INFLUENCE OF PHOSPHORUS ON ABSORPTION AND DYNAMICS OF NUTRIENTS IN RICE

By

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THESIS

submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

I hereby declare that the thesis entitled **"Influence of phosphorus on absorption and dynamics of nutrients in rice"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that the thesis entitled **"Influence of phosphorus on absorption and dynamics of nutrients in rice"** is a record of research work done independently by Mr.C.Ponnaiyan under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to him.

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Dedicated to

My beloved Grand parents

(Late) Angamuthu-Meaccheri

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PONNAIYAN.C

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ABBREVIATIONS

PUE	: Phosphorus use efficiency
%Pdff	: Per cent Phosphorus derived from fertilizer
DAP	: days after planting
et al	: and others
ml	: milli litre
ppm	: parts per million
RH	: Relative humidity
sp or spp	: species
viz	: namely

INTRODUCTION

I. INTRODUCTION

Rice is one of the major food crops grown in an area of nearly 43.92 million hectares in India with an annual production of 90.75 million tonnes (Hindu, 2002). In lowland rice cultivation, the soil is commonly submerged for most part of the crop growing cycle. The field water regime determines to a significant degree of the suitability of the land for field preparation, soil aeration and also nutrient availability.

Phosphorus (P) is less commonly deficient compared to other nutrients in rice soils. Submergence increases P availability (Ponnamperuma, 1972) through reduction of Fe-P, dissolution of occluded P, hydrolysis of Fe-P and Al-P, increased mineralisation of organic P in acid soils, increased solubilisation of Ca-P in calcareous soils, and greater diffusion of P.At the same time, increased availability can cause faster depletion of soil P under intensive cropping.

A judicious fertilizer schedule must be essential for the entire crop rotation in a cropping system. The variation of soil P under the rotation of rice influences the direct as well as residual effect of P fertilizers (Willet, 1979 and Bradley *et al.*, 1984). Ru-kun *et al.*, (1982) observed that the fertilizer P recovery by rice ranged from 8 to 20 per cent and 80 to 90 per cent of applied P was retained in the soil for the succeeding crop. While phosphorus utilization under acid and saline soil is very small, the unutilized part of fertilizer P gets fixed into the soil and converted into iron and aluminum phosphate (Pandey and Sinha, 1987).

The supply of phosphorus to crop plants depends on the concentration of phosphate in the soil solution. The low response of crops to P is due the transformation of applied P into different reaction products with lower availability.

In recent years, there has been a tremendous renewal of interest on the part of both researchers and farmers in the age-old practice of green manuring, for improving the soil fertility. The benefits derived from green manuring include increase in organic matter content and available plant nutrients and improvement in the microbiological and physical properties of the soil (Singh *et al.*, 1992). Although the role of green manures in supplying N and P are evident, of late a number of scientists reported on the substantial contribution of these manures to the soil inorganic pools and P nutrition of rice. (Nagarajah *et al.*, 1989.and Hundal *et al.*, 1992). Joseph (1994) claimed that the incorporation of organics and green manures to soil influence P uptake by the plants through either direct contribution of P contained in green manure or by the indirect effect on the availability of inorganic P present in the soil and applied as fertilizers.

An analysis of research work hitherto carried out on P nutrition of crops in lowland soils reveals that there is still a need to conduct systematic study to know the phosphorus needs of lowland rice crop in relation to the P supplying potentials of P fertilizer-single super phosphate, and also the role of organics such as Ung *(Pongamia glabra)* and rice straw in enhancing the P utilization by the rice crop. In this context, a study was contemplated with varying levels of P fertilizers and organics in two different soils with the following objectives,

1. To study the distribution pattern and content-effectiveness relation of phosphorus on rice productivity in relations to soil types and nutritional levels.
2. To elucidate the role of organics in regulating nutrient interactions.

Review of Literature

II. REVIEW OF LITERATURE

The literature pertaining to the influence of soil properties, organic matter, types of P fertilizers, rates of P application, effects of organic and green manure on the behaviour of P in rice soils with reference to its transformations, its distribution in various inorganic forms when applied through fertilizers, its availability to rice crop, its uptake by rice were reviewed here under.

2.1 PHYSICO CHEMICAL PROCESS GOVERNING PHOSPHORUS AVAILABILITY IN RICE SOILS

Water regimes strongly influence soil phosphorus both directly through changes in water content and indirectly through changes in soil physico-chemical conditions. The physico-chemical changes following flooding influences both the amount of labile P in the soil and the nature of P sorbing surfaces and consequently, the distribution of labile P between solid and solution.

2.1.1 Phosphorus transformation in submerged soils

Phosphorus is not directly involved in oxidation-reduction reactions in the redox potential range encountered in submerged soils, but is profoundly affected by the changes associated with anaerobiosis, particularly the reduction of ferric compounds (Ponnamperuma, 1972). The reduction of free hydrous Fe oxides during flooding and the liberation of sorbed and co-precipitated P results in increased levels of solution or extractable P in flooded acidic soil (Willet, 1986).

It was also shown (Willet, 1985) that if P sorbed on to ferric hydrous oxides is a significant source of P in soils then it is the rise in pH (associated with the reduction of Fe^{3+} compound) rather than the fall in redox potential, Eh (favouring the reductive dissolution of ferric hydrous oxides) that is responsible for the relatively high P concentration in waterlogged soil solutions. Increased soil pH in acid and strongly acid soils can also cause hydrolysis of $FePO_4.2H_2O$ and $AlPO_4.2H_2O$, resulting in their higher solubilisation (Ponnamperuma, 1972).

Mandal and Mandal (1973), and Bhattacharya and Das (1975) attributed the lowering fixation of applied P in the presence of organic matter in flooded acidic lowland rice soils to the complexation of soil Fe and Al by the decomposition products of organic matter. Some more studies have also shown the increased availability of P through the incorporation of green manure into soil both under laboratory (Prabhakar *et al.*, 1972; Hundal *et al.*, 1987;) conditions and field conditions (Singh and Beauchamp, 1986).

Mineralisation of organic P has been considered as a minor source of P in flooded soils (Patrick and Mahapatra, 1968.). But others (Perumal and Varadarajan, 1967; Hundal *et al.*, 1987) have reported substantial contribution by green manure's to rice crops P requirement at different stages of crop growth. Goswami and Banerjee (1978) have reported increased mineralization of organic P upon flooding. Willet (1986) reported that contribution of organic matter to P release during flooding appeared to be mainly through P mineralisation rather than by accelerating reduction of ferric compounds.

Increased phosphorus diffusion under submerged conditions is also quoted as a possible reason for increased P availability to paddy crop (Ponnamperuma, 1972). Increased buffer capacity due to flooding has been attributed to phosphorus adsorption from soil solution by the reprecipitated poorly crystalline ferrous hydroxides or carbonates of Fe^{2+} ions formed by soil reduction (Patrick *et al.*, 1985).

2.2 TRANSFORMATION OF NATIVE AND APPLIED PHOSPHOROUS IN RICE SOILS

Waterlogging a soil triggers off a course of physicochemical changes in soil, which affect the transformations of native and applied phosphorus. Several investigators have reported an increasing trend in the contents of Al-P and Fe-P due to continuous waterlogging of soil (Mahapatra and Patrick, 1969; Singhania and Agarwal *et al.*, 1987). Mahapatra and Patrick (1969) suggested that Fe-P and Al-P content in soil increased as a result of the transformation of reductant soluble P under submerged conditions. With passage of time, a portion of the Al-P might be converted to Fe-P and/or Ca-P depending upon the soil characteristics (Singhania *et al.*, 1976; Lal and Mahapatra, 1979; Singh and Dixit, 1983; Kumaraswamy and Ramulu, 1991).

Soil characteristics have a significant role to play in the transformation pattern and distribution of native and applied P. Ivanov (1975) reported that most of the applied P from monocalcium phosphate sources was transformed into Al-P and Fe-P in carbonate free soil, but into Ca-P in calcareous soil. Singhania *et al.* (1976) who studied the transformation of applied P using ^{32}P-labelled superphosphate suggested that the variation in per cent distribution of applied P in different fraction was related mainly to pH and texture of the soil. The order of distribution of applied P in the P fraction was Ca-P > Al-P > Fe-P > Saloid P in all but clay soil and was Fe-P > Ca-P > Al-P > Saloid P in clay soil. In a tracer study it was found (Sadanandan *et al.*, 1982) that added P in water soluble form was converted mainly to Al-P and Fe-P in red loams and shallow black soils.

Flooding the soils increased the contents of Fe-P, Al-P and saloid-P and decreased the concentrations of Reductant soluble-P, occluded-P and Ca-P with time (Mathews and Jose, 1984). Laterite soil contained relatively higher amounts of Fe-P, Al-P reductant soluble P and occluded-P than Kari soil and which contained higher amounts of saloid-P and Ca-P than laterite soils.

Tomar and Tekchand (1992) found an increase in the native Fe-P, Ca-P and available P at the expense of saloid-P and Al-P in acid soils of Haryana after eight weeks of incubation. Clay and extractable Fe content increased the transformation of added P into Fe-P, whereas Ca-P increased with pH but decreased with extractable Fe and Al.

