumar, 1986). During ripening, high temperature produced an undesirably chalky appearance in rice kernel and increased the bran thickness. Yield attributes like filled grain percentage, panicle weight and degree of ripening were negatively correlated with minimum temperature during reproductive and ripening stages. Chaudhary and Ghildyal (1970) reported that at low temperature, translocation of photosynthates to grain took place at a slower rate, delaying the maturity period. This is the reason generally considered responsible for high grain yields in temperate countries than in tropical countries. Long day length and a high level of solar energy during the ripening period also contribute to high grain yields.

The effect of solar radiation on rice has been reported to operate in all stages of growth and development. Shanker and Gupta (1981) reported a significant positive correlation between height of two varieties of paddy and the duration of sunshine. Radiation also has been reported to influence tillering during vegetative phase. Sreedharan and Vamadevan (1981) reported that LAI reduced to a great extent in plants shaded either from planting to panicle initiation or from flowering to harvest. A similar result was reported by Venkateswarlu (1977). A study by Singh *et al.* (1988) showed that induced low light (50% sunlight) from 40 days after planting to harvest in the field reduced tiller number, stem weight ratio, total dry matter, photosynthetic potential and net assimilation rate and increased plant height, leaf area index and leaf chlorophyll content at harvest.

The effect of low solar radiation was more pronounced during the reproductive stage than the vegetative stage, as it drastically reduced spikelet number per panicle and impaired grain filling (Patro and Sahu, 1986; Yoshida and Parao, 1976). Nayak *et al.* (1979) have also reported that low light intensity reduced leaf area development, photosynthetic efficiency and translocation of photosynthates to the panicles. Similar results have also been reported by Lenka and Misra (1980), Krishnakumar (1986), Dinesh *et al.* (1986), Vijayalakshmi *et al.* (1987), Singh *et al.* (1988) and Khushu and Mavi (1991).

The indirect effect of light intensity on growth and development of rice is evident in the observation that in seasons of high solar energy reception, all the yield attributes and yield responded to a higher level of fertilizers, whereas during rainy and cloudy weather, the crop responded to only half the amounts applied in the dry season (Sreedharan and Vamadevan, 1981). Temperature has also been reported to influence the uptake of N, P, K and Zn by rice throughout the year at different growth stages (Subbiah, 1983).

Rainfall and soil moisture are other important weather parameters affecting rice growth, and rainfall variability is more critical for upland rice than for lowland rice. Chatterjee (1970) observed that in a number of varieties of rice, tillering is continued upto 42-45 days in rainy season, whereas in dry season, it is 50-55 days. High panicle number (500) in rabi compared to kharif (400) season, and corresponding higher yield in rabi were attributed to rainfall variability (Venkateswarlu *et al.*, 1976). It was also reported by Sahu and Murty (1976) that dry matter production and grain yield were invariably lower by about 50 and 54 per cent respectively in wet (July-October) season than in dry (January-May) season. Corroborating this view, Viswambharan *et al.* (1989) reported a negative correlation between yield and number of rainy days during maturity stage. Contrarily, a negative correlation between yield and moisture stress was reported by Lenka and Garnayak (1991) and Yang *et al.* (1995).

Taking into consideration the effect of meteorological factors on growth and yield, a number of experiments were conducted to determine the best time of sowing or transplanting rice to optimise yields. Studies on best sowing dates for rainfed rice were conducted by Bhattacharya and Paul (1970) and Singh and Pillai (1995). Various transplanting dates for rice were evaluated by Singh *et al.* (1972), Kalita and Bhattacharjee (1984) and Rao (1994). A study combining the effects of dates of planting and irrigation was conducted by Joseph and Havanagi (1987), while Majumdar (1971) and Singh and Paliwal (1980) studied the effect of fertilizer application in concurrence with sowing time.

2.3 Mineral nutrition and rice growth

Mineral nutrition is one of the most important environmental factors affecting growth and productivity of a crop. Where rice is concerned, the stage of growth is also important as it decides the physiological requirements of each element. In addition to the specific functions of each nutrient, the interacting influences of the different nutrients absorbed by the rice plant have to be considered, and nutrient ratios may be more important than the content of individual elements absorbed when soil contents of these elements are either at deficient or toxic levels.

Nitrogen is a vitally important plant nutrient, being involved in the formation of proteins, as well as the chlorophyll molecule. An adequate supply of N is associated with vigorous vegetative growth and a deep green colour and also with carbohydrate utilisation (Tisdale *et al.*, 1995). Rice plants require a large amount of N at the early and mid-tillering stages to maximize the number of panicles. The number of tillers produced are also correlated positively with concentration of NH_4-N in the soil (LaiDing *et al.*, 1993). Nitrogen absorbed at the panicle initiation stage may increase spikelet number per panicle. Some N is also required at the ripening stage (De Datta, 1981).

Recovery of fertilizer N in upland rice is low mainly because of soil moisture stress and profuse weed growth (Mishra *et al.*, 1995). Short statured and long duration varieties may respond to high N dose under low soil fertility conditions. Traditional varieties tend to lodge at higher level of N (Gupta and O'Toole, 1986). Based on various reports (Mahapatra and Srivastava, 1983; Singh *et al.*, 1983; Singh *et al.*, 1994) the economically optimum dose for upland rice was found to be 40-60 kg N ha^{-1}. However, increased grain yields with higher N rates, upto 180 kg ha^{-1} were observed by Singh and Om (1993) and Monapara *et al.* (1993).

Plant N content in rice is maximum at early growth stage and subsequently decreases with advancement of age (Rao and Murty, 1975). Rao *et al.* (1974) reported a lag period in N uptake of dry-sown rice during 40-70 days after seeding, resulting in a steep decrease in N content, indicating that N accumulation could not keep pace with rapid increase in dry matter production.

Phosphorus, classed as a major plant nutrient (with N and K), occurs in most plants in quantities that are much smaller than those of N and K. Phosphorus is associated with root development, early flowering and ripening and active tillering (De Geus, 1954). It has an important role to play in many of the metabolic processes such as synthesis and breakdown of carbohydrates, fats and proteins and in the transfer and conservation of energy (Anonymous, 1961). An adequate supply of P is associated with greater strength of cereal straw (Tisdale *et al.*, 1995).

In rice, a plentiful supply of P in the early stages promotes early growth because such a high supply increases the content of nucleic acid P and phosphilipid P. Nucleic acids can actually promote heading in rice as it controls vegetative growth through protein biosynthesis and reproductive growth through flower initiation (Fujiwara, 1964). P manuring increases early tiller formation the greater part of which ultimately provides more grains of heavier weight, and also stimulates early and synchronous flowering (Bhattacharya and Chatterjee, 1978). Favourable influence of P application on tillering was also observed by Nair *et al.* (1972), Bharadwaj *et al.* (1974) and Chowdhury *et al.* (1978). However, Alexander *et al.* (1973a), Kalyanikutty and Morachan (1974) and Suseelan *et al.* (1977) have reported lack of any response to P application in rice tillering.

Majumdar (1971) observed that P nutrition effected a significant increase in the number of productive tillers, an observation supported by Nair *et al.* (1972) and Bhattacharya and Chatterjee (1978). The latter have also reported a higher test weight due to P application.

Contradictory reports are available on the effect of P on rice grain yields. Favourable responses have been reported by Mohanty and Patnaik (1974), Kalyanikutty and Morachan (1974), Ittiyavarah *et al.* (1979) and Kalita and Baroova (1994). However, several workers have reported that mean grain yields were not significantly affected by P fertilizers (Dargan and Chillar, 1978; Mandal and Sahu, 1978; Dargan *et al.* 1980; Rao and Kumar, 1994).

Thandapani and Rao (1974) and Agarwal (1978) reported that increasing P application favourably influenced the protein N in grain. However, an opposite effect was reported by Ageeb and Yousif (1978).

Regarding the uptake of P, Alexander *et al.* (1973b) observed that there was a gradual increase in the P uptake from maximum tillering to flowering stages and then a rapid increase from flowering to harvest. Similar views have been reported by Patnaik *et al.* (1965), Chandrasekharan and Durairaj (1969), Mohanty and Patnaik (1974) and Iruthayaraj and Morachan (1980).

Response to applied P varies with the type of soil. De Datta *et al.* (1966) reported that only 8 to 27 per cent of the total P in an indica variety of rice tested was derived from applied P, whereas Majumdar (1973) found that recovery of applied P_2O_5 was only 2 per cent. Kalam *et al* (1966) reported that the magnitude of response to P was much lower than that of N due to the high status of available P in the soil, an opinion endorsed by Alexander *et al.* (1973b). Soil moisture content also affects P uptake as is evident from the observation that drying of soil decreased the available P content (Patrick and Mahapatra, 1968). Mosi *et al.* (1973) concluded that lowland rice was not as likely to respond to addition of phosphatic fertilizers as upland crops which may be due not so much to a lower nutritional requirment for P as to the release of soil P under submerged conditions. The increase in solubility of P in a flooded soil may be attributed to reduction of ferric phosphate to the more soluble ferrous phosphate, and displacement of phosphate from ferric and aluminium phosphate by organic anions (Islam and Elahi, 1954; Ponnamperuma, 1955; Shapiro, 1958; Datta and Datta, 1963). However, the beneficial effects of flooding on phosphate availability depend on the intensity of reduction and on the Fe content of the soil (Davide, 1960).

Plant requirements of K, the third so-called major element, are high. Potassium apparently does not form an integral part of any plant component, and its function is catalytic in nature. It is essential for the physiological functions of carbohydrate metabolism, N metabolism and synthesis of proteins, control and regulation of activities of various essential mineral elements, neutralization of physiologically important organic acids, activation of various enzymes, promotion of the growth of meristematic tissue and adjustment of stomatal movement and water relations (Tisdale *et al.*, 1995). It is also involved in imparting resistance to drought, frost, lodging, pests, diseases and physiological disorders (Balram *et al.*, 1977; Singh and Tripathi, 1979).

Significant increase in rice plant height with increase in the levels of K was observed by Vijayan and Sreedharan (1972) and Venkatasubbaiah *et al.* (1982). A positive correlation between K application and leaf area index (LAI) in rice was observed by Mandal and Dasmahapatra (1983). Ray and Choudhuri (1980) observed increase in chlorophyll content of flag leaf due to K application. Potassium checks the chlorophyll degradation and promotes the synthesis of both chlorophyll a and b.

Mengel *et al.* (1981) and Ray and Choudhuri (1980) reported that K increased the rate of translocation of amino acids to the grain and rate of protein formation.

K application favourably influences yield attributes in rice. Increased number of panicles per sq.m and thousand grain weight with K application were reported by Mandal and Dasmahapatra (1983). Varma *et al.* (1979) observed longer panicles with increased K rates while Vijayan and Sreedharan (1972) reported greater number of spikelets per panicle. Higher grain and straw yields were reported by Gurmani *et al.* (1984). Similar results were reported by Ghosh *et al.* (1994) and Mahalle and Thorat (1994).

Calcium is an element required by all higher plants. In rice, it is seen as a constituent of the cementing material of plant cells. It is an important constituent of calcium pectate, which strengthens the cell wall. It maintains the turgidity of cell walls and promotes normal root growth and development. Similar functions are also conducted by magnesium, which in addition, is a constituent of the chlorophyll molecule essential for photosynthesis and of several essential enzymes. Magnesium application was found to increase the grain yield in rice (Mani *et al.*, 1993; Muralidharan and Jose, 1993; Varughese and Jose, 1993). Pot culture experiments on rice conducted by Varghese and Money (1965) and Padmaja and Varghese (1966) indicated that Mg either alone or in combination with Ca and Si appreciably improved crop growth and significantly increased grain yield.

Sulphur, another important element in rice nutrition is a constituent of the amino acids cystine, cysteine and methionine, and the plant hormones thiamin and biotin. It is also an important factor in the functioning of many plant enzymes, enzyme activators, and oxidation-reduction reactions. Raju *et al.* (1995) reported that application of 25 or 50 kg S ha^{-1} significantly increased rice cv. Chaitanya grain yields.

An important micronutrient affecting growth and yield of rice in Kerala is Fe. High availability of Fe in the soil and its excessive accumulation in the plant is suspected to be one of the reasons of low fertilizer responsiveness of high yielding genotypes in the state. In the rice plant, Fe is related to the formation of chlorophyll, but is not a constituent of it. It is a possible catalyst in an organic form or combined with organic compounds as a component of redox enzymes and is an inhibitor of the absorption of K by the rice plant. Rice is known to have a particular capacity to exclude Fe from its normal metabolic process by either preventing its absorption from the soil or limiting its accumulation in the roots (Tadano and Yoshida, 1978). It is also known that varieties differ in their potential Fe exclusion power (Ponnamperuma, 1976).

Manganese is another element which occurs in excess concentrations in soils of many parts of the state and which may be as important as Fe in limiting rice productivity. Manganese serves as a factor in photosynthesis and as an activator of several enzymes. When present in interstitial water of soil in large concentrations, Mn is reported to inhibit biomass synthesis (Tate, 1987).

A micronutrient of importance in rice involved in the activation of many enzymatic reactions and in N metabolism is Zn. Salam and Subramanian (1993) reported that Zn application improved grain yields, plant height, tillering, LAI and root growth. Similar results were reported by Tomar *et al.* (1994).

Copper, a micronutrient in rice which functions as a component of metalloenzymes and as a regulator of enzymatic actions, is reported to decrease grain yields when applied at the rate of 40 kg ha^{-1} (Agrawal and Gupta, 1994). However, Zhou *et al.* (1994) observed sterility of rice plants when Cu was deficient. Copper application was seen to inhibit plant growth (Che, 1993).

Silicon is a micronutrient required specifically for rice. On soils low in available silicon, the application of silicon will increase yields of a modern variety at high rates of N fertilizer application (De Datta, 1981). Silicon is essential for normal growth of rice plants. It plays a role in water economy and disease and insect resistance. Wang *et al.* (1994) reported that application of silicon fertilizer increased the plant height, rice grain weight and yield and decreased the *Helminthosporium* leaf spot of rice plants and rice sheath blight disease.

Multilocational trials have shown that many of the high yielding varieties of rice fail to express their yield potential in laterite soils (KAU, 1988). Marykutty *et al.* (1992) found that ratios of elements in tissues and not the absolute levels in tissues or levels of application to soil govern the productivity expression of rice. Thus it appears that the cause of low productivity of rice in laterite soils rests on unbalanced nutrition. Information on the ionic relation to their productivity will help to identify the limiting and promoting nutritional factors on yield on rice. Hasegawa *et al.* (1995) found that K deficiency caused preferential accumulation of Na in leaf sheaths, while Mg and Ca were predominantly distributed into the leaf blades. Sreemannarayana and Sairam (1995) reported that increasing K rate decreased leaf Fe and Mn contents while it increased leaf Zn content slightly. Similarly, Koch and Mengel (1977) showed that K application increased N uptake of rice and N content in the grain. It was observed that the total uptake and percentage translocation of N, P and K by rice increased significantly with increasing levels of K (Singh and Singh, 1987). A similar trend with increasing S rate was noticed by Singh *et al.* (1994). Salam and Subramanian (1993) reported that increasing Zn application resulted in increased contents of P and Zn in the grain but lowered the Ca content. A reverse effect was seen in rice straw. Che (1993) observed that when N is at a high level, Cu can greatly improve N, P, Mg and Cu absorption and N and C metabolism of rice. It can also increase K and Ca absorption. Bridgit *et al.* (1993) reported that a wider N/Fe and S/Fe ratio in leaves and a narrow Fe/P ratio in stems and roots appeared to be the most important factors for obtaining better yield expressions in rice in the iron rich laterite soils of Kerala.

2.4 Integrated nutrient management in rice

Soil organic matter is unquestionably the largest pool of plant nutrients in the world's soil. But, not all the nutrients, whether stimulatory or inhibitory to plant growth, present in soil are available. Since nutrient availability is a major controlling factor in biomass productivity and ecosystem stability, understanding the processes contributing to nutrient exchanges in the soil and arriving at an optimum integration of organic and inorganic nutrient sources becomes necessary. The efficiency of plant biomass synthesis and the rate of return of this biomass to the soil ecosystem also controls ecosystem productivity (Tate, 1987).

In addition to being a source of nutrients, organic matter improves the growth of the rice crop indirectly by way of improving the physico-chemical and microbiological properties of soil. Sahu and Nayak (1971) and Sinde and Ghosh (1971) have highlighted the manifold beneficial effects of the combined application of organic and inorganic manures on soils, rice and environment. Pooled analysis of grain yield data for 25 years generated from a permanent manurial experiment with tall indica rice varieties revealed that during the first crop season (Kharif), the treatment receiving combined application of cattle manure and NPK was significantly superior to others (Anilakumar *et al.*, 1993). Similar results were reported by Pillai and Vamadevan (1978). An experiment on the integrated use of organic, biological and chemical fertilizers in rice and rice-based cropping systems revealed that the contribution of green manure ranged from 45-80 kg N ha^{-1} and that application of farmyard manure (FYM) showed considerable direct and residual effect on crop yields and improved soil fertility (Meelu and Morris, 1984). Tanveer *et al.* (1993) reported that the yield and yield attributing characters of rainy season rice were significantly influenced by the residual effects of farmyard manure, source and level of P. Various experiments studying the effect of bio, organic and chemical fertilizers alone and in combination showed that suplementing chemical fertilizers with bioorganic fertilizers was always superior to chemical fertilizers alone (Saravanan and Ramanathan, 1984; Joseph and Kuriakose, 1985; Mahapatra *et al.*, 1987). Lui *et al.* (1990) explained that the use of organic manures in addition to chemical fertilizer increased soil organic matter and total N, increased the effectiveness of soil P, increased the proportion of soil organisms, especially some bacteria, and increased the activities of soil enzymes such as urease. Organic fertilizers also increased the utilization of N, P and K by rice. Results of a trial supplementing chemical N fertilizer with prickly sesban and blue green algae revealed that the latter had residual effect in increasing the solubility and availability of S present in the soil, thereby effecting more S uptake and higher seed yield (Mohapatra and Jee, 1993). Suzuki *et al.* (1990) studied the effects of continuous application of inorganic or organic fertilizers containing the same amounts of N, P and K on rice soil fertility and rice yields in a 60 year long-term field experiment. They found that the trend of initial lower yields in the organically fertilised plots was gradually reversed.

The use of biofertilizers in integrated nutrient management system to supplement N sources has been long adopted and the efficacy of *Azolla* has been established beyond doubt in this context. *Azospirillum* is a non-symbiotic N fixer used for augumenting rice yields. However, response to *Azospirillum* inoculation varies. Positive responses have been reported by a number of workers. Nayak *et al.* (1986) observed that inoculation increased tiller number; plant height and early reproductive growth as well as grain yield and dry matter yield. Similar results were reported by Jeyaraman and Ramiah (1986), Purushothaman (1988) and Gopalaswamy and Vidhyasekharan (1987). Responses to *Azospirillum* inoculation were higher at lower levels of fertilizer N application (Murali and Purushothaman, 1987; Balasubramanian and Kumar, 1987). It was suggested by Purushothaman *et al.* (1987) that initial growth responses to inoculation might be due more to the secretion of growth promoting substances than to biological N-fixation. Hastuti and Gunarto (1993) reported that inoculation with *Azospirillum* increased growth of low land rice more than upland rice.

Contrary to these reports, Dunigan *et al.* (1983) reported that *Azospirillum* inoculation had little effect on N fixation. A similar result was observed by Dunigan *et al.* (1984) and it was attributed to poor survival of *Azospirillum* in the field.

2.5 Environmental influences on quality of medicinal plants

The active principles in medicinal and aromatic plants are due to the presence of certain secondary metabolites, alkaloids, glycosides, coumarins or steroids in case of medicinal plants and volatile oils containing terpenes or phenols in case of aromatic plants. The secondary metabolites are not directly involved in growth and reproduction and these are perhaps produced by the plants as a bio-chemical adaptation to safeguard or to prevent illness or as defence against predators or adaptation in a particular ecological or edaphic or climatic niche (Pushpangadan, 1992). The biosynthesis of these compounds although controlled genetically is greatly affected by the above environmental factors. A thorough understanding on the reproductive and growth biology of medicinal plants as well as identification of biological and ecological constraints leading to their reduced fitness, restricted distribution or even extinction is therefore, necessary.

In the last three decades, several medicinal and aromatic crops have been introduced in different agroclimatic zones to make better utilization of resources and improve the economics of cultivation. Pareek and Gupta (1993) have suggested that psyllium, senna, periwinkle, rauvolfia, lemongrass, vetiver and palmarosa grass can be grown over low fertility soils and jasmine basil and anise over medium fertility soils. The production of medicinal plants as part of agroforestry system holds a large potential to be utilized (Gupta and Pareek, 1985; Gupta, 1987). Rainfed cultivation is done of a few crops only such as lemongrass in Kerala and asgand in Madhya Pradesh. An endeavour in this direction was carried out by Nair *et al.* (1991) who intercropped 13 medicinal/aromatic plants in a 12 year old coconut plantation and revealed the possibility of growing these plants as intercrop in 8-20 year old coconut plantations, where no other intercrops are usually recommended. In a similar study, Vishwanathan *et al.* (1993) identified 2 promising varieties of patchouli suitable for intercropping in coconut gardens.

Most medicinal and aromatic plants are adapted to a wide range of soil texture and reaction. Palmarosa and vetiver are adapted to grow over shallow soils and are recommended for growing over bunds and contours to control soil erosion and conserve run-off soil moisture (Gupta and Chadha, 1995). Vetiver in particular, is unique for its tolerance to soil alkalinity and periodic flooding and waterlogging of fields; these conditions have been found to decrease root yield but has produced no adverse effect on oil content and oil composition of the root. Patil and Patil (1983) found that increasing salinity reduced the K, Ca, Mg, Zn and Fe in the leaves and roots of *Syzygium cumini*, and increased the content of leaf Na. Dikshit and Pathak (1992) reported that with increasing levels of stress (sodicity and salinity), total free amino acids increased significantly, while protein bound amino acids showed a reverse trend, in Indian gooseberry. A study on the yield and composition of tagetes oil (*Tagetes minuta* L.) revealed that inherent soil deficiencies of N, P and S as responsible for variation in the yield and composition (Graven *et al.*, 1991).

Light intensity plays an important role in affecting yield and quality of medicinal plants. In mints, ample sunshine is necessary at maturity to enable plants to synthesise higher content of oil and menthol (Gupta and Chadha, 1995). Similarly, Pillai and Chinnamma (1994) found that with increasing shade, herbage yield and percentage of oil of clocimum decreased, through the quality of oil was not affected. Contrary to this, in pathchouli, herbage yield and oil content were less in open conditions than under shade (Radhakrishnan *et al.*, 1991). Jayachandran *et al.* (1991) found that the yield of ginger under 50 per cent shade was nearly comparable to that cultivated in open conditions.

Various studies conducted on the effect of water stress on secondary metabolites have revealed that alkaloid and essential oil content generally increase under dry conditons (Yaniv and Palevitch, 1982). The increase of secondary metabolites in plants under limited water supply points towards the possibility of involvement of these compounds in the adaptability to drought conditions. Pareek *et al.* (1991) found that moisture stress conditions in rauvolfia and periwinkle produced longer root, improved root : shoot ratio and produced higher total alkaloid content in the roots. Similar favourable influences on the essential oil content and composition of sweet basil was reported by Simon *et al.* (1992).

The effect of seasonal variation in temperature on flowering in pyrethrum at Kodaikanal hills was investigated by Mohandass *et al.* (1986). They found that plants exposed to lower minimum temperature in the year produced maximum flowering with higher dry matter content and high total pyrethrin content. Seasonal effects on secondary metabolites are seen to be compound specific. Each individual compound has its specific favourite season. In *Catharanthus roseus*, the highest quantity of ajmalicine was obtained during summer, lowest in winter, while total alkaloid was highest in winter, lowest in summer (Sen and Datta, 1986). A completely opposite effect was seen in *Rauvolfia serpentina* with regard to accumulation of alkaloids.

Exhaustive work has been done on fertilizer management in medicinal and aromatic plants. Application of fertilizer, particularly N, was effective in increasing the total yield as well as medicinal component content in most of the cases (Maheshwari *et al.*, 1988; Shetty *et al.*, 1990; Maheswari *et al.*, 1991). However, Pareek and Gupta (1981) reported an increase in grain yield of fenugreek with fertilizer application, but a decrease in diosgenin content. Similar results were noticed in *Hyoscyamus muticus* by Yadav *et al* (1982) and in *Ocimum sanctum* by Dey and Choudhuri (1984).

Sri Vasuki *et al.* (1980) studied the effect of micronutrients and their interactions on growth and alkaloid production in *Catharanthus roseus* and reported a positive influence of Fe, Cu, Zn and B aplication on growth and alkaloid content. Similarly, Fe, Zn and Mn application significantly increased the seed and oil yield of aniseed, but did not affect the physical and chemical parameters of essential oil (Gangrade *et al.*, 1989). In an experiment studying the effect of Mn with Fe and Zn on the yield and nutrient uptake in opium poppy, an antagonism between the levels of Mn and Fe and that of Mn and Zn at higher levels was observed (Anwar *et al.*, 1991).

Use of biofertilizers is a new development which can save on use of inorganic fertilizers in medicinal plant cultivation. Pareek *et al.* (1992) reported that use of *Azotobacter* increased latex, seed and husk yield in opium poppy. Maheswari *et al.* (1991) found increase in herb and oil yield in palmarosa oil grass by use of *Azotobacter* culture used as a slurry dripped near root zone applied together with 80 kg N. An investigation carried out by Mallick *et al.* (1991) revealed that higher levels of leaf mould, FYM and *Azotobacter* increased the shoot and root yield and alkaloid content of ipecac root, and *Azotobacter* proved to be the best among the three. However, Kahar *et al.* (1989) have reported no significant effect of *Azotobacter* culture when used as seed treatment in opium poppy.

Very little work has been done on medicinal rice, its medicinal components and environmental influences on its growth and development, Glutamic acid is reported to be the commonest amino acid in rice husks and grains (Blanco *et al.*, 1984), and electrophoretograms show that all rice types possess similar protein components, although relative amounts of components vary, especially between glutinous and nonglutinous, and between indica and japonica varieties (Kusama *et al.*, 1984). Fernandes (1991) studied the effects of environmental stress on the relationship of free amino-N to fresh weight of rice plants and found that high light or temperature resulted in large amino-N pools, and a negative relationship existed between free amino-N and plant fresh weight. With low light and temperature, amino-N and fresh weight were linearly and positively related.

Material and Methods

3. MATERIAL AND METHODS

Experiments of the research project entitled "Effect of different inputs on productivity and quality relations in *Njavara* (*Oryza sativa*)" were conducted during 1994-96 at the Regional Agricultural Research Station, Pilicode. The details of materials used and methods adopted in the conduct of the experiments as well as evaluation of the results are presented in this chapter.

3.1 Location

The Regional Agricultural Research Station, Pilicode, located at 12° 12' N latitude and 75° 10' E longitude and at an altitude of 15 M above sea level, is situated in North Malabar, 329 km north of Thrissur and 82 km south of the northern border of Kerala State.

3.2 Weather and climate

The experimental area, situated in the narrow strip of land between the sea and the Western Ghats in the monsoonic belt, experiences humid tropical climate. Mean weather data show that the summer is hot, dry and rainless, the dry spell extending from November to May. Most of the mean average rainfall of 3378 mm is concentrated during the months of June, July and August with a mean intensity of 30 mm day^{-1}, which may go up to 200 mm on individual days.

The mean maximum temperature experienced is 32.8°C, while the mean minimum temperature is 20.2°C. Weather conditions prevailing during the experimental period are presented in Appendix I and II and Fig.3.1.a and 3.1.b.

Fig.3.1.a Weekly weather at Pilicode from 1-6-94 to 4-10-94

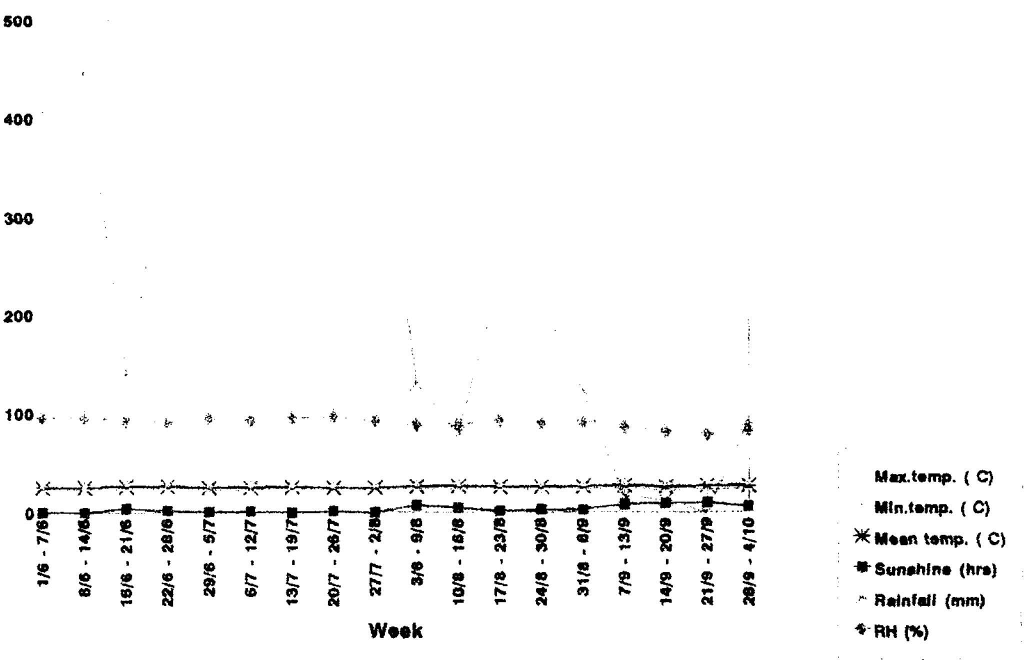


Fig 3.1.b Weekly weather at Pilicode from 7-5-95 to 30-12-95

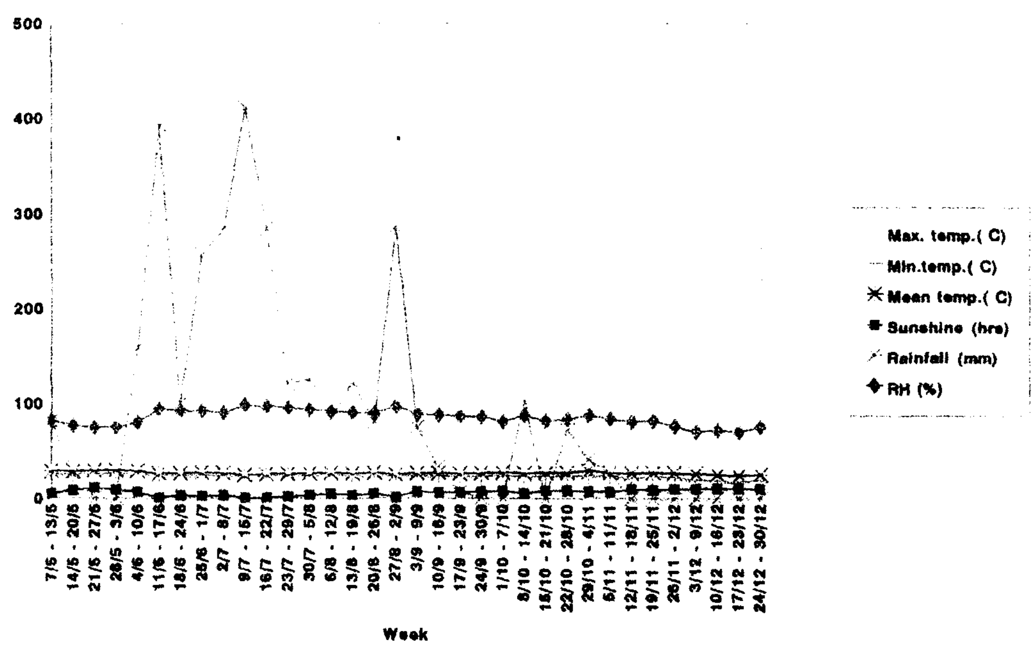


Table 3.1. Physico-chemical properties of the soil of experimental sites

a. Physical properties

	Bulk density g cc^{-1}	Particle density g cc^{-1}	Mechanical composition		
			Sand (%)	Silt (%)	Clay (%)
1. Upland	1.16	2.336	57	9	34
2. Wet land	1.19	2.40	46.5	15	38.5

b. Chemical properties

Site	Soil reaction pH	Electrical conductivity dS m^{-1}	Organic C %	Available P_2O_5 kg ha^{-1}	Available K_2O kg ha^{-1}	DPTA extractable Ca ppm	DPTA extractable Mg ppm	DPTA extractable Fe ppm	DPTA extractable Mn ppm	DPTA extractable Zn ppm	DPTA extractable Cu ppm
1. Wet land	5.2	<0.05	1.11	48	120	88	25	76	3.2	1.5	1.1
2. Open upland	5.3	<0.05	0.91	22	112	39	18	24	4.0	2.0	1.0
3. Coconut garden with 50-70% shade	5.3	<0.05	0.98	18	202	42	16	40	2.0	3.0	0.8
4. Coconut garden with 20-40% shade	5.0	<0.05	0.91	17	291	37	15	37	6.0	3.5	1.0

Table 3.2. Treatment details are provided in Table 3.3. Layout of experimental plots are depicted in Fig.3.2.a, 3.2.b and 3.2.c.

3.7 Crop culture

General principles of upland and lowland rice culture (KAU, 1993a) were followed in the management of all experiments uniformly.

The experimental area was ploughed twice, harrowed and levelled and brought to a weed-free good tilth. The land was laid out as per design of the individual experiments, with strong bunds of 30 x 30 cm separating the plots.

Black glumed *Njavara* seeds were obtained from Regional Agricultural Research Station, Pattambi and those of golden yellow glumed *Njavara* locally from ayurvedic physicians.

In Experiment I (Growth and Development Analysis), where both the types were tested, 24 day old seedling were transplanted from the nursery raised for the purpose, in the case of wetland situation. In upland situation in all the experiments, viable seeds were dry sown by dibbling. During dibbling, spacings of 15 cm (inter row) and 10 cm (intra row) were maintained, in all the experiments.