Soils amended with dhaincha green manure caused increase in Fe-P fraction with simultaneous decrease of Ca-P and Al-P indicating inter-conversion among the fractions (Singh, 1988). Tripathi and Minhas (1991) reported an increase in the rate and magnitude of transformation of applied P due to the addition of FYM.

Increased levels of P application normally increased the amounts of various P fractions during the initial period of soil incubation (Singh and Dixit, 1983; Patel *et al.*, 1992). Krishnappa (1988) also obtained similar results in a field experiment.

2.3 PHOSPHORUS UPTAKE AND PHOSPHORUS USE EFFICIENCY IN RICE

Within the overall effect of a P fertilizer at a given rate, it is important to distinguish between the quantities of phosphorus derived from soil and that derived from the applied fertilizer (Bouldin and Black, 1960).

Using ^{32}P, several researchers (Datta *et al.*, 1966; Ru-kun *et al.*, 1982; Basak and Dravid, 1992) have made attempts to know the phosphorus adsorption pattern and to quantify P derived from the fertilizer sources by the rice crop.

Based on the dry matter yield, total P uptake and percentage P derived from fertilizer (%Pdff), Dravid *et al.* (1976) concluded that Udaipur rock phosphate was almost at par with super phosphate in acid soils. Sadanandan *et al.* (1980) reported that irrespective of sources (Ammonium nitrate phosphate or polyphosphate), the dry matter production and P uptake of paddy increased with increased levels of P application in different soils. In another tracer study (Sreekantan and Palaniappan, 1990), it was found that P uptake and phosphorus use efficiency (PUE) of rice crop was higher for SSP than MRP. But, Nair and Aiyer (1988) had reported that the two sources were equally effective in terms of their influence on P uptake and rice yield in wetland rice soils of Kerala.

In acid soils of Kerala, grain yield, total P uptake and phosphorus derived from fertilizers by rice crop were found to increase with increased levels of P application (60 to120 kg P_2O_5 ha^{-1}) to rice crop (Dayanand *et al.*, 1976). Sinha *et* *al.* (1980) have also reported increased straw and grain yield, total P uptake and %Pdff with increased rates (0-90 kg P_2O_5 ha^{-1}) of P application. Other workers have reported similar results for various types of soils also (Sadanandan *et al.*, 1980; Rastogi *et al.*, 1981; Basak and Dravid, 1992).

Although total P uptake and %Pdff increased with increased rates of P application, Per cent Phosphorus Utilization (PPU) by paddy decreased with increased doses of P applied (Sinha *et al.*, 1980; Rastogi *et al.*, 1981; Nair and Aiyer, 1988), indicating higher efficiency of applied P at lower doses only.

Rastogi *et al.* (1981) studied the utilization of applied P by rice cultivars at tillering, flowering and harvest stages. At all the three stages he found the total P uptake and %Pdff increased, but PPU, decreased with increased P levels (upto 60 kg P_2O_5 ha^{-1}). Phosphorus uptake from soil was found to be more at lower doses of P application. A similar study by Gosh (1985) also revealed that %Pdff and PUE varied at different growth stages of paddy in acid soils of Nagaland. For 35 days old crop, it varied from 13 to 43 per cent, for 25 day old crop, it varied from 13 to 55 per cent and for 90 days old crop it ranged from 25 to 52 per cent in different soils. The values of PPU were 0.8 to 6.3, 6.1 to 14.4 and 2.7 to 27.9 per cent for 35, 75 and 90 days old crops respectively.

The wetland flooded condition with the increased availability of native phosphorus due to flooding, plants may be able to obtain sufficient amount of this nutrient from the limited supply of available phosphorus in the soil, thereby making the application of phosphorus ineffective (Bridgit, 1999).

2.4 EFFECT OF P MOBILIZING AGENTS ON THE P USE EFFICIENCY

Combinations of readily decomposable organic residues and insoluble phosphates could increase the yield of crops much more than the phosphates alone (Marawaha and Kanwa, 1981; Joseph, 1994). Organic acids formed during the decomposition of organic materials in flooded soils solubilized water insoluble phosphates (Pareek and Gaur, 1973) and maintained a higher amount of P in available forms (Ramasami and Vimal, 1975; Mathur *et al.*, 1980).

Phosphorus uptake was maximum when P fertilizers were applied with FYM, and was highly pronounced in red soil (Singh and Patiram, 1977). Jagadeesan *et al.* (1986) reported increased efficiency of MRP when combined with green manures. Karuppiah and Thangamuthu (1986) claimed that the efficiency of both superphosphate and rock phosphate could be improved when they were combined with organic manures.

The effect of green manuring in increasing the availability of P was more pronounced in strongly acidic and alkaline soils than normal soils. Singh *et al.* (1981) reported that pH changes in an acid soil amended with organic residues were significantly correlated with available P.

Ramankutty and Padmaja (1972) reported that in rice there was a definite increase in yield at 30 kg and 60 kg of P_2O_5 only when applied in conjunction with 4 tonnes and 6 tonnes of green leaf per hectare. The yield was not increased with increased doses of superphosphate applied alone.

Under continuously flooded conditions, the growth of rice was vigorous without straw addition and there was a strong response of rice growth to addition of P fertilizer. Straw addition enhanced P uptake by rice plants during loss of soil water saturation (Seng *et al.*, 1999).

Kurumthottical (1982) reported that in the permanent manurial experiment on dwarf indica, rice at Pattambi, application of phosphatic fertilizers in combination with organic manures had resulted in higher content of available P as compared to inorganic fertilizer alone. The available P content in soil ranged from 40.5kg ha^{-1}, with application of ammonium phosphate alone, to 318.5 kg ha^{-1}, recorded by the treatment which involved application of green manures along with NPK fertilizers. Mohanty and Mandal (1989) reported that the application of nitrogen, FYM and organic matter enhance the phosphorus utilization. Datta *et al.*

(1966) inferred that an Indian variety of rice derived only 8 to 27 per cent total phosphorus from applied phosphorus.

2.5 RESPONSE OF RICE AND RESIDUAL CROPS TO PHOSPHORUS APPLICATION

Phosphorus is considered less commonly deficient for rice than upland crops because of its increased concentration in soil solution under flooded conditions (Datta, 1981). However, it is still considered as a frequent constraint to rice production in many developing countries in Asia. The experiments conducted in five countries under the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), showed grain response to P to the tune of 1.3 t/ha^{-1} when P was applied with N (Datta, 1983).

There was ample number of reports, which indicated the response of rice to P fertilization. Beltran *et al.* (1982) indicated that P rate upto 60-90 kg P_2O_5 ha^{-1} generally registered higher grain yield of rice than the unfertilized control. The higher rates, however, had no beneficial effect. Singh *et al.* (1985) reported a response of 3.9 and 7.3q ha^{-1} of rice grain, due to the application of 30 kg and 60kg P_2O_5 ha^{-1} respectively. The response per kg of phosphorus showed declining trend on its level increased.

Deshpande *et al.* (1988) observed more than 50 per cent response to P fertilization at 32.5 kg P_2O_5 ha^{-1} in terms of grain yield. Verma *et al.* (1989) reported highest grain yield of rice to the application of 90 kg P_2O_5 ha^{-1} along with 120 kg N, and 60 kg K_2O ha^{-1}. Subbiah (1991) recorded highest grain yield of rice for P application at 90 kg P_2O_5 ha^{-1}. Uptake of all the three major nutrients increased as the level of P application increased from 0 to 90 kg P_2O_5 ha^{-1}.

Application of P at 0, 20, 40, 60 and 80 kg P_2O_5 ha^{-1} levels to a sandy loam soil containing 37.2 kg P_2O_5 ha^{-1} of native P, resulted in rice yields of 3.94, 4.40, 4.63, 4.74 and 4.80 t ha^{-1} respectively (Latchanna *et al.* 1989). Singh and Singh

(1990) also observed significant increase in dry matter yield and P uptake of rice as the level of P fertilizer application increased.

There is a build up of P in soil due to continuous application of P fertilizer as the recovery of added P being only around 20 per cent. Residual effect of the P fertilizers added to the main crop has been reported by a number of workers in a rice based cropping system (Sarkar and Sarkar, 1982; Meelu and Morris, 1984; Pillai *et al.*, 1986 and Chandrasekaran, 1989).

2.6 NUTRIENT-PHOSPHORUS FUNCTION AND PLANT BEHAVIOUR

The most essential function of P in plants is in energy storage and transfer. Adenosine di and tri phosphates (ADP and ATP) act as "energy currency" with in plants (Tisdale *et al.*, 1997).

Phosphorus associated with root development, early flowering and ripening (Geus, 1954). An adequate supply of P is associated with greater strength of cereal straw (Tisdale *et al.*, 1997). In rice, an adequate supply of P in the early stages of crop growth promotes by increasing the content of nucleic acids and phospholipids. Nucleic acids can actually promote heading in rice as they control vegetative growth through protein biosynthesis and reproductive growth through flower initiation (Fujiwara, 1964).