A basal dose of farmyard manure at the rate of 3 MT ha^{-1} was applied in all the experimental plots uniformly before final ploughing, and incorporated. In addition, the crop was manured with a uniform dose of 40:20:20 kg N, P_2O_5 and K_2O per ha (KAU, 1993a). The entire dose of P was applied basally, while two-third N and K were applied basally and one-third at panicle initiation, by broadcasting. In Experiment III and IV, fertilizers were applied as detailed in Table 3.3. In

Table 3.2. Basic experimental details

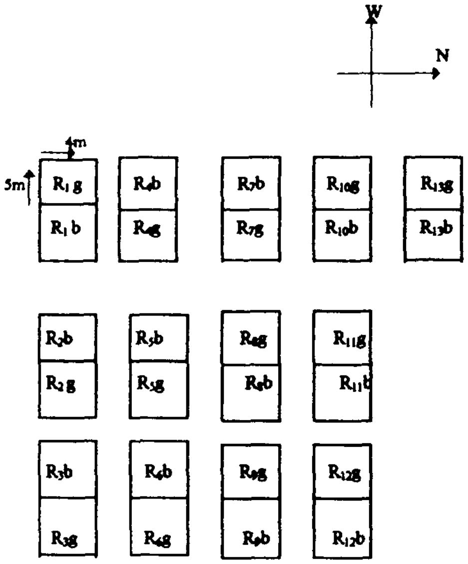
Experiment No.	Title	Design	No.of replication		Plot size(sq.m) Gross	Net
I	Growth and development analysis in *Njavara*	RBD	13	a) In wetland and open upland	20 (5x4)	14.88 (4.4x3.2)
				b) In coconut gardens	20 (5x4)	15.21 (4.4x3.2)
					20 (3.2x6.25)	15.21 (2.6x5.85)
II	Effect of time of sowing on productivity of *Njavara*	Split plot	3		20 (5x4)	14.08 (4.4x3.2)
III	Nutritional management in relation to ionic balance and productivity	$3^3 + 2$ partially confounded design	2		20 (3.2x6.25)	15.21 (2.6x5.85)
IV	Integrated supply of nutrients through organic and inorganic sources	RBD	4		20 (3.2x6.25)	15.21 (2.6x5.85)

Table 3.3. Details of treatments of the experiments

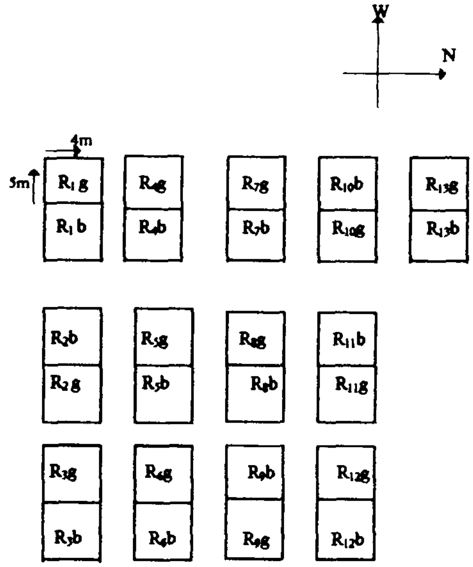
	Experiment I	Experiment II	Experiment III	Experiment IV
1. Treatments	Biotypes-2 Black glumed and golden yellow glumed The experiment was conducted in 4 situations Situations i) Wetland ii) Open upland iii) In coconut garden with 30-50% light infiltration iv) In coconut garden with 60-80% light infiltration (site selection in coconut garden was done as per Nair, 1979)	(1) Main plot treatments -10 10 sowings from May 15th at fortnightly intervals (S_1 to S_{10}) (2) Sub-plot treatments-2 i) Black glumed *Njavara* (b) ii) Golden yellow glumed *Njavara* (g)	Fertilizer levels - Nitrogen Phosphorus and Potassium, each at 15, 30 and 45 kg ha^{-1} (ie., N_0, N_1 and N_2, P_0, P_1 and P_2, K_0, K_1 and K_2 respectively) Control: 1) Standard control (C_1) -3 tonnes FYM ha^{-1} 2) Absolute Control (C_2) - no manure Treatments confounded - NPK^2 in replication 1 and NP^2K^2 in replication II	Nutrient sources 1) 100% N, P and K through fertilisers (T_1) 2)100% N, P and K through organic manure (FYM) (T_2) 3) 75% N through fertilisers and 25% through organic manure (T_3) 4) 50% N through fertilisers and 50% through organic manure (T_4) 5) 75% organic manure + *Azospirillum*, 2 kg ha^{-1} (T_5) 6) 50% organic manure + *Azospirillum* 2 kg ha^{-1} (T_6) 7) 25% organic manure + *Azospirillum* 2 kg ha^{-1} (T_7) Optimum fertiliser dose fixed from Experiment III as 30:30:30 kg NPK ha^{-1} *Azospirillum* was procured from TNAU
2. Total No. of treatment combinations	2	20	29	7
3. Total No. of plots	26	60	66	28

Fig.3.2.a. Layout of experimental plots in Experiment I

Situation I - Wetland



Situation II - Open upland

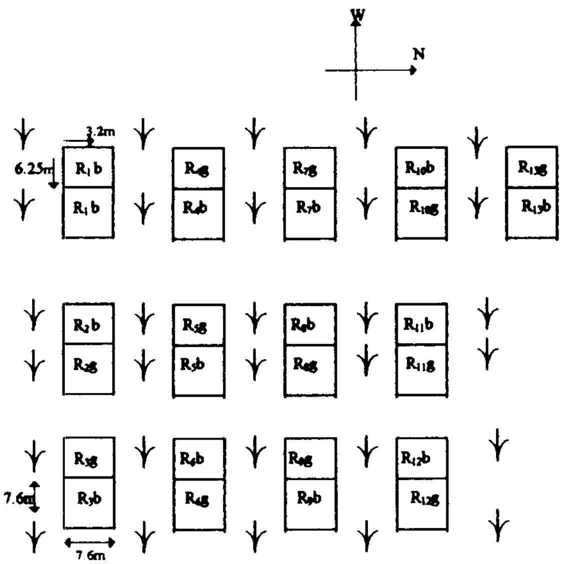


b - Black glumed Njavara

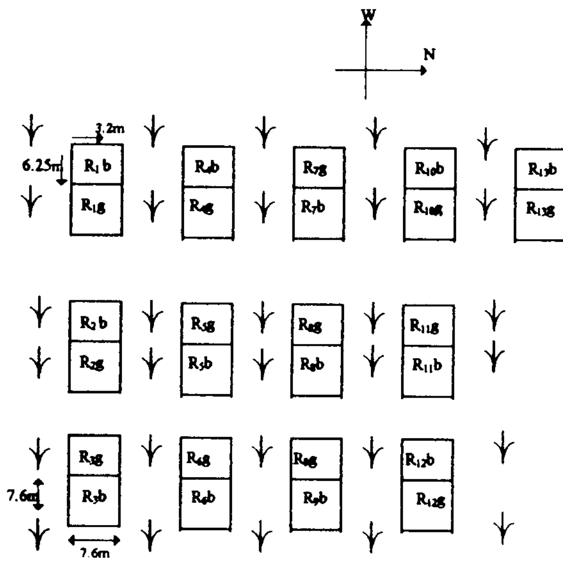
g - Golden yellow Njavara

Continued

Situation III - Coconut garden with 30 - 50% light infilteration



Situation IV - Coconut garden with 60 - 80% light infilteration



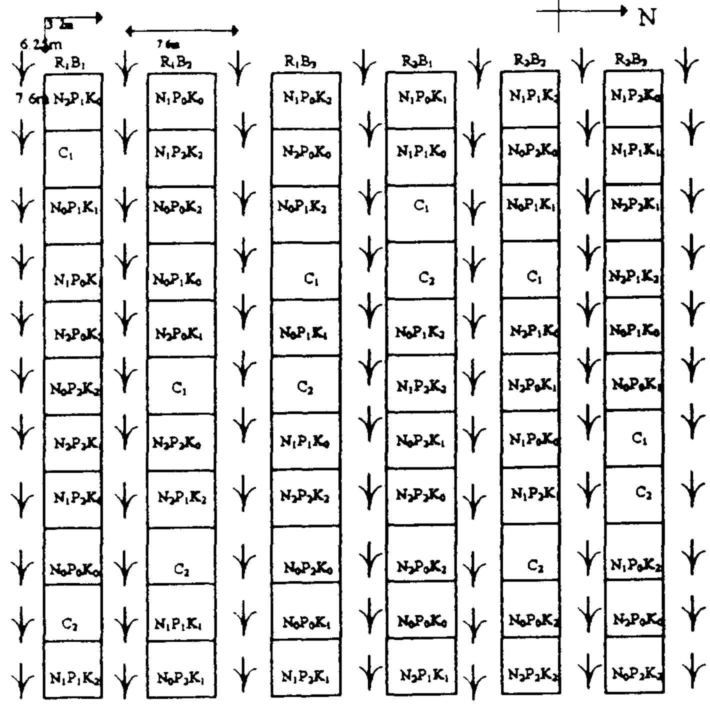
b - Black glumed Njavara

g - Golden yellow Njavara

- Coconut palm

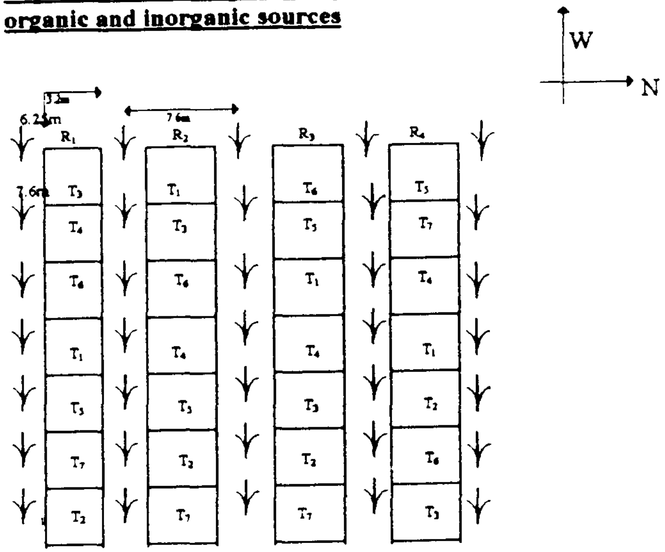
Fig.3.2.c.Layout of experimental plots in Experiments III and IV

Experiment III: Nutritional management in relation to ionic balance and productivity



N_0 , N_1 , N_2 - N levels i.e. 15, 30 and 45 kg ha^{-1}
P_0 , P_1 , P_2 - P levels i.e. 15, 30 and 45 kg ha^{-1}
K_0 , K_1 , K_2 - K levels i.e. 15, 30 and 45 kg ha^{-1}
C_1 - Standard control i.e., FYM at 3 tonnes ha^{-1}
C_2 - Absolute control i.e., no manure
- Coconut palm

Experiment IV: Integrated supply of nutrients through organic and inorganic sources



T_1 - 100 % N, P, K through fertilizers
T_2 - 100 % N, P, K through organic manures
T_3 - 75 % N through fertilizers and 25 % through organic manure
T_4 - 50 % N through fertilizers and 50 % through organic manure
T_5 - 75 % N through organic manure + Azospirillum, 2 Kg ha^{-1}
T_6 - 50 % N through organic manure + Azospirillum, 2 Kg ha^{-1}
T_7 - 25 % N through organic manure + Azospirillum, 2 Kg ha^{-1}

- Coconut palm

all the experiments, fertilizer N was applied in the form of urea, P in the form of mussorie phos and K as muriate of potash.

Throughout the period under study, the crops were treated as rainfed crops and so, no irrigation was done.

All the experimental fields were hand weeded twice, 20 and 45 days after sowing.

In Experiment I (wetland and open upland situation) and Experiment II, Bavistin was sprayed against incidence of blast in the maximum tillering stage. No other plant protection measure was found required.

Dates of sowing and harvesting in the various experiments are tabulated in Table 3.4.

Experimental crops were harvested when matured. Plants in two border rows on all sides of every plot were harvested and removed first. Net plots were harvested by cutting at the base. Threshing was done on the same day and wet yield of grain and straw were recorded. Dry yields of grain and straw on per hectare basis were recorded after sun drying.

3.8 Observations

A. Biometric observations

1. Height of plants (cm)	-	At three stages, viz., maximum tillering, panicle initiation and harvest
2. Tiller count (No./hill)	-	,,
3. Dry matter production (kg ha^{-1})	-	,,

Table 3.4. Sowing and harvesting dates of crops in the experiments

Experiment	Date of sowing	Biotype	Date of harvest	Duration (no. of days)
I. Situation I	11-7-'95	Black	25-9-'95	99
	(Transplanted)	Golden yellow	29-9-'95	103
Situation II	16-6-'95	Black	20-9-'95	94
		Golden yellow	21-9-'95	95
Situation III	15-6-'95	Black	18-9-'95	93
		Golden yellow	27-9-'95	102
Situation IV	17-6-'95	Black	20-9-'95	93
		Golden yellow	26-9-'95	99
II	1-5-'95	Black	31-8-'95	106
		Golden yellow	15-9-'95	120
	30-5-'95	Black	15-9-'95	105
		Golden yellow	18-8-'95	108
	15-6-'95	Black	15-9-'95	90
		Golden yellow	25-9-'95	100
	30-6-'95	Black	18-9-'95	79
		Golden yellow	4-10-'95	94
	15-7-'95	Black	26-10-'95	101
		Golden yellow	2-11-'95	107
	30-7-'95	Black	2-11-'95	92
		Golden yellow	12-11-'95	102
	15-8-'95*	Black	22-11-'95	97
		Golden yellow	22-11-'95	97
III	16-6-'94		24-4-'94	97
IV	19-6-'95		22-9-'95	93

* Crops sown on 30-8-'95, 15-9-'95 and 30-9-'95 failed due to adverse weather situations

4. Productive tillers/hill (No./hill) - At harvest

5. Length of panicle (cm) - ,,

6. No. of grains/panicle - ,,

7. No. of filled grains/panicle - ,,

8. Grain yield (kg ha^{-1})

9. Straw yield (kg ha^{-1})

10. Pest and disease incidence

11. Lodging of plants

B. Physiological observations

(a) Chlorophyll content - Chlorophyll content of index leaves was estimated colorimetrically in a Spectronic-20 spectrophotometer (Yoshida *et al.*, 1972) at panicle initiation, 50 per cent flowering and harvest

(b) Plant sap pH - Plant sap pH was estimated at three stages of growth, viz., at panicle initiation 50 per cent flowering and harvest, using a pH meter. A 1:2.5 leaf sample-water suspension was utilised (Jackson, 1973)

(c) Leaf Area Index (LAI) - Leaf area was recorded at panicle initiation, 50 per cent flowering and harvest using a portable leaf area meter (Model LI-3000 A). LAI was computed using the formula

$$LAI = \frac{\text{Total leaf area}}{\text{Total land area}}$$

C. Chemical observations

Crop samples were dried in a hot air oven, powdered well in a Wiley Mill and analysed for nutrient contents by methods given in Table 3.5. Nutrient ratios were also worked out.

Table 3.5. Methods used for plant chemical analysis

Sl.No.	Nutrient	Method	Reference
1	Nitrogen	Microkjeldahl method	Jackson, 1973
2	Phosphorus	Diacid extract estimated colorimetrically in a Spectronic-20 Spectrophotometer by Vanadomolybdophosphoric yellow colour method	Jackson, 1973
3	Potassium	Diacid extract method using a EEL Flame photometer	Jackson, 1973
4	Calcium	Diacid extract method using atomic absorption spectrophotometer (Perkin Elmer model)	Jackson, 1973
5	Magnesium	,,	,,
6	Sulphur	Turbidimetric using Spectronic-20 spectrophotometer	Hart, 1961
7	Iron	Diacid extract method using atomic absorption spectrophotometer (Perkin Elmer model)	Jackson, 1973
8	Manganese	,,	,,
9	Zinc	,,	,,
10	Copper	,,	,,
11	Aluminium	,,	,,
12	Molybdnenum	,,	,,
13	Silica	Gravimetric estimation on wet ashing in a muffle furnace	Yoshida *et al.*, 1972

D. i) Percentage of filled grains	-	Computed using the number of filled grains and total number of grains per panicle
ii) Grain-straw ratio	-	Computed from grain yield and straw yield
iii) Partitioning co-efficient	-	Computed from grain yield and total dry matter accumulation at harvest
iv) Nutrient uptake	-	Computed from nutrient content and dry matter accumulation at each stage
v) Net assimilation rate	-	Computed from total dry weights and leaf areas of the plants using the procedure given by Watson (1958) as modified by Buttery (1970).

3.9 Observations on *Azospirillum* population in soil

One month after application of *Azospirillum*, bacterial population was observed using dilution plate technique (Skinner *et al.*, 1952).

3.10 Statistical analysis

Sampling unit: Five hills/plot selected at random were used as observational plants for recording biometric observations and chemical analysis. Five other hills were separately selected and used for estimation of chlorophyll and leaf sap pH.

Statistical analysis was done as per design adopted in each experiment using the analysis of variance technique (Panse and Sukhatme, 1978). In Experiment I, each situation was considered as a separate experiment in randomised block design and analysed accordingly (Appendix III to VIII). Other than this, a pooled analysis of the data was attempted as in the case of groups of experiments. When the error variances were heterogeneous and the interaction of situations and treatments were insignificant, a procedure for overall comparison of treatments pooled over situations does not exist. In such cases the critical difference (C.D) has not been given. Yield and nutrient uptake were analysed on per hectare basis. Path coefficient analysis and multiple regression analysis (Singh and Choudhary, 1977) were also done to work out the relationship between yield and yield attributes, nutrients and nutrient ratios, and yield and weather parameters. MSTATC and SPAR I packages were used for computation.

3.11 Qualitative analysis

The grain of *Njavara* types grown in four varying situations in Experiment I were compared with local Chitteni rice. Analysis of free amino acids was done using thin layer chromatography (Sadasivam and Manickam, 1992). Total free amino acids were estimated colorimetrically in a Spectronic 20-D spectrophotometer (Milton Roy Model) according to the procedure suggested by Sadasivam and Manickam (1992).

Results

4. RESULTS

The results of the individual experiments are presented in the following paragraphs.

4.1 EXPERIMENT I

Information was generated on the plant specific characteristics of the *Njavara* types in respect of morphological, physiological, nutritional and productive development, variations between the biotypes as well as the environmental effects on these aspects in this experiment entitled 'Growth and development analysis in *Njavara*'. The results are presented below.

4.1.1 Growth attributes

Data on growth characters of the black and golden types in the four situations are presented in Table 4.1.1. a. The data showed that the golden yellow glumed type was taller than the black glumed at harvest in all the four situations and the differences were significant. The mean increase in height was of the order of 17.62 per cent.

A comparison between wetland and upland (open) situation at panicle initiation stage showed that dwarfer plants were produced in the uplands. Shade from coconut palms tended to produce taller plants and the tendency increased with increasing intensity of shade. But even shade to the extent of 50 to 70 per cent failed to increase the mean height of plants to a level matching that of the wetland

Table 4.1.1.a. Effect of situation and biotype on growth and yield characteristics of *Njavara*

	Height of plant at M.T (cm)	Height of plant at P.I (cm)	Height of plant at harvest (cm)	No.of tillers per hill at M.T	No.of tillers per hill at P.I	No.of tillers per hill at harvest	D.M accumulation at M.T ($kg\ ha^{-1}$)	D.M. accumulation at P.I. ($kg\ ha^{-1}$)	D.M. accumulation at harvest ($kg\ ha^{-1}$)	Grain yield ($kg\ ha^{-1}$)	Straw yield ($kg\ ha^{-1}$)	Grain-straw ratio	No. of productive tillers per hill	Length of panicle (cm)	No. of grains per panicle	No. of filled grains per panicle	Percentage of filled grain per panicle	1000 grain weight (g)
Situation																		
Wet land	59.73	91.70	102.31	5.99	5.11	5.56	1615.37	3483.30	5172.40	2401.27	2770.82	0.91	5.56	19.82	66.39	66.39	89.54	17.42
Open upland	45.27	62.02	85.68	5.00	5.48	5.15	1011.10	2434.59	2588.61	841.83	1746.79	0.47	5.15	19.66	64.86	64.86	86.49	14.62
50-70% shaded upland	63.98	77.31	89.18	3.17	3.76	3.50	851.27	2541.00	2012.82	684.53	1327.42	0.53	3.51	18.92	50.72	43.74	86.99	16.64
20-40% shaded upland	58.89	69.19	89.09	3.37	3.52	4.08	1064.95	2819.20	2083.54	728.82	1354.84	0.54	4.07	20.41	61.89	54.09	86.85	15.94
CD(0.05)	8.58	12.84	3.46	-	NS	NS	152.76	466.61	-	-	213.43	0.06	NS	NS	NS	NS	NS	1.90
Biotype																		
Black	56.24	75.95	84.15	4.43	4.68	4.51	1085.46	2864.08	2263.23	911.55	1351.68	0.61	4.51	17.81	50.19	46.43	86.37	15.52
Golden yellow	57.69	74.16	98.98	4.34	4.25	4.64	1185.88	2724.97	3665.45	1416.67	2248.25	0.62	4.64	21.59	74.74	68.11	88.56	16.79
CD(0.05)	NS	NS	NS	-	NS	NS	NS	NS	-	-	153.73	NS	NS	1.19	3.29	2.75	1.79	NS

NS - Non significant

situation. Thus the situation with 50 to 70 per cent shade recorded 12.27 and 10.31 per cent taller plants in black glumed *Njavara* and 38.62 and 13.07 per cent taller plants in golden yellow glumed type compared to that in open condition and in 20 to 40 per cent shaded condition respectively but its mean height was 24.14 and 6.2 per cent less compared to that of wetland situation for black and golden glumed types respectively.

A scrutiny of the pattern of elongation of the two types revealed that the types significantly differed between themselves in that while golden yellow glumed type continued to elongate till harvest, elongation considerably slowed down after panicle initiation stage in the black glumed type.

The two types differed significantly between themselves in the tiller number per hill at the three growth stages. Number of tillers was also affected by the situation. Though black glumed type recorded higher tiller number per hill at all the three stages in the wet situation, this superiority waned progressively in open upland and upland shaded situations. Thus in open uplands, black glumed type was inferior to golden yellow glumed type at harvest, and in both shaded upland situations, ~ 'den yellow glumed type was significantly superior to the black type at all three stages. Thus black glumed type produced 11.09, 24.89 and 12 per cent more tillers at maximum tillering, panicle initiation and harvest in wetland situation, whereas it was lower by 37.34, 39.29 and 29.68 per cent respectively at the three stages than golden yellow glumed type in the heavily shaded upland situation.

It was seen that the golden yellow type, though produced comparitively fewer tillers, did not manifest any tiller decline at any stage in any situation. In open upland situation, black glumed types declined the tiller number by 57.62 per cent from panicle initiation to harvest. However, in the shaded situation, the crop did not show any tiller decline at any time of observation.

Data presented in Table 4.1.1.a showed that while the difference between biotypes in dry matter accumulation was significant only at the time of harvest, the influence of situations was significant at all the three stages of observation. Wet situation favoured a higher dry matter accumulation at all stages than upland situation. Upland situations did not differ among themselves during maximum tillering and panicle initiation stages,but at the time of harvest, open uplands registered a higher dry matter accumulation compared to upland shaded situations. Thus, wetland situation recorded a mean dry matter accumulation of 1615, 3483 and 5172 kg ha^{-1} at the three stages of growth, which was higher by 59.76, 43.08 and 99.81 per cent than upland open situation, 89.76, 37.08 and 156.97 per cent than heavily shaded upland situation and 51.69, 28.10 and 148.25 per cent that lightly shaded upland situation.

Data on grain yield showed that while upland situations did not differ much among themselves, the wetland situation showed a three fold increase over the other situations. The golden yellow glumed biotype was superior to the black glumed biotype, producing 55.41 per cent more grain (Fig. 4.1.1 and 4.1.2). A similar trend was noticed in straw yield also. When grain-straw ratio was compared, while golden yellow and black glumed biotypes did not differ significantly, variation was seen when situations were considered, with wetland situation showing a much higher grain-straw ratio. When other yield attributes were considered, situations did not differ significantly except in the case of 1000 grain weight, in which the open upland situation was seen to be significantly inferior.

Fig.4.1.1 Grain yield (kg/ha) of Njavara biotypes in different situations

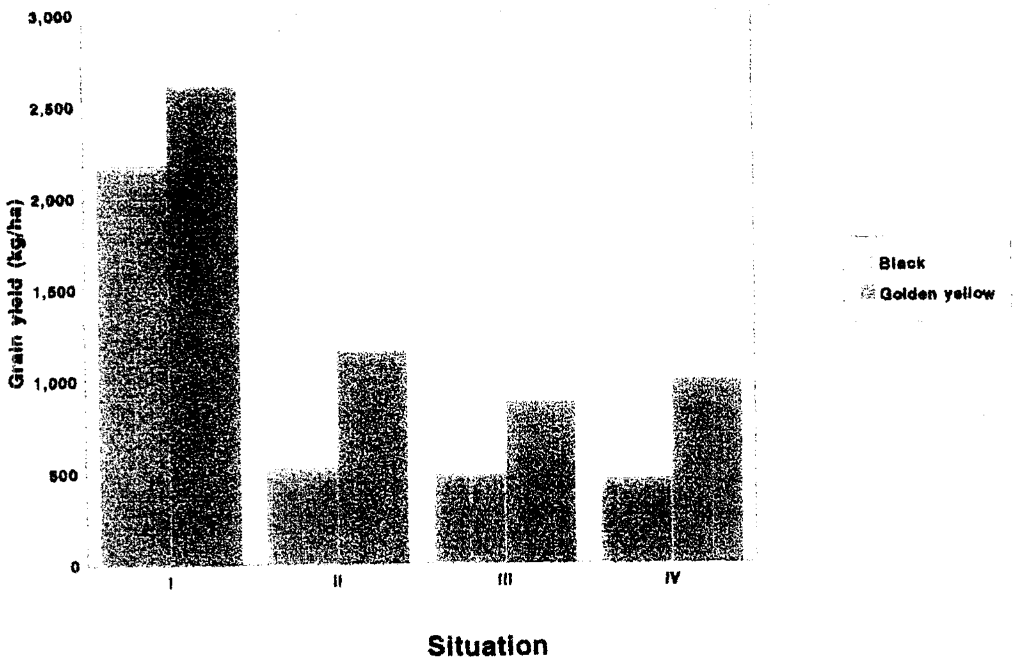
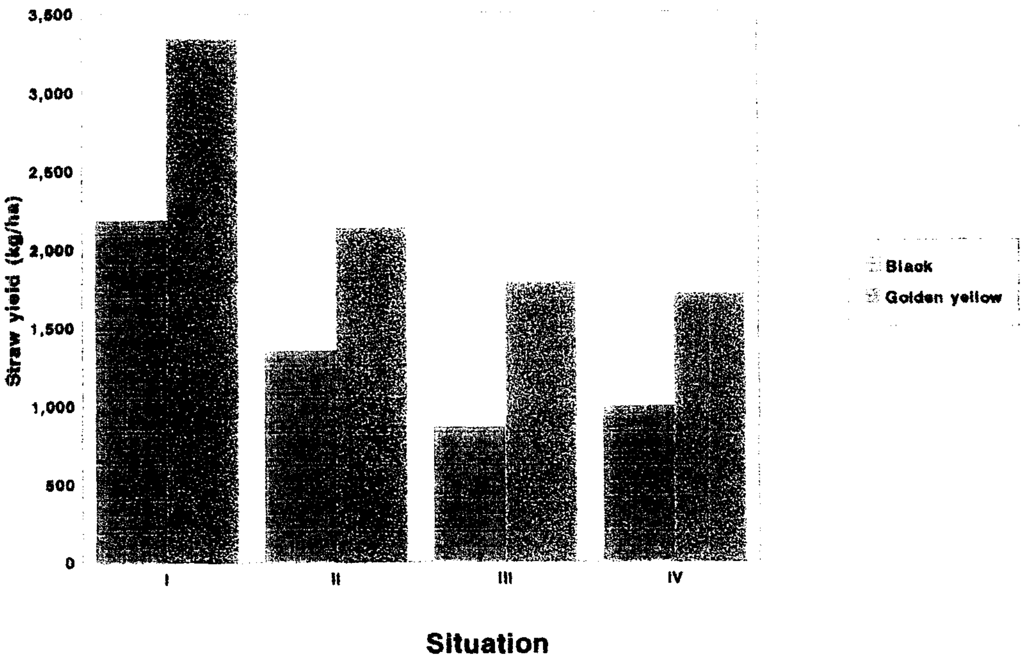


Fig.4.1.2 Straw yield (kg/ha) of Njavara biotypes in different situations



When biotypes were considered, the golden yellow glumed biotype was significantly superior in length of panicle, number of grains per panicle, number of filled grains per panicle and percentage of filled grain.

The interaction effect between biotypes and cropping situation was found significant at maximum tillering stage (Table 4.1.1b). Performance of black glumed biotype was found to be significantly inferior in the upland situation compared to that in wetlands but the upland situations did not differ significantly among themselves. Among the upland situations, poorest performance was in the open situation till panicle initiation stage when the trend was changed, and at harvest, this was found to be better than the shaded situation.

However, in the case of golden yellow glumed biotype, the heavily shaded situation was the poorest at all stages, and the difference compared to open upland situation was significant statistically.

4.1.2 Physiological attributes

Chlorophyll and its constituent components as well as leaf area index (LAI) were found to be affected by the biotypes and situation of plant growth (Table 4.1.2a). The data showed that the black glumed biotype contained significantly higher chlorophyll at panicle initiation and 50 per cent flowering, while at harvest, the golden yellow glumed biotype was found to have higher chlorophyll content.

Among the situations, the lowest chlorophyll content was recorded in the wet situation at panicle initiation and 50 per cent flowering. Among the upland situations, though the open uplands recorded the poorest chlorophyll content at

Table 4.1.1.b. Interaction effect of situation and biotype on growth and yield characteristics of *Njavara*

	Height of plants at M.T (cm)		Height of plants at P.I (cm)		Height of plants at harvest (cm)		Tiller count per hill at P.I		Tiller count per hill at harvest		DM accumulation at MT (kg ha^{-1})		Grain-straw ratio		No.of productive tillers per hill		Length of panicle (cm)		No. of grains per panicle	
	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow
Situation																				
Wet land	63.15	56.31	97.31	86.09	98.03	106.59	5.68	4.54	5.88	5.25	1779.5	1451.3	1.01	0.81	5.88	5.25	17.91	21.73	54.87	77.91
Open upland	41.50	49.02	65.75	58.29	81.82	89.54	6.82	4.14	5.79	4.52	714.5	1307.7	0.39	0.55	6.09	4.52	16.95	22.37	46.48	82.48
50-70% shaded upland	63.22	64.75	73.82	80.80	75.96	102.41	3.32	2.20	2.89	4.11	870.1	830.9	0.56	0.50	2.89	4.12	17.52	20.32	47.19	54.26
20-40% shaded upland	57.09	60.70	66.92	71.46	80.80	97.39	2.89	4.14	3.49	4.66	977.8	1152.1	0.48	0.61	3.48	4.66	18.86	21.96	51.45	72.32
CD(0.05)	12.16		17.86		4.88		3.69		0.71		216.07		9.57		0.77		2.36		6.59	

Table 4.1.2.a Effect of situation and biotype on physiological characteristics of *Njavara*

	Chl.a content at P.I ($mg\ g^{-1}$)	Chl.a content of 50% flowering ($mg\ g^{-1}$)	Chl.a content at harvest ($mg\ g^{-1}$)	Chl.b content at P.I ($mg\ g^{-1}$)	Chl.b content at 50% flowering ($mg\ g^{-1}$)	Chl.b content at harvest ($mg\ g^{-1}$)	Total chlorophyll content at at P.I ($mg\ g^{-1}$)	Total chlorophyll content at 50% flowering (mg g-1)	Total chlorophyll content at harvest (mg g-1)	LAI at P.I	LAI at 50% flowering	LAI at harvest	Cell sap pH at P.I	Cell sap pH at 50% flowering	Cell sap pH at harvest	NAR at harvest ($g\ m^{2}\ day^{-1}$)
Situation																
Wet land	1.05	1.18	0.41	0.31	1.04	0.24	1.32	2.22	0.66	1.09	1.44	0.93	6.12	6.43	6.52	4.18
Open upland	1.17	1.77	0.20	0.56	1.88	0.27	1.72	3.65	0.50	1.32	1.53	0.77	6.08	6.42	6.36	0.37
50-70% shaded upland	1.35	1.55	0.32	0.69	1.68	0.45	2.04	3.22	0.78	1.43	1.12	0.83	6.14	6.43	6.42	-1.17
20-40% shaded upland	1.63	1.68	0.24	1.14	1.62	0.36	2.70	3.30	0.56	1.40	1.29	0.51	6.10	6.39	6.44	-1.66
CD(0.05)	-	-	NS	-	0.11	NS	-	-	NS	-	-	NS	NS	NS	NS	-
Biotype																
Black	1.37	1.64	0.21	0.78	1.76	0.23	2.10	3.39	0.44	1.19	1.29	0.56	6.11	6.40	6.49	-0.41
Golden yellow	1.23	1.45	0.38	0.57	1.35	0.43	1.78	2.80	0.81	1.42	1.40	0.95	6.11	6.43	6.38	1.98
CD(0.05)	-	-	0.11	-	0.09	0.19	-	-	0.09	-	-	NS	NS	0.02	NS	-

panicle initiation, it accounted for the highest content (3.646 mg g^{-1}) at 50 per cent flowering. Net assimilation rate (NAR) was seen to be negative in the shaded upland situations and in the black biotype.

Data on the significant interaction effect of situations and biotypes showed that at harvest, the heavily shaded situation (Table 4.1.2.b) recorded the highest chlorophyll content.

4.1.3 Nutrient content at maximum tillering stage

Percentage contents of nutrients in the plants at maximum tillering stage are given in Table 4.1.3.

1) Effect of biotype

The data showed that the biotypes significantly differed between themselves only in the Mn content of plants. Black glumed biotype recorded a content of 926 ppm Mn which was 13.09 per cent higher than the golden yellow glumed biotype.

2) Effect of situation

Influence of situations on the percentage contents of individual nutrients was significant in respect of all nutrients except S, Mn and Cu. It was seen that the effect of situation was not uniform.

Upland situation with partial shade of coconut (20-40%) had significantly higher N and Fe contents than all other situations. This situation also recorded the highest K content which was significantly superior to wet and open upland

Table 4.1.2.b. Interaction effect of situation and biotype on physiological characteristics of *Njavara*

	Chl.a content at harvest ($mg\ g^{-1}$)		Chl.b content at harvest ($mg\ g^{-1}$)		Chl.a+b content at harvest ($mg\ g^{-1}$)		LAI at harvest		Cell sap pH at harvest	
	Black	Golden yellow	Black	Golden yellow	Black	Golden	Black yellow	Golden	Black	Golden yellow
Situation										
Wet land	0.35	0.48	0.16	0.33	0.52	0.80	0.60	1.26	6.69	6.36
Open upland	0.14	0.27	0.30	0.25	0.47	0.52	0.42	1.11	6.44	6.27
50-70% shaded upland	0.29	0.36	0.28	0.61	0.58	0.97	0.91	0.75	6.41	6.44
20-40% shaded upland	0.07	0.42	0.19	0.52	0.18	0.93	0.32	0.69	6.43	6.44
CD(0.05)	0.26		0.40		0.17		0.80		0.34	

Table 4.1.3. Effect of situation and biotypes on nutrient contents of *Njavara* at maximum tillering

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Situation										
Wetland	0.89	0.16	3.19	0.35	0.19	0.23	425.69	213.62	70.23	5.96
Open upland	1.55	0.39	3.16	0.24	1.31	0.25	613.39	671.27	338.89	17.46
50-70% shaded upland	1.80	0.22	3.59	0.24	0.94	0.32	521.42	1540.85	148.42	10.62
20-40% shaded upland	1.98	0.33	3.75	0.25	1.09	0.24	845.00	1053.46	210.27	12.42
CD(0.05)	0.22	0.05	0.32	0.08	0.05	NS	39.65	-	29.42	-
Biotype										
Black	1.48	0.26	3.40	0.30	0.86	0.24	622.31	920.60	201.65	11.60
Golden yellow	1.62	0.29	3.45	0.25	0.90	0.28	580.54	819.00	182.25	11.64
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	-	NS	-

NS - Non significant

situations. The relative increase in N and Fe contents in partially shaded situation were 122.47 and 98.55 per cent over wet and 27.74 and 37.79 per cent over open upland situation.

Wetland culture gave the highest content of 0.35 per cent Ca, which was significantly superior to all other situations. Mg content of 0.19 per cent in wetland situation was significantly inferior to all other situations.

Open uplands favoured highest accumulation of P, Mg and Zn and was significantly superior to both wetland and coconut shaded upland situations. The corresponding increases were 143.75, 589.47 and 382.54 per cent over wetland and 77.27, 39.36 and 128.33 per cent and 18.18, 20.18 and 16.17 per cent for shaded situations with high and low shade intensities respectively.

Heavily shaded upland open situation favoured highest content of S and this was 39.13 per cent more than that in wetland situation and 28.00 per cent more than that in open upland situation.

3) Interaction effects

The interacting influences between biotypes and situations, differed significantly in specific cases and for different nutrients. The data are presented in Table 4.1.4.

Observations on the interacting influences of biotypes and situation showed that while the wet situation facilitated a significantly higher content of Ca over upland situation, in the case of Mg, the higher accumulation was noticed in the upland situation. Black glumed biotype appeared to have a higher capacity to

Table 4.1.4. Interaction effect of situation and biotype on nutrient contents of *Njavara* at maximum tillering

	Ca (%)		Mg (%)		Fe (ppm)		Zn (ppm)	
	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow
Wet land	0.41	0.30	0.21	0.16	456.60	394.80	75.85	64.62
Open upland	0.27	0.22	1.35	1.27	679.40	547.50	400.31	277.46
50-70% shaded upland	0.27	0.21	0.86	1.03	470.40	572.50	147.77	149.77
20-40% shaded upland	0.24	0.27	1.03	1.16	883.00	807.00	182.69	237.85
CD(0.05)	0.06		0.07		56.09		41.61	

accumulate Ca in wet situation as its increased Ca content over golden yellow glumed type worked out to 36.67 per cent. The data also showed that except for the heavily shaded situation, in all situations the black glumed biotype was significantly superior to golden yellow glumed biotype in accumulation of Mg.

Both the biotypes showed higher percentage content of Zn in open uplands, though black glumed biotype was significantly superior to golden yellow glumed type. In the case of Fe, lightly shaded upland situation recorded the highest content, and the black glumed type was superior.