P manuring increases early litter formation, the greater part of which ultimately provides more grains of heavier weight and also stimulates early and synchronous flowering (Battacharya and Chatterjee, 1978). Favourable influence of P application on tillering was also observed by Nair *et al.* (1972), and Choudhary *et al.* (1978). However Alexander *et al.* (1973), Kalyanikutty and Morachan (1974) and Suseelan *et al.* (1978) have reported lack of any response to P application on rice tillering.

Majumdar (1971) observed that there was significant increase in number of productive tillers and 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 Kalyanikutty and Morachan (1974), Kalita and Baroove (1994). However several workers have reported that mean grain yields was not significantly affected by P fertilizers (Pargan *et al.*, 1980 and Rao and Kumar, 1994).

2.7 PHOSPHORUS NUTRIENT INTERACTIONS WITH OTHER NUTRIENTS IN RICE

Alakh and Dev (1978) indicated that higher application of phosphorus resulted in an increase in sulphur content in soil solution as a result of anion exchange, ultimately resulting in higher sulphur absorption. An increase in the available N and P content of the soils by the application of graded levels of lime has been observed by Marykutty (1986).

Bridgit (1999) and Lakshmikanthan (2000) reported that at higher level of K uptake of P significantly increased at maximum tillering stage in rice. High phosphate concentration creates a zinc deficiency as a result of precipitation of zinc phosphate in soil (Sindhu, 2002).

Materials and Methods

III. MATERIALS AND METHODS

The experiment, "Influence of phosphorus on absorption and dynamics of nutrients in rice" was conducted at Radiotracer Laboratory (RTL), College of Horticulture, Kerala Agricultural University, Vellanikkara, during December 2002 to April 2003. The materials used and methods adopted during the course of investigation are presented in this chapter.

3.1 LOCATION

The experiment was conducted at Radiotracer Laboratory College of Horticulture, Kerala Agricultural University, and Vellanikkara. This laboratory is geographically located at 10°31′ N latitude and 76°10′ E longitude at an altitude of 22.5 meter above mean sea level.

3.2 CLIMATE

The area enjoys tropical humid climate. The relevant meteorological data pertaining to the experimental site during the period of investigation are presented in Appendix -1.

3.3 COLLECTION AND PREPARATION OF THE SOIL

The experiment was carried out with two different soil types such as laterite soil and *Kole* soil. Soil from the top 0 to15 cm depth of laterite and *Kole* lands were collected from Regional Agricultural Research Station (RARS), Pattambi and from the farmers field at Adat area near Thrissur, respectively. The soil was air dried, powdered with a wooden mallet and passed through 2 mm sieve. The soil was analysed for pH, total nitrogen, available P, available K and available Fe. The physical and chemical properties of the soil types are given in table 3.1.

Table 3.1. Physical and chemical properties of the laterite and *Kole* soils.

Properties	Laterite soil	*Kole* soil	Reference
PH	5.73	5.23	Jackson, 1973
EC (dsm^{-1})	0.3	0.48	Jackson, 1973
Particle density (gcm^{-3})	2.3	2.1	Piper, 1958
Bulk density (gcm^{-3})	1.18	1.11	Blake, 1942
Water holding capacity (%)	31.42	43.6	Piper, 1958
Porosity (%)	38.9	48.7	Piper, 1958
Mechanical composition of the soils			
Sand (%)	50.2	45.69	Piper, 1958
Silt (%)	22.4	26.06	
Clay (%)	27.2	28.75	
Chemical composition of the soils			
Organic Carbon (%)	0.58	1.18	Walkely and Black, 1934
N (%)	.049	.058	Jackson, 1973
P ($mgkg^{-1}$)	14	11.2	Watanabe and Olsen, 1965
K (%)	.003	.004	Cheng and Bray, 1951
Fe ($mgkg^{-1}$)	378	428	Jackson, 1973

3.4 POT CULTURE EXPERIMENT TO STUDY THE PHOSPHORUS UTILIZATION BY RICE USING ^{32}P-LABELLED SINGLE SUPERPHOSPHATE

Earthen pots with uniform size (10"*12") were used for the study. The pots were filled with 5 kg of processed soil. Sufficient water was added to the pots to wet the soil and to bring out a puddled condition. After that water was maintained upto a depth of 5 cm in all the pots. The organics such as *Ung*(*Pongamia glabra*) @ 5 t ha^{-1} and rice straw @ 5 t ha^{-1} on dry weight basis were applied and incorporated at top 15 cm of the soil for 15 days before sowing the rice seeds. Fresh weight, driage and nutrient contribution of organics are given in table.3.2 and the chemical composition of the organics presented in the table.3.3.

Rice variety "*Jyothi*" was used for the study. Seeds were collected from the Agricultural Research Station, Mannuthy. One hill with two sprouted seeds per hill was sown. In each pot, three hills were maintained. Initially, two centimeter of standing water was maintained upto germination of rice seeds. After that 5 cm of standing water was maintained upto harvest. The pots were arranged in the open on polythene sheets, so as to simulate a natural field environment with respect to solar radiation, ambient temperature and relative humidity.

3.5 DETAILS OF THE EXPERIMENT

The experiment was conducted during *Punja* (summer crop) season December-April of 2002 to 2003. The experiment was laid out in completely randomized design with 18 treatments and 6 replications of which three replication were used for destructive sampling for radio assay and for nutrient analysis at specified intervals and the other three for growth and yield studies.

Treatments:

T_1 - Laterite soil + 90:45:45 $kgha^{-1}$ of NPK + no organics

T_2 - Laterite soil + 90:45:45 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}

T_3 - Laterite soil + 90:45:45 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}

T_4 - Laterite soil + 90:22.5:90 $kgha^{-1}$ of NPK + no organic

T_5 - Laterite soil + 90:22.5:90 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}

T_6 - Laterite soil + 90:22.5:90 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}

T_7 - Laterite soil + 90:67.5:135 $kgha^{-1}$ of NPK + no organics

T_8 - Laterite soil + 90:67.5:135 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}

T_9 - Laterite soil + 90:67.5:135 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}

T_{10} - *Kole* soil + 90:45:45 $kgha^{-1}$ of NPK + no organics

T_{11} - *Kole* soil + 90:45:45 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}

T_{12} - *Kole* soil + 90:45:45 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}

T_{13} - *Kole* soil + 90:22.5:90 $kgha^{-1}$ of NPK + no organics

T_{14} - *Kole* soil + 90:22.5:90 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}

T_{15} - *Kole* soil + 90:22.5:90 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}

T_{16} - *Kole* soil + 90:67.5:135 $kgha^{-1}$ of NPK + no organics

T_{17} - *Kole* soil + 90:67.5:135 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}

T_{18} - *Kole* soil + 90:67.5:135 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}

T_{19}- Absolute control for *Kole* soil

T_{20}- Absolute control for laterite soil.

Fertilizer application was done according to the package of practices recommendation (KAU, 2003) for high yielding medium duration varieties. Nitrogen, phosphorus and potassium were applied as per treatments respectively

Table 3. 2. Fresh weight, driage and Nutrient contribution of organics

Sl. No.	Organics	Fresh weight (t ha^{-1})	Driage (%)	Nutrient contribution at 5 tha^{-1}		
				N (kgha^{-1})	P (kgha^{-1})	K (kgha^{-1})
1	*Ung(Pongamia glabra)*	23.80	21	155.5	10.5	91
2	Rice straw	5	-	45.5	6.5	97

Table .3.3. Chemical characteristics of organics

Sl. No.	Nutrients	Pongamia leaves	Rice straw
1	Organic carbon (%)	33.1%	44.2
2	N (%)	3.11	0.91
3	P (%)	0.21	0.13
4	K (%)	1.82	1.94
5	Ca (mgg^{-1})	15.56	3.72
6	Mg (mgg^{-1})	3.89	1.41

in the form of urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O), respectively. Full dose of phosphorus was applied as basal dressing and nitrogen and potassium were applied in split doses. Nitrogen was applied in three equal split doses, first at basal, second at tillering stage (three weeks after seeding) and third at panicle initiation stage (about 30 days before flowering). Potassium was applied in two equal splits, first as basal, and second at panicle initiation stage.

Single super phosphate was labelled with ^{32}P with a specific activity of 0.3 $mCig^{-1}$ of P_2O_5 and applied as band placement. The seeds were sown in the fertilizer banded area.

3.5.1 Radio assay

For the determination of ^{32}P in plant samples, the Cerenkov counting method developed by Wahid *et al.* (1985) was followed. This method consisted of wet digestion of the oven-dried and finely cut leaves with 2:1 nitric acid - perchloric acid mixture and determination of radioactivity in the digest after transferring it quantitatively into a 20 ml scintillation counting vial with distilled water.

The radioactivity was determined in a microprocessor controlled liquid scintillation system (Pharmacia LKB Wallac-Oy, Finland). The rates (counts per minute or cpm) were corrected for background and decay.

The total P in the plant tissue was estimated by vanadomolybdo phosphoric yellow colour method (Jackson, 1973) using an aliquot of the diacid digest. The intensity of the colour was measured at 470 nm.

Phosphorus uptake by the crop was computed from their respective chemical concentration and drymatter production.