4) Nutrient uptake

Data presented on nutrient uptake at maximum tillering stage (Table 4.1.5 and Fig.4.1.4) showed that wetland situation was significantly superior in recording higher uptake of Ca to the tune of 139.1 per cent over that in open situation. However, the latter favoured highest uptake of Mg and Zn, while lightly shaded situation favoured Fe uptake. When biotypes were compared, the golden yellow glumed *Njavara* favoured accumulation of all elements except Ca, in which element the black glumed biotype showed an increased uptake by 12.42 per cent.

4.1.4 Nutrient content at panicle initiation stage

Data on nutrient content at panicle initiation are presented in Table 4.1.6.

1) Effect of biotypes

Data presented in the table showed that the biotypes significantly differed in percentage contents of K, Ca, Fe, Mn and Cu. Golden yellow glumed biotype

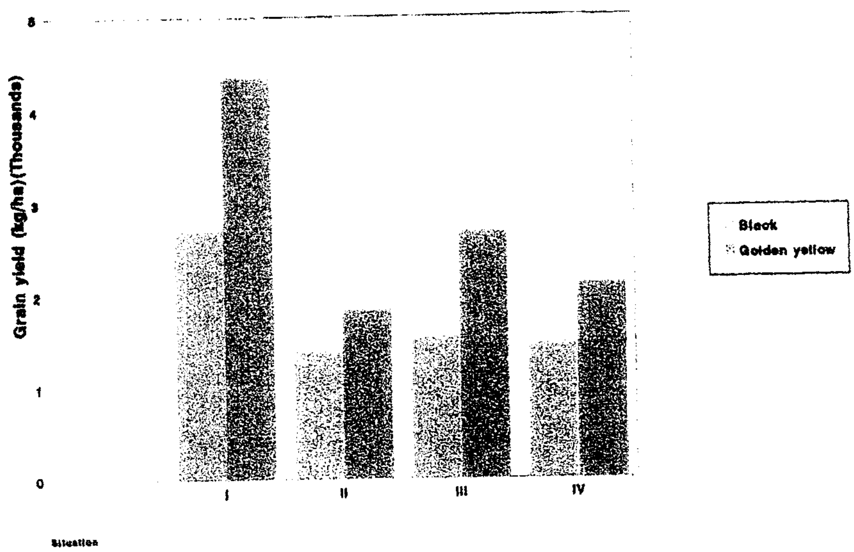
Table 4.1.5. Effect of situation and biotype on nutrient uptake (kg ha^{-1}) of *Njavara* at maximum tillering

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
Situation										
Wetland	13.91	2.37	53.56	5.81	3.07	3.63	0.69	0.35	0.11	0.01
Open upland	16.27	4.20	32.07	2.43	12.76	2.45	0.59	0.61	0.32	0.02
50-70% shaded upland	14.69	1.87	30.51	2.07	8.04	2.72	0.44	1.13	0.13	0.01
20-40% shaded upland	20.88	3.47	40.22	2.70	11.64	2.56	0.90	1.13	0.22	0.01
CD(0.05)	-	-	NS	0.69	1.40	NS	0.26	-	0.03	-
Biotype										
Black	14.64	2.55	37.37	3.44	7.67	2.56	0.64	0.85	0.18	0.01
Golden yellow	18.24	3.40	40.81	3.06	10.09	3.13	0.69	0.86	0.21	0.01
CD(0.05)	-	-	NS	NS	NS	NS	NS	-	NS	-

NS - Non significant

Fig 4.1.3 Grain yield produced per kg of select micronutrients absorbed under different situations

a) Iron



b) Manganese

c) Zinc

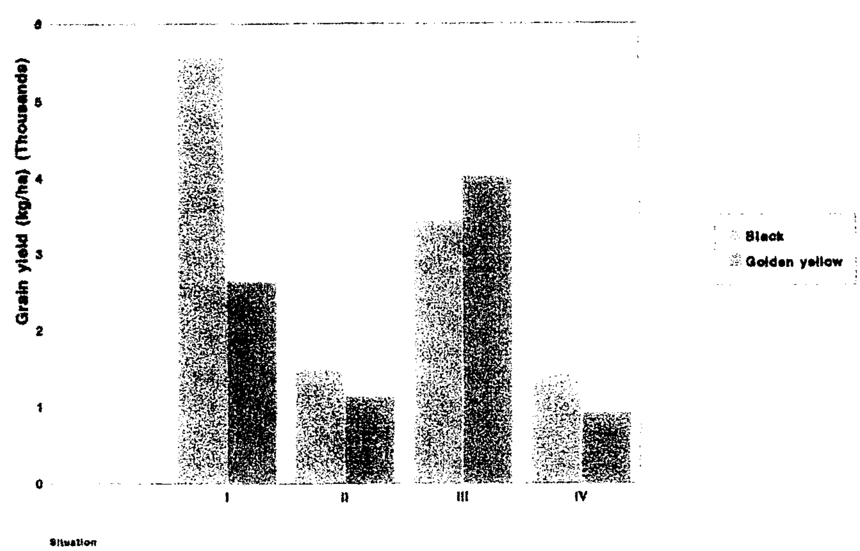
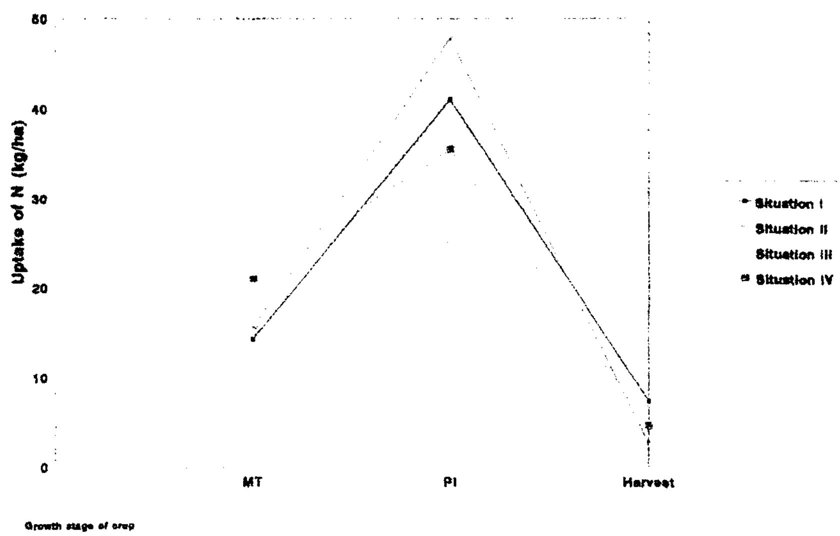
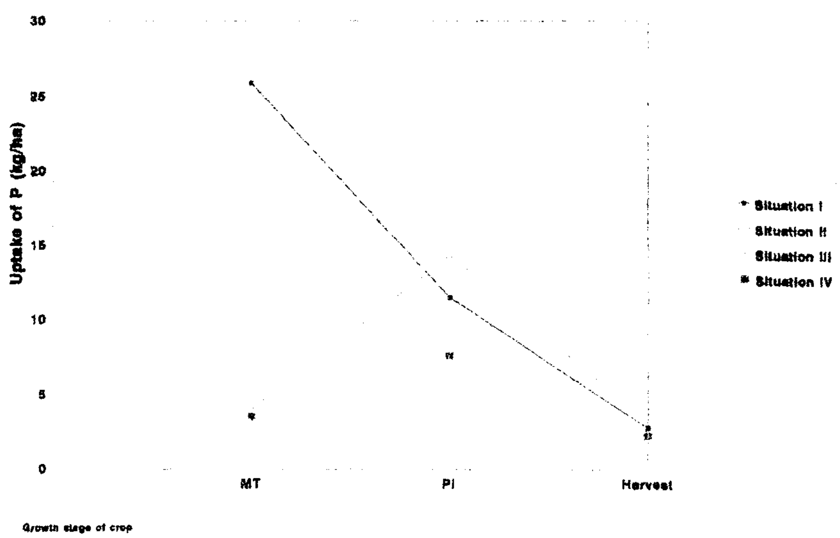


Fig 4.1.4. Mean nutrient uptake pattern of Njavara under different situations

a) Uptake pattern of N



b) Uptake pattern of P



c) Uptake pattern of K

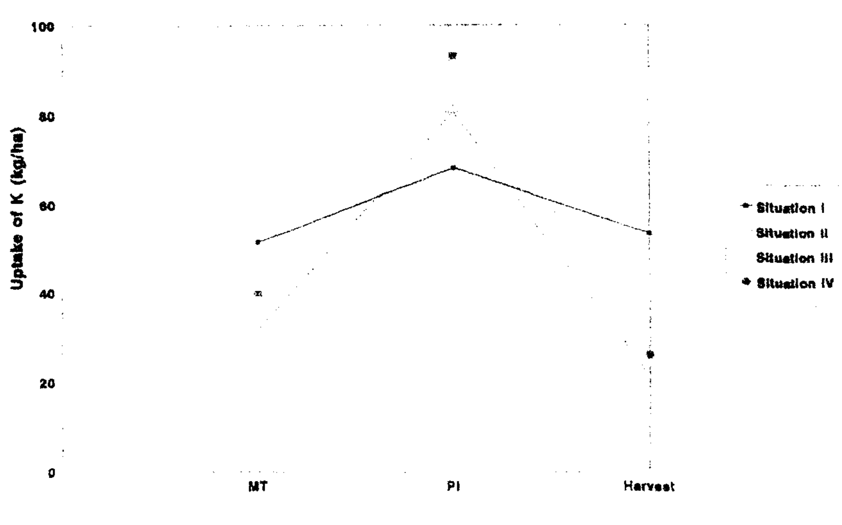


Table 4.1.6. Effect of situation and biotype on nutrient contents of *Njavara* at panicle initiation

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Situation										
Wetland	1.18	0.33	1.96	0.28	0.21	0.07	210.04	281.81	77.15	3.39
Open upland	1.97	0.59	3.32	0.24	1.07	0.21	499.77	415.04	179.58	11.89
50-70% shaded upland	1.39	0.19	3.28	0.15	1.06	0.24	410.62	1475.04	127.35	10.54
20-40% shaded upland	1.31	0.28	3.43	0.21	0.17	0.26	872.69	876.89	208.23	8.19
CD(0.05)	-	-	0.25	0.07	-	-	41.01	179.12	NS	2.49
Biotype										
Black	1.48	0.33	2.77	0.24	0.62	0.21	512.90	793.42	159.25	9.46
Golden yellow	1.45	0.37	3.20	0.20	0.64	0.18	483.65	730.96	136.90	7.54
CD(0.05)	-	-	0.17	NS	-	-	NS	NS	NS	1.76

NS - Non significant

recorded 14.70 per cent higher K content than black glumed biotype, whereas black glumed biotype showed higher content of Cu, and the percentage increase worked out to 25.46 per cent.

2) Effect of situation

Cropping situation significantly influenced the contents of K, Ca, Fe, Mn and Cu. Percentage content of all the nutrients except Ca were lowest in wetland situation. Highest content of Cu was recorded in open uplands and it was 250.74 per cent higher than in the wetlands. K and Fe were found to be highest in the situation of partial shade and the increases worked out to 75.00 and 315.49 per cent respectively, over the wetland situation.

Heavily shaded situation significantly increased the Mn content compared to other situations and the rates of increase were 423.42, 255.40 and 68.21 per cent over wet, open upland and partially shaded upland situations.

3) Interaction effects

It can be seen from Table 4.1.7 that the difference in response of black and golden yellow glumed biotypes to differential environments assumed significant levels in the case of Ca. Ca content was lowest in both biotypes in the heavily shaded situation.

Interaction effect of situations and biotypes reached significant levels in the case of Fe, Mn, Zn and Cu. Golden yellow glumed biotype had a significantly higher content of Fe and Mn in open uplands. In shaded upland situations, black glumed biotype recorded a higher Fe content irrespective of shade level, but in the

Table 4.1.7. Interaction effect of situation and biotype on nutrient contents of *Njavara* at panicle initiation

	Ca (%)		Fe (ppm)		Mn (ppm)		Zn (ppm)		Cu (ppm)	
	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow
Wet land	0.28	0.27	223.08	197.00	289.00	274.62	77.31	77.00	3.69	3.08
Upland	0.20	0.29	441.31	558.23	343.31	486.77	240.62	118.54	12.00	11.69
50-70% shaded upland	0.18	0.11	463.00	358.23	1830.46	1119.62	133.46	121.23	11.85	9.23
20-40% shaded upland	0.20	0.20	924.23	821.15	710.92	1042.85	185.62	230.85	10.23	6.15
CD (0.05)	0.10		57.99		253.33		39.50		3.52	

case of Mn, black glumed biotype registered its superiority only in densely shaded situation. Thus while golden yellow glumed biotype had increased Fe and Mn contents by 26.49 and 41.79 per cent over black glumed type in open uplands, the increase in the contents of these elements in the black glumed biotype worked out to 129.35 and 63.49 per cent more than that in the golden yellow glumed biotype in heavily shaded upland situation. Both biotypes recorded highest Cu content in open upland situation while in the case of Zn, black recorded higher content in open upland and golden yellow type in lightly shaded situation.

4) Nutrient uptake

By panicle initiation, uptake of nutrients by *Njavara* showed a changing trend, with the lightly shaded situation registering highest uptake of K, S, Fe and Zn (Table 4.1.8 and Fig.4.1.4). Open situation showed highest uptake of N and P, the values being 16.69 and 24.99 per cent higher than that in wetland situation, respectively. Wetland situation was superior in Ca uptake, while heavily shaded situation took the lead in Mn uptake. When biotypes were compared, a changed trend was again detected, with golden yellow glumed *Njavara* showing higher uptake of only P, K and Mg, the increases being 6.67, 9.12 and 3.7 per cent respectively over black glumed type.

4.1.5 Nutrient content of straw at harvest

Results of the experiment, presented in Table 4.1.9, showed that the composition of the straw was affected by the biotypes, cropping situation as well as the interaction between the two.

Table 4.1.8. Effect of situation and biotype on nutrient uptake (kg ha^{-1}) of *Njavara* at panicle initiation

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
Situation										
Wetland	40.24	11.41	68.05	9.57	7.15	2.34	0.73	0.98	0.27	0.01
Open upland	47.59	14.45	81.33	5.83	26.18	5.22	1.22	1.03	0.42	0.03
50-70% shaded upland	34.89	4.64	81.26	3.02	26.58	6.15	1.04	3.71	0.32	0.03
20-42% shaded upland	36.08	7.33	94.17	5.80	4.69	7.41	2.37	2.40	0.59	0.02
CD(0.05)	-	-	16.13	2.22	-	-	-	NS	NS	NS
Biotype										
Black	40.54	8.93	76.13	6.87	15.86	5.71	1.37	2.11	0.42	0.03
Golden yellow	38.86	9.98	86.28	5.62	16.44	4.85	1.32	1.95	0.37	0.02
CD(0.05)	-	-	NS	NS	-	-	-	NS	NS	NS

NS - Non significant

Table 4.1.9. Effect of situation and biotype on nutrient contents of *Njavara* straw of harvest

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Situation										
Wetland	0.27	0.10	1.93	0.37	0.17	0.05	253.58	268.50	94.08	0.00
Open upland	0.16	0.18	1.21	0.34	0.94	0.07	170.19	405.23	235.15	11.58
50-70% shaded upland	0.23	0.17	1.87	0.27	0.74	0.12	306.58	1752.00	104.35	5.89
20-40% shaded upland	0.35	0.17	1.93	0.27	0.83	0.08	236.58	395.31	355.31	8.54
CD(0.05)	0.09	0.03	0.15	NS	0.07	-	29.00	29.90	NS	3.29
Biotype										
Black	0.28	0.16	1.67	0.34	0.73	0.07	266.02	765.62	144.56	6.81
Golden yellow	0.22	0.15	1.80	0.29	0.61	0.08	217.44	644.90	249.89	6.19
CD(0.05)	NS	NS	0.11	NS	NS	-	20.48	28.20	NS	NS

NS - Non significant

1) Effect of biotype

Data on the elemental composition of the straw showed that the black glumed biotype contained significantly higher contents of Fe and **Mn**, and the percentage increases were 22.34 and 18.72 per cent respectively over golden yellow glumed biotype.

2) Effect of situation

Elemental composition of straw was significantly influenced by the cropping situation. Wetland situation recorded the lowest percentage content of P, Mg, Mn and Cu, and compared to open uplands the corresponding decreases were 44.44, 81.91, 33.74 and 100.00 respectively.

Open uplands recorded the lowest contents of N and K and the lightly shaded upland situation gave the highest contents, which were 118.75 and 59.50 per cent higher than the former.

Highest contents of Fe and Mn were recorded in heavily shaded upland situation which were 20.90 and 552.51 per cent higher than that of the wetland situation. Mg content was highest in the open upland situation.

3) Interaction effects

Significant variation in the elemental composition of straw (presented in Table 4.1.10) due to the interacting influence of biotype and situation was noticed in the case of N, Ca, Mg, Mn, Zn and Cu.

Positive response of biotypes to cropping situation was noticed in respect of N and Ca in wetland and open upland situations respectively, Mg and Cu in open upland situation, Mn in heavily shaded and Zn in lightly shaded upland situations.

An observation of the results also show that the black glumed biotype was more subject to environmental influence than the golden yellow glumed biotype.

4) Nutrient uptake

S and Mn uptake were highest in densely shaded situation (Table 4.1.11 and Fig.4.1.4). Golden yellow glumed *Njavara* exhibited a superiority in uptake of all nutrients.

4.1.6 Nutrient content of grain

1) Effect of biotype

Data on the elemental composition of grain, presented in Table 4.1.12 showed that the grain of golden yellow glumed biotype was richer in Mg and Si contents. Grains of the two biotypes did not significantly differ in the content of any other nutrient.

2) Effect of situation

Cropping situation significantly affected the nutrient content of the grains in respect of N, Mg, Fe and Zn.

Upland open situation gave the highest contents of Fe and Zn in the grain and they were significantly superior to all other situations. Highest contents of N and Mg were recorded in upland heavily shaded situation. Fig. 4.1.3 depicts grain yield produced per kg of select micronutrients, viz., Fe, Mn and Zn, absorbed under different situations.

Table 4.1.11. Effect of situation and biotype on nutrient uptake (kg ha^{-1}) of *Njavara* straw at harvest

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
Situation										
Wetland	7.11	2.77	53.87	10.54	4.73	1.42	0.70	0.74	0.26	-
Open upland	2.84	3.03	21.40	5.81	15.78	1.24	0.30	0.69	0.45	0.02
50-70% shaded upland	3.09	2.33	24.67	3.12	9.45	1.51	0.39	2.29	0.14	0.01
20-40% shaded upland	4.58	2.30	26.71	3.66	11.69	1.06	0.32	0.48	0.54	0.01
CD(0.05)	-	NS	-	-	-	0.33	-	0.27	NS	NS
Biotype										
Black	3.84	2.04	22.84	4.72	8.57	0.91	0.36	0.83	0.19	0.01
Golden yellow	4.97	3.17	40.48	6.84	12.25	1.71	0.49	1.27	0.50	0.01
CD(0.05)	-	0.43	-	-	-	0.24	-	NS	0.08	NS

NS - Non significant

Table 4.1.12. Effect of situation and biotype on nutrient contents of *Njavara* grain

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Si (ppm)
Situation											
Wetland	1.27	0.28	0.30	0.10	0.13	0.06	61.77	39.69	72.73	6.00	1.30
Open upland	1.29	0.81	0.23	0.06	0.36	0.06	234.12	65.50	287.08	7.12	1.45
50-70% shaded upland	1.85	0.34	0.28	0.07	0.67	0.07	70.12	112.85	80.69	5.08	1.48
20-40% shaded upland	1.42	0.22	0.27	0.21	0.58	0.05	107.58	151.23	220.69	5.31	1.60
CD(0.05)	0.34	-	-	NS	0.04	-	17.92	-	28.06	-	-
Biotype											
Black	1.57	0.41	0.26	0.12	0.37	0.06	113.79	103.65	175.67	5.71	1.31
Golden yellow	1.35	0.41	0.28	0.10	0.50	0.06	123.00	80.98	154.92	6.04	1.61
CD(0.05)	NS	-	-	NS	0.03	-	NS	-	NS	-	0.18

NS - Non significant

3) Interaction effects

Interaction between biotype and situation had significant influence on the elemental composition of the grain (Table 4.1.13). Data showed that the black glumed biotype gave a significantly higher content of N in heavily shaded situation than the golden yellow glumed biotype while the latter showed significantly higher content of Fe and Cu in open upland situation. Highest Ca content and lowest Mg content was seen in the lightly shaded upland and wetland situations respectively while black glumed *Njavara* biotype recorded the highest Zn content of 344 ppm in the grain in the open upland situation.

4) Nutrient uptake of *Njavara* grain

Table 4.1.14 and Fig. 4.1.4 showed that the *Njavara* grain in wetland situation recorded highest uptake of N, K, Ca, S, Cu and Si. The latter situation recorded highest values of 7.01, 0.20 and 0.22 kg ha^{-1} of P, Fe and Zn respectively. Mg uptake was highest in heavily shaded situation and Mn in lightly shaded situation. As in the case of straw, between biotypes, golden yellow glumed *Njavara* recorded higher uptake of all nutrients studied. Data on total nutrient uptake by *Njavara* grain and straw, and difference in uptake between harvest and panicle initiation are given in Tables 4.1.15 and 4.1.16.

4.1.7 Duration of crops

Data on the observations on duration (Table 3.4) showed that the biotypes differed in duration. Time of crop commencement also affected the variation. The maximum duration of 93 days for the black glumed and 102 days for the golden

Table 4.1.13. Interaction effect of situation and biotype on nutrient contents of *Njavara* grain

	N (%)		Ca (%)		Mg (%)		Fe (ppm)		Zn (ppm)		Cu (ppm)	
	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow
Wet land	1.31	1.23	0.08	0.12	0.10	0.17	77.15	46.38	73.62	71.85	6.62	5.39
Open upland	1.34	1.25	0.07	0.05	0.34	0.37	212.23	256.00	344.85	229.31	6.08	8.15
50-70% shaded upland	2.13	1.56	0.04	0.10	0.55	0.79	43.55	96.69	91.54	69.85	5.54	4.62
20-40% shaded upland	1.48	1.35	0.29	0.14	0.48	0.67	122.23	92.92	192.69	248.69	4.62	6.00
CD(0.05)	0.47		0.05		0.05		25.33		39.67		3.32	

Table 4.1.14. Effect of situation and biotype on nutrient uptake (kg ha^{-1}) of *Njavara* grain

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Si
Situation											
Wetland	30.40	6.65	7.45	2.40	3.32	1.37	0.14	0.09	0.17	0.01	32.10
Open upland	10.78	7.01	1.96	0.45	3.04	0.54	0.20	0.05	0.22	0.006	12.40
50-70% shaded upland	11.87	2.31	1.95	0.56	4.89	0.49	0.05	0.07	0.05	0.003	10.52
20-40% shaded upland	10.04	1.59	1.95	1.34	4.53	0.35	0.07	0.11	0.16	0.004	11.83
CD(0.05)	-	1.08	-	0.22	NS	0.07	NS	NS	0.02	11.56	-
Biotype											
Black	13.17	3.40	2.50	0.92	2.18	0.57	0.09	0.07	0.12	0.005	10.79
Golden yellow	18.37	5.38	4.15	1.46	5.71	10.81	0.15	0.09	0.19	0.008	22.64
CD(0.05)	-	NS	-	NS	0.33	0.05	NS	NS	0.03	NS	-

NS - Non significant

Table 4.1.15. Effect of situation and biotype on total nutrient uptake (kg ha^{-1}) of *Njavara* at harvest

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
Situation										
Wetland	37.51	9.42	61.32	12.94	8.05	2.79	0.84	0.83	0.43	0.01
Open upland	13.62	10.04	23.36	6.26	18.82	1.78	0.50	0.74	0.67	0.026
50-70% shaded upland	14.96	4.64	26.62	3.68	14.34	2.00	0.44	2.36	0.19	0.013
20-40% shaded upland	14.62	3.89	28.66	5.08	16.22	1.41	0.39	0.59	0.70	0.014
CD(0.05)	-	-	-	-	-	0.40	-	NS	NS	NS
Biotype										
Black	17.01	5.44	25.34	5.64	10.75	1.48	0.45	0.90	0.31	0.015
Golden yellow	23.34	8.55	44.63	8.30	17.96	2.52	1.09	1.36	0.69	0.018
CD(0.05)	-	-	-	-	-	0.29	-	NS	0.007	NS

NS - Non significant

Table 4.1.16. Effect of situation and biotype on difference in nutrient uptake (kg ha^{-1}) from panicle initiation to harvest

Treatment	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
Situation										
Wetland	-2.73	-1.99	-6.73	+3.37	+0.90	+0.45	+0.11	-0.15	+0.16	0
Open upland	-33.97	-4.41	-57.97	+0.43	-7.32	-3.44	-0.72	-0.29	+0.25	-0.004
50-70% shaded upland	-19.93	0	-54.64	+0.66	-12.24	-4.15	-0.60	-1.35	-0.13	-0.017
20-40% shaded upland	-21.46	-3.44	-65.51	-0.74	-11.53	-6.00	-1.98	-1.81	+0.11	-0.006
Biotype										
Black glumed	-23.53	-3.49	-50.79	-1.23	-5.11	-4.23	-0.92	-1.21	-0.11	-0.015
Golden yellow glumed	-15.52	-1.43	-41.65	+2.68	+1.52	-2.33	-0.23	-0.59	+0.32	-0.002

yellow glumed biotype was observed when the crops were sown in heavily shaded situation.

4.1.8 Path coefficient analysis

Path coefficient analysis averaged over situations and biotypes were done for dry matter accumulation and yield of grain using parameters of yield and the data on direct and indirect effects are presented in Table 4.1.17.a and 4.1.17.b.

It shall be seen from the data on the direct and indirect effects of yield attributes on dry matter accumulation that number of productive tillers per hill and number of filled grains per panicle had the maximum effect. Indirect effects in all cases were found to be very marginal. It can also be seen that the residual value was 0.589 which indicated that the parameters selected which included all the components expected to be available at harvest could explain only 41 per cent of the yield of dry matter.

From the data on direct and indirect effects on grain yield of *Njavara* it can be seen that the pattern was similar. Among yield components number of filled grains per panicle had the maximum contribution and 1000 grain weight, the minimum. Here also these components could explain only 41 per cent of the yield as the residual value of 0.59 indicated.

As the biometric yield attributes failed to satisfactorily explain the yield of dry matter accumulation and grain yield, efficacy of nutritional characteristics were tested and the data on path coefficient analysis for direct and indirect effects as well as the functional model for dry matter accumulation and yield are presented in Tables 4.1.18 and 4.1.19.

Table 4.1.17.a. Direct and indirect effects of yield attributes on dry matter accumulation of *Njavara* at harvest

	No. of productive tillers	Length of panicle	No. of filled grains per panicle	1000 grain weight	Correlation coefficient
No. of productive tillers	**0.377**	0.005	0.061	-0.057	0.386
Length of panicle	-0.025	**-0.083**	0.419	0.049	0.360
No. of filled grains per panicle	0.048	-0.073	**0.481**	0.042	0.498
1000 grain weight	-0.088	-0.017	0.083	**0.244**	0.222

Residual path value : 0.5899
R^2 : 0.65

Table 4.1.17.b. Direct and indirect effects of yield attributes on grain yield of *Njavara*

	No. of productive tillers	Length of panicle	No. of filled grains per panicle	1000 grains weight	Correlation coefficient
No. of productive tillers	**0.389**	0.014	0.068	-0.069	0.402
Length of panicle	-0.025	**-0.220**	0.467	0.060	0.282
No. of filled grains per panicle	0.049	-0.192	**0.536**	0.051	0.444
1000 grain weight	-0.090	-0.045	0.092	**0.299**	0.256

Residual path value : 0.5908
R^2 : 0.65

Table 4.1.18. Functional model of dry matter accumulation in *Njavara* averaged over situations and biotypes

Model: y = -152.66 + 2.101 x1** + 758.375 x2 + 200.056 x3 - 36.053 x4

Direct and indirect effects of dry matter accumulation determing factors

	Grain yield (x1)	P content at PI (x2)	K content at PI (x3)	Ca/Fe ratio at MT (x4)	Correlation coefficient
Grain yield (x1)	**1.060**	0.001	-0.059	-0.043	0.968
P content at PI (x2)	0.008	**0.096**	-0.010	-0.004	0.09
K content at PI (x3)	-0.603	-0.010	**0.104**	0.049	-0.46
Ca/Fe ratio at MT (x4)	0.622	0.005	-0.070	**-0.073**	0.484

Residual path value : 0.0583
R^2 : 0.99

Table 4.1.19. Functional model of grain yield in *Njavara* averaged over situations and biotypes

Model:

$$y = 863.38 + 0.315\ x_1^{**} + 28.944\ x_2 + 2.468\ x_3 - 220.031\ x_4^{*} - 0.136\ x_5^{*} - 4.905\ x_6 - 342.07\ x_7 - 67.448\ x_8 - 522.741\ x_9^{*} - 0.671\ x_{10}^{*} - 13.838\ x_{11}$$

Direct and indirect effect of grain yield determining factors

	Dry mater accumu-lation (x_1)	No. of product-ive tillers (x_2)	No. of filled grain per panicle (x_3)	Mg content at M.T (x_4)	Mn content at M.T (x_5)	Cu content at M.T (x_6)	P content at P.I (x_7)	K content at P.I (x_8)	S content at P.I (x_9)	Zn content at P.I (x_{10})	Cu content at P.I (x_{11})	Correlation coefficient
Dry matter accumulation (x_1)	**0.624**	0.021	0.025	0.083	0.065	-0.041	-0.008	0.032	0.050	0.035	0.073	0.959
No.of productive tillers (x_2)	0.241	**0.055**	0.006	0.025	0.043	0.070	-0.036	0.024	0.016	-0.001	-0.041	0.402
No.of filled grain per panicle (x_3)	0.311	0.007	**0.050**	0.006	0.038	-0.057	-0.010	-0.005	0.027	0.010	0.067	0.444
Mg content at M.T (x_4)	-0.401	-0.011	-0.003	**-0.129**	-0.042	-0.010	-0.015	-0.050	-0.035	-0.037	-0.018	-0.751
Mn content at M.T (x_5)	-0.441	-0.026	-0.021	-0.059	**-0.092**	0.008	0.035	-0.035	-0.042	-0.016	-0.036	-0.725
Cu content at M.T (x_6)	-0.077	0.012	-0.009	0.004	-0.002	**0.334**	-0.049	0.018	-0.050	-0.018	-0.301	-0.138
P content at P.I (x_7)	0.056	0.023	0.006	-0.022	0.038	0.190	**-0.086**	0.007	-0.019	-0.014	-0.171	0.008
K content at P.I (x_8)	-0.287	-0.019	0.003	-0.093	-0.046	-0.084	0.009	**-0.070**	-0.019	-0.021	0.057	-0.57
S content at P.I (x_9)	-0.396	-0.011	-0.017	-0.056	-0.048	0.211	-0.020	-0.017	**-0.079**	-0.034	-0.210	-0.677
Zn content at P.I (x_{10})	-0.337	0.001	-0.008	-0.074	-0.023	0.092	-0.019	-0.023	-0.043	**-0.064**	-0.094	-0.592
Cu content at P.I (x_{11})	-0.147	0.007	-0.011	-0.008	-0.011	0.327	-0.048	0.013	-0.054	-0.020	**-0.308**	-0.26

Residual path value : 0.059
$R^2 = 0.99$

Data on dry matter accumulation showed that nutritional parameters with grain yield could explain almost fully the dry matter accumulation. Direct effects on dry matter accumulation were marginal. Among the affecting factors, the effect of K and Ca/Fe ratio at maximum tillering stage were most pronounced. Effect of K was negative and that of Ca/Fe ratio was positive.

General functional model of grain yield of the *Njavara* crop averaged over situation and biotypes derived from step wise regression of 26 observations is presented in Table 4.1.19.

It can be seen that 11 factors are involved in the process. Among conventionally applied elements, N was not involved in the yield process. Role of P and K had been marginal. Native non-applied elements alone had significant effect. At maximum tillering stage Mg and Mn alone affected growth and though their direct effect had been small at this stage, their effect had been through the indirect effect on dry matter and sum of direct and indirect effects had been highly negative and significant.

Cu manifested a positive direct effect at maximum tillering stage which turned negative at panicle initiation stage.

Zn and S contents negatively correlated with yield expression. Here again it shall be seen that the direct effect was negligible and the negative net effect had been through the indirect effects on dry matter and contents of other elements.

4.1.9 Quality aspects of *Njavara* grain

Amino acid content

Data on total free amino acid content and probable amino acids present in *Njavara* grain are presented in Table 4.1.20. It can be seen that black glumed *Njavara* contained higher amounts of free amino acids in all the four situations, the maximum content being in heavily shaded upland condition. However, the highest content in golden yellow glumed *Njavara* was seen in open upland situation. In the other three situations, the content was even less than that in Chitteni variety of rice. The probable amino acids present in the grain, identified by thin layer chromatography are presented in the table and in Plates 1, 2, 3 and 4.

4.1.10 Lodging

It was observed that the black glumed *Njavara* biotype in all four situations lodged by harvest. However golden yellow glumed *Njavara* exhibited lodging tendency only to a small extent, mainly in the wetland situation. In the upland conditions, lodging was minimal.

4.1.11 Insect pests and diseases

Insect pest attack was not a problem during the course of the experiment. However, an interesting observation was that medium infestation of blast was seen only in the black glumed biotype in the wetland situation. A lower level of incidence was seen in the black glumed biotype in open upland situation also. The shaded situations were free from disease incidence.