3.5.2 Interpretation of data for radioassay of ^{32}P (IAEA, 1976)

Using the data of total P content ($mgPg^{-1}$) and radioactivity of ^{32}P (cpm) in plant samples and single superphosphate, the following were worked out.

1. Specific activity of ^{32}P

$$\text{Specific activity of } ^{32}P = \frac{^{32}P \text{ activity (cpm)}}{\text{Total P content } (mgPg^{-1})}$$

2. % Pdff: The percentage of total P in the plant tissue derived from the fertilizer

$$\% \text{ Pdff} = \frac{\text{Specific activity of plant sample (cpm } mgP^{-1} \text{ in plant)}}{\text{Specific activity of fertilizer standard (cpm } mgP^{-1} \text{ in plant)}} \times 100$$

3. % Pdfs: The percentage of total P in the plant tissue derived from the soil

% Pdfs: 100 - % Pdff

4. A value:

$$\frac{\%\text{Pdfs}}{\%\text{ Pdff}} \times \text{rate of fertilizer application in mg } P^{-1}\text{g of soil}$$

5. % Uptake of applied fertilizer

$$\frac{\%\text{ Pdff} \times \text{ P uptake (mg } pot^{-1})}{\text{Amount of fertilizer added to each pot (in mg)}}$$

P uptake is calculated by multiplying mg of P in the plant tissue into dry weight of plant material.

3.6 CHEMICAL ANALYSIS

The plant samples were collected at maximum tillering, 50% flowering and at harvest stages by cutting them above the level of water, dried separately in a hot air oven to constant weight, and then chopped into small pieces and analysed for radioactivity. The content of N, P, K, Ca, Mg, S, Fe and Na were estimated by employing the following methods and the concentration of the nutrients at three different stages are reported. The methods used to analysis of plants are presented in table 3.4.

3.7 CHLOROPHYLL ESTIMATION

The total chlorophyll content was estimated from the third fully opened leaf from the top at panicle initiation and at 50% flowering.

The total chlorophyll content, chlorophyll 'a' and chlorophyll 'b' were estimated colorimetrically (Yoshida *et al.*, 1972) in a spectronic 20 – spectrophotometer, using the following formula and expressed in mg/g fresh weight of leaves.

Total chlorophyll = 8.05 A 663 + 20.29 A 645

Chlorophyll 'a' = 12.72 A 663 - 2.58 A 645

Chlorophyll 'b' = 22.87 A 645 - 4.67 A 663

Where A is the absorbance at 645 and 663 nm

The cell sap pH is also estimated from the third fully opened leaves from the top at 50 per cent flowering stage. By macerating the fresh leaf sample, the cell sap was extracted and one ml of it was diluted into 5 ml and read in the pH meter.

3.8 POT CULTURE EXPERIMENT FOR GROWTH AND YIELD STUDIES

To study the effect of phosphorus on the growth and yield of rice, a pot culture experiment was done with *Kole* soil and laterite soil. In this experiment, nitrogen as urea, phosphorus as single super phosphate, potassium as Muriate of potash, and organics such as Pongamia *leaves (Ung)* and rice straws were included.

Table .3.4. Methods used for plant analysis

Nutrient	Method	Reference
1. Nitrogen	Microkjeldhal method	Jackson, 1958
2. Phosphorus	Diacid extract estimated calorimetrically in a spectronic-20, spectro photometer by vanadomolybdo phosphoric yellow colour method	Jackson, 1973
3. Potassium	Diacid extract method, using flame photometer	Jackson, 1973
4. Calcium	Versenate titration method	Jackson, 1973
5. Magnesium	Versenate titration method	Jackson, 1973
6. Sulphur	Turbidimetric method, using spectronic 20 spectrophotometer	Hart, 1961
7. Iron	Colorimetric method, using spectronic 20 spectrophotometer	Jackson, 1988
8.Sodium	Diacid extract method, using flame photometer	Jackson, 1973

3.8.1 Crop growth characters

3.8.1.1 Plant height

Plant height was recorded at two weeks interval after sowing upto harvest. Height was measured from the bottom of the plant to the tip of the longest leaves.At harvest, the height was recorded from the base of the plant to the tip of the longest panicle and the mean height was computed and expressed in cm.

3.8.1.2 Number of tillers

Tiller production started four weeks after sowing. Number of tillers in each hill was counted at two weeks interval.

3.8.1.3 Observations on yield and yield attributes

1. Number of panicles

Number of panicles on each hill was recorded at harvest.

2. Number of spikelets per panicle

Total number of spikelets was taken from the hill and spikelets per panicles (mean value) were worked out.

3. Panicle length

Total number of panicles was taken from the hills, length measured from the base to the tip of the panicle and the mean expressed in cm.

4. Panicle weight

Panicles from each hill were weighed separately. Mean weight worked out and expressed in gram.

5. Percentage of filled grains

The grain from the panicles of each hill was separated, filled and unfilled grains were counted and the percentage of filled grains was worked out.

7. 1000 grain weight

1000 grains collected from randomly selected panicles of each pot were counted and mean weight recorded in gram.

8. Grain yield

The grains from each pot were harvested, dried, cleaned, weighed and mean expressed in g pot^{-1}.

9. Straw yield

The straw from each pot was harvested, dried, weighed and mean expressed in $gpot^{-1}$.

3.9 STATISTICAL ANALYSIS

Statistical analysis was done as per the methods suggested by Panse and Sukhatme (1978). Duncans Multiple Range Test (DMRT) values were used for comparison of treatments.

Results

IV. RESULTS

The results pertaining to the studies on "Influence of phosphorus on absorption and dynamics of nutrients in rice" are furnished hereunder.

4.1 CROP GROWTH CHARACTERS

Crop growth characteristics such as plant height, number of tillers, and dry matter production are presented here.

4.1.1 Height of plants

All treatments had significant influence on height of plants at different stages of crop growth (Table 4.1).

At 60 DAS, tallest plant (33.33 cm) was observed in *kole* soil treated with 90:45:45 kgha^{-1} NPK along with Pongamia leaves 5 tha^{-1}(T_{11}) which was comparable with all other treatments. Whereas, at 75 DAS height of the plant was more in T_{11} (59.66 cm) and was superior to most of the other treatments. The lowest plant height was recorded in T_4 (52.44 cm).

At 90 DAS T_{11} was the best treatment with 70.77 cm. while T_4 recorded lowest plant height of 61.00 cm.

At harvest, height of the plant was more (83.11 cm) in T_{11} which was comparable with most other treatments. The lowest height was recorded in control for laterite soil (T_{20}) with 68.00 cm.

4.1.2 Number of tillers

The observations on number of tillers were summarized in table 4.2.

At 60 DAS, number of tillers was comparable in all treatments and tiller numbers varied from 3.73 to 5.60. Highest number of tillers was observed in control for laterite soil (5.60) while the lowest was in T_8 (3.73).

Table 4.1. Effect of treatments on height of the plants (in cm) at different stages

T.no	60 DAS	75 DAS	90 DAS	Harvest
T_1	31.11^{a}	55.88^{abcde}	63.00^{cdef}	76.22^{abcde}
T_2	30.39^{a}	56.16^{abcde}	65.44^{abcdef}	78.44^{abcd}
T_3	32.55^{a}	53.22^{cdef}	61.77^{def}	76.44^{abcd}
T_4	29.77^{a}	52.44^{def}	61.00^{def}	75.22^{abcde}
T_5	32.65^{a}	55.88^{abcde}	63.99^{bcdef}	77.22^{abcd}
T_6	30.22^{a}	58.66^{abc}	61.82^{def}	78.00^{abcd}
T_7	31.77^{a}	55.27^{abcdef}	64.27^{abcdef}	80.11^{abc}
T_8	30.27^{a}	54.33^{bcdef}	62.22^{cdef}	72.89^{bcde}
T_9	29.00^{a}	56.66^{abcd}	61.22^{cdef}	76.44^{abcd}
T_{10}	32.38^{a}	54.66^{abcdef}	62.11^{cdef}	75.33^{abcde}
T_{11}	32.03^{a}	59.66^{a}	70.77^{a}	83.11^{a}
T_{12}	32.55^{a}	56.72^{abcd}	66.33^{abcde}	73.66^{bcde}
T_{13}	32.55^{a}	58.27^{abc}	67.77^{abcd}	78.27^{abcd}
T_{14}	31.48^{a}	58.94^{ab}	67.89^{abc}	77.88^{abcd}
T_{15}	33.33^{a}	56.27^{abcde}	65.11^{abcdef}	77.00^{abcd}
T_{16}	32.11^{a}	57.60^{abc}	65.11^{abcdef}	75.44^{abcde}
T_{17}	31.11^{a}	58.05^{abc}	70.55^{ab}	80.55^{ab}
T_{18}	32.50^{a}	56.66^{abcd}	64.77^{abcdef}	78.77^{abcd}
T_{19}	29.33^{a}	50.66^{f}	58.77^{f}	70.44^{de}
T_{20}	28.66^{a}	51.50^{ef}	56.44^{f}	68.00^{e}