Table 4.1.20. Total free amino acid content and some probable amino acids present in *Njavara* as compared to Chitteni grain

Situation	Amino acids identified	Total free amino acid content, mg/g
I. Black glumed *Njavara*		
1. Wetland	DL-2-Amino-n-butyric acid & DL-iso-Leucine	0.316
2. Open upland	L-Histidine monohydrochloride, L-Leucine, DL-Methionine & L-Proline	0.670
3. 50-70% shaded upland	DL-2-Amino-butyric acid, L-Cysteine hydrochloride monohydrate, DL-Methionine & DL-iso-Leucine	0.814
4. 20-40% shaded upland	DL-Threonine, DL-Methionine & L-Leucine	0.334
II. Golden yellow glumed *Njavara*		
1. Wetland	L-Histidine monochloride, L-Ornithine monohydrochloride & DL-iso-Leucine	0.089
2. Open upland	DL-2-Amino-butyric acid, L-Proline, DL-Methionine & L-Leucine	0.424
3. 50-70% shaded upland	DL-Threonine, DL-Methionine & DL-iso-Leucine	0.169
4. 20-40% shaded upland	DL-Threonine, DL-Methionine & L-Leucine	0.164
III. Chitteni in wetland situation	DL-Serine	0.183

Plate 1. TLC of standard amino acids

Sl.No.	Amino acid
1	DL-Alanine
2	DL-2-Amino-n-butyric acid
3	L Arginine monohydrochloride
4	DL Aspartic acid
5	L Cysteine hydrochloride monohydrate
6	L Cystine
7	3-(3,4-Dihydroxyphenyl)-DL-alanine (DL-DOPA)
8	L-Glutamic acid

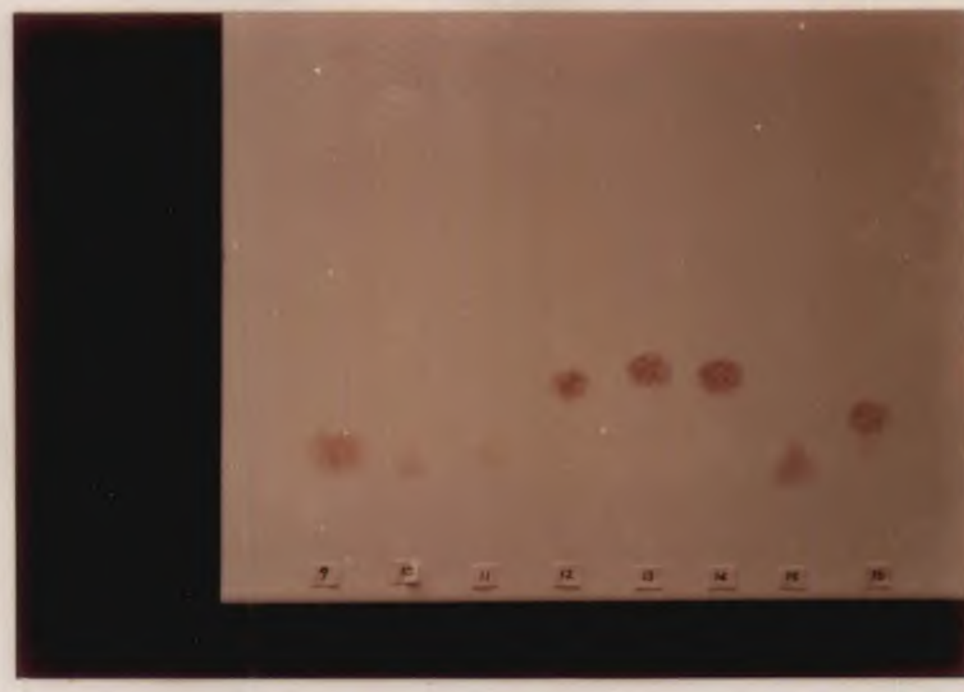


Plate 2. TLC of standard amino acids

Sl.No.	Amino acid
9	Glycine
10	L-Histidine monohydrochloride
11	L-Hydroxyproline
12	DL-iso-Leucine
13	DL-nor-Leucine
14	L-Leucine
15	L-Lysine monohydrochloride
16	DL-Methionine

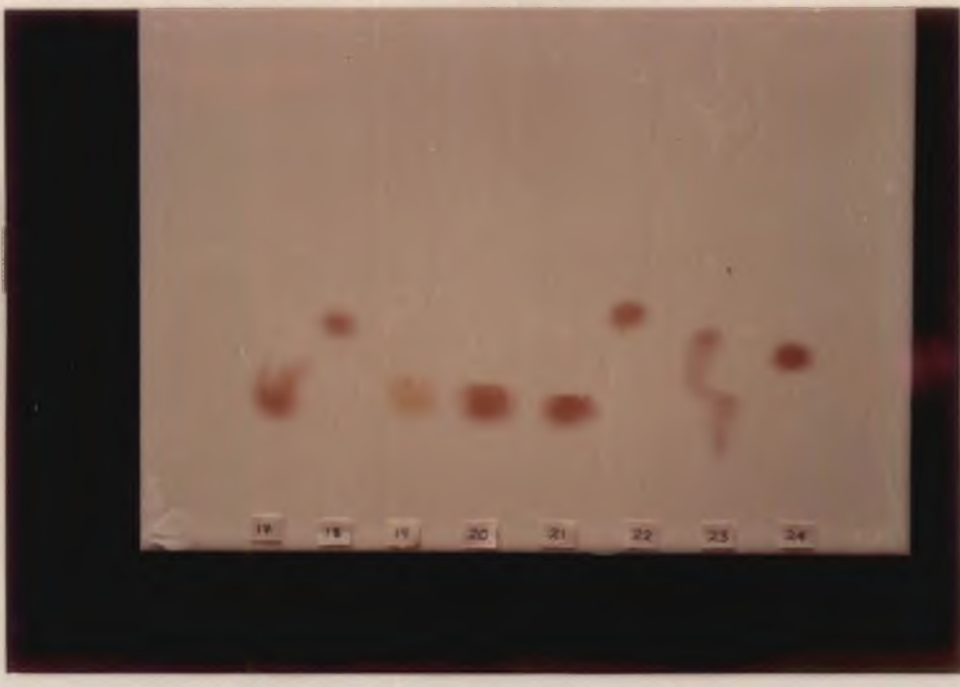


Plate 3. TLC of standard amino acids

Sl.No.	Amino acid
17	L-Ornithine monohydrochloride
18	DL-B-Phenyl alanine
19	L-Proline
20	DL-Serine
21	DL-Threonine
22	DL-Tryptophan
23	L-Tyrosine
24	DL-Valine

Plate 4. TLC of free amino acids of *Njavara* and Chitteni grain

Sl.No.	Sample
1	Black glumed *Njavara* of wetland situation
2	Golden yellow glumed *Njavara* of wetland situation
3	Black glumed *Njavara* of open upland situation
4	Golden yellow glumed *Njavara* of open upland situation
5	Black glumed *Njavara* of 50-70% shaded upland
6	Golden yellow glumed *Njavara* of 50-70% shaded upland
7	Black glumed *Njavara* of 20-40% shaded upland
8	Golden yellow glumed *Njavara* of 20-40% shaded upland
9	Chitteni of wetland situation

4.2 EXPERIMENT II

This experiment entitled 'Effect of time of sowing on productivity of *Njavara*' studied the relationship of cumulative weather phenomena on productivity of the crop. The ideal time of cultivation of the crop under open upland conditions is also identified.

4.2.1 Yield and yield attributes

Data on yield and yield attributes are presented in Table 4.2.1 as affected by date of crop commencement and biotype.

4.2.1.1 Effect of date of sowing

It can be seen from Table 4.2.1 and Fig. 4.2.2 that grain yield and straw yield did not follow the same trend. When grain yield was considered, S_2, S_3 and S_4 were on par and were significantly superior to all other treatments. Highest straw yields were recorded in S_3 and S_4 which were significantly superior to all other treatments. Both grain yield and straw yield were the least in S_7 (631 and 500 kg ha^{-1} respectively). However, grain-straw ratio was highest (1.28) in this treatment.

It can be seen from the data that variation in date of sowing significantly affected all the attributes studied in the experiment.

Maximum dry matter accumulation and number of productive tillers were recorded in S_4. It was significantly superior to all other treatments except S_3 with which it was on par. Thus sowing on June 30th resulted in the highest dry matter accumulation of 13706 kg ha^{-1} which was higher by 328.33, 61.51 and 98.74

Table 4.2.1 Dry matter accumulation, yield and yield attributes of black and golden yellow glumed *Njavara* biotypes of different dates of sowing

Treatment	Dry matter accumulation (kg ha^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Grain-straw ratio	No. of productive tillers	Length of panicle (cm)	No. of grains per panicle	No. of filled grains per panicle	Percentage of filled grain	1000 grain weight (g)
Sowing date										
S_1	3200.00	1380.00	1820.00	0.86	3.47	19.23	51.85	45.48	86.24	11.08
S_2	8486.67	4526.67	3960.00	1.11	4.10	20.63	71.01	63.14	89.21	11.08
S_3	12986.67	4586.67	8400.00	0.74	5.27	19.99	70.57	63.29	89.79	11.00
S_4	13706.67	5340.00	8366.67	0.69	8.60	18.72	53.90	47.00	87.54	10.75
S_5	6896.67	2380.00	4350.00	0.56	3.23	15.57	34.74	23.36	66.58	10.08
S_6	2990.00	1331.67	1658.33	0.81	3.10	13.89	42.41	37.07	85.07	9.04
S_7	1132.71	631.67	500.83	1.28	3.03	10.70	24.93	14.57	61.66	9.33
CD(0.05)	2434.75	1627.71	2640.86	0.25	2.52	1.87	8.88	9.35	10.26	0.93
Biotype										
Black glumed	5703.33	2519.29	3136.43	0.92	4.24	14.64	32.15	27.15	80.87	10.32
Golden yellow glumed	8410.71	3245.48	5165.24	0.81	4.56	19.27	67.68	60.02	80.87	10.36
CD(0.05)	NS	NS	NS	NS	NS	1.10	6.62	6.14	NS	NS

NS - Non significant

Fig.4.2.1 Grain yield (kg/ha) of Njavara biotypes in different dates of sowing

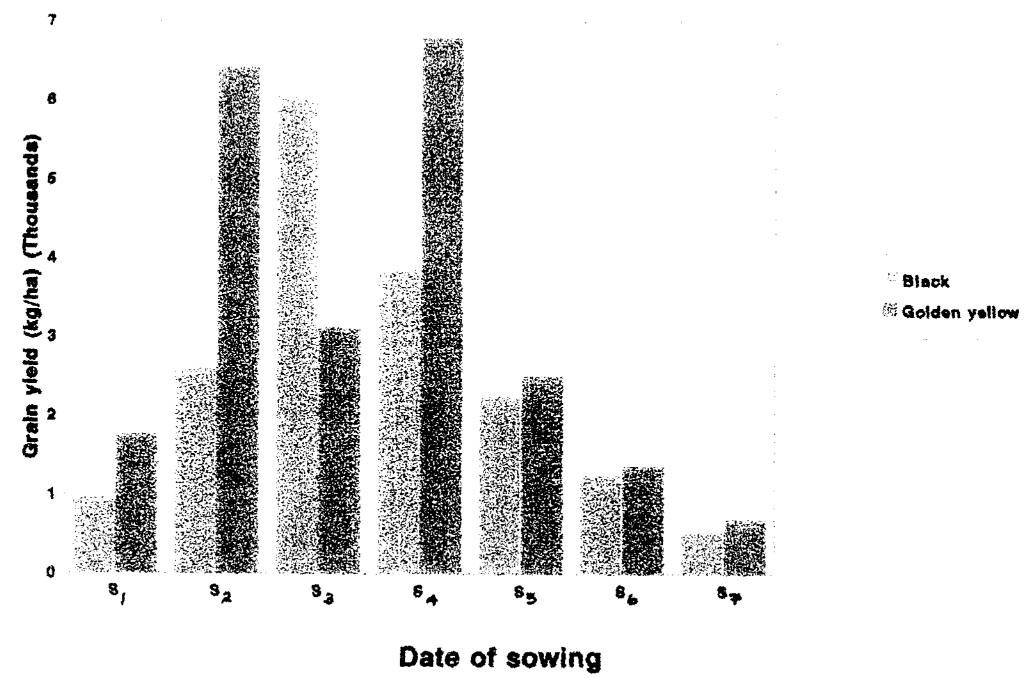
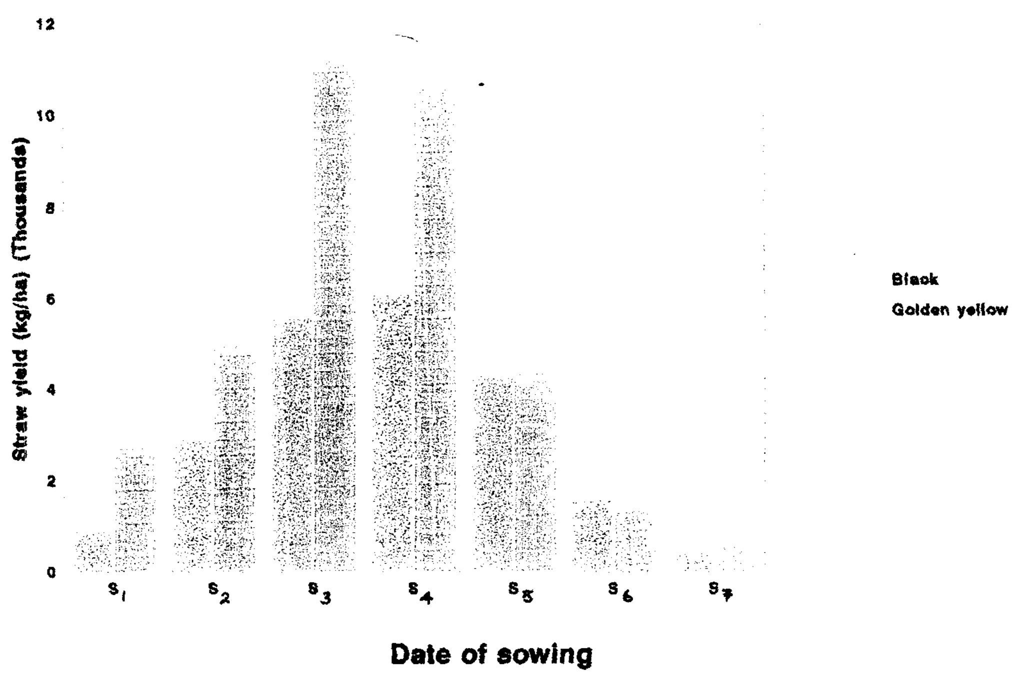


Fig.4.2.2 Straw yield (kg/ha) of Njavara biotypes in different dates of sowing



per cent over S_1, S_2 and S_5, and the corresponding increases in the number of productive tillers were 147.84, 109.76 and 166.25 per cent respectively.

Treatment S_2 recorded the maximum panicle length and number of grains per panicle. Sowing beyond June 30th led to significantly lower number of grains per panicle as well as panicle length. It can also be seen that S_2, though recorded panicle length comparable to S_2, failed to produce sufficient florets to match S_2.

The results also showed that dates of sowing ideal for production of florets and grain filling are not the same. S_3 resulted in significantly higher number of filled grains than in other treatments. Sowing beyond June 15th significantly reduced the number of filled grains per panicle.

Percentage of filled grain, which is a combined function of the number of filled grains as well as number of florets produced, also showed significant variation. Results also showed that sowings on July 15th and August 15th were significantly inferior to all other dates of sowing in respect of this attribute. Highest percentage of filled grain was recorded when seeds were sown on June 15th which was 34.86 and 45.62 per cent higher than that recorded in S_5 and S_7.

Data on 1000 grain weight showed that progressive delay in sowing led to a corresponding decline in the test weight. Mean maximum 1000 grain weight was recorded in S_1 and S_2, and the minimum in S_6. The reduction in the latter worked out to 22.57 per cent.

4.2.1.2 Effect of biotypes

Significant variations between the two biotypes were noticed only in the cases of length of panicle, number of grains per panicle and number of filled grains per panicle. Golden yellow glumed biotype was significantly superior to black glumed biotype and the increases worked out to 31.63, 110.51 and 121.07 per cent respectively. Though the differences were not significant, the golden yellow glumed biotype recorded its superiority over the black in dry matter accumulation, grain yield and straw yield.

4.2.1.3 Interaction effects

Data on interaction effects are presented in Table 4.2.2. The pattern of response of the black and golden yellow glumed biotypes under varying dates of sowing varied significantly in respect of grain-straw ratio, number of grains per panicle and number of filled grains per panicle. With respect to grain number and filled grain number per panicle, they behaved similarly only when sown on June 30th, in which treatment black and golden yellow glumed biotypes were on par. The responses were significantly different when sown on all other dates and the maximum difference was seen when sowing was preponed to May 15th, when total grain number and filled grain number per panicle varied by as much as 143.55 and 154.64 per cent respectively.

4.2.2 Elemental composition of straw

Data on elemental composition of straw as affected by biotypes and dates of sowing are presented in Table 4.2.3.

Table 4.2.2. Interaction effects of sowing date and biotype on yield characters of *Njavara*

	Grain - straw ratio		No. of grains per panicle		No. of filled grains per panicle	
	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow
Sowing time						
S_1	1.18	0.55	21.38	82.32	18.30	72.67
S_2	0.96	1.27	45.82	96.20	41.75	84.53
S_3	1.04	0.44	52.07	89.07	46.60	79.98
S_4	0.64	0.74	50.27	57.53	43.93	50.07
S_5	0.52	0.60	21.60	47.88	14.07	32.65
S_6	0.81	0.81	20.23	65.58	16.53	57.60
S_7	1.29	1.26	13.70	36.17	8.83	20.30
CD (0.05)	0.39 (0.6)*		17.50 (39.09)		16.26 (46.37)	

* Figures in parentheses give CD for comparison of same main plot means between same or different sub plot levels

Table 4.2.3. Nutrient content of straw of black and golden yellow glumed *Njavara* of different dates of sowing

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Sowing date										
S_1	0.30	0.07	2.03	0.46	0.72	0.10	103.83	866.00	255.33	17.33
S_2	0.44	0.12	1.54	0.42	0.80	0.11	272.00	673.17	229.67	15.17
S_3	0.21	0.13	1.68	0.34	0.83	0.10	208.17	395.00	261.00	14.17
S_4	0.24	0.17	1.57	0.37	0.92	0.11	254.00	609.00	288.17	11.50
S_5	0.15	0.16	1.77	0.37	0.94	0.10	337.17	661.50	326.00	15.67
S_6	0.13	0.12	1.63	0.29	0.82	0.12	303.83	411.50	259.00	13.83
S_7	0.09	0.07	1.58	0.25	0.74	0.10	283.17	472.83	249.00	14.83
CD(0.05)	0.10	0.05	NS	0.08	NS	NS	56.24	89.60	43.94	2.52
Biotype										
Black glumed	0.23	0.12	1.52	0.38	0.95	0.11	282.33	599.43	316.48	15.33
Golden yellow glumed	0.22	0.12	1.85	0.34	0.70	0.10	219.43	568.86	217.29	13.95
CD(0.05)	NS	NS	NS	NS	NS	NS	31.25	NS	30.91	1.11

NS - Non significant

4.2.2.1 Effect of date of sowing

Data showed that the contents of N, P, Ca, Fe, Mn, Zn and Cu of straw were significantly affected by dates of sowing. Highest content of N in straw was recorded in S_2 and it was significantly superior to all other treatments. S_4 recorded highest P content but it was superior only to S_1 and S_7 and was on par statistically with all other treatments.

Early sowing on May 15th resulted in highest accumulation of Ca, Mn and Cu and lowest accumulation of Fe (103.83 ppm). Highest Fe content was seen in S_5, which was 224.73 per cent higher than in S_1.

Sowing on July 15th resulted in maximum Zn content of 326 ppm which was statistically higher to all other treatments except S_5.

4.2.2.2 Effect of biotypes

Biotypic variation with respect to elemental composition of straw was significant only in the case of Fe, Zn and Cu. The black glumed biotype was superior in the accumulation of these elements and the increases over the contents in golden yellow glumed biotype worked out to 28.67, 45.65 and 9.89 per cent respectively.

4.2.2.3 Interaction effects

Interaction effects of time of sowing and biotypes on nutrient contents of straw are presented in Table 4.2.4. Interaction effects were significant with respect to contents of K, Fe, Mn, Zn and Cu.

Table 4.2.4. Interaction effects of sowing date and biotype on nutrient contents of *Njavara* straw

	K content (%)		Fe content (ppm)		Mn content (ppm)		Zn content (ppm)		Cu content (ppm)	
	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow
Sowing time										
S_1	1.68	2.37	121.00	86.67	856.00	876.00	324.33	186.33	18.67	16.00
S_2	1.57	1.52	451.00	93.00	895.00	451.33	235.67	223.67	15.67	14.67
S_3	1.52	1.85	316.00	100.33	401.33	388.67	356.33	165.67	16.33	12.00
S_4	1.48	1.65	403.67	104.33	482.67	735.33	396.00	180.33	15.00	8.00
S_5	1.67	1.87	230.33	432.00	649.00	674.00	346.00	306.00	15.67	15.67
S_6	1.40	1.87	223.00	384.00	397.67	425.33	288.67	229.33	12.67	15.00
S_7	1.35	1.80	231.33	335.00	514.33	431.33	268.33	229.67	13.33	16.33
CD (0.05)	0.66(0.59)*		82.67(171.76)		82.91(366.96)		81.77(88.43)		2.92(4.36)	

* Figures in parentheses give CD for comparison of same main plot means between same or different sub plot levels

K, Mn and Cu contents were maximum in the earliest date of sowing, ie., May 15th. K accumulation tended to be higher in the golden yellow glumed biotype.

The trend of accumulation of Fe, Mn and Zn varied with the biotype. In the black biotype, highest Fe and Mn contents were recorded in S_4, while in the golden yellow glumed biotype, highest contents of Fe and Zn were seen in S_5.

An interesting observation in the trend of Fe accumulation was that upto the June 30th sowing, the black glumed biotype was the better accumulator of Fe, but after that the trend was reversed with the golden yellow glumed biotype taking the lead. In all the sowing dates, the black glumed biotype had the higher content of Zn.

4.2.3 Nutrient uptake of straw

Table 4.2.5 depicts the variation in nutrient uptake of straw as affected by different dates of sowing and biotypes.

4.2.3.1 Effect of date of sowing

Date of sowing significantly affected uptake of all nutrients in straw.

The data showed that except for K, uptake of all nutrients was maximum in the crop sown on June 30th. Postponement of sowing date beyond June 30th resulted in a steep decline in uptake of all elements.

Table 4.2.5. Nutrient uptake (kg ha^{-1}) in straw of *Njavara* biotypes of different dates of sowing

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
Sowing date										
S_1	5.41	1.22	36.86	8.39	13.07	1.73	0.19	1.58	0.46	0.03
S_2	17.58	4.83	61.06	16.75	31.68	4.47	1.08	2.67	0.91	0.06
S_3	17.47	10.50	141.37	28.81	69.30	8.74	1.75	3.32	2.19	0.12
S_4	19.83	14.31	131.11	31.12	76.56	9.04	2.13	5.10	2.41	0.12
S_5	6.44	6.87	76.86	15.88	40.85	4.52	1.44	2.88	1.42	0.07
S_6	2.22	1.91	27.08	4.84	13.52	1.91	0.50	0.68	0.43	0.02
S_7	0.45	0.33	7.89	1.23	3.69	0.49	0.14	0.24	0.12	0.01
CD(0.05)	2.59	1.32	12.60	2.22	5.20	0.21	0.15	0.24	0.12	0.01
Biotype										
Black glumed	7.06	3.64	36.40	11.82	29.70	3.39	0.89	1.88	0.99	0.05
Golden yellow glumed	11.36	6.15	95.30	17.41	35.95	5.32	1.13	2.94	1.12	0.07
CD(0.05)	1.37	0.43	5.67	1.37	2.35	0.27	0.07	0.07	NS	NS

NS - Non significant

4.2.3.2 Effect of biotypes

Effect of biotypes was also significant in the case of all nutrients except Zn and Cu. Invariably, golden yellow glumed biotype was superior in nutrient uptake as compared to black glumed biotype, and the increases in uptake of N, P, K, Ca, Mg, S, Fe and Mn were 60.91, 68.96, 161.81, 47.29, 21.04, 56.93, 26.97 and 56.38 per cent respectively.

4.2.4 Elemental composition of grain

4.2.4.1 Effect of date of sowing

Data presented in Table 4.2.6 showed that date of sowing significantly affected the N, P, S, Fe and Zn contents of grain. Highest and lowest contents of both N and P in the grain were recorded by S_4 and S_7 respectively and the range was 0.21 to 1.27 per cent for N and 0.25 to 0.65 per cent for P.

S content in S_2 and S_7 ranged between 0.07 and 0.11 per cent and the difference was statistically significant.

S_3 recorded the highest Fe content of 141 ppm in [illegible] grain which was significantly higher than the lowest contents of 63.67 and 63.[illegible] [illegible] [illegible]ded in S_4 and S_5 respectively.

Data also showed that sowing delayed beyond June 15th or preponed to May 15th led to significantly low content of Zn. Highest content of 561 ppm of Zn was recorded in S_3 and lowest of 230 ppm in S_7, and the difference worked out to 144.09 per cent.

Table 4.2.6. Nutrient content of grain of *Njavara* biotypes of different dates of sowing

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Sowing date										
S_1	0.61	0.35	0.30	0.27	0.87	0.10	113.17	115.67	370.33	5.83
S_2	0.83	0.35	0.33	0.31	1.07	0.07	114.67	121.33	517.17	6.00
S_3	0.83	0.52	0.32	0.45	1.18	0.10	141.17	98.50	561.83	6.00
S_4	1.27	0.65	0.34	0.17	0.68	0.09	63.67	96.33	291.67	5.83
S_5	0.92	0.57	0.36	0.14	0.84	0.10	63.83	108.33	297.83	7.17
S_6	0.50	0.37	0.33	0.19	0.70	0.09	97.67	122.67	241.17	6.83
S_7	0.21	0.25	0.30	0.42	0.62	0.11	128.17	85.83	230.17	6.33
CD(0.05)	0.17	0.22	NS	NS	NS	0.02	25.96	NS	68.07	NS
Biotype										
Black glumed	0.74	0.43	0.33	0.28	0.71	0.09	105.19	114.81	310.38	5.62
Golden yellow glumed	0.74	0.45	0.32	0.28	1.00	0.09	101.19	99.10	406.81	6.95
CD(0.05)	NS	NS	NS	NS	0.26	NS	NS	15.49	39.49	1.00

NS - Non significant

4.2.4.2 Effect of biotypes

The biotypes significantly differed in Mg, Mn, Zn and Cu contents of the grain. Golden yellow glumed biotype contained significantly higher amounts of Mg, Zn and Cu than the black glumed biotype and the increases worked out to 40.85, 31.07 and 23.67 per cent respectively.

4.2.4.3 Interaction effects

Observations on the interaction effect between date of sowing and biotype showed that early and late sowings varied in their effect on elemental composition of grain (Table 4.2.7).

June 30th sowing produced the highest content of N in the grain in the black glumed biotype. All the pre and postponement sowings led to a significant reduction in grain N content in the black glumed biotype, whereas only the August 15th sowing decreased the N content of the grain significantly in the golden yellow glumed biotype.

June 30th sowing also recorded the highest content of P in both biotypes, which tended to decline when sowing dates were pre or postponed. Golden yellow glumed biotype appeared to be more sensitive and the decline in P content was significant in all cases. In the case of black glumed biotype, the P content of grain remained statistically on par when sown on June 30th and July 15th.

Highest S content in grain was seen in S_5 and S_7 in the black glumed biotype and in S_6 in the golden yellow glumed biotype, indicating that delayed sowing increased the S content of the grain. Highest Fe contents of 153 ppm and

Table 4.2.7. Interaction effects of sowing date and biotype on nutrient contents of *Njavara* grain

	N content (%)		P content (%)		S content (%)		Fe content (ppm)		Zn content (ppm)	
	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow	Black	Golden yellow
Sowing time										
S_1	0.51	0.71	0.26	0.44	0.12	0.08	153.33	73.00	392.00	348.67
S_2	0.71	0.95	0.23	0.41	0.06	0.08	62.00	167.33	326.67	707.67
S_3	0.89	0.77	0.51	0.53	0.10	0.09	133.33	149.00	361.33	762.33
S_4	1.66	0.89	0.59	0.71	0.08	0.10	55.67	71.67	289.33	294.00
S_5	0.95	0.89	0.55	0.58	0.11	0.09	62.00	65.67	261.33	334.33
S_6	0.30	0.71	0.51	0.23	0.06	0.11	121.00	74.33	277.76	204.67
S_7	0.18	0.24	0.29	0.22	0.11	0.10	149.00	107.33	264.33	196.00
CD (0.05)	0.44(0.79)*		0.07(0.33)		0.03(0.03)		44.24(71.59)		104.47(292.59)	

* Figures in parentheses give CD for comparison of same main plot means between same or different sub plot levels

167.33 ppm in the grain were seen in S_1 and S_2 in the case of black and golden yellow glumed biotypes respectively, while the lowest was seen in S_4 for the former and S_5 for the latter.

Observations on the interaction effect on Zn content revealed that the highest content of Zn was recorded in S_1 by black and in S_3 by golden yellow glumed biotypes. Sowing delayed beyond S_4 failed significantly to record comparable Zn levels in black glumed biotype while sowing on May 15th or after June 15th resulted in significantly inferior grain content of Zn in the golden yellow glumed biotype.

4.2.5 Nutrient uptake of grain

Data on nutrient uptake of grain are presented in Table 4.2.8.

4.2.5.1 Effect of date of sowing

The data showed that date of sowing significantly affected uptake of all nutrients in the grain. Sowing by June 30th facilitated the maximum uptake of N, P, K and S. S_3 showed the maximum uptake of Ca, Mg and Fe.

4.2.5.2 Effect of biotypes

Grain of golden yellow glumed biotype recorded significantly higher uptake of N, P, K, Mg and Zn over black glumed biotype and the increases worked out to 27.98, 34.86, 26.14, 81.98 and 69.23 per cent respectively.

4.2.6 Influence of weather at different growth periods on yield

Data on the direct and indirect effects of select weather factors from

Table 4.2.8. Nutrient uptake (kg ha^{-1}) in grain of *Njavara* biotypes of different dates of sowing

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
Sowing date										
S_1	8.43	4.79	4.17	4.90	12.03	1.37	0.16	0.16	0.51	0.01
S_2	37.57	15.71	15.07	13.94	48.39	3.03	0.52	0.55	2.34	0.03
S_3	38.07	23.90	14.45	20.41	54.31	4.36	0.65	0.45	2.58	0.03
S_4	68.03	38.02	18.26	9.29	36.26	4.65	0.34	0.51	1.56	0.03
S_5	21.87	13.47	8.59	3.31	19.92	2.31	0.15	0.26	0.71	0.02
S_6	6.71	4.94	4.43	2.57	9.26	1.13	0.13	0.16	0.27	0.01
S_7	1.31	1.60	1.92	2.63	3.89	0.66	0.08	0.05	0.15	0.004
CD(0.05)	2.80	3.53	0.70	4.90	6.30	0.34	0.04	0.04	0.11	0.003
Biotype										
Black glumed	18.69	10.73	8.34	7.03	17.76	2.27	0.27	0.29	0.78	0.01
Golden yellow glumed	23.92	14.47	10.52	8.96	32.32	2.99	0.33	0.32	1.32	0.02
CD(0.05)	2.20	0.78	0.45	NS	3.37	NS	NS	NS	0.05	NS

NS - Non significant

maximum tillering to harvest and panicle initiation to harvest are presented in Tables 4.2.9 and 4.2.10.

Data revealed that total rainfall and humidity showed positive correlation with yield in the period from maximum tillering to harvest. Sunshine showed a negative influence in this period. Direct effects of weather elements were only marginal.

However, from panicle initiation to harvest, maximum direct effect was observed for sunshine hours. Relative humidity and total rainfall had only marginal influence though they continued to be correlated with yield.

4.3 EXPERIMENT III

Application of major nutrients influence productivity not merely by increasing their respective availability or absorption, but also by affecting the absorption of other elements. The influence of application of three graded levels of N, P and K in combination on the absorption of ten essential elements as well as on productivity of *Njavara* studied in the trial entitled "Nutritional management in relation to ionic balance and productivity" is presented below. Main effects of treatments and significant interaction effects have been tabulated.

4.3.1 Growth attributes

4.3.1.1 Main effects

Significant effect of fertilizer treatments on growth attributes was seen only in dry matter accumulation. This became evident only from panicle initiation state. Application of N at 45 kg ha^{-1}, P at 15 and 45 kg ha^{-1} and K at 30 and 45 kg

Table 4.2.9. Direct and indirect effect of prevailing weather conditions from maximum tillering to harvest on grain yield of *Njavara*

	Total maximum temper-ature (°C)	Total minimum temper-ature (°C)	Difference between maximum and minimum temperature (°C)	Mean temperature (°C)	Total sunshine hours	Total rainfall (mm)	Mean RH (%)	Correlation coefficient
Total maximum temperature (°C)	-2025.98	-1.04	290.80	1736.60	0.01	0.91	-1.45	-0.15
Total minimum temperature (°C)	-1784.10	-1.19	82.23	1703.33	0.01	0.59	-1.09	-0.22
Difference between maximum and minimum temperature (°C)	-1225.76	-0.20	480.64	745.59	0.01	0.88	-1.19	-0.03
Mean temperature (°C)	-1978.39	-1.14	201.51	1778.37	0.01	0.80	-1.33	-0.17
Total sunshine hours	-1460.79	-0.67	268.73	1192.94	0.01	1.77	-2.43	-0.44
Total rainfall (mm)	967.72	0.37	-221.86	-746.38	-0.01	-1.90	2.37	0.31
Mean RH (%)	1176.86	0.52	-230.57	-946.98	-0.01	-1.81	2.49	0.50

Residual path value : 0.3756

R^2 : 0.86

Table 4.2.10. Direct and indirect effect of prevailing weather conditions from flowering to harvest on grain yield of *Njavara*

	Total maximum temper-ature (°C)	Total minimum temper-ature (°C)	Difference between maximum and minimum temperature (°C)	Mean temperature (°C)	Total sunshine hours	Total rainfall (mm)	Mean RH (%)	Correlation coefficient
Total maximum temperature (°C)	**-80.81**	1178.64	258.92	-1357.58	0.69	0.04	0.04	-0.06
Total minimum temperature (°C)	-75.29	**1265.10**	153.97	-1344.29	0.56	0.00	0.01	0.06
Difference between maximum and minimum temperature (°C)	-59.25	551.56	**353.15**	-846.57	0.67	-0.09	0.08	-0.45
Mean temperature (°C)	-79.78	1236.76	217.41	**-1375.10**	0.65	-0.02	0.03	-0.05
Total sunshine hours	-64.07	812.67	268.91	-1018.36	**0.88**	-0.06	0.06	0.03
Total rainfall (mm)	28.18	3.91	-307.09	275.95	-0.49	**0.10**	-0.08	0.48
Mean RH (%)	40.26	-203.97	-329.17	493.92	-0.59	0.10	**-0.09**	0.46

Residual path value : 0.44
R^2 : 0.81

ha^{-1} recorded significantly higher dry matter compared to absolute control and the increases were 79.93 per cent, 56.55 per cent, 58.12 per cent, 59.51 per cent and 62.83 per cent, respectively (Table 4.3.1.a).

Treatment differences became more pronounced at the time of harvest. Standard control recorded 1767.21 kg dry matter per ha and was significantly superior to absolute control as well as to fertilizer N applied at the rate of 15 kg ha^{-1}. Among the levels of N, P and K, N at 45 kg, P at 30 kg and K at 30 kg recorded significantly higher dry matter production than absolute control. A comparison among levels of nutrients showed that dry matter accumulation did not differ among levels except in the case of N. The difference between N_0 and N_2 was significant.

4.3.1.2 Interaction effects

Data on interaction effects of fertilizers on growth characters are given in Table 4.3.1b.

a) N x P interaction

n_1p_1 and n_2p_2 recorded the maximum heights of 23.47 and 67.12 cm at maximum tillering and panicle initiation stages respectively which were significantly superior to n_0p_0 at both stages. Combining P with N tended to reduce the dry matter accumulation at P at 15 kg level. Increasing the level of P to 30 kg however, showed further beneficial effects.

b) N x K interaction

Data in Table 4.3.1.b showed that 45 kg N along with 15 kg K was

Table 4.3.1.a. Main effects of fertiliser levels on growth characters

	Height of plants (cm)			No. of tillers per hill			Dry matter accumulation, $kgha^{-1}$		
	At maximum tillering	At panicle initiation	At harvest	At maximum tillering	At panicle initiation	At harvest	At maximum tillering	At panicle initiation	At harvest
C_1	24.48	68.68	74.77	5.87	4.07	5.53	260.52	956.47	1767.21
C_2	23.65	64.15	66.20	4.61	4.10	5.03	208.41	710.83	1004.69
N_0	22.32	61.40	75.40	4.28	4.31	4.90	229.50	903.12	1168.85
N_1	22.49	65.26	81.37	4.97	5.11	5.82	335.50	987.48	1497.91
N_2	22.58	68.41	82.49	5.28	4.91	5.27	307.66	1279.01	1724.90
P_0	22.38	64.31	78.16	4.69	4.71	5.06	252.39	1112.78	1358.44
P_1	23.17	66.06	81.82	4.71	5.04	5.51	290.29	932.90	1630.44
P_2	21.84	64.69	79.27	5.12	4.58	5.42	329.99	1123.94	1402.78
K_0	22.81	63.39	79.27	4.67	4.20	5.68	258.59	878.31	1428.02
K_1	22.70	66.15	79.83	4.60	5.24	4.90	270.44	1133.87	1527.32
K_2	21.87	65.53	80.17	5.26	4.89	5.34	343.63	1157.44	1436.32
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	326.02	506.91

C_1 - Standard control; C_2 - Absolute control

Table 4.3.1.b. Interaction effects of fertilizer levels on growth characters

I. N x P interaction

	Height at maximum tillering			Height at panicle initiation			Dry matter production at panicle initiation		
	N0	N1	N2	N0	N1	N2	N0	N1	N2
P0	22.33	22.25	22.56	54.72	68.61	69.61	863.43	1094.17	1380.74
P1	22.80	23.47	23.23	65.62	64.05	68.51	807.60	781.55	1209.54
P2	21.82	21.74	21.95	63.84	63.10	67.12	1038.35	1086.73	1246.76
CD(0.05)	0.99			12.23			564.68		

II. N x K interaction

	Height at maximum tillering			Height at panicle initiation			Dry matter production at maximum tillering			Dry matter production at panicle initiation		
	N0	N1	N2	N0	N1	N2	N0	N1	N2	N0	N1	N2
K0	23.11	22.20	23.12	64.18	63.15	62.85	227.02	291.96	256.80	926.70	788.99	919.25
K1	22.74	22.80	22.80	58.92	66.82	72.70	204.69	372.16	234.47	975.08	900.64	1525.88
K2	21.10	22.46	22.46	61.09	65.79	69.70	256.80	342.39	431.71	807.60	1272.81	1391.90
CD (0.05)	0.99			12.23			226.47			564.68		

III. P x K interaction

	Height at maximum tillering			Dry matter production at maximum tillering			Dry matter production at panicle initiation		
	P0	P1	P2	P0	P1	P2	P0	P1	P2
K0	23.07	23.59	21.77	247.30	182.36	346.12	934.14	725.73	975.08
K1	21.72	23.55	22.84	256.79	264.24	290.29	1190.93	911.81	1298.86
K2	22.34	22.35	20.91	253.07	424.27	353.56	1213.26	1161.16	1097.89
CD (0.05)	0.99			226.47			564.68		

sufficient to record maximum height at maximum tillering, but at panicle initiation, 30 kg K was required to produce the same effect.