Table 4.2. Effect of treatments on number of tillers at different stages

T.No	60 DAS	75 DAS	90 DAS	Harvest
T_1	4.17^{a}	5.17^{g}	5.56^{defg}	6.33^{cdef}
T_2	5.07^{a}	5.63^{cdef}	6.07^{cdefg}	6.73^{bcdef}
T_3	4.63^{a}	4.86^{fg}	5.10^{g}	6.46^{cdef}
T_4	3.87^{a}	5.30^{def}	5.30^{efg}	5.18^{def}
T_5	4.87^{a}	6.06^{abcdef}	6.80^{abcdef}	6.91^{bcdef}
T_6	3.83^{a}	6.16^{abcdef}	5.43^{defg}	7.06^{bcdef}
T_7	4.73^{a}	5.86^{bcdef}	5.63^{defg}	6.30^{def}
T_8	3.73^{a}	6.63^{abcde}	6.63^{bcdefg}	6.86^{def}
T_9	4.06^{a}	5.30^{def}	5.46^{defg}	6.90^{bcdef}
T_{10}	4.73^{a}	6.20^{abc}	6.63^{bcdefg}	7.63^{abcde}
T_{11}	4.20^{a}	7.63^{a}	8.43^{a}	9.20^{a}
T_{12}	5.06^{a}	6.43^{abcdef}	6.40^{bcdefg}	6.73^{bcdef}
T_{13}	4.40^{a}	6.86^{abcd}	6.33^{bcdefg}	7.30^{bcdef}
T_{14}	4.86^{a}	7.26^{abc}	7.96^{ab}	7.73^{abcde}
T_{15}	5.06^{a}	6.73^{abcde}	7.06^{abcd}	8.16^{abcd}
T_{16}	5.50^{a}	7.50^{ab}	7.53^{abc}	7.96^{abcde}
T_{17}	4.63^{a}	7.53^{ab}	7.63^{abc}	8.60^{ab}
T_{18}	5.43^{a}	7.16^{abc}	7.50^{abc}	8.20^{abc}
T_{19}	5.00^{a}	5.30^{def}	5.30^{efg}	6.00^{f}
T_{20}	5.60^{a}	6.50^{abcdef}	6.50^{bcdefg}	6.86^{def}

At 75 DAS, *kole* soil incorporated with 90:45:45 kgha^{-1} NPK along with Pongamia leaves @ 5 tha^{-1} (T_{11}) recorded the highest tiller number (7.63) and lowest in T_1 (5.17). At 90 DAS, T_{11} gave the highest number of tillers (8.43) followed by T_{14} and T_{17}. T_3 registered the lowest number of tillers (5.10).

At harvest also T_{11} had the highest number of tillers (9.20) which was followed by T_{17} and T_{18} with a value of 8.60 and 8.20, respectively. The lowest number of tillers (5.18) was recorded in T_4.

4.1.3 Physiological parameters

4.1.3.1 Chlorophyll content

Chlorophyll content recorded during various growth stages of plants are presented in table 4.3.

At PI stage, chlorophyll 'a' content was highest in T_{11} (2.63 μgg^{-1}), and lowest in T_{13} (2.33 μgg^{-1}) . T_3 gave the highest amount of chlorophyll 'b' (0.61 μgg^{-1}) and T_6 recorded the lowest (0.40 μgg^{-1}). In case of total chlorophyll content, T_{11} recorded the highest content of 3.22 μgg^{-1}. Whereas, T_{13} recorded the lowest amount of total chlorophyll content of 2.82 μgg^{-1} which is on par with T_{16}, T_{17}, T_{18}, T_4, T_6, T_9 and T_{10}.

At 50 per cent flowering, T_8 registered the highest amount of chlorophyll 'a' (2.88 μgg^{-1}) whereas; control for laterite soil gave the lowest amount of chlorophyll 'a' (2.42 μgg^{-1}). In case of chlorophyll b also, T_{11} recorded the highest content of chlorophyll 'b' (1.06 μgg^{-1}) followed by T_2 (0.933 μgg^{-1}). All other treatments except control (laterite) were comparable. Control (laterite) recorded the lowest amount of the chlorophyll 'b' of 0.22 μgg^{-1}. The total chlorophyll content was also highest in T_{11} (3.83 μgg^{-1}). The lowest total chlorophyll content was recorded in control (laterite) 2.64 μgg^{-1}.

Table 4.3. Effect of treatment on chlorophyll content of plants at different stages.

T. No	Panicle initiation stage			50% Flowering stage		
	Chlorophyll *a* (μgg^{-1})	Chlorophyll *b*. (μgg^{-1}))	Total (μgg^{-1})	Chlorophyll *a*. (μgg^{-1})	Chlorophyll *b*. (μgg^{-1})	Total(μgg^{-1})
T_1	2.36^{de}	0.57^{abcde}	2.93^{bcd}	2.52^{bc}	0.56^{cd}	3.09^{e}
T_2	2.55^{abc}	0.60^{ab}	3.15^{ab}	2.78^{abc}	0.93^{ab}	3.72^{b}
T_3	2.53^{abc}	0.61^{a}	3.15^{ab}	2.69^{bc}	0.73^{bc}	3.42^{bc}
T_4	2.39^{de}	0.56^{abcde}	2.95^{bcd}	2.69^{bc}	0.70^{bc}	3.07
T_5	2.43^{d}	0.59^{ab}	3.02^{bc}	2.69^{bc}	0.73^{bc}	3.43^{bc}
T_6	2.45^{d}	0.40^{g}	2.88^{bcd}	2.65^{bc}	0.32^{cd}	3.17^{d}
T_7	2.43^{d}	0.61^{ab}	3.04^{bc}	2.63^{bc}	0.60^{cd}	3.23^{d}
T_8	2.63^{a}	0.52^{bcdef}	3.15^{ab}	2.73^{abc}	0.88^{b}	3.62^{b}
T_9	2.42^{d}	0.47^{fg}	2.89^{bcd}	2.69^{bc}	0.85^{b}	3.55^{bc}
T10	2.42^{d}	0.50^{cdef}	2.92^{bcd}	2.53^{bc}	0.48^{cd}	3.02^{f}
T_{11}	2.63^{a}	0.59^{ab}	3.22^{a}	2.88^{a}	1.06^{a}	3.83^{a}
T_{12}	2.50^{c}	0.58^{abcd}	3.08^{bc}	2.64^{bc}	0.60^{cd}	3.24^{d}
T_{13}	2.33^{e}	0.49^{ef}	2.82^{bcd}	2.77^{abc}	0.73^{bc}	3.50^{bc}
T_{14}	2.42^{d}	0.58^{abc}	3.01^{bc}	2.65^{bc}	0.79^{bc}	3.44^{bc}
T_{15}	2.57^{abc}	0.54^{abcdef}	3.11^{bc}	2.59^{bc}	0.54	3.13^{e}
T_{16}	2.43^{d}	0.53^{abcdef}	2.96^{bcd}	2.59^{bc}	0.85^{b}	3.44^{bc}
T_{17}	2.59^{abc}	0.24^{h}	2.83^{bcd}	2.81^{ab}	0.84^{b}	3.65^{b}
T_{18}	2.60^{ab}	0.50^{def}	2.84^{bcd}	2.66^{bc}	0.52^{cd}	3.18^{d}
T_{19}	2.37^{de}	0.50^{def}	2.87^{bcd}	2.47^{cd}	0.57^{cd}	3.00^{e}
T_{20}	2.39^{de}	0.59^{abc}	2.98^{bcd}	2.42^{d}	0.22^{d}	2.64^{f}

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4.1.3.2 *Cell sap pH*

At panicle initiation, control for both *kole* and laterite soil recorded the highest cell sap pH of 6.80 and 6.74, respectively (Table 4.4). The lowest value was recorded in T_2 (6.34). At 50 per cent flowering, control for laterite soil registered highest cell sap pH of 6.68. The lowest value was recorded in T_2 with 6.14, which was on par with T_{13}.

4.1.4 Yield attributes

The yield attributes such as number of productive tillers, spikelets per panicles; length of panicle, 1000-grain weight and sterility percentage are given in table 4.5.

More productive tillers were observed in T_{11} (7.23 per hill). The lowest number of productive tillers (5.50 per hill) was with plants in control for *kole* soil.

Longest panicle (18.22 cm) was observed in T_2 i.e., laterite soil treated with 90:45:45 $kgha^{-1}$ of NPK along with Pongamia leaves @ 5 tha^{-1}. The lowest panicle length was recorded in control for laterite soil (16.0 cm).

The number of spikelets per panicle was highest (101.06) in T_{11} i.e., *kole* soil treated with 90:45:45 $kgha^{-1}$ NPK along with Pongamia leaves @ 5 tha^{-1}. T_{11} was closely followed by T_{14} (95.45) and T_8 (91.50) All other treatments except control for both *kole* and laterite soil were on par.

The 1000 grain weight was highest (27.94g) in T_{17} i.e.,*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK along with Pongamia leaves @ 5 tha^{-1} and lowest in control for laterite soil (23.14g). Though the sterility percentage was highest in control for laterite soil (22.13%), no significant difference was observed among the treatments.