The pattern of response was different in dry matter accumulation by *Njavara*. At maximum tillering stage, combined application of N and K at the highest level was required to produce maximum dry matter of 431 kg ha^{-1}, but the treatment failed to sustain its superiority at panicle initiation when the combination of 45 kg N and 30 kg K recorded the highest dry matter accumulation.

c) P x K interaction

Combined application of P at 30 kg with K at 45 kg increased the dry matter accumulation at maximum tillering. Further increase in the level of P tended to decrease dry matter accumulation. Highest dry matter content at maximum tillering and panicle initiation stages were recorded by k_2p_1 and k_2p_2 combinations respectively. Both were significantly superior to k_0p_1.

4.3.2 Yield and yield attributes

4.3.2.1 Main effects

Data on main effects of treatments are presented in Table 4.3.2a.

a) Grain yield

Treatments did not significantly affect the grain yields as is evident in Fig. 4.3.1.

b) Straw yield

Treatments affected straw yield significantly (Fig. 4.3.2). Absolute

Table 4.3.2.a. Main effects of fertilizer levels on yield and yield attributes

	Grain yield kg ha^{-1}	Straw yield kg ha^{-1}	Grain-straw ratio	Length of panicle (cm)	No. of grains per panicle	Percentage of filled grain	1000 grain weight (g)
C_1	496.17	1271.04	0.36	15.55	27.9	80.46	14.18
C_2	344.99	659.69	0.53	15.41	26.73	85.25	16.28
N_0	370.42	798.44	0.49	16.47	34.72	83.66	15.62
N_1	437.50	1060.41	0.48	16.95	37.71	81.25	15.32
N_2	457.50	1267.40	0.37	17.59	39.21	77.35	15.60
P_0	377.29	981.15	0.42	16.35	34.00	82.02	14.97
P_1	478.54	1151.90	0.42	17.42	40.21	80.86	15.59
P_2	409.58	993.19	0.50	17.24	37.43	79.38	15.98
K_0	410.83	1017.19	0.42	16.92	36.46	82.93	15.69
K_1	417.50	1109.82	0.40	16.87	37.10	78.32	15.10
K_2	437.08	999.24	0.53	17.21	38.09	81.01	15.75
CD (0.05)	NS	369.27	0.14	1.64	6.88	5.80	NS

C_1 - Standard control; C_2 - Absolute control

Fig.4.3.1 Grain yield (kg/ha) of Njavara under different nutrient levels

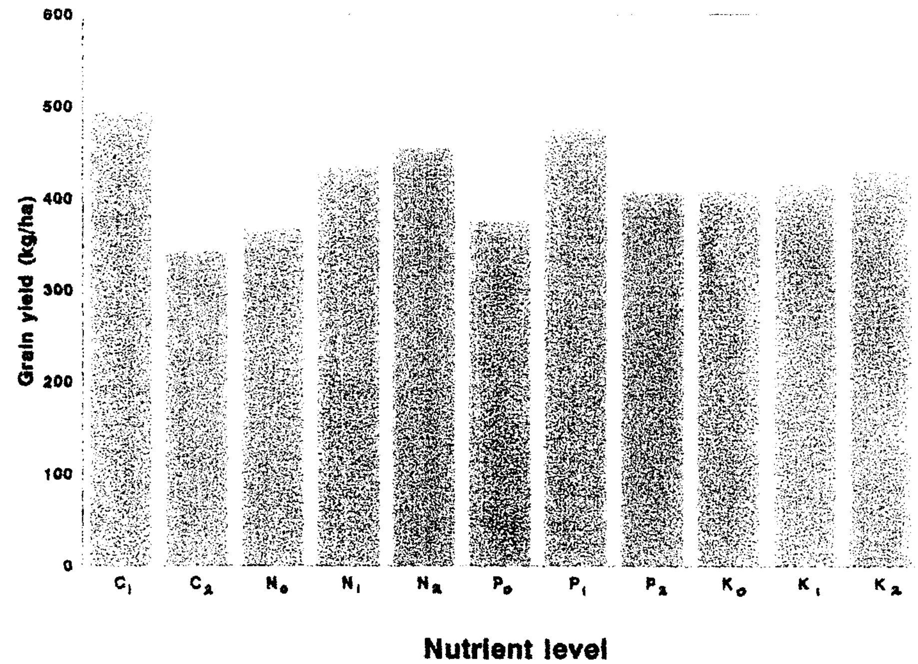
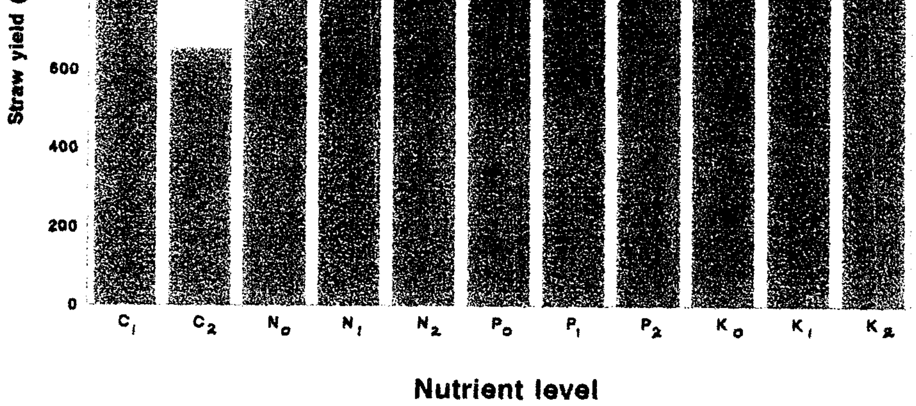


Fig.4.3.2 Straw yield (kg/ha) of Njavara under different nutrient levels



control and N_0 was significantly inferior to standard control, while all other treatments were on par with it. Standard control recorded highest straw yield. Among levels of nutrients, highest straw yields were obtained at N_2, P_1 and K_1 levels.

c) Grain-straw ratio

Application of FYM at 3 tonnes ha^{-1} and N at 45 kg ha^{-1} significantly reduced the grain-straw ratio in comparison with absolute control. The former 2 treatments recorded ratios of 0.36 and 0.37, while absolute control gave a higher ratio of 0.53.

d) Length of panicle

Data presented in Table 4.3.2.a show that N and K applied each at 45 kg ha^{-1}, and P at 30 kg ha^{-1} significantly increased the length of panicle over absolute control, and the increases were 14.15, 11.68 and 13.04 per cent respectively. A similar result was obtained in the case of standard control.

e) Number of grains per panicle

The effect of fertilizer elements on increasing the number of grains per panicle over absolute and standard controls was significant. Maximum number of grains were recorded at 45 kg level in the case of N and K and 30 kg level in the case of P. Levels did not significantly differ among themselves.

f) Percentage of filled grain

Percentage of filled grain manifested an inverse relationship with N. Increasing N levels reduced the filling percentage. Filling percentage was 7.54 per cent less at N_2 level compared to N_0.

g) 1000 grain weight

None of the treatments had any significant effect on 1000 grain weight.

4.3.2.2 Interaction effects

Data on interaction effects on yield attributes are given in Table 4.3.2b.

a) N x P interaction

Data show that combined application of N and P each at 45 kg ha^{-1} produced the longest panicles. The lowest number of grains per panicle was also recorded when N and P were applied at 15 kg ha^{-1} each. However, with regard to the percentage of filling, the trend was reversed, with n_2p_2 recording the lowest percentage (73.61) and n_0p_0 recording the highest (84.88).

b) N x K interaction

At constant K levels, increasing N levels tended to reduce both grain-straw ratio and percentage of filling. Increase in K levels at constant N levels increased grain-straw ratio. This trend, however, was not noticed in percentage of filled grains.

c) P x K interaction

Effect of P x K interaction was significant only in the case of number of grains per panicle. P applied at 30 kg ha^{-1} in combination with K at 45 kg ha^{-1} significantly increased number of grains per panicle.

Table 4.3.2.b. Interaction effects of fertilizer levels on yield characters

I. N x P interaction

	Length of panicle			No.of grains/ panicle			Percentage of filled grain		
	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2
P_0	15.06	17.05	16.96	28.43	37.17	37.37	84.88	78.33	82.86
P_1	17.16	17.20	17.89	38.37	41.53	34.43	83.28	83.72	75.57
P_2	17.19	16.61	17.91	37.37	40.73	40.50	82.81	81.71	73.61
CD (0.05)	2.84			11.92			10.04		

II. N x K interaction

	Grain straw ratio			Percentage of filling		
	N_0	N_1	N_2	N_0	N_1	N_2
K_0	0.45	0.44	0.37	86.94	80.47	81.39
K_1	0.43	0.42	0.34	79.78	83.12	72.06
K_2	0.59	0.58	0.40	84.26	80.17	78.59
CD (0.05)	0.24			10.04		

III. P x K interaction

	No.of grains/panicle		
	P_0	P_1	P_2
K_0	36.33	37.27	35.77
K_1	34.03	39.60	37.67
K_2	31.63	43.77	38.87
CD (0.05)	11.92		

4.3.3 Elemental composition at maximum tillering

4.3.3.1 Main effects

a) Nutrient contents

Application of 3 tonnes of FYM per ha increased the contents of N, P, K, Ca and Mg over absolute control by 35.27, 25.81, 10.29, 65.71 and 30.88 per cent respectively (Table 4.3.3a). Mn and Zn contents were reduced significantly by 16.20 and 59.79 per cent. S content was not affected.

Application of fertilizer N at 45 kg ha^{-1} significantly increased the K and Ca contents by 16.76 and 48.57 per cent and reduced the contents of Fe, Mn and Zn by 10.33, 10.17 and 30.86 per cent over absolute control.

P application at all 3 levels significantly increased K content over absolute control. At 45 kg ha^{-1}, P application significantly increased the Ca and Mg contents by 78.57 and 27.94 per cent over absolute control, and significantly reduced the Fe and Mn contents by 10.52 and 22.29 per cent respectively. P application did not have any effect on P, S and Zn contents of the plants.

K application also significantly increased K, Ca and Mg contents and reduced Fe, Mn and Zn contents. Varying levels of K did not have any effect on P and S contents.

A comparison of standard control with fertilizer levels showed that N at 30 kg, P at 15 kg and 45 kg, and K at 30 kg and 45 kg levels reduced Fe content significantly. Standard control was better than fertilizer levels in improving the P and Mg and reducing the Zn contents of the plants at maximum tillering stage. Content of Al and Mo were too minute to be detected at this stage.

Table 4.3.3.a. Main effects of fertilizer levels on nutrient contents at maximum tillering

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
C_1	2.8	0.39	3.75	1.16	0.89	0.39	1279.5	1193.83	126.33	23.0
C_2	2.07	0.31	3.40	0.70	0.68	0.39	1234.33	1424.67	314.17	23.67
N_0	2.65	0.30	3.71	0.92	0.80	0.38	1111.22	1078.83	336.28	18.22
N_1	2.94	0.32	4.04	0.84	0.80	0.37	1141.00	1116.50	299.00	19.33
N_2	3.15	0.32	3.97	1.04	0.75	0.38	1106.83	1279.72	217.22	19.89
P_0	2.91	0.28	3.98	0.83	0.73	0.35	1048.61	1096.72	284.72	18.44
P_1	3.01	0.33	3.86	0.72	0.75	0.40	1206.00	1271.22	282.94	20.39
P_2	2.83	0.33	3.88	1.25	0.87	0.40	1104.44	1107.11	284.83	18.61
K_0	3.04	0.30	3.90	0.93	0.77	0.39	1223.56	1137.22	257.72	19.83
K_1	2.97	0.32	3.90	1.15	0.86	0.38	1062.06	1101.44	378.61	20.50
K_2	2.73	0.32	3.92	0.71	0.73	0.37	1073.44	1236.39	216.17	17.11
CD (0.05)	NS	NS	0.17	0.20	0.11	NS	86.84	120.05	59.87	NS

C_1 - Standard control; C_2 - Absolute control
NS - Non significant

b) Nutrient uptake

Significant effect of fertilizer nutrient application on influencing the uptake was confined to N. N_1 recorded the highest N uptake of 9.86 kg ha^{-1} as against 4.31 kg ha^{-1} in absolute control (Table 4.3.3.b).

4.3.3.2 Interaction effects

a) N x P interaction

Interaction effects of fertilizer application on nutrient contents at maximum tillering are presented in Table 4.3.3c.

The positive influence was maximum upto 30 kg level each of N and P in the case of N, S and Zn, at n_1p_2 level in the case of P, at n_0p_2 in the case of Ca and Mg, n_0p_1 for Fe and n_2p_1 for Mn.

b) N x K interaction

N and K interacted significantly in affecting the elemental composition of the plant at maximum tillering stage though the nature and extent of influence varied with elements. Highest contents of P, Mg and Cu and lowest content of Mn were recorded at 30 kg level each of N and K. Increasing the levels of N or K beyond 30 kg failed to improve contents of P, Mg and Cu.

At each K level, increasing levels of N increased the N content. A similar trend was noticed with respect to Ca, but only upto 30 kg K, and also in K, but only at higher levels of 30 kg and 45 kg K.

Table 4.3.3.b. Main effects of fertiliser levels on nutrient uptake (kg ha^{-1}) at maximum tillering

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
C_1	7.29	1.02	9.77	3.02	2.32	1.02	0.33	0.31	0.03	0.006
C_2	4.31	0.65	7.09	1.46	1.42	0.81	0.26	0.30	0.07	0.005
N_0	6.08	0.51	8.51	2.11	1.84	0.87	0.26	0.25	0.08	0.004
N_1	9.86	1.07	13.55	2.81	2.68	1.24	0.38	0.37	0.10	0.006
N_2	9.69	0.98	12.21	3.20	2.31	1.17	0.39	0.39	0.07	0.006
P_0	7.34	0.71	10.05	2.09	1.84	0.88	0.26	0.28	0.07	0.005
P_1	8.74	0.96	11.21	2.09	2.18	1.16	0.35	0.37	0.08	0.006
P_2	9.34	1.09	12.80	4.12	2.78	1.32	0.36	0.37	0.09	0.006
K_0	7.86	0.78	10.09	2.40	1.99	1.01	0.32	0.29	0.07	0.005
K_1	8.03	0.87	10.55	3.11	2.33	1.03	0.29	0.30	0.10	0.006
K_2	9.38	1.10	13.47	2.44	2.51	1.27	0.37	0.42	0.07	0.006
CD (0.05)	0.76	NS	NS	NS	NS	NS	NS	NS	NS	NS

C_1 - Standard control; C_2 - Absolute control
NS - Non significant

Table 4.3.3.c. Interaction effects of fertilizer levels on nutrient contents at maximum tillering
I. N x P interaction

	N content (%)			P content (%)			Ca content (%)			Mg content (%)		
	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2
P_0	2.46	2.84	3.42	0.26	0.28	0.31	0.61	0.61	1.27	0.69	0.70	0.79
P_1	2.83	3.00	3.19	0.32	0.34	0.32	0.61	0.46	1.08	0.74	.89	0.62
P_2	2.65	3.00	2.86	0.31	0.35	0.34	1.52	1.45	0.77	0.96	0.81	0.85
CD(0.05)	0.10			0.05			0.35			0.19		

	S content (%)			Fe content (ppm)			Mn content (ppm)			Zn content (ppm)		
	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2
P_0	0.37	0.33	0.34	864.2	1114.0	1167.7	967.7	1100.8	1224.7	357.5	210.5	286.2
P_1	0.39	0.41	0.40	1354.8	1117.8	1085.3	1151.5	1241.0	1421.2	270.3	449.3	129.2
P_2	0.40	0.38	0.40	1114.7	1131.2	1067.5	1120.3	1007.7	1193.3	381.0	237.2	236.3
CD	0.04			150.4			207.9			103.7		

Contd.

Increasing levels of K tended to inversely affect the N effect on the Fe content and at 30 kg along with 15 kg N, the lowest Fe content of 989.7 ppm was recorded as against the highest content of 1309.2 per cent in N_1 x K_0 levels. This level also recorded the highest K content.

c) P x K interaction

Application of 30 kg K along with increasing levels of P upto 45 kg significantly increased P, Ca and Mg contents. Interacting influence of P x K varied with the elements. At 30 kg level of P application of K at 15 kg increased the contents of N, S and Zn. Increase in the level of K to 45 kg increased Fe and Mn contents significantly.

4.3.3.3 Nutrient ratios

Data on effects of fertilizer levels on nutrient ratios at maximum tillering stage, presented in Table 4.3.3.d revealed that the widest ratio with regard to Zn in respect of all 3 applied nutrients (viz. N, P and K) was seen in the treatment receiving only 3 tonnes FYM ha^{-1}. Standard control also resulted in the widest ratios of P/Fe and P/Mn.

Application of N at 30 kg ha^{-1} was responsible for effecting highest K absorption with respect to contents of Mn and Cu. However, with respest to Fe, P at 15 kg ha^{-1} was more effective. This treatment was also the best at obtaining widest N/Fe ratio. It can be seen that P/Ca and K/Ca ratios were highest when 45 kg K per ha was applied.

Table 4.3.3.d. Main effects of fertilizer levels on nutrient ratios at maximum tillering

	N/Ca	N/Fe	N/Mn	N/Zn	N/Cu	P/Ca	P/Fe	P/Mn	P/Zn	P/Cu	K/Ca	K/Fe	K/Mn	K/Zn	K/Cu	Ca/Fe	Ca+Mg/K
C_1	2.41	21.54	23.33	280.00	1400.0	0.34	3.00	3.25	39.00	195.0	3.23	28.85	31.25	375.00	1875.00	8.92	0.55
C_2	2.96	17.25	14.79	69.00	1035.0	0.44	2.58	2.21	10.33	155.0	4.86	28.33	24.29	113.33	1700.00	5.83	0.41
N_0	2.88	24.09	24.09	88.33	1325.0	0.33	2.73	2.73	10.00	150.0	4.03	33.73	33.73	123.67	1855.00	8.36	0.46
N_1	3.50	26.73	26.73	98.00	1470.0	0.38	2.91	2.91	10.67	160.0	4.81	36.73	36.73	134.67	2020.00	7.64	0.41
N_2	3.03	28.64	24.23	157.50	1575.0	0.31	2.91	2.46	16.00	160.0	3.82	36.09	30.54	198.50	1985.00	9.45	0.45
P_0	3.51	29.10	26.45	97.00	1455.0	0.34	2.80	2.55	9.33	140.0	4.80	39.80	36.18	132.67	1990.00	8.30	0.39
P_1	4.18	25.08	23.15	100.33	1505.0	0.46	2.75	2.54	11.00	165.0	5.36	32.17	29.69	128.67	1930.00	6.00	0.38
P_2	2.26	25.73	25.73	94.33	1415.0	0.26	3.00	3.00	11.00	165.0	3.10	35.27	35.27	129.33	1940.00	11.36	0.55
K_0	3.27	25.33	27.64	101.33	1520.0	0.32	2.50	2.73	10.00	150.0	4.19	32.50	35.45	130.00	1950.00	7.75	0.44
K_1	2.58	27.00	27.00	74.25	1485.0	0.28	2.91	2.91	8.00	160.0	3.39	35.45	35.45	97.50	1950.00	10.45	0.52
K_2	3.85	24.82	22.75	136.5	1365.0	0.45	2.91	2.67	16.00	160.0	5.52	35.64	32.67	196.00	1960.00	6.45	0.37
CD(0.05)	NS	NS	NS	96.67	NS	NS	NS	NS	5.00	NS	NS	NS	NS	28.33	NS	NS	NS

C_1 - Standard control; C_2 - Absolute control
NS - Non significant

Table 4.3.3.c. Interaction effects of fertilizer levels on nutrient contents at maximum tillering
I. N x P interaction

	N content (%)			P content (%)			Ca content (%)			Mg content (%)		
	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2
P_0	2.46	2.84	3.42	0.26	0.28	0.31	0.61	0.61	1.27	0.69	0.70	0.79
P_1	2.83	3.00	3.19	0.32	0.34	0.32	0.61	0.46	1.08	0.74	.89	0.62
P_2	2.65	3.00	2.86	0.31	0.35	0.34	1.52	1.45	0.77	0.96	0.81	0.85
CD(0.05)	0.10			0.05			0.35			0.19		

	S content (%)			Fe content (ppm)			Mn content (ppm)			Zn content (ppm)		
	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2
P_0	0.37	0.33	0.34	864.2	1114.0	1167.7	967.7	1100.8	1224.7	357.5	210.5	286.2
P_1	0.39	0.41	0.40	1354.8	1117.8	1085.3	1151.5	1241.0	1421.2	270.3	449.3	129.2
P_2	0.40	0.38	0.40	1114.7	1131.2	1067.5	1120.3	1007.7	1193.3	381.0	237.2	236.3
CD	0.04			150.4			207.9			103.7		

Contd.

II. N x K interaction

	N content (%)			P content (%)			K content (%)			Ca content(%)		
	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2
K_0	2.91	3.05	3.16	0.31	0.27	0.31	3.64	4.16	3.90	1.06	0.46	1.27
K_1	2.42	3.12	3.36	0.30	0.36	0.30	3.75	3.97	3.98	1.05	1.04	1.36
K_2	2.60	2.66	2.94	0.28	0.34	0.35	3.73	4.01	4.03	0.64	1.02	0.48
CD (0.05)	0.10			0.05			0.29			0.35		

	Mg content(%)			Fe content (ppm)			Mn content (ppm)			Zn content(ppm)		
	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2
K_0	0.87	0.70	0.73	1212.5	1309.2	1149.0	1026.2	1131.0	1254.5	398.0	275.3	99.8
K_1	0.90	0.97	0.70	989.7	1046.7	1149.8	998.0	975.5	1330.8	403.7	401.2	331.0
K_2	0.62	0.73	0.83	1131.5	1067.2	1021.7	1212.3	1243.0	1253.8	207.2	220.5	220.8
CD	0.19			150.4			207.9			103.7		

	Cu content (ppm)		
	N_0	N_1	N_2
K_0	20.5	17.3	21.7
K_1	17.2	25.3	19.0
K_2	17.0	15.3	19.0
CD (0.05)	7.21		

Contd.

4.3.4 Elemental composition at panicle initiation

4.3.4.1 Main effects

a) Nutrient contents

Observations on the data presented in Table 4.3.4.a. showed that standard control recorded higher contents of N and Cu and a lower content of Mn compared to absolute control. The increase in N and Cu and decrease in Mn worked out to 11.11, 9.89 and 11.52 per cent respectively.

Application of fertilizer N and its levels increased the Ca content of the plants at panicle initiation. Ca content increased by 2.17, 106.52 and 71.74 per cent at N_0, N_1 and N_2 levels, over standard control.

Main effect of P presented in the table showed that P at 15 kg significantly increased Ca and S contents over absolute and standard controls. P at 45 kg reduced Mn content by 13.65 per cent compared to absolute control.

Application of K at 45 kg ha^{-1} significantly increased, the Ca content over both controls and the Mg content over standard control. Al and Mo were present only in traces and hence, have not been tabulated.

b) Nutrient uptake

It can be seen from the data presented in Table 4.3.4.b. that, compared to absolute control, standard control showed a significant increase in the uptake of Ca and Mg and the increases were 18.92 and 25.63 per cent respectively. Increasing levels of N and K upto 45 kg ha^{-1} had brought about linear increase in the uptake of Ca and Mg. Highest uptake of Ca and Mg due to P effect were recorded at P_0 and P_2 levels respectively.

Table 4.3.4.a. Main effects of fertilizer levels on nutrient contents at panicle initiation

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
C_1	1.90	0.42	2.83	0.46	0.42	0.26	1197.5	1275.83	111.67	13.0
C_2	1.71	0.50	2.92	0.52	0.45	0.26	1297.0	1442.0	147.83	11.83
N_0	1.69	0.45	2.84	0.47	0.45	0.27	1336.33	1297.11	130.44	12.72
N_1	1.81	0.46	3.05	0.95	0.47	0.26	1275.94	1298.89	138.61	12.61
N_2	1.89	0.47	3.05	0.79	0.46	0.25	1440.89	1402.56	108.50	12.78
P_0	1.88	0.47	2.96	0.79	0.46	0.29	1330.89	1329.67	142.72	12.44
P_1	1.76	0.44	3.02	0.67	0.46	0.24	1348.67	1423.72	114.83	12.67
P_2	1.75	0.47	2.95	0.56	0.47	0.25	1373.61	1245.17	120.00	13.00
K_0	1.90	0.46	2.91	0.57	0.46	0.27	1513.56	1465.61	119.50	12.33
K_1	1.76	0.45	2.97	0.71	0.45	0.26	1288.67	1306.67	116.56	12.33
K_2	1.72	0.47	3.05	0.74	0.48	0.25	1250.94	1226.28	141.50	13.44
CD (0.05)	NS	NS	NS	0.21	NS	NS	225.38	NS	NS	NS

C_1 - Standard control; C_2 - Absolute control
NS - Non significant

Table 4.3.4.b. Main effects of fertilizer levels on nutrient uptake (kg ha^{-1}) at panicle initiation

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
C_1	18.17	4.02	27.07	4.40	4.02	2.49	1.15	1.22	0.11	0.01
C_2	12.16	3.55	20.76	3.70	3.20	1.85	0.92	1.03	0.11	0.01
N_0	15.26	4.06	25.65	4.24	4.06	2.44	1.21	1.17	0.12	0.01
N_1	17.87	4.54	30.12	9.38	4.64	2.57	1.26	1.28	0.14	0.01
N_2	24.17	6.01	39.01	10.10	5.88	3.20	1.84	1.79	0.14	0.02
P_0	20.92	5.23	32.94	8.79	5.12	3.23	1.48	1.48	0.16	0.01
P_1	16.42	4.10	28.17	6.25	4.29	2.24	1.26	1.33	0.11	0.01
P_2	19.67	5.28	33.16	6.29	5.28	2.81	1.54	1.40	0.14	0.01
K_0	16.69	4.04	25.56	5.01	4.04	2.37	1.33	1.29	0.11	0.01
K_1	19.96	5.10	33.68	8.05	5.10	2.95	1.46	1.48	0.13	0.01
K_2	19.91	5.44	35.30	8.57	5.56	2.89	1.45	1.42	0.16	0.02
CD (0.05)	NS	NS	NS	0.68	0.13	NS	NS	NS	NS	NS

C_1 - Standard control; C_2 - Absolute control
NS - Non significant

4.3.4.2 Interaction effects

Data on interaction effects are presented in Table 4.3.4.c.

a) N x P interaction

P and S contents alone were affected by N x P interaction. Highest P content of 0.52 per cent and highest S content of 0.32 per cent were recorded at n_0p_0 level, while the lowest was recorded at n_0p_2 and n_0p_1 respectively. At constant level of N, increasing P levels tended to decrease the S content. At 30 and 45 kg levels of N, increasing levels of P brought about an increase in the P content.

b) N x K interaction

Interaction effect of N and K on nutrient absorption at panicle initiation stage showed that combined application of N at 30 kg and K at 45 kg significantly increased the K, Mg and Zn contents of the plant over n_2k_2 and n_1k_1 levels.

K can be seen to have significatly interacted with N in reducing the Fe and Mn contents. Highest Fe and Mn contents of 1538 and 1628 ppm were recorded at n_2k_0 level which were reduced by the interaction to 1296 and 1281 ppm respectively.

c) P x K interaction

Interaction effect between P and K on the contents of P, Ca, S, Fe, Mn and Zn were significant and are given in Table 4.3.4.c. It can be seen that the highest contents of Ca and S in the plants at panicle initiation stage were recorded at

Table 4.3.4.c. Interaction effects of fertilizer levels on nutrient contents at panicle initiation

I.N x P interaction

	P content (%)			S content (%)		
	N0	N1	N2	N0	N1	N2
P0	0.52	0.43	0.46	0.32	0.27	0.26
P1	0.44	0.46	0.44	0.22	0.25	0.25
P2	0.40	0.49	0.51	0.25	0.26	0.24
CD (0.05)	0.10			0.05		

II. N x K interaction

	P content (%)			K content (%)			Ca content (%)			Mg content (%)		
	N0	N1	N2	N0	N1	N2	N0	N1	N2	N0	N1	N2
K0	0.45	0.50	0.44	2.79	2.93	3.02	0.51	0.49	0.72	0.44	0.43	0.51
K1	0.44	0.41	0.51	2.79	2.96	3.17	0.52	1.11	0.48	0.44	0.45	0.45
K2	0.53	0.43	0.46	2.93	3.27	2.96	0.47	0.95	0.79	0.48	0.54	0.43
CD (0.05)	0.10			0.36			0.36			0.06		

	Fe content (ppm)			Mn content (ppm)			Zn content (ppm)		
	N0	N1	N2	N0	N1	N2	N0	N1	N2
K0	1478.7	1523.8	1538.2	1309.8	1458.3	1628.7	114.7	116.5	127.3
K1	1290.8	1087.0	1488.2	1279.3	1343.3	1297.3	140.5	113.3	95.8
K2	1239.5	1217.0	1296.3	1302.2	1095.0	1281.7	136.2	186.0	102.8
CD (0.05)	390.4			340.8			81.9		

Contd.

III. P x K interaction

	P content (%)			Ca content (%)			S content (%)			Fe content (ppm)		
	P0	P1	P2	P0	P1	P2	P0	P1	P2	P0	P1	P2
K0	0.45	0.50	0.44	0.51	0.70	0.51	0.28	0.27	0.26	1611.8	1348.8	1580.0
K1	0.44	0.41	0.51	1.10	0.51	0.50	0.32	0.25	0.22	1073.5	1384.5	1408.0
K2	0.53	0.43	0.46	0.76	0.79	0.66	0.26	0.22	0.27	1307.3	1312.7	1132.8
CD (0.05)	0.10			0.36			0.05			390.4		

	Mn content (ppm)			Zn content (ppm)		
	P0	P1	P2	P0	P1	P2
K0	1529.8	1403.2	1463.8	130.3	105.0	123.2
K1	1290.2	1455.8	1174.0	127.3	84.7	137.7
K2	1169.0	1412.2	1097.7	170.5	154.8	99.2
CD (0.05)	340.8			81.9		

p_0k_1 level, Fe and Mn at p_0k_0 level and P and Zn at a combination of P at 15 kg and K at 45 kg level. Thus low levels of P combined with high levels of K led to higher P and Zn contents and P and K at lower levels of combination led to high Fe and Mn contents.

4.3.4.3 Nutrient ratios

It can be seen from Table 4.3.4.d that main effects of fertilizer levels did not have any significant influence on nutrient ratios analysed in the present experiment.

4.3.5 Elemental composition of straw at harvest

4.3.5.1 Main effects

a) Nutrient contents

Data on the main effects of treatments on the elemental composition of straw are given in Table 4.3.5.a. It can be seen that treatment effects on elemental composition of straw was significant only in the case of N and K. Standard control increased the N and K contents over absolute control by 2.22 and 8.70 per cent respectively.

Application of N at 30 and 40 kg ha^{-1} increased the N and K contents of straw over absolute control. However, the effect of fertilizer N in improving the elemental composition over standard control was manifested only in the case of N. At N_2 level the increase in N content worked out to 21.74 per cent. Effect of P was seen mostly at 15 kg level, when it increased the N content by 16.3 per cent. Application of K could not bring about significant increase in K content of straw over standard and absolute controls. Its effect was also confined to N. K at 30 kg recorded the maximum content of 1.02 per cent N.

Table 4.3.4.d. Main effects of fertilizer levels on nutrient ratios at panicle initiation

	N/Ca	N/Fe	N/Mn	N/Zn	N/Cu	P/Ca	P/Fe	P/Mn	P/Zn	P/Cu	K/Ca	K/Fe	K/Mn	K/Zn	K/Cu	Ca/Fe	Ca+Mg/K
C_1	4.13	15.83	14.62	190.00	1900.00	0.91	3.50	3.23	42.0	420.0	6.15	23.58	21.77	283.0	2830.0	3.83	0.31
C_2	3.29	13.15	12.21	171.00	1710.00	0.96	3.85	3.57	50.0	500.0	5.62	22.46	20.86	292.0	2920.0	4.00	0.33
N_0	3.60	13.00	13.00	169.00	1690.00	0.96	3.46	3.46	45.0	450.0	6.04	21.85	21.85	284.0	2840.0	3.62	0.32
N_1	1.91	13.92	13.92	181.00	1810.00	0.48	3.54	3.54	46.0	460.0	3.21	23.46	23.46	305.0	3050.0	7.31	0.47
N_2	2.39	13.50	13.50	189.00	1890.00	0.59	3.36	3.36	47.0	470.0	3.86	21.79	21.79	305.0	3050.0	5.64	0.41
P_0	2.38	14.46	14.46	188.00	1880.00	0.59	3.62	3.62	47.0	470.0	3.75	22.77	22.77	296.0	2960.0	6.08	0.42
P_1	2.63	13.54	12.57	176.00	1760.00	0.66	3.38	3.14	44.0	440.0	4.51	23.23	21.57	302.0	3020.0	5.15	0.37
P_2	3.13	12.50	14.58	175.00	1750.00	0.84	3.36	3.92	47.0	470.0	5.27	21.07	24.58	295.0	2950.0	4.00	0.35
K_0	3.33	12.67	12.67	190.00	1900.00	0.81	3.07	3.07	46.0	460.0	5.11	19.40	19.40	291.0	2910.0	3.80	0.35
K_1	2.48	13.54	13.54	176.00	1760.00	0.63	3.46	3.46	45.0	450.0	4.18	22.85	22.85	297.0	2970.0	5.46	0.39
K_2	2.32	13.23	14.33	172.00	1720.00	0.64	3.62	3.92	47.0	470.0	4.12	23.46	25.42	305.0	3050.0	5.69	0.40
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

C_1 - Standard control; C_2 - Absolute control
NS - Non significant

Table 4.3.5.a. Main effects of fertilizer levels on nutrient contents of straw at harvest

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
C_1	0.92	0.23	4.00	2.44	1.66	0.11	983.33	1886.50	310.50	11.83
C_2	0.90	0.26	3.68	2.08	1.62	0.08	1047.67	1653.00	371.50	12.83
N_0	0.88	0.30	3.59	2.12	1.54	0.10	1054.56	1929.89	330.28	12.28
N_1	0.99	0.25	3.82	2.01	1.53	0.09	901.83	1784.67	382.33	12.67
N_2	1.12	0.31	3.97	1.95	1.73	0.09	1028.28	1936.39	332.61	12.50
P_0	1.07	0.26	3.95	1.90	1.48	0.10	989.56	1803.33	303.89	12.17
P_1	0.95	0.29	3.74	2.00	1.77	0.10	996.94	1836.28	384.22	12.56
P_2	0.96	0.32	3.69	2.18	1.54	0.09	998.17	2011.33	357.11	12.72
K_0	0.98	0.34	3.74	1.97	1.62	0.10	978.28	2042.11	299.94	12.56
K_1	1.02	0.28	3.82	2.07	1.53	0.10	884.22	1718.94	362.78	12.17
K_2	0.99	0.25	3.82	2.04	1.65	0.09	1122.17	1889.89	382.50	12.72
CD (0.05)	0.13	NS	0.25	NS	NS	NS	NS	NS	NS	NS

C_1 - Standard control; C_2 - Absolute control
NS - Non significant

b) Nutrient uptake

Data on the uptake of elements in the straw are presented in Table 4.3.5.b. Significant main effects of treatments on nutrient uptake in straw was confined to N, K and Ca only. Plants under standard control had absorbed the maximum quantities of 11.69, 50.84 and 31.01 kg ha^{-1} of N, K and Ca respectively. Among the levels, application of N at 45 kg ha^{-1} recorded a significantly higher uptake of N in the straw but was inferior in Ca uptake to standard control. There was no significant difference in K uptake between the two treatments. P and K at all levels failed to record uptakes comparable with that of standard control.