Table 4.4 Effect of treatments on cell sap P^H of rice plant at different intervals

T No	Cellsap P^H at panicle Initiation	Cell sap p^H at flowering
T_1	6.51ab	6.36abc
T_2	6.34b	6.14c
T_3	6.51ab	6.41abc
T_4	6.42b	6.33abc
T_5	6.52ab	6.31abc
T_6	6.51ab	6.44abc
T_7	6.54ab	6.41abc
T_8	6.44b	6.29abc
T_9	6.73a	6.39abc
T_{10}	6.54ab	6.27abc
T_{11}	6.37b	6.26c
T_{12}	6.59ab	6.15abc
T_{13}	6.41b	6.18c
T_{14}	6.58ab	6.45abc
T_{15}	6.67ab	6.57a
T_{16}	6.66ab	6.42abc
T_{17}	6.59ab	6.48ab
T_{18}	6.42b	6.31abc
T_{19}	6.80a	6.63a
T_{20}	6.74_a	6.68_a

Table 4.5. Effect of treatments on yield attributes

T.No	Number of productive tillers per hill	Length of panicle (cm)	Spikelets/panicle (in numbers)	1000 seed weight (g)	Chaff (%)
T_1	5.73^{cd}	16.97^{bcdef}	80.88^{ab}	26.60^{ab}	19.51^{a}
T_2	5.93^{bcd}	18.22^{a}	86.36^{ab}	27.68^{a}	18.39^{a}
T_3	5.66^{cd}	17.16^{bcde}	82.87^{ab}	27.04^{a}	19.17^{a}
T_4	5.80^{bcd}	17.28^{bcde}	86.51^{ab}	25.84^{abc}	20.91^{a}
T_5	6.30^{bc}	17.55^{abcd}	88.03^{ab}	27.32^{a}	16.15^{a}
T_6	5.93^{bcd}	16.22^{fg}	84.24^{ab}	26.63^{ab}	19.74^{a}
T_7	5.63^{cd}	17.11^{bcde}	90.00^{ab}	26.63^{ab}	16.41^{a}
T_8	5.86^{bcd}	17.28^{bcde}	91.50^{ab}	27.91^{a}	17.11^{a}
T_9	5.93^{bcd}	16.94^{bcdef}	90.20^{ab}	27.53^{a}	15.26^{a}
T_{10}	6.40^{abc}	17.64^{abc}	87.57^{ab}	26.32^{abc}	17.88^{a}
T_{11}	7.23^{a}	17.44^{abcd}	101.06^{a}	27.75^{a}	19.91^{a}
T_{12}	5.90^{bcd}	16.72^{defg}	86.06^{ab}	27.15^{a}	20.29^{a}
T_{13}	6.30^{abc}	16.94^{bcdef}	88.60^{ab}	24.91^{abc}	16.93^{a}
T_{14}	6.83^{abc}	17.22^{bcde}	95.45^{ab}	25.70^{abc}	15.35^{a}
T_{15}	7.20^{ab}	17.33^{bcde}	88.00^{ab}	26.96^{a}	15.90^{a}
T_{16}	6.93^{ab}	17.05^{bcdef}	86.00^{ab}	26.11^{abc}	16.27^{a}
T_{17}	6.96^{ab}	17.77^{ab}	91.00^{ab}	27.94^{a}	18.30^{a}
T_{18}	6.96^{ab}	16.83^{cdef}	90.15^{ab}	27.90^{a}	15.28^{a}
T_{19}	5.50^{d}	16.50^{efg}	74.24^{b}	23.78^{c}	21.38^{a}
T_{20}	6.10^{bcd}	16.00^{g}	76.51^{b}	23.14^{c}	22.13^{a}

4.1.5 Effect of treatments on straw yield grain yield and dry matter production

4.1.5.1 Straw yield

The data on the effect of various treatments on straw yield are presented in table 4.6.

The treatments manifested significant variation in straw yield per pot. T_{11} (*kole* soil treated with 90:45:45 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1}) recorded the highest yield of 62.50 g pot^{-1} followed by T_{17} (laterite soil treated with 90:45:45 kgha^{-1} NPK + Pongamia leaves @ 5 tha^{-1}) with 56.81 gpot^{-1} and the lowest yield of straw was recorded in the control for laterite soil (T_{20}) with 25.27 g pot^{-1}.

4.1.5.2 Grain yield

The data on the effect of various treatments on grain yield per pot are presented in table 4.6.

The grain yield showed variations among the treatments. The variation ranged from 9.36 g pot^{-1} to 23.15 g pot^{-1}. The highest grain yield (23.15 g pot^{-1}) was recorded in T_{11} i.e., *kole* soil treated with 90:45:45 kgha^{-1} NPK along with Pongamia leaves @5 tha^{-1}. It was comparable with T_8 and T_{17}. The lowest yield was recorded in the control for laterite soil with 9.36 g pot^{-1}.

4.1.5.3 Total dry matter production per pot

The data on the effect of treatments on the dry matter production per pot are presented in table 4.6.

T_{11} recorded the highest dry matter production of 85.65 gpot^{-1} followed by T_{17} with 76.86 gpot^{-1}. The lowest dry matter production was registered the control for laterite soil with 34.64 gpot^{-1}.

Table 4.6 Effect of treatment on straw , grain and dry matter production of rice.

T.No	Straw yield/pot ($gpot^{-1}$)	Grain yield ($gpot^{-1}$)	Dry matter Production ($gpot^{-1}$)
T_1	39.64^{cdef}	14.68^{defgh}	54.34^{def}
T_2	55.53^{ab}	19.14^{abcde}	74.64^{ab}
T_3	36.57^{efg}	13.54^{fghi}	50.11^{efg}
T_4	27.92^{fg}	11.08^{hi}	34.64^{g}
T_5	41.92^{cdef}	15.53^{cdefgh}	57.44^{cde}
T_6	31.08^{fg}	11.51^{hi}	42.60^{efg}
T_7	39.61^{cdef}	14.67^{defgh}	54.28^{def}
T_8	51.67^{abcd}	20.57^{ab}	72.24^{abc}
T_9	52.66^{abc}	19.51^{abcd}	72.17^{abc}
T_{10}	39.61^{cdef}	14.67^{defgh}	54.28^{def}
T_{11}	62.50^{a}	23.15^{a}	85.65^{a}
T_{12}	48.57^{bcde}	17.17^{bcdefg}	65.74^{bcd}
T_{13}	30.70^{fg}	11.31^{hi}	42.07^{efg}
T_{14}	39.14^{def}	14.50^{efgh}	53.63def
T_{15}	33.30^{fg}	12.34^{ghi}	45.664^{efg}
T_{16}	41.92^{cdef}	15.53^{cdefgh}	57.44^{cde}
T_{17}	56.81^{ab}	20.06^{abc}	76.86^{ab}
T_{18}	48.12^{bcde}	17.86^{bcdef}	65.98^{bcd}
T_{19}	28.86^{fg}	10.69^{fghi}	39.55^{fg}
T_{20}	25.27^{g}	9.36^{i}	34.64^{g}

4.2 ELEMENTAL COMPOSITION OF RICE PLANT

4.2.1 Maximum Tillering

Elemental composition of rice plant at maximum tillering is presented in table 4.7.

Nitrogen

At maximum tillering, N concentrations of all the treatments were on par and varied between 2.29 to 3.20 per cent. T_8 recorded the highest value of 3.20 per cent. Plants in control (both *kole* and laterite soil) had the lowest concentration of 2.28 per cent and 2.29 per cent, respectively.

Phosphorus

Observations at similar intervals as in the case of nitrogen estimations have been carried out for the determination of phosphorus concentrations and the results are presented in table 4.7. At maximum tillering, phosphorus concentrations of all treatments were similar. T_{17} i.e., *Kole* soil treated with 90:67.5:135 kgha^{-1} NPK along with Pongamia leaves @ 5 tha^{-1} recorded the highest percentage of 0.35 followed by T_8 and T_{12} (0.34).Control for *kole* soil (T_{19}) gave the lowest concentration of phosphorus (0.30 %).

Potassium

The concentration of K at maximum tillering ranged between 2.53 and 3.28 per cent. Highest concentration of K (3.28%) was observed in T_8, whereas, the lowest concentration was recorded in T_{16} (2.53 %).

Secondary and Micronutrients

Analysis have been carried out for the determination of secondary nutrients such as calcium (Ca), Magnesium (Mg), micronutrients like iron (Fe) and sodium (Na) and the details are presented in tables 4.7. From the results, at MT, Ca content was highest in T_8 i.e., Laterite soil treated with 90:67.5:135 kgha^{-1}

Table 4.7. Effect of treatments on elemental composition of rice at maximum tillering.