4.3.5.2 Interaction effects

Interaction effects are given in Table 4.3.5.c.

a) N x P interaction

Increasing levels of N at constant levels of P increased the N, K and Mg contents significantly. Highest Ca content was observed in n_1p_2 level. No definite trend of behaviour could be observed.

b) N x K interaction

At constant level of K, increasing levels of N tended to increase K and Mg contents. In the case of Ca, increasing effect of N was noticed only at 45 kg K level. Mn behaved similarly to Ca but the effect was noticed only in 15 kg level of

Table 4.3.5.c. Interaction effects of fertilizer levels on nutrient contents of straw at harvest

I. N x P interaction

	N content (%)			K content (%)			Ca content (%)			Mg content (%)		
	N0	N1	N2	N0	N1	N2	N0	N1	N2	N0	N1	N2
P0	0.87	1.12	1.23	3.92	3.89	4.05	2.31	1.39	2.00	1.52	1.33	1.59
P1	0.87	0.92	1.06	3.43	3.83	3.96	2.24	1.99	1.76	1.68	1.57	2.07
P2	0.90	0.92	1.06	3.43	3.73	3.89	1.80	2.64	2.10	1.43	1.69	1.52
CD (0.05)	0.23			0.43			0.62			0.45		

II. N x K interaction

	K content (%)			Ca content(%)			Mg content (%)			S content (%)		
	N0	N1	N2	N0	N1	N2	N0	N1	N2	N0	N1	N2
K0	3.55	3.89	3.77	2.13	2.15	1.64	1.58	1.68	1.59	0.10	0.09	0.11
K1	3.67	3.83	3.96	2.44	1.82	1.93	1.52	1.52	1.54	0.11	0.09	0.10
K2	3.57	3.73	4.17	1.78	2.05	2.29	1.53	1.39	2.05	0.09	0.11	0.07
CD (0.05)	0.43			0.62			0.45			0.03		

	Mn content (ppm)			Zn content (ppm)		
	N0	N1	N2	N0	N1	N2
K0	1911.7	2031.3	2183.3	345.2	215.0	339.7
K1	1944.5	1464.2	1745.2	285.7	446.0	356.7
K2	1930.5	1858.5	1880.7	360.0	486.0	301.5
CD (0.05)	673.3			175.7		

Contd.

III. P x K interaction

	N content (%)			Ca content (%)			Mg content (%)		
	P0	P1	P2	P0	P1	P2	P0	P1	P2
K0	1.15	0.95	0.84	1.57	2.07	2.27	1.43	1.83	1.58
K1	1.15	0.92	0.98	1.84	1.72	2.64	1.46	1.56	1.56
K2	0.92	0.98	1.06	2.29	2.20	1.63	1.54	1.93	1.49
CD (0.05)	0.23			0.62			0.45		

Table 4.3.6.b. Main effects of fertilizer levels on nutrient uptake (kg ha^{-1}) of grain

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
C_1	9.03	1.98	1.74	2.83	1.54	0.25	0.38	0.75	0.05	0.01
C_2	5.04	1.41	1.28	1.93	1.03	0.21	0.30	0.65	0.04	0.004
N_0	5.45	1.44	1.22	2.22	1.00	0.22	0.30	0.63	0.04	0.004
N_1	7.04	1.66	1.53	2.63	1.05	0.26	0.34	0.80	0.05	0.005
N_2	7.64	1.74	1.56	2.42	1.28	0.27	0.38	0.82	0.05	0.005
P_0	5.73	1.43	1.28	2.30	1.09	0.26	0.31	0.64	0.04	0.005
P_1	7.37	1.81	1.58	2.58	1.20	0.29	0.39	0.82	0.05	0.005
P_2	6.92	1.60	1.43	2.33	1.06	0.25	0.32	0.78	0.05	0.005
K_0	6.45	1.56	1.31	2.26	1.07	0.25	0.31	0.71	0.06	0.005
K_1	6.76	1.54	1.50	2.63	1.04	0.25	0.31	0.73	0.04	0.005
K_2	6.82	1.70	1.49	2.40	1.31	0.26	0.41	0.80	0.05	0.005
CD (0.05)	0.30	NS	NS	NS	NS	NS	NS	NS	NS	NS

C_1 - Standard control; C_2 - Absolute control
NS - Non significant

4.3.6.2 Interaction effects

a) N x P interaction

Effect of N x P interaction on the elemental composition is presented in Table 4.3.6.c. The data showed that while progressive increase in levels of both N and P upto 45 kg ha^{-1} increased the N content in grain, the interaction effect was negative in the case of P and Mg. The combined effect of N and P application on Cu content of grain tended to turn quadratic beyond 30 kg level of P.

b) N x K interaction

Combined application of N and K had significant influence only on the N and P content of grain and the effect was linear at constant levels of N in the case of P content, but there was no definite trend for N.

c) P x K interaction

At 45 kg level of P, increasing levels of K tended to reduce P and Fe contents. However, this effect was seen in Ca only at 15 kg level of P.

4.3.7 Net balance nutrient uptake

Data on the net balance nutrient uptake in the post-panicle initiation stage are presented in Table 4.3.7. An increase in the uptake of all elements except N, P, S and Fe in some cases, was seen.

4.3.8 Correlations between associated yield and nutritional characters

Intercorrelations among yield and yield attributes and select nutrient

Table 4.3.6.c. Interaction effects of fertilizer levels on nutrient contents of grain

I. N x P interaction

	N content (%)			P content (%)			Mg content(%)			Cu content (ppm)		
	N0	N1	N2	N0	N1	N2	N0	N1	N2	N0	N1	N2
P0	1.40	1.57	1.60	0.39	0.39	0.38	0.22	0.29	0.35	10.33	12.83	12.67
P1	1.37	1.62	1.62	0.38	0.36	0.39	0.27	0.23	0.25	10.67	10.83	11.00
P2	1.65	1.62	1.79	0.41	0.38	0.38	0.34	0.22	0.24	11.33	12.33	11.00
CD (0.05)	0.34			0.03			0.12			2.06		

II. N x K interaction

	N content (%)			P content (%)		
	N0	N1	N2	N0	N1	N2
K0	1.40	1.68	1.62	0.39	0.36	0.39
K1	1.57	1.48	1.82	0.38	0.38	0.36
K2	1.46	1.65	1.57	0.39	0.39	0.40
CD (0.05)	0.34			0.03		

III. P x K interaction

	P content (%)			Ca content (%)			Fe content (ppm)		
	P0	P1	P2	P0	P1	P2	P0	P1	P2
K0	0.37	0.37	0.40	0.63	0.50	0.50	750.8	617.2	878.8
K1	0.37	0.38	0.37	0.66	0.52	0.70	795.8	697.7	735.2
K2	0.41	0.38	0.39	0.55	0.60	0.49	955.0	1134.8	698.3
CD (0.05)	0.03			0.17			411.4		

Table 4.3.7. Net balance nutrient uptake in the post-panicle initiation stage

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
C_1	2.55	0.88	25.51	29.44	18.62	-0.84	0.48	1.93	0.33	0.02
C_2	-1.18	-0.42	9.13	11.95	8.52	4.89	0.07	0.71	0.18	0.002
N_0	-1.19	-0.22	4.24	14.91	9.24	-1.42	-0.07	1.00	0.16	0.004
N_1	-0.33	-0.23	11.92	14.56	3.63	-1.36	0.04	1.41	0.32	0.005
N_2	-2.34	-0.34	12.87	17.03	17.33	-1.79	-0.16	1.48	0.33	0.005
P_0	-4.69	-0.76	7.10	12.15	10.49	-1.99	-0.20	0.93	0.18	0.005
P_1	1.89	1.06	16.49	39.41	17.30	-0.80	0.28	1.61	0.38	0.005
P_2	-3.22	-0.5	4.72	17.69	11.08	-1.63	-0.22	1.38	0.26	0.005
K_0	-0.27	0.98	13.79	17.29	13.51	-1.1	-0.02	1.50	0.66	0.005
K_1	-1.88	-0.45	10.22	17.55	12.92	-1.59	-0.17	1.16	0.31	0.005
K_2	-3.2	-1.24	4.36	14.21	12.24	-1.73	0.08	1.27	0.27	0.005

C_1 - Standard control; C_2 - Absolute control

Table 4.3.8. Correlation coefficients of associated yield and nutritional characters

	Grain yield	Straw yield (x1)	Grain-straw ratio (x2)	No. of filled grain per panicle (x3)	N content at harvest (x4)	Ca content at harvest (x5)
Grain yield	1.000					
Straw yield (x1)	0.8222	1.000				
Grain straw (x2)	0.1172	0.3465	1.000			
No. of filled grains per panicle (x3)	0.5571	0.3056	0.3170	1.000		
N content at harvest (x4)	0.0402	0.1206	0.0058	0.0657	1.000	
Ca content at harvest (x5)	0.0572	0.1073	0.1622	0.0003	-0.2465	1.000

The multiple regression model is as follows:

$$y = 66.26 + 0.341\ x1^{**} + 342.715\ x2 + 3.331\ x\ 3 - 57.417\ x4 - 37.389\ x5$$

in Table 4.4.1. It can be seen that dry matter accumulation alone was significantly affected. Integrated nutrient management at 1:1 inorganic-organic ratio was significantly superior to exclusive use of farmyard manure or 3:1 fertilizer-organic manure ratio at maximum tillering stage and the increases were 88.66 per cent and 74.29 per cent respectively.

Azospirillum inoculation in combination with reduced supply of organics by 25, 50 and 75 per cent equivalents of N significantly reduced the dry matter accumulation at maximum tillering and panicle initiation stages and the reduction from full dose application through organics worked out to 5.15, 10.31 and 12.37 per cent at the former stage and 36.75, 30.72 and 36.14 per cent at the latter stage.

Dry matter accumulation at panicle initiation and harvest with exclusive use of fertilizers or organics or their integration at 3:1 or 1:1 ratios were statistically on par. At harvest, *Azospirillum* inoculation in combination with 75 per cent N equivalent through organic sources was on par with the first four treatments. But further reduction of organic nutrient sources to 50 and 25 per cent N equivalents significantly reduced the dry matter accumulation by 20.44 and 25.74 per cent respectively, in comparison with the accumulation at 100 per cent N supply through farmyard manure.

It can also be seen that at panicle initiation stage, application at full level of N sources in the ratio 1 inorganic : 1 organic recorded the highest dry matter accumulation while at harvest, sources fully applied in the form of fertilizers gave the maximum dry matter accumulation.

Table 4.4.1. Effect of integrated nutrient management on growth characters of *Njavara*

Treatment	Height of plant (cm)			No. of tiller/hill			Dry matter accumulation (kg ha^{-1})		
	At maximum tillering	At panicle initiation	At harvest	At maximum tillering	At panicle initiation	At harvest	At maximum tillering	At panicle initiation	At harvest
T_1	48.53	61.25	69.05	3.80	3.80	3.15	838.88	1349.99	1556.81
T_2	48.03	53.75	62.35	5.20	5.45	4.15	538.88	1383.32	1214.02
T_3	46.50	58.98	67.50	4.60	5.25	4.25	583.33	1649.98	1450.77
T_4	51.23	61.00	61.63	4.45	4.45	3.45	1016.66	1808.32	1452.66
T_5	43.63	52.75	56.88	4.00	4.80	3.90	511.11	874.99	1202.66
T_6	46.95	54.15	66.03	4.75	4.55	3.40	483.33	958.33	965.92
T_7	44.98	52.70	64.03	3.55	3.55	3.25	472.22	883.33	901.52
CD (0.05)	NS	NS	NS	NS	NS	NS	321.61	462.02	366.82

4.4.2 Yield and yield attributes

Significant differences due to treatment effects were noticed in the length of panicle, number of grains per panicle, number of filled grains per panicle as well as grain yield, as is evident in Table 4.4.2 and Fig.4.4.1. Application of N completely through fertilizers resulted in the maximum number of total and filled grains per panicle. Source variation and source combinations did not significantly affect any attribute. Straw yields as affected by different N sources and source balances are shown in Fig.4.4.2.

Reduced use of input to 25, 50 and 75 per cent of N equivalent in the form of organic sources combined with *Azospirillum* inoculation caused the minimum panicle length as well as the lowest number of total and filled grains per panicle in that order and were significantly inferior to full level application as fertilizer alone or 3:1 or 1:1 inorganic-organic ratios.

Application of full dose of nutrients in the ratio 3:1 (inorganic-organic) gave the highest grain yield of 465 kg ha^{-1}. Treatments with full dose of application but with variations in source and source combination did not differ significantly.

Azospirillum inoculation together with reduction of manure input by 50 and 75 per cent gave the lowest yield of grain and was significantly inferior to treatments receiving full dose N equivalents. However, reduction of manure input by 25 per cent did not affect the yield of grain. Straw yield was not significantly affected by any of the treatments.

Table 4.4.2. Effect of integrated nutrient management on yield and yield attributes of *Njavara*

Treatment	Grain yield (kg ha-1)	Straw yield (kg ha-1)	Grain-straw ratio	No. of product-tive tillers	Length of panicle (cm)	No. of grains per panicle	No. of filled grains per panicle	Percentage of filled grain per panicle	1000 grain weight (g)
T_1	439.40	1117.43	0.41	3.15	17.26	39.85	32.25	81.04	16.50
T_2	418.56	852.28	0.48	4.15	16.68	36.30	29.85	83.02	18.25
T_3	465.91	984.86	0.48	4.25	17.23	37.90	30.05	79.92	17.00
T_4	448.87	1003.79	0.46	3.45	17.42	38.60	31.95	82.84	17.88
T_5	369.32	833.34	0.49	3.90	16.83	34.60	29.85	86.80	17.88
T_6	284.10	681.82	0.43	3.40	15.57	30.35	26.65	87.22	16.00
T_7	238.64	662.88	0.34	3.25	14.83	27.45	23.85	86.95	16.50
CD(0.05)	119.51	NS	NS	NS	1.62	4.82	5.21	NS	NS

Fig.4.4.1 Grain yield (kg/ha) of Njavara under different N sources and source balances

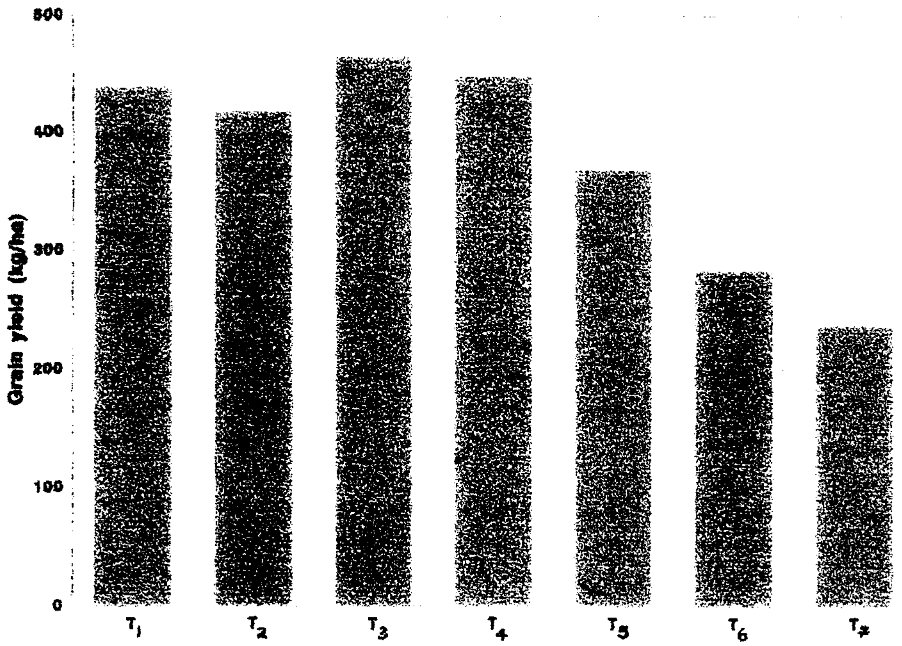
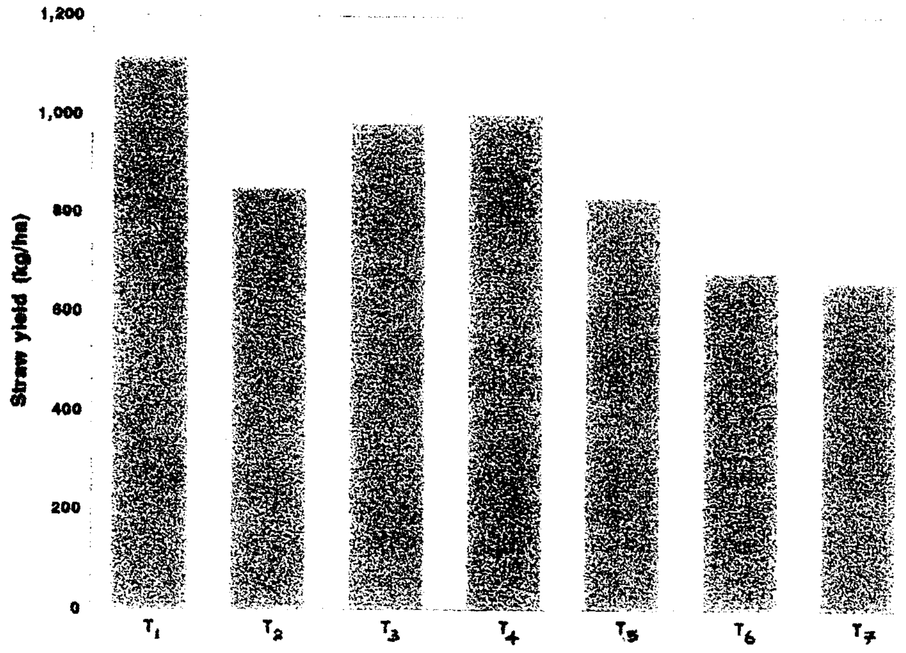


Fig.4.4.2 Straw yield (kg/ha) of Njavara under different N sources and source balances



4.4.3.1 Nutrient content at maximum tillering

N, P, K and S contents alone at maximum tillering were significantly affected by treatments (Table 4.4.3.a). Highest N and K contents were recorded by application of full dose of input as fertilizer and S content by full dose of inputs in the ratio 3 inorganic : 1 organic. Highest P content was recorded when input use was reduced by 50 per cent N equivalent. Lowest contents of N, P and K were recorded by treatments 2, 1 and 7 respectively. Al and Mo were present only in traces.

4.4.3.2 Nutrient uptake

Data on the uptake, presented in Table 4.4.3.b. showed that there was significant variation among treatments. The treatment receiving full dose of nutrient inputs, 50 per cent through inorganic sources and 50 per cent through organic sources recorded the highest uptake of N, P and K at maximum tillering stage and this was 9.82, 106.83 and 3.28 per cent more than that receiving full dose through fertilizers and 132.33, 65.67 and 80.35 per cent more than that receiving full dose through organic sources. It can also be seen that N uptake in T_2, T_6 and T_7 were on par.

4.4.4.1 Nutrient content at panicle initiation stage

Data on nutrient content of the plant at panicle initiation stage (Table 4.4.4.a) showed that application of full dose of N through fertilizers gave the highest content of N and Mn and was significantly superior to full dose applied through organic sources, and the increases were 81.58 per cent and 42.29 per cent respectively.

Table 4.4.3.a. Effect of integrated nutrient management on nutrient contents of *Njavara* at maximum tillering

Treat-ment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe ppm	Mn ppm	Zn ppm	Cu ppm
T_1	2.36	0.19	3.81	1.78	1.85	0.29	526.75	593.50	157.25	15.75
T_2	1.73	0.37	3.40	1.72	1.47	0.29	418.75	685.50	176.50	9.75
T_3	2.18	0.27	2.66	2.19	1.74	0.37	634.50	731.50	242.00	13.75
T_4	2.13	0.33	3.25	1.79	1.53	0.27	668.25	489.25	212.75	10.75
T_5	2.09	0.37	2.84	2.24	1.67	0.25	558.75	728.50	271.25	12.25
T_6	1.73	0.39	2.90	1.63	1.50	0.28	419.75	661.75	138.50	11.50
T_7	1.91	0.33	2.23	3.83	1.57	0.22	542.00	858.00	293.25	12.75
CD (0.05)	0.41	0.09	0.66	NS	NS	0.08	NS	NS	NS	NS

Table 4.4.3.b. Effect of integrated nutrient management on nutrient uptake (kg ha^{-1}) of *Njavara* at maximum tillering

Treat-ment	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
T_1	19.76	1.61	31.99	14.9	15.51	2.47	0.44	0.50	0.13	0.01
T_2	9.34	2.01	18.32	9.3	7.91	1.54	0.23	0.37	0.10	0.005
T_3	12.72	1.57	15.53	12.8	10.15	2.15	0.37	0.43	0.14	0.01
T_4	21.70	3.33	33.04	18.2	15.55	2.76	0.68	0.50	0.22	0.01
T_5	10.68	1.87	14.51	11.4	8.51	1.25	0.29	0.37	0.14	0.01
T_6	8.38	1.89	14.02	7.9	7.24	1.34	0.20	0.32	0.07	0.01
T_7	9.03	1.57	10.51	18.1	7.40	1.03	0.26	0.41	0.14	0.01
CD (0.05	1.32	0.28	2.12	5.5	NS	0.25	0.07	0.09	0.03	0.001

NS - Non significant

Table 4.4.4.a. Effect of integrated nutrient management on nutrient contents of *Njavara* at panicle initiation

Treat-ment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe ppm	Mn ppm	Zn ppm	Cu ppm
T_1	1.38	0.21	2.29	1.70	0.70	0.16	414.50	757.00	315.50	14.75
T_2	0.76	0.33	2.19	1.16	0.41	0.16	356.00	532.00	250.25	14.25
T_3	1.11	0.19	2.13	1.13	0.53	0.13	338.25	679.00	407.50	13.75
T_4	1.07	0.25	2.00	1.84	0.67	0.17	574.75	670.00	491.50	14.00
T_5	0.98	0.29	1.98	2.00	0.78	0.29	351.00	736.00	447.00	14.50
T_6	0.80	0.33	1.94	0.94	0.46	0.17	306.25	659.25	310.00	13.50
T_7	0.76	0.38	2.04	1.02	0.35	0.18	366.50	614.50	326.25	14.25
CD (0.05)	0.35	0.06	NS	0.60	0.17	0.07	NS	126.29	NS	NS

Table 4.4.4.b. Effect of integrated nutrient management on nutrient uptake (kg ha^{-1}) of *Njavara* at panicle initiation

Treat-ment	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
T_1	18.60	2.77	30.87	22.94	9.45	2.21	0.56	1.02	0.43	0.02
T_2	10.46	4.50	30.25	16.05	5.69	2.20	0.49	0.74	0.35	0.02
T_3	18.33	3.14	35.06	18.60	8.71	2.18	0.56	1.12	0.67	0.02
T_4	19.29	4.54	36.17	33.22	12.12	3.06	1.04	1.21	0.89	0.03
T_5	8.56	2.57	17.28	17.50	6.83	2.49	0.31	0.64	0.39	0.01
T_6	7.67	3.19	18.56	9.04	4.36	1.59	0.29	0.63	0.30	0.01
T_7	6.68	3.32	17.99	8.98	3.10	1.59	0.32	0.54	0.29	0.01
CD (0.05)	1.61	NS	1.20	2.76	0.79	NS	0.09	0.06	0.08	NS

NS - Non significant

Inoculation with *Azospirillum* and reduction of applied inputs by 25 per cent of N equivalent gave the highest contents of Ca, Mg, and S, ie., 2.0, 0.78 and 0.29 per cent respectively. S content in this treatment was significantly higher than in all other treatments. Ca and Mg contents were also significantly higher than when full dose of inputs was applied through organic sources.

Highest P content was recorded by the treatment receiving 25 per cent of the total inputs as organic manure in addition to *Azospirillum* inoculation and was significantly superior to all treatments with fertilizer combinations.

Al and Mo were present only in trace amounts.

4.4.4.2 Nutrient uptake

Data presented in Table 4.4.4.b reveal that the treatment receiving full N dose, through inorganic and organic sources in the ratio 1:1 recorded the highest uptake of all elements, and it was significantly superior to all other treatments. The increase in uptake over that when full dose was applied through fertilizers was 3.71, 63.9 and 17.17 per cent for N, P and K and over full dose applied through organics was 84.42, 0.89 and 19.57 per cent respectively.

Azospirillum inoculation with a concurrent reduction of inputs reduced the uptake of all elements and it declined in tune with the reduction of organic sources. Comparing with the uptake in the treatment receiving full input dose through organic manure, the reduction in N, P and K uptake at 25 per cent input application worked out to 36.14, 26.22 and 40.53 per cent and at 50 per cent input application, 26.67, 29.11 and 38.64 per cent respectively.

4.4.5.1 Nutrient content of straw at harvest

Data presented in Table 4.4.5.a revealed that application of full dose of N through fertilizers gave the highest content of N and Mn in the straw and it was 72.22 and 19.65 per cent more than that of Treatment 3 which gave the highest yield of grain.

Treatment 4, receiving the full nutrient input from inorganic and organic sources in the ratio 3:1, recorded the highest content of P and lowest content of Mg in the straw.

Treatment 5 recorded the highest contents of Ca, Mg and Zn in the straw which were 26.49, 62.5 and 33.86 per cent more than that of Treatment 4.

Lowest contents of the nutrients were recorded in T_7 which received only 25 per cent of N equivalent applied in organic form.

In straw of all seven treatments, presence of Al or Mo could not be detected.

4.4.5.2 Nutrient uptake

Uptake studies revealed that highest uptakes of N, K, Mg, Fe, Mn and Cu were recorded in the straw when full dose of N was supplied through fertilizers and they were 66.67, 93.04, 51.48, 123.53, 61.7 and 100 per cent more than T_2 and 94.68, 21.0, 37.4, 15.15, 33.33 and 100 per cent more than T_4 (Table 4.4.5.b). T_4 gave the highest uptake of P and S.

Table 4.4.5.a. Effect of integrated nutrient management on nutrient contents of *Njavara* straw at harvest

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe ppm	Mn ppm	Zn ppm	Cu ppm
T_1	0.62	0.02	1.71	1.51	0.69	0.09	680.00	677.50	340.25	16.25
T_2	0.49	0.04	1.16	1.84	0.51	0.09	403.00	552.75	351.25	15.75
T_3	0.36	0.03	1.51	1.92	0.61	0.10	699.50	600.75	265.25	13.75
T_4	0.36	0.05	1.58	1.85	0.48	0.11	655.00	566.25	461.50	14.75
T_5	0.36	0.02	1.31	2.34	0.78	0.10	683.75	625.25	617.75	16.75
T_6	0.45	0.04	1.06	2.03	0.59	0.11	576.25	507.25	411.75	14.75
T_7	0.27	0.02	1.38	1.67	0.49	0.10	734.75	498.00	404.75	13.75
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	153.78	1.89

Table 4.4.5.b. Effect of integrated nutrient management on nutrient uptake (kg ha^{-1}) of *Njavara* straw at harvest

Treatment	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
T_1	6.95	0.23	19.13	16.91	6.65	1.05	0.76	0.76	0.38	0.02
T_2	4.17	0.31	9.91	15.65	4.39	0.74	0.34	0.47	0.30	0.01
T_3	3.51	0.25	14.89	18.95	6.05	0.97	0.69	0.59	0.26	0.01
T_4	3.57	0.47	15.81	18.57	4.84	1.07	0.66	0.57	0.46	0.01
T_5	2.97	0.18	10.94	19.52	6.50	0.83	0.57	0.52	0.51	0.01
T_6	3.03	0.27	7.25	13.83	4.04	0.75	0.39	0.35	0.28	0.01
T_7	1.77	0.12	9.11	11.04	3.27	0.63	0.49	0.33	0.27	0.01
CD (0.05)	0.84	0.06	1.72	2.86	NS	0.11	0.09	0.04	NS	NS

NS - Non significant

Reduction in the quantity of nutrient inputs gave lower quantities of elements in the straw. A reduction in the input even by 25 per cent resulted in a significant reduction of N and P uptake when compared to full nutrient dose applied through organic sources and the reduction worked out to 28.78 and 41.94 per cent respectively.

4.4.6.1 Nutrient content of grain

Treatment effects on nutrient contents of grain (Table 4.4.6.a) revealed that among the treatments receiving full dose of N, the one in which N was applied 50 per cent in inorganic form and 50 per cent in organic form recorded the lowest N content and highest Fe content of 0.98 per cent and 132.75 ppm respectively. It was significantly inferior to the treatment receiving fertilizers and organic manures in the ratio 3:1 with regard to N content. Application of full dose of N through organics gave the lowest Fe content of 35 ppm.

Reducing the nutrient inputs tended to bring down the N content. It also increased the Fe content. Among these treatments, reduction of inputs by 50 per cent N equivalent gave the lowest N and highest Fe contents of 0.85 per cent and 162.25 ppm respectively. Data on Al and Mo have not been presented in the tables because they were present only in traces.

4.4.6.2 Nutrient uptake

Treatments varied in their effects on uptake of elements in the grain (Table 4.4.6.b). Integrated application of full dose in 3:1 ratio gave the highest uptake of N, K and Ca (7.04, 1.57 and 2.82 kg ha^{-1} respectively). Application entirely through organics gave the highest uptake of P and in 1:1 inorganic-organic

Table 4.4.6.a. Effect of integrated nutrient management on nutrient contents of *Njavara* grain

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe ppm	Mn ppm	Zn ppm	Cu ppm
T_1	1.22	0.12	0.31	0.27	0.95	0.08	39.25	73.00	179.75	8.00
T_2	1.29	0.14	0.31	0.30	1.36	0.06	35.00	71.75	316.00	6.50
T_3	1.51	0.12	0.34	0.61	1.56	0.08	84.25	70.25	378.75	7.75
T_4	0.98	0.11	0.31	0.46	1.80	0.06	132.75	68.75	468.25	8.00
T_5	1.10	0.12	0.30	0.18	0.90	0.06	76.75	77.75	221.25	7.75
T_6	0.85	0.12	0.33	0.44	2.16	0.05	162.25	76.50	321.50	9.25
T_7	0.89	0.11	0.31	0.68	2.34	0.05	81.25	79.25	507.00	8.25
CD (0.05)	0.40	NS	NS	NS	NS	NS	65.52	NS	NS	NS

Table 4.4.6.b. Effect of integrated nutrient management on nutrient uptake (kg ha^{-1}) of *Njavara* grain

Treatment	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
T_1	5.35	0.52	1.38	1.16	4.17	0.33	0.02	0.03	0.08	0.004
T_2	5.40	0.58	1.31	1.27	5.70	0.23	0.01	0.03	0.13	0.003
T_3	7.04	0.57	1.57	2.82	7.27	0.38	0.04	0.03	0.18	0.004
T_4	4.39	0.50	1.41	2.05	8.06	0.26	0.06	0.03	0.21	0.004
T_5	4.92	0.43	1.11	0.67	3.34	0.21	0.03	0.03	0.08	0.003
T_6	2.40	0.34	0.92	1.24	6.15	0.13	0.05	0.02	0.09	0.003
T_7	2.12	0.26	0.75	1.63	5.57	0.12	0.02	0.02	0.12	0.002
CD	0.48	NS	NS	NS	1.90	NS	NS	NS	NS	NS

NS - Non significant

ratio, highest uptake of Mg, Fe and Zn. All these were significantly superior to Treatments 1 and 2.

Reducing the inputs through application of organics alone proportionally reduced the uptake of elements significantly.

4.4.7 Bacterial population in soil

Bacterial population in soil was recorded one month after sowing. The counts are given below.

Bacterial population per g of soil

Total bacteria	*Azospirillum*	Total nitrogen fixing bacteria
T_1 - 35.5 x 10^7	T_2 - 1.4 x 10^5	T_1 - 56.08 x 10^5
T_2 - 16.38 x 10^7	T_7 - 4.9 x 10^5	T_2 - 9.31 x 10^5
T_5 - 53.26 x 10^7		T_5 - 29.96 x 10^5
T_6 - 34.32 x 10^7		T_6 - 9.15 x 10^5
T_7 - 33.18 x 10^7		T_7 - 8.79 x 10^5

The population of *Azospirillum* was meagre and was noticed only in T_2 and T_7.

4.4.8 Lodging

It was observed that the entire crop lodged in all the treatments in all the replications.

4.4.9 Pests and diseases

Pests and diseases were not a problem in the course of the experiment.

The overall yield forming process

Analysis of the yield process taking into account important situation, biotype and weather factors considering Njavara as the test crop resulted in the following regression equation:

$$y = 263.05 - 2194.199\, x_1^* - 1.607\, x_2^* + 0.304\, x_3^{**} + 3.754\, x_4$$

where,

y	- grain yield
x_1	- P content at panicle initiation
x_2	- Zn content at panicle initiation
x_3	- dry matter accumulation at harvest
x_4	- sunshine hours

Based on these four variables, a linear response model was derived as follows:

$$y = 340.8 - 1997.6\, x_1^* - 2.4329\, x_2^* + 0.2991\, x_3^{**} + 3.6131\, x_4$$

A similar linear response model for black glumed Njavara was:

$$y = 154.27 - 2451.6\, x_1^* - 1.07\, x_2^* + 0.345\, x_3^{**} + 3.724\, x_4$$

For golden yellow glumed *Njavara*, it was

$$y = 572.50 - 1868.2\, x_1^* - 3.858\, x_2^* + 0.28\, x_3^{**} + 3.391\, x_4$$

It can be seen from the data that yield of *Njavara* could be explained taking into account four factors. All the nutritional aspects could be represented by the anion P and the cation Zn, weather by sunshine hours and plant characters by dry matter accumulation.

It can also be seen that the variation between the types also could be explained based on the differential requirements mainly of the nutritional factors. High yielding golden yellow glumed biotype was less affected by P and more affected by Zn.

Discussion

5. DISCUSSION

The results of the individual experiments presented in the previous chapter are discussed in the following paragraphs. An overall discussion of the results based on all experiments concludes the chapter.

5.1 EXPERIMENT-I

Situation effects

Different cropping situations integrate favourable and unfavourable production factors in varying extents and depending on the balance between the magnitudes of the desired and undesired factors, yield expression is expected to show wide fluctuations. In the present trial, the yield variation had been of the order of 350 per cent between the highest and lowest yield situation (Table 4.1.la and Fig.4.1.1) and had been more than double the mean yield of the biotypes. This would mean that the habitat effect is the overriding factor affecting yield, rather than the biotype or variety. National evaluation of varietal performance in rice has also shown similar results. The habitat effect on productivity will be through modifying the rate of growth and development process and the effects and influences are discussed in the context of the four situations.

A comparison of the grain yield under the different cropping situations showed that it was related to the dry matter accumulation. Yield variation was clearly related to dry matter accumulation at the maximum tillering stage and the magnitude of variation to the dry matter accumulation in the post-panicle initiation stage. Positive accumulation in the post-panicle initiation stage increased significantly the development of post-panicle initiation components viz., number of grains per panicle, grain-straw ratio, percentage of filling and 1000 grain weight, whereas the dry matter accumulation at maximum tillering stage affected the floret number only. Matsushima (1957) reported that floret number is decided by the carbohydrates accumulated one month before heading. Grain yields in small seeded cereals are known to be substantially affected by the dry matter produced in the post panicle initiation stage (Buttrose and May, 1959).

Pattern of variation in the grain-straw ratio can also be related to dry matter accumulation in the primary and post-panicle initiation stages. Continued accumulation in the wetland situation led to a ratio of 0.91 as against 0.53 in the heavily shaded situation, where dry matter decline was noticed in the post-panicle initiation stage. Grain yield in the latter case depended probably entirely on early dry matter accumulation in the pre-panicle initiation stage, which may be the reason for the wide grain-straw ratio.

The wide variation in the grain-straw ratio also suggests that it is an environmental identification and is an expression of growth, production and metabolic efficiencies shaped by the environment. This is evidence to the fact that habitat effect through its influence on dry matter production and partitioning coefficient affects the entire process of production of economic yield.

In spite of consistently low dry matter accumulation in the upland situations, leaf area index and chlorophyll content at panicle initiation and flowering stages have been significantly high here (Table 4.1.2.a). Number of florets per panicle as well as the seed weight were also low in these situations. This points out to the possibility of inhibited photosynthetic process. Musthafa (1995) has found that the rice crop, due to stress effect from Fe, manifests a protracted tillering effect in the maturity phase which immediately declines. Low dry matter accumulation may be either due to stress effects leading to production of short lived late tillers which contribute to high LAI and chlorophyll content, or due to the effect of diversion of photosynthates to other metabolic pathways for biosynthesis of characteristic qualitative products, or both. Improvement in the contents of free amino acids along with chlorophyll in the upland situations and a positive correlation between them suggests that at least in part, this is a possibility. However, these aspects require detailed investigation.

Elemental composition of the plant as well as its uptake (Table 4.1.3 and Fig. 4.1.4) at maximum tillering stage showed that plants in the upland situations had a higher N content and they had taken up higher quantities of N at this stage (Table 4.1.5). Viewed in the context of dry matter production in the four situations, the results indicated that situations did not differ in N supplying power. Nutritionally, growth is defined as the capacity of the plant to dilute N (Wilcox, 1937). The difference in growth in the four situations appeared to be in all probability, due to some inhibiting factor. Uptake of P, K, Ca, S and Fe being in tune with dry matter production, and consistently high uptake of Mn and Zn in the uplands would suggest that their contents in the plant might have been the limiting factor for N dilution by the plant. Lower nutrient use efficiency in the uplands is also evident from the data.

De Datta (1981) has reported that 2500 ppm is the upper critical (toxic) level of Mn. Similar results of excess absorption inhibiting growth have been reported in the case of Fe in rice (Bridgit *et al.*, 1993; Musthafa, 1995) and in Mn in coconut (Mathewkutty, 1994) in soils of lateritic origin. Low content of P in these situations would suggest that low P availability may also be involved. Thus the results suggest that situation differences are due, at least in part, to variation in the availability and absorption of elements or their balances.

The fact that elemental composition did not show much change at the panicle initiation stage (Table 4.1.6) coupled with a general two fold increase in uptake against a nearly three fold increase in dry matter would indicate that dilution to any significant extent did not take place (Table 4.1.8). This would suggest that the grand growth phase is largely a plant factor and rate of increase of dry matter at this stage is almost independent of situation. Fig.4.1.3 depicts a representation of grain yield produced per kg of select micronutrients (Fe, Mn and Zn) absorbed under different situations.

The most conspicuous observation on the nutritional front has been provided in Table 4.1.16 which is the net balance sheet of elements used in the production process in the post-panicle initiation stage. Large scale shedding of some elements as well as selective absorption of others had taken place. The data showed that low productivity in the uplands had not been due to an insufficiency of elements. Yield differences among the upland situations is indicative of the sunlight effect. But the fact that the difference in yield between open uplands and wetlands cannot be explained by this points out to nutritional imbalances probably leading to such a situation. Musthafa (1995) has reported such nutrient shedding in rice and attributed the phenomenon to be a plant mechanism to shed excess Fe in plants. Here, Mn was the element shed uniformly in all the situations. Its content had also been high. Working out the relationship will show that to shed 0.1 kg Mn, the plant had to shed 14.3, 1.83 and 24.06 kgs of N, P and K respectively.

Large scale shedding of elements is the indication of non-productive metabolic processes and plant growth. Shedding of almost all elements in uplands, where quality of produce was higher, would suggest that nutrient imbalances and exigencies of metabolic changes may be the cause. Probably, the nutritional requirements for biomass yield and quality are different. Biomass yield and quality may also be inversely related. This may also suggest the possibility of improving quality through specific nutritional management.

Minimum shedding in the wetland situation coupled with lowest content of amino acids and a three fold increase in yield would probably suggest that shedding, at least in part, is due to a change in the metabolic pathway from carbohydrate accumulation to carbohydrate utilisation for free amino acid synthesis. Reduction of one mole of N requires 12 electrons, and so a large diversion of carbohydrates might have been required for large scale synthesis of amino acids. Assimilate diversion might have led to the loss of some vegetative tissues already produced. Large scale shedding of nutrients (Table 4.1.16) along with higher production of amino acids (Table 4.1.20) may also point out to the possibility that metabolic requirements are different for the process.

Significant differences in the dry matter accumulation pattern in different situations also appear to be related to the elemental composition. A low content of micro elements with a high content of P showed continued dry matter accumulation (Table 4.1.1.a) while the reverse was true in the case where shedding of dry matter took place. P availability has been reported to be higher in the wet situation due to reduction of ferric phosphate to the more soluble ferrous phosphate (Islam and Elahi, 1954).

Data presented in Table 4.1.20 showed that the cropping situations influenced the free amino acids of the grain both in total content as well as in types of amino acids. Wetland recorded the lowest contents and open uplands the highest. Wet and open uplands differ mainly in stress effect of moisture which indicate that amino acids accumulate under stress situation. Similar results have been reported with respect to total alkaloid content in rauvolfia and periwinkle by Pareek *et al.* (1991). In accordance with these results, in the present study also, proline, an amino acid which accumulates in stress conditions, had been detected in the *Njavara* grain in upland situations.

Types of amino acids also have varied with the situations. Histidine monohydrochloride and DL-2-Amino-butyric acid were found only in open situations and ornithine was detected only in shaded situations. Methionine was seen only in the grain of uplands. Variations in types of free amino acids as well as their quantity suggest that quality is a function shaped by the habitat.

Among the upland situations, free amino acid content varied inversely with the availability of radiation. Along with this, its positive relationship with chlorophyll content pointed out to the possibility of free amino acid formation being linked with chloroplasts and photosynthesis. Rice is a C_3 plant where rate of net photosynthesis is inversely related to the glycolate pathway. Glycolate pathway is a temperature dependent reaction and probably diverts intermediary products of photosynthesis for the formation of amino acids in *Njavara* as in any other C_3 plant. Static or negative dry matter accumulation in the post-panicle initiation stage and decreased grain yield with increased yield of free amino acids suggest that free amino acid production is at the expense of grain yield and that the shift commences at panicle initiation stage or at least immediately after.

A scrutiny of variation in the free amino acid content in the context of elemental composition of the grains revealed that it had followed the trend of Mn accumulation in the grain. This phenomenon along with tendency for higher accumulation of Mn by the plant indicated the possibility of involvement of Mn in the synthesis of amino acids-it might have been a co-factor.

The general functional model of grain yield of the *Njavara* crop averaged over situation and biotypes revealed the involvement of 11 factors in the process (Table 4.1.19). The most significant aspect of the result has been that N was not apparently involved in the process. Moreover, it appeared that the role of P had been marginal and the effect of K negative. This indicates the futility of nutritional management with N, P and K to increase grain yield in the habitat under study. *Njavara* is a totally untuned land race valued for its qualitative properties. Fertiliser responsiveness is an attribute inducted through genetic manipulation and selection process.

Still more striking is the negative influence of Mg and Mn at maximum tillering stage, and Cu, Zn and S at panicle initiation stage. They are elements which are not applied and the crop depends on the native soil contents for absorption. Plant content of all these elements were also high and ranged between 0.19 to 1.31 per cent for Mg and 77 to 208 ppm for Zn. Cu content ranged from 5.96 to 17.46 ppm at maximum tillering stage (Table 4.1.3) and from 3.39 to 11.89 ppm at panicle initiation stage (Table 4.1.6). The critical levels of these micro elements beyond which tolerance is exceeded are 2500 ppm for Mn, 1500 ppm for Zn and 30 ppm for Cu (Tanaka and Yoshida, 1970).

Thus a higher content of these elements in the plant as well as the negative relations suggest that non-applied secondary and micro elements are the limiting factors of production. Such a situation is evidently due to the highly weathered nature of the soil, a consequence of the tropical monsoonic weather pattern. Anilakumar *et al.* (1992) have reported that even high yielding varieties of rice do not respond to fertilizers in highly weathered laterite soil. Bridgit *et al.* (1993) have identified the cause and limiting factor as Fe. Musthafa and Potty (1996) attributed the cause to the interference of Fe in N nutrition.

The negative influence of these elements on productivity is further confirmed by the observation of shedding of elements by the crop in the post-panicle initiation stage (Table 4.1.16). The data showed that it was neither unavailability of the elements nor their low absorption that inhibited the productivity of the crop. The plant failed to utilise absorbed nutrients for grain production. This situation calls for formulation of effective soil amendment measures first. Positive relationship of Ca/Fe ratio at maximum tillering with dry matter accumulation (Table 4.1.18) indicates that liming may be helpful to improve the situation.

Very high residual values of 0.59 in the path coefficient analyses of dry matter accumulation and grain yield with yield attributes of plants is another conspicuous observation (Table 4.1.17.a and b). The two possibilities leading to such a situation are the persistence of non-productive tillers and/or dry matter decline in the productive phase. Dry matter decline in the uplands coupled with nutrient shedding, selective in rate and extent for individual elements, lead to the conclusion that it is the cause for the high residual value. Large scale diversion of photosynthates for biosynthesis of quality components in the productive stage may be another reason.

Signifiance of non-applied elements in governing grain yield, absence or negative influence of applied elements and their non-metabolic accumulation in the generalised context lead to the inevitable conclusion of the essentiality of detailed analysis of plant behaviour and situation specific influences.

The efficacy of nutritional parameters to explain completely the phenomena of dry matter accumulation and grain yield as against the failure of biometric yield components would suggest that yield limiting factors are metabolic ones and are linked to disproportionate levels of native secondary and microelements. They are probably limiting the response of applied fertilizers also. The fact that the present results cover a wide yield variation of the order of 350 per cent points out that this has relevance in the context of general crop production especially of rice. Reasons for stagnant productivity and failure to improve the yield further in spite of high yielding varieties and heavy input use may be because of the limitations imposed by excess levels of non-applied secondary and microelements. Thus these results call for a change in nutritional management of crops for realising potential yields.

Biotype variations

Growth process analysis (Table 4.1.1.a) revealed three specific phases in the development of the crop after establishment - (1) a primary phase of high elongation and rapid expansion in tiller number as well as heavy accumulation of nutrients, probably indiscriminately, but a commensurably low level of dry matter accumulation. (2) a grand growth phase characterised by a rapid rate of dry matter accumulation and (3) a diversion phase - this is an unstable phase, characterised by slight increase in height, decline in tiller number, increase or decrease in dry matter, and selective absorption and sometimes shedding of nutrients, probably for maximum metabolic utilisation of absorbed nutrients. A strong relationship of this phase to panicle characteristics as well as quality suggests that this is the phase most crucial in productivity both in respect of yield and quality and the biotype variations are manifested more in this phase.

Productivity characteristics showed that the golden yellow glumed type produced 52 per cent more grain than the black glumed type, with nearly the same grain-straw ratios. Both the biotypes produced nearly the same dry matter amounts by panicle initiation. But subsequently, while dry matter declined by 600 kg in the black glumed biotype, the golden yellow glumed type recorded an increase of 940 kg. This difference in dry matter accumulation in the post-panicle initiation stage has evidently been the cause of differences in yield. Dry matter accumulation in the post-flowering phase is substantial and is the main component of grain yield.

Considering the components of grain yield, significant increase in length of panicle and number of grains as well as number of filled grains per panicle in golden yellow glumed biotype was responsible for its higher yield (Table 4.1.1.a). A higher dry matter production that continued till harvest as well as a more efficient translocation system contributed to the superior performance of the golden yellow glumed biotype. Better panicle length and higher number of florets are indicative of the superiority of the golden yellow type for grain yield. This appears to be purely a genetic characteristic.

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A decline in dry matter accumulation and net assimilation rate in the black glumed type in spite of comparable leaf area and higher chlorophyll content would indicate a failure in the carbohydrate accumulation process, either due to an accumulation of carbohydrates in the sites of synthesis or due to diversion of the same for biosynthesis of quality components as in the glycolate pathway and in amino acid synthesis in the chloroplasts. Inhibitory effects of photosynthate accumulation due to failure in transport system has been reported by Asana (1966). A negative NAR really indicated that the plant life in the post-panicle initiation stage continued on already stored photosynthates. Thus, low grain yield in black glumed biotype appeared to be a function of the dry matter accumulation in the pre-panicle initiation stage.

Elemental composition of the plant at maximum tillering (Table 4.1.3) and panicle initiation stages (Table 4.1.6) showed that the biotypes differed in nutrient contents. Golden yellow glumed type showed a higher N content and tended to have higher levels of P, K, Mg and S, while black glumed type showed higher contents of Ca and Mn and tended to have a higher Fe content at maximum tillering stage. But at panicle initiation, while black glumed biotype continued to have significantly higher content of Mn, the other type had higher P and K contents. Uptake figures showed the same trend at maximum tillering and panicle initiation stages. Higher contents of N, P and K and a comparitively low content of Mn might have facilitated continued dry matter accumulation of the plant and higher yield of golden yellow glumed type while a higher Mn content of the plant with lower contents of P and K might have been responsible for the shedding of dry matter and low yield but higher quality in black glumed type.

Uptake differences between panicle initiation and harvest showed that the black glumed biotype shed more of N, P and K than the golden yellow glumed biotype but the latter absorbed Ca continuously till harvest. This is an instance of selective absorption and it is possible that a variation in metabolic pathways between the types had been a contributory factor for the differences in yield.

Changing pattern of uptake of elements (Tables 4.1.5, 4.1.8, 4.1.11 and 4.1.14) showed that increasing nutrient uptake closely followed the dry matter accumulation, with the accumulation failing to bring about any significant dilution in the elemental composition of the biotypes. It is possible that shedding of nutrients in the final phase is the natural result of this. The plant had higher concentrations of Fe, Zn and Mn than was required for normal growth. It is possible that dilution and more growth could not occur due to toxic levels of these microelements. Marykutty (1986) found that toxic levels of Mn, Fe and Zn limit the yield in rice.

The higher contents of elements in the plants in the early stages may suggest higher level of availability from the soil. Similarly, selective absorption of Ca by golden yellow glumed *Njavara* and the higher content of Mn in black glumed type may be biotype attributes. Yoshida (1981) has reported that plant types vary in their requirement of elements.

Observations on quality characteristics (Table 4.1.20) revealed that the black glumed biotype had a higher content of free amino acids than the golden yellow glumed and the mean variation was 0.322 mgg^{-1}. The similar dry matter accumulation patterns till panicle initiation and variation in the post-panicle initiation stage when the black glumed biotype was characterised by a dry matter decline would suggest that dry matter decline itself was the result of biosynthesis of free amino acids.

Higher production of free amino acids in spite of a lower leaf area index (Table 4.1.2.a) in the black glumed biotype indicated that leaf surface area is not important in their synthesis. The role of surface area in trapping of sunlight and non-involvement of surface area indicates that it is a dark reaction. It is probable that the site of synthesis is the stroma of the chloroplasts.

A negative net assimilation rate (Table 4.1.2.a) also appears to have significance. Osborne (1962) reported that lack of sufficient cytokinins in the leaf will lead to breakdown of proteins to amino acids for translocation to the grain. The tendency for free amino acid accumulation may be due to insufficiency of cytokinins, but this requires detailed investigation.

Black glumed biotype was characterised by a higher content of Mn. It is possible that Mn is involved in the synthesis of amino acids.

Data on the duration of biotypes (Table 3.4) showed that no specific duration could be attributed to any biotype. It appeared to be an environmental function and was probably fixed by heat unit accumulation. Duration was also not related to the quality of the product.

5.2 EXPERIMENT II

Variation in date of sowing

Results presented in Table 4.2.1 show that maximum yield of 5340 kg grain ha^{-1} was recorded when seeds were sown on June 30th. Yield of *Njavara* grown in uplands has been found to be significantly correlated only with rainfall and relative humidity in the post flowering phase (Table 4.2.10). Progressive reduction in yield with advancing sowing dates therefore has been due to the declining rainfall and relative humidity.

Yield variation from 630 to 5340 kg ha^{-1} (Table 4.2.1 and Fig.4.2.1) show that weather has enormous influence on deciding the yield. This is to be expected as grain yield is a metabolic end product and weather influence shall only be on modifying the rate of the metabolic process of the plant (Alexander *et al.*, 1990). High yield of more than 5000 kg ha^{-1} obtained in the case of both the bio-types show that our genetic resources have very high yield potential, and we are unable to realise it only because of our failure to integrate cultivation with weather. Results also show that the biotypes differed in their response to weather in giving maximum yield. This would mean that ideal weather requirements for qualitative and quantitative development may not be the same.

These response characteristics appear to have much significance in the context of crop production in general. It would mean that our yields remain low because of lack of favourable integration with weather and that we can have a varietal spectrum for changing weather requirements.

The interrelationship of rainfall and sunshine manifested in the present study has been apparently confusing. A positive relationship with sunshine hours and negative relationship with rainfall in the post flowering phase is to be naturally expected. The lack of significant positive relationship in part may be an indication of preferential adaptation to shade and/or an indirect expression of stress influence. Moisture stress will be the most important limiting factor in uplands especially for hydrophyllic crops in the rice group. Observations on weather data (Appendix II) show that increase in sunshine hours had been accompanied by high temperature, low rainfall and low relative humidity, all of which contributed to increased evaporation and resultant drying of soil, which in turn inhibited the differentiation and development. This is illustrated in the weather and yield data in the present trial where high yield has been obtained when crops flowered in August-September.

With the adaptability to high rainfall and relative humidity and comparatively shorter duration of sunshine, *Njavara* can fit in well as the first rainy season intercrop in coconut gardens (A closer scrutiny of the data will reveal that sowings on May 30th or June 15th are statistically as good as that on June 30th from the view point of grain yield).

Results of the experiment have also thrown light on the role of weather in varying the pathways of yield formation. A comparison of S_2 and S_4 (Table 4.2.1) will show that a narrow grain-straw ratio (1.114) in the former and a high dry matter accumulation in the latter contributed to grain yield. An increased dry matter production of 5300 kg in the former could lead to an increase of only 814 kg in the grain yield over the latter. These differential pathways are likely to have different pre-requisites and implications.

Consideration of the role of contributing components on yield will show that highest yield in S_4 was the result of a higher number of productive tillers per hill. An increase of more than 100 per cent in the number of productive tillers had been recorded in comparison to S_2. A highly favourable early environment in July might have been favoured growth and productive tiller production in S_4. Matsushima (1957) reported that prevailing weather situations one month before flowering decides the number of florets in rice. A higher number of florets per plant has contributed to high yield in this treatment. This agrees with the concept of Murata (1969) that yield is a function of number of panicles, number of florets per panicle and test weight.

Lower number of grains and filled grains per panicle as well as lower seed weight in S_4 in spite of a larger number of grains per plant compared favourably with S_2 and S_3 in the distribution of assimilates. This would suggest that a nutritional enrichment of soil just before panicle initiation could have led to a better yield and grain-straw ratio in S_4 comparable with S_2. By the same token it would mean that a higher assimilate and nutrient accumulation is conducive to a narrow grain-straw ratio.

The data show that dry matter accumulation and grain-straw ratio varied greatly in different sowing dates, from 1132 to 13706 kg ha^{-1} and 0.56 to 1.28 respectively. Growth and partitioning with progressive advancement of sowing dates can be seen to have followed a sigmoid pattern in tune with that of rainfall but with different peaks. High yield resulted where high rainfall coincided with the active growth phase, underlining the importance of moisture availability in this period. The different peaks suggest that dry matter production and partitioning are independent physiological processes and are differentially influenced and modulated by weather. As the variation in the grain and straw contents of nutrients is limited, it appears that this specific weather effect is linked to nutritional implications.

Analysis of nutrient contents in grain (Table 4.2.6) and straw (Table 4.2.3) show that sowing beyond July tended to reduce both content and uptake of elements in the crop and that contents were higher in June sowings. This would mean that plants sown in June could absorb a larger quantity of all essential elements, which facilitated better growth and higher yield.

Biotypic variation

Comparison of yield and yield attributes of the black and golden yellow glumed biotypes show that they did not significantly differ in yield of grain and straw though the golden yellow type tended to be superior (Fig.4.2.1 and 4.2.2). It appears that the significant superiority of the golden yellow glumed type in length of panicle, number of grains per panicle and number of filled grains per panicle was substantially marked by a higher grain-straw ratio in the black glumed type.

Nutrient removal, utilisation and translocation pattern and response to weather have indicated the distinct differences between the black and golden yellow glumed types as is evident from a close scrutiny of the data.

Among the primary yield contributing factors, the two biotypes differed significantly in length of panicle, number of grains as well as number of filled grains per panicle and the grain-straw ratio (Table 4.2.1). Among these, superiority of the black type was confined only to the grain-straw ratio. Similar varietal differences have been reported in rice also (Yoshida, 1981). Murata (1969) has reported that floret number is decided one month before flowering and is a function of mobilisable carbohydrates available at that time.

Differential response to weather has been another point of difference between these biotypes. The two types differed significantly in the number of grains per panicle as well as filled grains per panicle in all dates of sowing. As the number of florets is decided one month before flowering and depends on the growth made before that, it suggests that the golden yellow glumed biotype had a faster early growth than the black glumed biotype. Grain filling is through photosynthesis in the later stages as well as by translocation from the vegetative portion. Experimental evidences indicate that 75 per cent comes from current photosynthates and 25 per cent from translocation (Porter *et al.*, 1950). Thus, the higher number of filled grains would suggest that golden yellow glumed type had a higher photosynthetic and translocation efficiency as substantiated by the higher dry matter accumulation to the tune of 32 per cent and that the two biotypes are physiologically different.

Grain-straw ratio is the index of partitioning of carbohydrates. Black glumed biotype had manifested a significantly higher grain-straw ratio than the golden yellow glumed type and the difference was of the order of 11.75 per cent. A narrow grain-straw ratio coupled with a low photosynthetic ratio suggests that the black glumed type had a higher accumulation of translocatable assimilates in the vegetative portion and a higher translocating efficiency.

Significant differences between the biotypes was noticed in the case of absorption of elements, their utilisation and translocation (Table 4.2.3 and 4.2.6). Black glumed type, in general, had absorbed similar quantities of all elements, suggesting the presence of a less efficient root system. Mn content of grain in the black glumed biotype was higher but content in the straw was low, whereas Mg, Zn and Cu contents of the grain of the golden yellow glumed biotype were higher, while that of the straw was lower. This indicates selective and differential translocation of elements to the grain in the two biotypes. Considering specific accumulation of Mn, 1 kg ha^{-1} of Mn in the grain accounted for 10142 kg grain in the golden yellow glumed biotype as against 8687 kg in the black glumed biotype. Comparable levels of nutrient use efficiency in all elements with the exception of Mn, suggests that Mn content appears to be linked to quality. The superiority of the black glumed biotype in Mn accumulation was observed in almost all weather situations.The data also indicate that the low yield of the variety may be because of the high Mn content, which in turn might have contributed to a higher content of free amino acids.

Two significant observations on relation of weather situation to productivity as evident from path analysis done using weather characterisitcs from maximum tillering to harvest (Table 4.2.9) and flowering to harvest (Table 4.2.10) have been the high residual path value and the positive influence of rainfall and relative humidity. A high residual value would mean in sufficiency of weather factors to explain the phenomenon of yield process completely. This may be because of the characteristics of biosynthesis of free amino acids, and dry matter decline in the productive phase. This result is in line with that obtained in the experiment on growth and development analysis where contributing factors together explained the yield only by 59 per cent.

Positive relationship of rainfall and relative humidity which go together would suggest that the crop can be grown in the June-September period when rainfall and relative humidity are high and that external stress influence especially water stress will not affect the growth process.

5.3 EXPERIMENT III

The most outstanding result arising from the fertilizer trial is the failure of the *Njavara* plant to transform the growth advantages to grain yield (Table

4.3.2.a). Nutritional treatments have tended to increase the yield of grain but the increase did not reach the level of significance. On the contrary, straw yield increased significantly. Increase in straw yield to the tune of 48.10, 47.95, 42.73 and 40.56 per cent were observed by application of FYM at the rate of 3 MT ha^{-1}, N at 45 kg level, P at 30 kg level and K at 30 kg level respectively as compared to absolute control. *Njavara* is an untuned land race with all the characteristics of traditional indica rice which are non responsive to fertilizers (Tanaka *et al.*, 1964), and with a grain-straw ratio of 1:2 and above. Failure of the fertilizer elements to favourably influence the grain-straw ratio appeared to be the cause of the non-significant effect on grain yield. Musthafa (1995) has also reported that increasing N levels tended to increase straw yield more than grain.

Observations on yield attributes (Table 4.3.2.a) will further show that grain yield did not significantly increase in spite of significant increase in length of panicle and number of grains per panicle. Data on percentage of filled grain show that it was in the negative order of number of filled grains. 1000 grain weight was also lower in fertilizer treated plots. Percentage of filled grain as well as 1000 grain weight are indices of post-flowering photosynthetic efficiency as well as translocation. Thus, failure of fertilizer application to increase grain yield may be due to its failure to effect carbohydrate accumulation through photosynthesis and its translocation to the grain in the post-panicle initiation stage.

Njavara is valued for its medicinal values - probably the amino acids content. Results in the growth and development studies showed that net assimilation rate (NAR) is negative in this plant in the post-panicle initiation stage and that the photosynthates are diverted for biosynthesis of amino acids. Thus the failure in filling the grains may be due to the possible shift in metabolic processes of the plant.

In the *Njavara* plant, the seed is the part valued for medicinal properties and failure to increase the seed yield may indirectly mean that application of fertilizer elements are ineffective for the purpose. It is possible that input requirements for growth, differentiation and quality forming processes are different in plants.

Significant increase in dry matter accumulation at panicle initiation and harvest stages in spite of lack of any significant influence on height or tiller counts at any stage of growth (Table 4.3.1a) will suggest that the role of fertilizer application on expanded growth is through further strengthening the expressed growth probably by better photosynthetic efficiency. Failure to increase tiller number significantly appears to be a factor in the lack of reflection of fertilizer responsiveness of the crop in yield of grain. Failure of tillers enriched with higher dry matter to produce higher yield may be because of the shift in metabolic processes from carbohydrate accumulation to biosynthesis of amino acids. Experiments on medicinal plants have shown that fertilizers do not increase the yield significantly in crops concerned with biosynthesis of quality products like essential oil (KAU, 1993b).

Observations on dry matter production pattern show that the conspicuous effect of nutritional treatments was after maximum tillering stage, farmyard manure and increasing levels of fertilizers progressively increasing the dry matter accumulation more intensely till harvest. This establishes the growth promoting effects of the elements and suggests that productivity improved by fertilizers is through improving growth.

However, growth and development analysis of *Njavara* showed that morphological growth expansion is at the expense of quality and stress effects nullify growth after panicle initiation stage and improve the quality. The trial was conducted in the uplands and subjected to stress for moisture. Thus, though the fertilizer treatments could change the growth pattern, the fact that yield could not be improved may imply that the basic adaptation of the plant cannot be changed. Lack of adaptability of *Njavara* can be noted from the final removal of various elements. Highest removal of N, P and K at harvest was 21.83 kg, 5.67 kg and 51.88 kg and subtracted from control to work out the fertilizer effect, the corresponding figures were 10.85 kg, 2.54 kg and 26.32 kg respectively. Thus, lack of response appeared to be due to the poor production capacity and requirement of the crop.

Another interesting observation has been that farmyard manure applied at 15 kg N equivalent emerged as the most efficient dry matter accumulator (Table 4.3.1.a). Main effect of N, P or K at 45 kg level though statistically on par, failed to supercede farmyard manure effect in the long run. Farmyard manure produced a steady growth may be because of the slow effect. Similar results have been obtained from the permanent manurial trials (KAU, 1992). Superiority of farmyard manure suggests that factors other than major nutrients are involved in growth.

Data on the elemental composition of the plants at maximum tillering and panicle initiation stages reveal that farmyard manure altered the contents of all elements over control (Table 4.3.3.a and 4.3.4.a). Content of N, K, Ca and Mg increased while that of Fe and Mn decreased at maximum tillering stage. Upper critical levels of Fe and Mn in rice have been reported to be 300 and more than 2500 ppm respectively. Thus improvement in dry matter due to main effects of N, P and K fertilizers can be attributed not only to increase in applied elements but also to their effects on non-applied elements. Musthafa (1995) has attributed low productivity to high Fe content of the soil and its consequent absorption. Observations on elemental composition at panicle initiation stage will show that main effects of N, P and K while increasing the contents of these elements, failed to reduce the Fe content. N at 45 kg and both P and K at 15 kg could not reduce the Mn content while farmyard manure, though it failed to increase K, Ca or Mg contents succeeded in maintaining lowest levels of Fe and Mn. Realisation of maximum dry matter at harvest by farmyard manure appears therefore, at least in part, to be due to the reduced Fe and Mn contents. Musthafa in 1995 has reported similar results.

Data on interaction effects revealed that application of N, P and K through fertilizers led to positive effects on the absorption of elements. This appears to be due evidently to the cation-anion effects of elements on absorption as has been reported by Tisdale *et al.* (1995). However, interacting influences of major elements failed to produce significant effect on growth, yield or yield attributes. This is understandable in the light of the fact that major elements themselves were unable to affect any growth or yield attribute. However, positive interaction on absorption of elements coupled with failure to affect the yield showed that absorption and metabolic utilisation are independent phenomena and that absorption need not necessarily result in metabolic utilisation. This is further substantiated by the observations in Experiment I of the present project.

Observations on the phasic development of the crop showed that the effect of nutritional treatment has been on increasing the rate of dry matter accumulation in the grand growth phase and extending it till harvest, though the rate is gradually reduced. Viewed in the context of nutrient uptake in the three stages it can be seen that the first or the primary phase is the phase of accumulation of elements, the second or secondary phase is the dilution phase and the third is the diversion phase when differentiation takes place. It appears that increase in dry matter in the third phase is a function of absorption and accumulation of nutrients in the early phase. Results show that nutritional treatments did not modify the pattern of growth.

Net balance uptake in the post-panicle initiation stage (Table 4.3.7) shows that K, Ca, Mg, Mn, Zn and Cu have been absorbed and N, P, S and Fe shed by the crop and that fertilizer treatments have affected shedding and absorption as well as their extents. Discriminatory shedding and absorption in the productive phase should naturally affect the yield and quality of the crop. Non-significant influence of fertilizer treatments on yield appears to be due to this discriminatory absorption of Fe and Mn, which were already close to the critical levels, especially Fe.

Shedding of major nutrients and absorption of Fe and Mn appear to be related to their requirement in the biosynthesis of amino acids. However, the exact role can be found out only through detailed investigations.

It is also possible that selective shedding and absorption of elements in the productive phase is the plant's mechanism to avoid degradation of quality and may explain the reason for the reported results (Nair *et al.*, 1979; Dey and Choudhuri, 1986) that fertilizer application does not affect quality.

Data on correlation between yield, yield attributes and elemental composition of the plants at different stages of growth (Table 4.3.8) showed that grain yield of the plant is a function mainly of straw yield and number of filled grains per panicle. N content at harvest was found to have no relation with any attribute contributing to yield or yield itself.

The main effect of Ca at harvest was to counteract N as the data in the correlation matrix shows.

The multiple regression model showed that yield is a function of the net vegetative growth at harvest as well as the translocation efficiency of the plant represented by the number of filled grains and grain-straw ratio. Ca and N content appeared to have a negative effect.

5.4 EXPERIMENT IV

Dry matter accumulation and yield of grain have generally followed the pattern of variation in nutritional levels rather than that of the sources or source balances (Table 4.4.1). Thus the maximum yield of 465 kg grain per hectare was recorded at the highest level of nutrition of 30 kg N equivalent per hectare and the lowest yield at 7.5 kg N ha^{-1} and the reduction in yield at 15 kg and lower levels of N per hectare was statistically significant (Table 4.4.2).

Growth is a function of availability and absorption of nutrients and the level of application is the primary factor affecting availability. Source variations affect the rate of availability of the element in question as well the availability of other native elements which may only become apparent over a period of time or in long duration crops. Thus the results are in the order of quantity first and source second as is to be expected, especially at lower levels of production.

The generally low average yield of the crop is the combined function of its quality aspects on the one side and combined environmental stresses of upland cropping situation and heavy shade of coconut palms on the other, as in the other trials of the project.

A perusal of the development process along with absorption of elements revealed that three distinct phases could be identified. The first phase is an accumulation phase during which the crop accumulated nutrients indiscriminately. This phase extends upto maximum tillering stage. The uptake at this period ranged from 8.38 to 21.70 kg ha^{-1} of N and corresponding dry matter yields from 483.33 to 1016.66 kg ha^{-1} with a production efficiency of 57.68 kg to 46.85 kg. The accumulation phase is followed by a dilution phase extending from maximum tillering to panicle initiation stage when the crop accumulates dry matter rapidly. It is characterised by marginal or no increase in nutrient contents and a disproportionate increase in dry matter compared to nutrients absorbed. The dry matter production in this phase ranged from 883.33 to 1808.32 kg ha^{-1}. Finally, there occurs a diversion phase characterised by growth cessation, differentiation, and discriminatory shedding and accumulation of nutrients. Probably, organic management defines the phases well.

Higher levels of nutrient supply lead to heavier nutrient and plant tissue shedding by harvest. Shedding of produced dry matter and accumulated nutrients even by high yielding varieties have also been reported by Musthafa (1995) which was attributed to internal nutritional stresses. However, continued absorption of some elements till harvest and shedding of many others like N, P and K by *Njavara* to the tune of 80 per cent points to the possibility that the requirements for growth and quantitative production of grains are different from those of the quality aspects *Njavara* is valued for. It is also possible that this is the pattern of behaviour of nutritionally non responsive biotypes. Minimum shedding of nutrients under application of organic resources also suggest that fertilizer sources or integrated application will not be of any advantage in this crop.

A functional analysis of the data on yield attributes and yield will show that the sources effected subtle variations in the process of yield formation in spite of absence of any apparent difference in yield. Fertilizer sources affected the yield through an increase in dry matter accumulation and floret number per panicle while organic sources, on the other hand, had influence on increasing the number of productive tillers and 1000 grain weight. Combined application have affected both. Beneficial effects of fertilizer sources in increasing the yield through increase in number of florets have also been reported by Murata (1969).

This basic difference in the effects of organic and inorganic nutrient sources suggests that organics ensure a more steady and balanced development in the yield process. Denser grains are likely to be the index of better quality also. This in turn may be the effect of slow and steady availability of balanced nutrition offered by organics as against the high availability and intense effect of fertilizers (KAU, 1992).

Observations on the elemental composition of the crop at maximum tillering (Table 4.4.3.a) and panicle initiation (Table 4.4.4.a) stages can be seen to add credence to the above hypothesis. Exclusive fertilizer use effected the highest contents of 2.36 and 1.38 per cent N at these two stages which were significantly higher than the N contents of 1.73 and 0.76 per cent N recorded under exclusive organics. Among non-applied elements, Mn content of the plants was also significantly lower. Lack of significant difference in dry matter accumulation at panicle initiation and yield of grain at harvest between the treatments would suggest that the part of N in T_1 which exceeded N content in T_2 had not been utilized, probably due to a relative deficiency of P. Marykutty *et al.* (1992) have reported that the ratio between N and P in rice is around 10:1. The results thus indicate that the reason for the stable pathway of yield formation under organic resources is due to the balanced nutrition.

Organic sources had also registered a higher nutrient use efficiency (NUE) over fertilizers, the values being 1820.16 and 978.25 for N at panicle initiation stage. Fertility itself is the capacity of the soil to supply nutrients in proper quantities and time and proportion to the plant and as such organic resources contributed better to NUE as they contain all nutrients in balanced proportions. Similar results of higher NUE of organic sources have also been reported by Jacob (1995). Fertiliser materials being limited elemental sources, they are capable only of making up the deficiency of specific nutrients.

Influence of chemical and organic sources on absorption of non-applied elements like Ca, Mg, S, Fe, Mn and Zn showed that the absorption of all of them were stimulated under chemical treatments. Fe and Mn are considered to be at toxic levels beyond 300 and 2500 ppm respectively. Marykutty (1986) has also reported increased uptake of these elements under chemical fertilizer application. Accumulation of micronutrients at levels far higher than the critical levels may be a reason for the failure of increased N application in increasing the yield.

Nutrient use efficiency indices show that they oscillate between sources depending on elements. Thus the organic source effected a higher N use efficiency while the chemical source produced a higher P use efficiency. This would suggest that NUE indices based on any single limiting element may not be very meaningful in expressing growth efficiency.

Data in Table Nos.4.4.3.c and 4.4.4.c indicate that productivity did not follow the trend of ratios even in the case of N, P and K suggesting that the use of NUE based on any applied element alone as an index of productivity enhancement would not serve its purpose. This is understandable in the light of the fact that native functional elements either through a deficiency or excess are likely to develop into critical factors. Such interferences of Fe and Mn have been reported by Bridgit *et al.* (1993), Marykutty *et al.* (1992) and Mathewkutty (1994).

Heavy nutrient shedding in the post panicle initiation stage in respect of some elements and continued accumulation of some others will further substantiate the reduced significance of NUE indices.