T.No	N%	P%	K%	Ca%	Mg%	S%	Fe ($mgkg^{-1}$)	Na ($mgkg^{-1}$)
T_{1}	2.66^{a}	0.33^{a}	2.61^{bc}	0.54^{cde}	0.44^{ab}	0.10^{d}	3600^{a}	1450^{bc}
T_{2}	2.90^{a}	0.32^{a}	3.01^{abc}	0.82^{c}	0.44^{ab}	0.14^{bcd}	2667^{a}	2367^{a}
T_{3}	2.81^{a}	0.30^{a}	2.95^{abc}	0.67^{abcde}	0.57^{a}	0.16^{bcd}	3100^{a}	1367^{bc}
T_{4}	2.36^{a}	0.30^{a}	2.51^{c}	0.75^{abcde}	0.40^{ab}	0.14^{bcd}	4333^{a}	1283^{bc}
T_{5}	2.59^{a}	0.32^{a}	2.87^{abc}	0.90^{ab}	0.62^{a}	0.16^{bcd}	3200^{a}	1617^{bc}
T_{6}	2.84^{a}	0.33^{a}	2.79^{abc}	0.88^{ab}	0.45^{b}	0.14^{cd}	2633^{a}	1700^{bc}
T_{7}	3.00^{a}	0.31^{a}	2.97^{abc}	0.59^{bcde}	0.40^{ab}	0.13^{cd}	2500^{a}	1533^{bc}
T_{8}	3.20^{a}	0.34^{a}	3.28^{a}	0.92^{a}	0.53^{ab}	0.16^{bcd}	2100^{a}	1367^{bc}
T_{9}	3.08^{a}	0.34^{a}	3.17^{ab}	0.82^{abc}	0.58^{a}	0.15^{bcd}	3600^{a}	1450^{bc}
T_{10}	2.88^{a}	0.30^{a}	3.04^{abc}	0.66^{abcde}	0.42^{ab}	0.13^{cd}	3700^{a}	1116^{c}
T_{11}	3.06^{a}	0.33^{a}	2.87^{abc}	0.84^{ab}	0.53^{ab}	0.18^{bc}	2760^{a}	1367^{bc}
T_{12}	2.94^{a}	0.34^{a}	2.91^{abc}	0.74^{abcde}	0.45^{ab}	0.18^{bc}	2600^{a}	1533^{bc}
T_{13}	3.06^{a}	0.32^{a}	2.43^{c}	0.66^{abcde}	0.57^{a}	0.20^{ab}	2500^{a}	1700^{bc}
T_{14}	3.16^{a}	0.32^{a}	2.63^{c}	0.86^{ab}	0.61^{a}	0.12^{cd}	2900^{a}	1083^{bc}
T_{15}	3.10^{a}	0.32^{a}	2.60^{bc}	0.79^{abcd}	0.43^{ab}	0.12^{cd}	2500^{a}	1533^{bc}
T_{16}	2.98^{a}	0.32^{a}	2.53^{c}	0.50^{cde}	0.45^{ab}	0.13^{cd}	1933^{a}	1617^{bc}
T_{17}	3.11^{a}	0.35^{a}	2.77^{abc}	0.89^{ab}	0.51^{ab}	0.25^{a}	1633^{a}	1367^{bc}
T_{18}	3.01^{a}	0.32^{a}	2.73^{abc}	0.86^{ab}	0.44^{ab}	0.20^{ab}	2600^{a}	1867^{ab}
T_{19}	2.28^{a}	0.30^{a}	2.87^{abc}	0.44^{e}	0.32^{b}	0.10^{d}	3700^{a}	1200^{bc}
T_{20}	2.29^{a}	0.31^{a}	2.93^{abc}	0.50^{de}	0.39^{b}	0.18^{bc}	3600^{a}	1450^{bc}

NPK + Pongamia leaves @ 5 tha^{-1} (0.92%) followed by T_5 with 0.90 per cent, which was on par with T_{17} (0.89 %). In the case of Mg, T_5 (Laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) recorded the highest value of 0.62 per cent, which was on par with T_{14} (0.61 %), T_9 (0.58 %) and T_{13} (0.57 %). All other treatments except control for *kole* soil and laterite soil were similar. The control (*kole* soil) recorded the lowest Mg concentration of 0.32 per cent and followed by control (laterite soil) (0.39 %).

In case of sulphur (S), T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) gave highest concentration of 0.25 per cent whereas the lowest value was observed in T_1 (Laterile soil treated with 90:45:45 $kgha^{-1}$ NPK without organics) with 0.10 per cent followed by control for *kole* soil.

Iron (Fe) content ranged between 1633 $mgkg^{-1}$ in T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK with pongamia leaves @ 5 tha^{-1}) and 4333 $mgkg^{-1}$ in T_4 (laterite soil treated with 90:22.5:90 NPK $kgha^{-1}$ without organics) Concentration of sodium (Na) showed variation between 1200 $mgkg^{-1}$ in control (*kole* soil) and 2367 $mgkg^{-1}$ in T_2 (laterite soil treated with 90:45:45 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}).

4.2.2 Elemental composition of rice at flowering stage

At flowering and at harvest, parts of the rice plants such as leaf blade, leaf sheath, culm and panicles were analyzed separately. The results are presented in table 4.8.

4.2.2.1 Leaf blade

Nitrogen

Analysis of the leaf blade of rice plant at flowering showed variation in the total nitrogen concentrations between 1.41 and 1.70 per cent.Plants in T_{17} recorded the highest concentration of N (1.70 %) followed by T_{18} with 1.67 %.

Table 4.8. Effect of treatments on elemental composition leaf blade of flowering

T.No	N%	P%	K%	Ca%	Mg%	S%	Fe (mgkg^{-1})	Na (mgkg^{-1})
T_1	1.49^{cdefgh}	0.19^{a}	2.15^{a}	0.98^{b}	0.47^{bc}	0.15^{a}	1743^{a}	1500^{ab}
T_2	1.48^{cdefgh}	0.20^{a}	2.26^{a}	0.94^{bc}	0.69^{ab}	0.16^{a}	1740^{a}	1083^{b}
T_3	1.47^{defgh}	0.20^{a}	2.38^{a}	0.76^{bc}	0.48^{bc}	0.12^{a}	1787^{a}	1333^{ab}
T_4	1.46^{efgh}	0.20^{a}	2.52^{a}	0.91^{bc}	0.58^{abc}	0.13^{a}	1783^{a}	1583^{ab}
T_5	1.46^{fgh}	0.19^{a}	2.43^{a}	1.17^{a}	0.52^{abc}	0.15^{a}	1193^{a}	1667^{ab}
T_6	1.45^{gh}	0.21^{a}	2.44^{a}	0.92^{bc}	0.69^{ab}	0.16^{a}	1397^{a}	1083^{b}
T_7	1.53^{cd}	0.21^{a}	2.26^{a}	0.91^{bc}	0.65^{ab}	0.15^{a}	1487^{a}	13.33^{ab}
T_8	1.50^{cdefg}	0.22^{a}	2.40^{a}	0.79^{bc}	0.70^{ab}	0.15^{a}	1780^{a}	1333^{ab}
T_9	1.51^{cdefgh}	0.21^{a}	2.22^{a}	0.87^{bc}	0.73^{a}	0.16^{a}	1173^{a}	1417^{ab}
T_{10}	1.52^{c}	0.19^{a}	2.17^{a}	0.82^{bc}	0.59^{abc}	0.10^{a}	1787^{a}	1500^{ab}
T_{11}	1.53^{cdef}	0.20^{a}	1.98^{a}	0.89^{bc}	0.49^{bc}	0.13^{a}	1830^{a}	1500^{ab}
T_{12}	1.52^{cde}	0.21^{a}	2.31^{a}	0.87^{bc}	0.47^{bc}	0.15^{a}	1200^{a}	1917^{a}
T_{13}	1.48^{defgh}	0.19^{a}	2.34^{a}	0.95^{bc}	0.49^{bc}	0.17^{a}	1557^{a}	1500^{ab}
T_{14}	1.49^{cdefg}	0.19^{a}	2.39^{a}	0.95^{bc}	0.53^{abc}	0.14^{a}	1180^{a}	1583^{ab}
T_{15}	1.51^{cdefg}	0.20^{a}	2.46^{a}	0.95^{bc}	0.58^{abc}	0.19^{a}	976^{a}	1167^{ab}
T_{16}	1.60^{b}	0.20^{a}	2.28^{a}	0.96^{bc}	0.58^{abc}	0.14^{a}	1793^{a}	1500^{ab}
T_{17}	1.70^{a}	0.21^{a}	2.61^{a}	0.82^{bc}	0.63^{abc}	0.15^{a}	2193^{a}	1500^{ab}
T_{18}	1.67^{a}	0.20^{a}	2.51^{a}	0.83^{bc}	0.49^{bc}	0.12^{a}	1973^{a}	1500^{ab}
T_{19}	1.43^{h}	0.17^{a}	2.13^{a}	0.76^{bc}	0.61^{abc}	0.09^{a}	2110^{a}	1250^{ab}
T_{20}	1.41^{h}	0.18^{a}	2.36^{a}	0.74^{c}	0.42^{c}	0.11^{a}	1860^{a}	1250^{ab}

Lowest concentration of 1.41% N was observed in the leaf blade of plants in the control for laterite soil.