Specific accumulation and shedding pattern in the post-panicle initiation stage suggest the possibility of differential requirements for growth and production especially in the case of crops like *Njavara* where quality is important. Continued absorption of Mg and Fe may be linked to free amino acid synthesis. It also appears likely that panicle initiation which marks the differentiation from vegetative to productive phase also marks the differentiation in the biochemical synthetic process from carbohydrates to quality components.

Characterisation of absorption of elements and their utilisation will show that the crop expresses a unique phenomenon of total absorption in the beginning and selective shedding and absorption in the panicle initiation stage.

A perusal of the overall yield forming process will show that qualitative and quantitative characteristics are affected by the environment, especially, nutritional factors. Qualitatively superior black glumed biotype was affected more by P content and quantitatively superior golden yellow biotype by Zn content. This may suggest that superior quality is a microelement linked function whereas yield is macroelement linked. This nutritional relationship would suggest that quality can also be improved through specific management practices.

Involvement of P and Zn in quality-quantity relationship of black and golden yellow glumed *Njavara* may indicate a negative relationship between quantity and quality and points out to the possibility of striking a balance between the two. However, this requires detailed study. Variation in duration of sunshine appeared to be of little consequence in deciding the metabolic process.

General Discussion

Integrated over the effects of plant type, soil situation and weather relations, the crop performance analysis shows that productivity is decided by four factors, viz. P and Zn contents in the panicle initiation stage, sunshine hours in the post maximum tillering stage and dry matter accumulation at harvest. The concept of soil-plant-atmosphere continuum as the governing factor of crop productivity therefore, takes shape.

Variation in the stepped down multiple regression function in the two biotypes as well as varying functional correlations and path analysis patterns in the four situations suggest that the concept cannot be generalised. Variations appear to be inherent and are to be expected naturally because of the variations in the components as well as the variations induced by weather effects on soil and plant as well by soil on plant. Analysis of such an interaction will favour more subjective approach in production programmes.

One such aspect is the relation between qualitative and quantitative development in the plant. Both biotyes have yielded above 5000 kg grain ha^{-1} in the trial with different dates of sowing, which showed that their production potentials are high and more or less the same from the point of view of bulk yield of grain. The facts that the black glumed biotype had always recorded a lower yield but higher quality and that situations favouring high yield tended to reduce quality suggest that yield and quality are inversely related. This may appear natural as more photosynthates are diverted for synthesis of quality components. However, the results appear to caution against going in for higher yield in such medicinal plants.

A very rough estimate of the kinetics of free amino acid biosynthesis appears to be possible from the data. The efficiency of the process is assumed to be 50 per cent (efficiency of respiration is 68% and of photosynthesis is 50%). On the average, black and golden yellow glumed biotypes recorded a yield difference of 505 kg and a difference in free amino acid content of 1.288 mg per g of grain. This means that 261 kg of carbohydrates have been utilised for the synthesis of one g of free amino acid.

A comparitive scrutiny of the response models show that yield in the golden yellow glumed biotype was adversely affected more by P and less by Zn and vice versa in the black glumed biotype (The black glumed type was inferior to the golden yellow glumed type in Zn content, while both were on par in respect of P content). The fact that the golden yellow glumed biotype was poorer and the black glumed type richer in free amino acid contents would indirectly appear to suggest that qualitative and quantitative balancing at least in part is a nutritional function.

Low free amino acid content, higher yield, tendency for continued dry matter accumulation after panicle initiation and differential nutritional requirements all appear to suggest that qualitative yield in a pre-cursor of quantitative yield in the evolution of this crop and that golden yellow glumed *Njavara* has been evolved from the black glumed *Njavara*. Evolution is therefore, a function of the habitat. Habitat influence and ecological variation of rice in japonica and indica types have been reported by Nayar (1973). The fact that wild types are qualitatively better though quantitatively poor in yield gives credence to this view.

Another significant point that merits attention is that the negative influence of elements on crop productivity confined to P and Zn in the soil-plant-atmosphere continuum concept has expanded into Cu,Zn, Ca and in some cases, to Mn. Mathewkutty (1994) and Musthafa (1995) have also reported that excess absorption of Fe and Mn limit the yield and nullify the response of the crops to N in the case of coconut and rice respectively.

The general trend of negative relationship of Fe and Mn in the wetland and shaded upland situations indicate their negative influence on dry matter accumulation and yield. Positive relationship of dry matter accumulation with yield will indicate negative influence of these elements on yield, probably because of their higher availability and uptake on the one side and micro level requirement on the other. Thus, these elements appear to be growth inhibitors. It is possible that they limit the functional utility of the growth promoting elements, N, P and K.

Interesting to observe is the pattern of nutritional relations. An overall perusal as evident in Table 4.1.6 shows that micronutrient contents in the panicle initiation stage had a negative relationship with yield. The observation of the positive relationship of yield with dry matter accumulation in the post-panicle initiation stage and the reverse trend in quality indicates the involvement of microelements in the biosynthesis of amino acids at the expense of dry matter. From the panicle initiation stage onwards, the confinement of positive relationship of N to yield appears to be related to the qualitative biosynthetic processes. Thus the quality of grain appears to be a function of the net balancing influences between macro and micronutrients in the post-panicle initiation stage.

High contents and negative relationship of microelement contents at maximum tillering stage with yield is probably the reflection of the effect on dry matter accumulation, since yield and dry matter accumulation have a strong positive relationship. This is the dry matter accumulation phase of the plant and a negative influence will have nothing to do with quality. Inability of the plants in the upland situation to bring about higher increases in dry matter accumulation appear to be due to harmful effects of these elements.

The negative influences of microelements calls for amendment measures for better growth and the results are in line with those of Mathewkutty (1994) and

Musthafa (1995). However, the twin role of micro-nutrients as growth inhibitors in the early stage and quality promoters in the latter stage is evident.

However, the positive and negative fluctuations of correlations of the various micronutrients with yield which were independent of variations in the trend of quality changes make it difficult to arrive at any conclusion. Large scale shedding of almost all elements in the later stages of the crop also lead to doubts in the validity of these relationships. Based on the minimum relative quantity of elements shed, it appears that Mn and Fe, among microelements, are involved in the biosynthesis of quality components. This, however, requires further investigation.

Viewed from the angle of identifying the type to be cultivated and its adaptability, the results show that the black glumed type is best suited for the shaded upland situation in the middle valley laterites of the state during the south-west monsoon season.

As a medicinal plant, quality is more important than quantitative yields. Higher quality of the black glumed type and its higher quality in the shade than in the open make it the ideal crop for cultivation in the interspaces in coconut gardens.

The growth pattern of the crop shows that it has a well defined grand growth phase extending from 50 to 70 days from the date of sowing. Dry matter shedding and negative net assimulation rate, which appear to be linked to free amino acid biosynthesis, commence only after panicle initiation stage. Rainfall is concentrated in the months of June-July and declines subsequently. Thus, sowing in June will facilitate maximum build-up of dry matter during June-July and low rainfall in August will provide ideal conditions for quality build-up, and the crop will be ready for harvest by the end of August or early September, vacating the land for the regular intercrop.

Uptake figures show that the crop removes very little quantity of elements. Thus, its cultivation is not likely to affect coconut on the nutritional front. Its characteristic of shedding of elements in the organic form, coupled with turning in of straw will not only help in serving as a source of organic matter to the soil, but also in conserving and ensuring nutrient availability and in minimising the harmful effects of microelements (Fe, Mn and Zn) in these acid soils. Its low yield is more than compensated by the high cost of the seed.

In addition to these advantages, being a dense crop, it will minimise the possibility of soil erosion from bare coconut gardens where there are large non-intercropped areas. Gopinathan (1986) has estimated that the quantity of soil eroded from fallow plots comes to 352 M.T. per hectare per year.

Summary

6. SUMMARY

The research project entitled 'Effect of different inputs on productivity and quality relations in '*Njavara*' (*Oryza sativa*)' was carried out in the Regional Agricultural Research Station, Pilicode in 1994-96. The medicinal rice variety, *Njavara*, was the crop under study. In the first experiment viz. 'Growth and development analysis in *Njavara*', two biotypes, the black glumed and golden yellow glumed *Njavara* were grown in four situations, i.e., submerged open situation, open upland situation and as intercrops in coconut gardens with 30-50 per cent and 60-80 per cent light infiltration. In the second experiment also, which studied the effect of fortnightly sowing on productivity of *Njavara*, the two biotypes were compared. The third and fourth experiments, which were conducted in coconut gardens with 30-50 per cent light infiltration, concentrated only on the black glumed biotype. The third experiment entitled 'Nutritional management in relation to ionic balance and productivity' studied the effect of three levels of N, P and K from 15 to 45 kg ha^{-1} independently and in combination on productivity of *Njavara*. N level upto 30 kg ha^{-1} only, supplied by organic and inorganic sources in various combinations as well as with the biofertiliser *Azospirillum* were used to arrive at the optimum source and source balance in the fourth experiment, 'Integrated supply of nutrients through organic and inorganic sources.'

The results of the experiments are summarised below.

The two biotypes of *Njavara*, viz., black glumed and golden yellow glumed, differed between themselves in growth, yield and quality characteristics. Golden yellow glumed biotype yielded 35.66 per cent more grain than the black glumed one, while the latter produced 60 per cent more free amino acids in the grain.

The high yielding yellow glumed biotype manifested a continuous increase in dry matter accumulation from tillering to harvest. The black glumed biotype, though it showed a marginal superiority in dry matter accumulation till panicle initiation stage, showed a decline in dry matter to the extent of 26.55 per cent at harvest.

Growth process analysis of the biotypes showed that both types had three distinct phases in the dry matter accumulation process and behaved similarly in the first two phases. The first phase was characterised by low dry matter accumulation extending upto maximum tillering stage, followed by a phase of rapid dry matter accumulation upto panicle initiation, and finally, a diversion phase when dry matter accumulation could be positive or negative. The biotypes differed in the final phase. While the golden yellow glumed type continued dry matter accumulation in this phase, there was dry matter reduction in the black glumed type. This difference in plant behaviour appeared to be related to the difference in grain yield and quality characteristics.

Presence and high contents of methionine and cysteine - the sulphur containing amino acids - which are probably fore runners in thiamin (Vitamin B_1) biosynthesis was the unique attribute of the *Njavara* plant.

A negative net assimilation and decline in dry matter of the order of 600 kg ha^{-1} at harvest over that at panicle initiation stage suggested that the physiological process in black glumed *Njavara* differed from that of the golden glumed *Njavara* and this variation was responsible for the difference in grain yield. Grain yield in the black glumed biotype was only a partial function of photosynthate accumulates till panicle initiation.

A negative dry matter accumulation in spite of higher leaf area and higher chlorophyll content pointed out to the possibility of chlorophyll being the seat of biosynthesis of free amino acids. A dry matter decline in this phase indicated a heavy consumption of photosynthates in the biosynthesis.

The difference in the physiological process of the biotypes were accompanied by variations in the content and uptake pattern of elements. Continuously dry matter accumulating high yielding golden yellow glumed biotype tended to have higher contents of P and K, while the dry matter shedding, low yielding high quality black glumed biotype showed higher Mn content, suggesting nutritional involvement in biotype variability and metabolic processes.

Large scale shedding of elements in the final stage signified the failure of the biotypes to utilise the absorbed nutrients productively. Excess content of Fe, Zn and Mn at all stages of crop growth resulting probably from their high contents in the soil might have been responsible.

Situation effect was found to exert significant modifying influence on the expression of yield and quality characteristics. Yield and quality variation due to situation effect had been of the order of 71.5 and 80 per cent respectively and the variations appeared to be brought about through modification in the rate of growth and process of development.

Highest yield of 2401 kg ha^{-1} of *Njavara* grain was obtained in submerged open situation.

Yield of economic product - the grain - appeared to be related to the rate and duration of dry matter accumulation. In submerged situation fully exposed to light, rate of dry matter accumulation worked out to 51.7 kg/day and the process of accumulation continued till harvest. In open upland situation, dry matter accumulation ceased by panicle initiation and in shaded situations, dry matter showed significant decline.

Higher rate and continued dry matter accumulation led to a higher number of florets and a more efficient translocation to the earhead, higher 1000 grain weight and grain-straw ratio, which contributed to high yield.

From the nutritional point of view, the varying effects of situation were found to be not due to unavailability and reduced uptake of growth promoting substances but because of excess content and uptake of elements like Mn and Zn, which probably inhibited the dilution of absorbed N and led to their early non-productive accumulation and shedding after panicle initiation stage. Minimum imbalance and therefore, minimum shedding and consequently higher productive use leading to high yield was recorded in the wetlands.

The free amino acids as well as their contents varied with the situation. Methionine was found only in shaded situation and histidine in open situation.

The total quantity of free amino acids also varied with situation. Free amino acid content was 0.316 mg g^{-1} in wet situation as against 0.670 mg g^{-1} in open uplands for the black glumed biotype.

Variation in the type and quantity of free amino acid contents pointed out to the influence of cropping situation on rate of biosynthetic process as well as the effect of situations on modifying the process itself.

High content of Mn in the plant in upland situations, where higher quantity of amino acids were observed, suggested that plant content of Mn is involved in the biosynthetic process.

A comparison of the performance of the biotypes under the four situations showed that the range of variation was wide in the higher yielding golden yellow glumed type.

Range of dry matter production from 1132 to 13706 kg ha^{-1} and that of grain-straw ratio from 0.56 to 1.28 under the seven fortnightly sowings commencing from May 15th brought about the magnitude of effects of dates of sowing on the productivity of *Njavara* in uplands.

From the point of view of ultimate grain yield, sowing of seeds in uplands by 30th June was found to be the best. Rainfall and relative humidity were the weather factors positively influencing the yield of grain at this time of sowing.

Weather situationswere found to have specific effects on the pathway of grain yield formation. Early sowing (May 30th) contributed to a higher grain yield in spite of lower dry matter production with a higher grain-straw ratio while the higher yield for the June 30th sowing was due to higher dry matter accumulation. This was an expression of varying specific influences of weather in various growth phases.

From the nutritional point of view, higher yield in the June sowing was due to higher uptake of all elements by the plant. This appeared to be a weather-soil interaction. Crops in delayed sowings might have been deprived of sufficient levels of nutrients in the growth and development process due to washing off of nutrients in the intense rain.

Weather effect, though it caused wide variation in yield, did not basically affect the nutrient absorption or response pattern of the biotypes. Golden yellow glumed type manifested a significantly higher number of grains and filled grains per panicle which were offset by a higher grain-straw ratio in the black glumed biotype.

Black glumed biotype showed a higher Mn content, and golden yellow glumed biotype higher Mg, Zn and Cu contents in the grain.

High residual value in path analysis using weather factors suggested that weather relations could not fully explain the yield characteristics. This appeared to be due to biosynthesis of quality components.

Increasing levels of N, P or K applied through fertilizers, each from 15 to 45 kg ha^{-1} and their combinations failed to increase the yield of grain of *Njavara*, though straw yield was increased significantly to the extent of over 40 per cent.

Fertilizer application significantly increased the dry matter accumulation, length of panicle and number of florets. Failure to increase the yield in spite of this appeared to be due to the lower number of filled grains as well as low 1000 grain weight. This suggested that yield improvement by fertilizers is through growth promotion only.

Lower number of filled grains per panicle and 1000 grain weight indicated inefficient translocation to the grain as well as carbohydrate accumulation in the post-flowering phase. This, in all probability, appeared to be due to the diversion of photosynthates in this phase for biosynthesis of components of medicinal value or an altogether shift in the metabolic system.

Compared to fertilizers, farmyard manure applied at the rate of 3 tonnes ha^{-1} expressed a marginal superiority in dry matter production and grain yield.

Based on the elemental composition of the plant at maximum tillering and panicle initiation stages, the difference in yield appeared to be due to general efficiency variation.

Farmyard manure could increase the N, K, Ca and Mg levels and reduce the Fe and Mn contents which were high. Failure of the fertilizer levels therefore, appeared to be due to their failure to decrease the Fe and Mn contents.

Multiple regression analysis showed that Ca and N contents in the plants had negative effect on the yield of grain.

Comparison of organic and inorganic sources and source balances showed that more than the sources, the quantity was important in affecting the yield. Highest yield was obtained at 30 kg N ha^{-1} level. Reducing the level to 15 kg or below was found to significantly reduce the yield.

Organic sources tended to induce a more steady and balanced development in the yield process. It produced more productive tillers, fewer grains per panicle but a higher seed weight. Fertilizer sources, on the other hand, did not increase productive tillers, but increased the number of florets per panicle.

Balanced development ensured a higher efficiency of the use of elements.

Comparative ineffectiveness of fertilizer source was also found to be due to the higher uptake of Fe, Mn etc.

Azospirillum failed to affect yield as it could not survive in soil for long.

In general, the project results had brought out the following conclusions:

1) *Njavara* is a unique rice type having a high content of free amino acids. It requires a duration of 79 to 105 days to mature and possesses a very high yield potential.

2) Limiting factors of crop growth and yield of *Njavara* were found to be excess absorption and content of elements like Fe, Mn, Zn and Cu in plants and not the limited supply of growth promoting elements like N. These results may have applicability not only in the case of *Njavara* but also in crops like rice where production has reached stagnancy well below potential levels.

3) Cropping situations and weather which together constitute the habitat of the plant are the overriding factors governing productivity and quality of crops. Habitat could modify not only the rate of the processes but also the process of quality and yield formation. The influence of habitat may be far more than that of the material inputs. Integrating the crop with habitat can boost productivity.

4) Growth, yield and quality expressions of the biotypes and their overall relation suggested that the golden yellow glumed biotype of *Njavara* is probably a descendent from the black glumed biotype and quality is the precursor of quantity.

5) Role of conventional fertilizer elements is basically in promoting rate of growth and dry matter accumulation and their influence on modifying the physiological process is limited.

6) The results showed that yield could be better, explained by 'soil-plant-atmospheric continuum' concept which may be plant specific and yield determinants of *Njavara* in the situation under study were plant type characteristics, negative influence of native elements and positive effect of sunshine.

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Appendices

APPENDIX-I

Weekly weather data at Pilicode during the period 1-6-'94 to 4-10-'94

Week	Temperature °C			Mean RH(%)	Rainfall mm	No. of rainy days	Sunshine hours hours/ day
	Maximum	Minimum	Mean				
1/6-7/6	27.5	23.9	25.7	96.0	407.9	7	1.21
8/6-14/6	27.2	23.7	25.5	96.6	447.1	6	0.32
15/6-21/6	29.5	24.2	26.9	93.2	139.4	7	4.86
22/6-28/6	29.0	23.9	26.5	90.7	361.0	6	2.11
29/6-5/7	27.4	23.1	25.3	95.1	275.1	7	1.17
6/7-12/7	28.7	22.6	25.7	92.9	253.9	7	1.76
13/7-19/7	28.1	23.3	25.7	94.9	396.1	6	0.24
20/7-26/7	27.0	23.6	25.3	97.0	443.6	7	1.98
27/7-2/8	26.8	23.6	25.2	92.4	450.9	7	0.47
3/8-9/8	28.9	23.7	26.3	88.6	130.0	3	7.34
10/8-16/8	29.5	24.0	26.8	89.0	79.6	4	5.14
17/8-23/8	27.7	23.5	25.6	92.5	237.2	7	1.54
24/8-30/8	28.6	23.3	26.0	89.9	214.0	7	2.91
31/8-6/9	29.0	23.6	26.3	91.5	124.0	7	3.36
7/9-13/9	29.8	24.0	26.9	86.1	15.9	2	8.19
14/9-20/9	29.6	22.3	26.0	81.8	12.6	3	9.61
21/9-27/9	30.7	22.8	26.8	78.5	0.0	0	9.62
28/9-4/10	30.4	23.9	27.2	83.3	93.7	3	6.56

APPENDIX-II

Weekly weather data at Pilicode during the period 7-5-'95 to 30-12-'95

Week	Temperature °C			Mean RH(%)	Rainfall mm	No. of rainy days	Sunshine hours, hours/ day
	Maximum	Minimum	Mean				
7/5-13/5	32.9	25.4	29.2	81.9	81.2	3	5.3
14/5-20/5	32.1	25.2	28.7	76.1	25.8	3	8.5
21/5-27/5	33.2	25.5	29.4	74.7	-	-	11.3
28/5-3/6	33.5	26.6	30.0	74.6	-	-	9.4
4/6-10/6	32.9	25.5	29.2	79.4	159.0	4	6.8
11/6-17/6	27.7	24.4	26.1	94.1	393.2	7	0.8
18/6-24/6	28.2	23.7	26.0	91.2	99.4	6	3.0
25/6-1/7	29.8	24.2	27.0	91.7	257.6	7	2.3
2/7-8/7	29.3	23.7	26.5	89.8	283.8	7	3.3
9/7-15/7	26.5	23.2	24.9	98.4	412.2	7	0.8
16/7-22/7	27.3	23.6	25.5	96.6	285.4	7	0.8
23/7-29/7	28.0	23.8	25.9	95.2	120.4	6	1.9
30/7-5/8	28.4	24.1	26.3	93.3	124.6	7	3.5
6/8-12/8	29.3	24.5	26.9	91.4	84.5	5	4.8
13/8-19/8	29.2	24.0	26.6	90.4	122.2	6	3.9
20/8-26/8	29.5	24.8	27.2	89.5	80.4	4	5.1
27/8-2/9	27.1	23.3	25.2	97.3	287.2	7	1.5
3/9-9/9	29.3	24.1	26.7	88.9	75.0	7	7.5
10/9-16/9	29.9	23.8	26.8	87.9	33.0	2	6.6
17/9-23/9	29.4	23.9	26.6	86.8	6.5	3	7.3
24/9-30/9	30.3	23.5	26.9	86.3	0.6	1	7.6
1/10-7/10	30.6	24.2	27.4	80.6	0.2	1	7.9
8/10-14/10	30.1	23.6	26.9	87.5	102.8	6	5.4
15/10-21/10	30.8	23.4	27.1	81.4	-	-	8.5
22/10-28/10	31.2	23.8	27.5	83.6	71.8	4	8.6
29/10-4/11	35.1	24.2	29.6	87.3	41.3	2	7.8
5/11-11/11	30.5	23.3	25.9	83.2	27.4	3	6.9
12/11-18/11	31.2	21.4	26.3	80.2	-	-	9.8
19/11-25/11	31.1	23.1	27.1	81.3	-	-	8.9
26/11-2/12	31.4	22.2	26.8	75.5	-	-	10.3
3/12-9/12	32.2	19.5	25.9	69.6	-	-	10.2
10/12-16/12	31.3	18.5	24.9	71.1	-	-	10.3
17/12-23/12	30.6	17.0	23.8	69.3	-	-	10.5
24/12-30/12	31.0	19.2	25.1	75.0	-	-	10.1

APPENDIX-III

Growth characteristics of *Njavara* biotypes in four situations of growth

	Wetland			Open upland			50-70% shaded upland			20-40% shaded upland		
	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)
Height at M.T. (cm)	63.15	56.31	3.54	41.51	49.02	5.57	63.22	64.75	NS	57.09	60.65	NS
Height at P.I. (cm)	97.31	86.14	5.30	65.75	58.29	NS	73.82	80.80	NS	66.92	71.46	NS
Height at harvest (cm)	98.03	106.59	2.86	81.97	89.54	5.98	75.95	102.40	6.13	80.80	97.39	7.33
No. of tillers/ hill at M.T.	6.31	5.68	NS	6.15	3.92	2.03	2.45	3.91	1.23	2.82	3.97	0.28
No. of tillers/ hill at P.I	5.67	4.54	0.83	6.82	4.14	1.48	2.55	4.20	1.36	2.97	4.14	1.14
No. of tillers/ hill at harvest	5.88	5.25	0.59	2.89	4.11	0.71	2.89	4.11	0.71	3.49	4.66	NS
Dry matter accumulation at M.T. (kg ha^{-1})	1779.5	1451.3	NS	714.2	1307.7	380.87	870.1	832.5	NS	977.8	1152.13	157.7
Dry matter accumulation at P.I. (kg ha^{-1})	3889.7	3076.9	708.7	2325.6	2543.6	NS	2656.4	2425.6	NS	2584.6	2853.8	NS
Dry matter accumulation at harvest (kg ha^{-1})	4374.3	5969.9	481.1	1876.0	3301.3	506.14	1347.7	2678.0	215.5	1455.0	2712.1	348.6

APPENDIX-IV

Yield and yield attributes of *Njavara* biotypes in four situations of growth

	Wetland			Open upland			50-70% shaded upland			20-40% shaded upland		
	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden Yellow	CD (0.05)	Black	Golden Yellow	CD (0.05)
Grain yield (kg ha^{-1})	2182.0	2620.5	242.8	523.4	1160.3	141.7	482.0	887.0	81.90	458.8	998.9	112.9
Straw yield (kg ha^{-1})	2192.3	3349.4	409.2	1352.6	2141.0	378.1	865.6	1789.2	182.10	996.2	1713.4	293.5
Grain-straw ratio	1.01	0.81	0.15	0.39	0.55	0.06	0.56	0.50	NS	0.05	0.06	0.09
No.of productive tillers per hill	5.88	5.25	0.59	5.77	4.52	0.59	2.89	4.12	0.70	3.48	4.66	NS
Length of panicle (cm)	17.91	21.73	0.97	16.93	22.36	1.60	17.53	20.32	1.07	18.86	21.97	1.54
No.of grains per panicle	54.86	77.91	4.93	47.25	82.48	15.06	47.19	54.26	NS	51.45	72.32	7.36
No. of filled grains per panicle	49.20	69.97	4.80	40.57	72.28	13.15	39.86	47.54	NS	43.66	64.51	7.29
Percentage of filled grain	89.66	89.42	NS	84.91	88.06	NS	86.13	87.85	NS	84.78	88.92	3.74
1000 grain weight	17.81	17.04	NS	13.00	16.23	NS	15.96	17.31	NS	15.31	16.58	NS

APPENDIX-V

Physiological characteristics of *Njavara* biotypes in four situations of growth

	Wetland			Open upland			50-70% shaded upland			20-40% shaded upland		
	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)
Chlorophyll content at P.I (mg g^{-1})	1.29	1.34	NS	1.79	1.65	NS	2.14	1.93	NS	3.19	2.21	0.79
Chlorophyll content at 50% flowering (mg g^{-1})	2.39	2.05	0.28	3.82	3.48	NS	3.78	2.66	0.83	3.59	3.00	0.38
Chlorophyll content at harvest (mg g^{-1})	0.52	0.80	0.12	0.47	0.52	NS	0.58	0.97	0.36	0.18	0.93	0.23
Leaf area index at P.I	1.05	1.12	NS	1.13	1.50	0.32	1.41	1.46	NS	1.18	1.61	NS
Leaf area index at 50% flowering	1.44	1.43	NS	1.60	1.47	NS	1.00	1.25	0.18	1.12	1.45	NS
Leaf area index at harvest	0.60	1.26	0.24	0.42	1.11	0.24	0.91	0.75	NS	0.32	0.69	0.11
Cell sap pH at P.I.	6.13	6.12	NS	6.09	6.08	NS	6.12	6.15	NS	6.09	6.10	NS
Cell sap pH at 50% flowering	6.42	6.44	NS	6.41	6.43	NS	6.41	6.44	NS	6.37	6.42	0.04
Cell sap pH at harvest	6.69	6.36	0.05	6.44	6.27	0.09	6.41	6.44	NS	6.43	6.44	NS

APPENDIX-VI

Nutrient contents of *Njavara* biotypes at maximum tillering stage in four situations of growth

	Wetland			Open upland			50-70% shaded upland			20-40% shaded upland		
	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)
N (%)	0.88	0.90	NS	1.48	1.63	NS	1.52	2.08	0.40	2.07	1.89	NS
P (%)	0.15	0.18	NS	0.38	0.41	NS	0.21	0.23	NS	0.33	0.33	NS
K (%)	3.29	3.10	NS	3.05	3.27	NS	3.73	3.46	NS	3.54	3.97	NS
Ca (%)	0.41	0.30	0.06	0.27	0.22	NS	0.27	0.21	NS	0.24	0.27	NS
Mg (%)	0.21	0.16	0.03	1.35	1.27	NS	0.86	1.03	NS	1.03	1.16	NS
S (%)	0.20	0.26	NS	0.30	0.21	NS	0.25	0.39	0.07	0.22	0.26	NS
Fe (ppm)	456.6	394.8	NS	679.3	547.5	139.1	470.3	572.5	74.7	883.0	807.4	NS
Mn (ppm)	219.4	207.9	NS	813.9	528.7	235.2	1576.5	1503.2	NS	182.7	1034.3	191.6
Zn (ppm)	75.9	64.6	NS	400.3	277.5	90.0	147.8	149.1	NS	182.7	237.9	29.3
Cu (ppm)	6.6	5.3	NS	17.6	17.3	NS	9.6	11.6	1.88	12.5	12.3	NS

APPENDIX-VII

Nutrient contents of *Njavara* biotypes at panicle initiation stage in four situations of growth

	Wetland			Open upland			50-70% shaded upland			20-40% shaded upland		
	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)
N (%)	1.09	1.26	NS	2.04	1.89	NS	1.40	1.38	NS	1.37	1.26	NS
P (%)	0.29	0.37	0.06	0.58	0.60	NS	0.16	0.22	0.02	0.27	0.28	NS
K (%)	1.87	2.04	NS	3.05	3.60	0.37	3.04	3.45	NS	3.14	3.73	0.43
Ca (%)	0.28	0.27	NS	0.29	0.20	0.04	0.18	0.11	0.04	0.20	0.22	NS
Mg (%)	0.21	0.21	NS	1.02	1.13	NS	1.07	1.06	NS	1.38	1.06	NS
S (%)	0.07	0.07	NS	0.23	0.19	0.04	0.27	0.22	NS	0.28	0.25	NS
Fe (ppm)	223.1	197.0	22.0	441.3	558.2	103.15	463.0	358.2	NS	924.2	821.2	NS
Mn (ppm)	289.0	274.6	NS	343.3	486.8	83.31	1830.5	1119.6	181.8	710.9	1042.9	150.21
Zn (ppm)	77.3	77.0	NS	240.6	118.5	53.22	134.2	121.2	NS	185.6	230.9	41.27
Cu (ppm)	3.7	3.1	NS	12.1	11.7	NS	11.9	9.2	2.11	10.2	6.2	1.72

APPENDIX-VIII

Nutrient contents of straw of *Njavara* biotypes at harvest in four situations of growth

	Wetland			Open upland			50-70% shaded upland			20-40% shaded upland		
	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)	Black	Golden yellow	CD (0.05)
N (%)	0.33	0.21	0.08	0.18	0.15	NS	0.22	0.23	NS	0.40	0.30	0.10
P (%)	0.10	0.10	NS	0.19	0.17	NS	0.16	0.18	NS	0.19	0.15	0.02
K (%)	1.89	1.97	NS	1.12	1.31	NS	1.85	1.89	NS	1.83	2.03	NS
Ca (%)	0.35	0.40	NS	0.37	0.31	NS	0.34	0.20	0.10	0.31	0.24	NS
Mg (%)	0.18	0.17	NS	1.11	0.77	0.20	0.84	0.65	0.09	0.80	0.87	NS
S (%)	0.04	0.06	0.02	0.06	0.07	NS	0.12	0.11	NS	0.07	0.08	NS
Fe (ppm)	286.6	220.5	36.53	188.5	151.9	29.04	338.0	275.2	61.93	250.9	222.2	NS
Mn (ppm)	289.3	248.0	NS	429.5	381.0	NS	1818.9	1685.2	117.84	524.9	265.8	55.80
Zn (ppm)	104.8	83.4	13.37	123.7	346.6	93.66	118.3	90.4	18.82	231.5	479.2	105.83
Cu (ppm)	-	-	-	10.4	12.8	NS	6.6	5.2	NS	10.2	6.9	1.61

EFFECT OF DIFFERENT INPUTS ON PRODUCTIVITY AND QUALITY RELATIONS IN NJAVARA (*Oryza sativa*)

BY

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ABSTRACT OF THE THESIS

submitted in partial fulfilment of the
requirement for the degree

Doctor of Philosophy in Agriculture

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1996

ABSTRACT

Productivity characteristics of *Njavara* (*Oryza sativa*), a medicinal rice variety, were investigated based on the results of four separate experiments conducted at the Regional Agricultural Research Station, Pilicode, during 1994-96. The experiments were to study (i) growth and development characteristics (ii) crop-weather relations (iii) response to nitrogen, phosphorus and potassic fertilizers and (iv) the effect of integrated nutrient management. Two biotypes of *Njavara*, the black glumed and golden yellow glumed, were tested in the first two experiments. The black glumed biotype alone was studed in the third and fourth experiments.

The first experiment, consisting of the two biotypes as treatments, was conducted in wetland, open upland, heavily shaded upland and partially shaded upland, and pooled analyses of the data were conducted. Treatments of the second experiment which studied the effect of date of sowing on productivity of *Njavara* included 10 dates of sowing at fortnightly intervals starting from the 15th of May. Combinations of three levels of nitrogen, phosphorus and potassium, each at levels of 15, 30 and 45 kg ha^{-1} along with a standard and absolute control constituted the treatments of Experiment III. The last trial consisted of two treatments, one exclusively with farmyard manure and another with fertilizer alone, both at 30 kg nitrogen equivalent, two treatments with organic and inorganic manure in different ratios and three combinations of *Azospirillum* with 25, 50 and 75 per cent of the full farmyard manure dose. The second experiment was conducted in open upland and the third and fourth experiment in heavily shaded coconut gardens. Biometric,

nutritional and quality criteria estimated through accepted methodology were used for the evaluation of treatments. An abstract of the results obtained has been presented in the following paragraphs.

The results showed that three phases could be distinguished in the growth and development of *Njavara*. They are, a primary phase of absorption and accumulation of nutrients, a grand growth phase of rapid accumulation of dry matter and a diversion phase when the seed and quality develop. Continued growth till harvest gave high yield and dry matter decline in the final phase led to superior quality characteristics. Golden yellow glumed biotype exhibited continuous growth and higher yield of grain. Black glumed biotype manifested dry matter decline in the final phase, leading to lower yield of grain and higher free amino acid content in the grain.

Profound influence of cropping situation on yield and quality of grain was observed. Lowest yield of 684 kg ha^{-1} and highest amino acid content of 0.492 mg g^{-1} were observed in the uplands and highest yield of 2401 kg ha^{-1} and lowest amino acid content of 0.203 mg g^{-1} were observed when *Njavara* was sown in the wetlands. Viewed on the basis of variation in nutrition in the different situations, the results showed that yield limiting influences were not the deficiency of any element but the excess contents of Mg and Mn at maximum tillering and of P, K, S, Zn and Cu at panicle initiation stages in the plant. This appeared to be a highly significant result in the context of stagnant productivity of crops like rice.

Content of free amino acids in the grain appeared to be the unique characteristic of *Njavara* rice. Among the amino acids, sulphur containing amino acids, methionine and cysteine were also present. Possibly, these amino acids are related to the medicinal value of *Njavara* in the treatment of rheumatic complaints, the symptoms of which resemble thiamin deficiency.

Inherently high yield potential of *Njavara* was expressed in the date of sowing trial. Both the biotypes recorded grain yields of 6000 kg ha^{-1} when sown on most favourable dates. Weather influence contributed to the highest yield through two ways, firstly, by increasing the total dry matter yield and secondly, by improving the grain-straw ratio. The golden yellow glumed biotype produced higher grain yield than the black glumed biotype.

Application of N, P and K fertilizers increased the uptake of all the elements studied. Positive interaction of fertilizer elements on content and uptake of elements was also evident. However, application of fertilizers could influence only the straw yield significantly. One possible reason for the absence of significant improvement of grain yield by fertilizer application appeared to be due to the high levels of application. Even 15 kg ha^{-1} of N, P and K were found to be in excess in shaded situations.

Results of the integrated nutrient management studies showed that level of application was more important than the source in affecting the ultimate yield. Farmyard manaure application led to a more balanced development of the components of yield whereas fertilizer source improved only the floret number per panicle. Nutritional management at levels below 15 kg ha^{-1} N equivalent significantly reduced the yield. *Azospirillum* did not have any effect in increasing the yield of *Njavara*.

The results of the different experiment brought out the role of soil and atmospheric environment as well as the biotype influence on the yield and contributed to the development of the concept of soil-plant-atmospheric continuum on the technical side. On the pracical side they showed that *Njavara* is an ideal crop for growing in the first crop season in the uplands in North Malabar when no other crop can be grown and that growing in heavily shaded uplands will give high quality grain. Advantageously, the crop will not require intense management.