Phosphorus

Phosphorus (P) concentration in leaf blade of rice plants at flowering was observed to be in narrow range. It varied between 0.17 per cent and 0.22 per cent. All treatments were on par. T_8 recorded the highest value of 0.22 per cent followed by T_7 and T_{17} with the same value of 0.21 per cent. The lowest value was observed in the control (*kole* soil) with 0.17 per cent.

Potassium

The results showed that the concentration of K of leaf blade at flowering ranged between 1.98 per cent and 2.61 per cent. All treatments were similar. Highest concentration of K was observed in T_{17} i.e.,*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1} with 2.61 per cent whereas, the lowest concentration (1.98 per cent) was recorded in T_{11}.

Secondary and micronutrient contents of the leaf blade

Highest calcium content was recorded in T_5 i.e., laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1} (1.17 per cent). All other treatments except control for laterite soil were on par. Magnesium content was highest in T_9 i.e., laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1} with 0.73 per cent. Lowest Mg concentration of 0.42 per cent was observed in the control for laterite soil.

At flowering, sulphur content of leaf blade of all treatments was on par ranging from 0.09 per cent in T_2 and 0.19 per cent in T_{15}. The highest concentration (0.19 per cent) was obtained in T_{15} i.e.,*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1} and control for *kole* soil gave the lowest value of 0.09 per cent.

Iron (Fe) concentration of leaf blade at flowering ranged between 976 $mgkg^{-1}$ in T_{15} (*kole* soil treated with 90:22.5:90 $kgha^{-1}$NPK + rice straw @ 5 tha^{-1}) and 2193 $mgkg^{-1}$ in T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}), while concentration of sodium (Na) showed variations between 1083 $mgkg^{-1}$ in T_2 and 1917 $mgkg^{-1}$ in T_{12}.

4.2.2.2 Leaf sheath

The results are summarized in table 4.9.

Nitrogen

At flowering, the leaf sheath of rice plant recorded highest concentration of nitrogen of 2.04 per cent in T_{17} followed by T_{18} with 2.00 per cent. Control (both *kole* and laterite soil) recorded the lowest concentration of nitrogen (1.71 and 1.64 per cent, respectively).

Phosphorus

At flowering stage, no remarkable variation in the concentrations of P have been noticed, it varied between 0.13 per cent and 0.15 per cent. T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) recorded 0.15 per cent followed by T_8 and T_9. Control (both *kole* and laterite soil) recorded the lowest value of 0.13 per cent.

Potassium

The concentration of K of leaf sheath at flowering ranged between 1.70 per cent and 2.26 per cent. Highest concentration of K was observed in T_5 i.e.,laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1} (2.26 %). All other treatments except T_{18}, T_{10} and control (for *kole* soil) were on par. Control for *kole* and laterite soil recorded the lowest concentration of 1.75 and 1.71 per cent, respectively.

Concentration of calcium of leaf sheath in T_8 gave the highest concentration of 0.73 per cent followed by T_{18} ,T_{13} and T_{17} which were on par.

Table 4.9. Effect of treatments on elemental composition leaf sheath of flowering

T.No	N%	P%	K%	Ca%	Mg%	S%	Fe (mgkg^{-1})	Na (mgkg^{-1})
T_1	1.75^{cde}	0.14^{a}	2.09^{ab}	0.56^{abc}	0.30^{abcd}	0.18^{a}	1250^{a}	1250a
T_2	1.78^{cde}	0.15^{a}	1.97^{ab}	0.63^{ab}	0.31^{abcd}	0.20^{a}	1000^{a}	1000a
T_3	1.76^{cde}	0.14^{a}	1.90^{ab}	0.52^{abc}	0.20^{bcd}	0.15^{a}	1166^{a}	1166a
T_4	1.74^{cde}	0.14^{a}	1.86^{ab}	0.56^{abc}	0.27^{abcd}	0.16^{a}	1000^{a}	1000a
T_5	1.75^{cde}	0.14^{a}	2.26^{a}	0.58^{abc}	0.26^{abcd}	0.16^{a}	1166^{a}	1166a
T_6	1.75	0.14^{a}	2.80^{ab}	0.54^{abc}	0.22^{abcd}	0.09^{a}	1083^{a}	1083a
T_7	1.80^{cd}	0.14^{a}	2.05^{ab}	0.41^{bc}	0.36^{d}	0.14^{a}	1083^{a}	1083a
T_8	1.83^{c}	0.15^{a}	1.94^{ab}	0.73^{a}	0.32^{abcd}	0.09^{a}	1000^{a}	1000a
T_9	1.82^{c}	0.15^{a}	2.15^{ab}	0.47^{abc}	0.22^{abcd}	0.13^{a}	1166^{a}	1166a
T_{10}	1.82^{c}	0.14^{a}	1.70^{b}	0.63^{ab}	0.31^{abcd}	0.12^{a}	1083^{a}	1083a
T_{11}	1.84^{c}	0.15^{a}	1.90^{ab}	0.50^{abc}	0.18^{cd}	0.13^{a}	1166^{a}	1166a
T_{12}	1.83^{c}	0.14^{a}	1.83^{ab}	0.48^{abc}	0.16^{cd}	0.15^{a}	1083^{a}	1083a
T_{13}	1.77^{cde}	0.14^{a}	1.94^{ab}	0.70^{a}	0.38^{ab}	0.17^{a}	1166^{a}	1166a
T_{14}	1.79^{cde}	0.15^{a}	1.86^{ab}	0.51^{abc}	0.24^{abcd}	0.17^{a}	1083^{a}	1083a
T_{15}	1.78^{cde}	0.14^{a}	1.80^{ab}	0.55^{abc}	0.23^{abcd}	0.16^{a}	1000^{a}	1000a
T_{16}	1.92^{b}	0.14^{a}	1.86^{ab}	0.65^{ab}	0.35^{abc}	0.17^{a}	1166^{a}	1166a
T_{17}	2.04^{a}	0.15^{a}	1.94^{ab}	0.67^{a}	0.35^{abc}	0.17^{a}	1250^{a}	1250a
T_{18}	2.00^{a}	0.14^{a}	1.75^{b}	0.71^{a}	0.39^{a}	0.17^{a}	1250^{a}	1250a
T_{19}	1.71^{e}	0.13^{a}	1.75^{b}	0.33^{c}	0.17^{d}	0.21^{a}	1250^{a}	1250a
T_{20}	1.64^{e}	0.13^{a}	1.71^{b}	0.33^{c}	0.12^{d}	0.17^{a}	1250^{a}	1250a

T_{16} (*kole* soil treated with 90:67.5:135 kgha^{-1} NPK without organics), Control for *kole* and laterite soil recorded the lowest concentration of 0.33 per cent each.

In case of Mg, highest concentration was recorded in T_{18} (0.39 %) and lowest was recorded in control laterite soil with 0.12 per cent.

Sulphur concentrations in all treatments were on par and ranged between 0.12 per cent in control (*kole* soil) and 0.21 per cent in T_{16}.

Among the micronutrients, Fe content in the leaf sheath was not affected significantly by the treatment combinations. However the values ranged from 1000 mgkg^{-1} in T_8 , T_4 ,T_2 and T_{15} to 1250 mgkg^{-1} in T_1, T_{18} and controls. The concentrations of Na also showed no significant difference between the treatments, however the content varied from 1000 mgkg^{-1} to 1250 mgkg^{-1}.

4.2.2.3.*Culm*

The data on the elemental compositions of culm at flowering are presented in table 4.10.

The concentration of N in culm at flowering was highest in T_{18} i.e., *kole* soil treated with 90:67.5:135 kgha^{-1} NPK + rice straw @ 5 tha^{-1} (1.76 per cent) which is on par with T_{11} in *kole* soil treated with 90:45:45 kgha^{-1} NPK along with pongamia leaves @ 5 tha^{-1} (1.74 per cent). The lowest N content was recorded in control for *kole* and laterite soil with 1.43 and 1.46 per cent, respectively.

In case of P content, all treatments were comparable, however, the values ranged from 0.18 per cent in control (*kole* soil) to 0.22 per cent in T_{18} (*kole* soil treated with 90:67.5:135 kgha^{-1} of NPK + rice straw @ 5 tha^{-1}).

All treatments were on par with respect to potassium content also. The highest K concentration was recorded in T_4 (laterite soil treated with 90:22.5:90 kgha^{-1} NPK without organics) (2.22 %) followed by T_{10} and T_{17}.The lowest

Table 4.10. Effect of treatments on elemental composition of culm at flowering

T.No	N%	P%	K%	Ca%	Mg%	S%	Fe ($mgkg^{-1}$)	Na ($mgkg^{-1}$)
T_1	1.50^{efgh}	0.20^{a}	1.72^{a}	0.56^{abc}	0.30^{a}	0.11^{a}	1393^{a}	1333^{a}
T_2	1.68^{abc}	0.21^{a}	1.94^{a}	0.63^{abc}	0.31^{a}	0.18^{a}	1320^{a}	1250^{a}
T_3	1.61^{bcde}	0.21^{a}	1.70^{a}	0.52^{abc}	0.20^{a}	0.16^{a}	1563^{a}	1333^{a}
T_4	1.47^{fgh}	0.20^{a}	2.22^{a}	0.56^{abc}	0.27^{a}	0.13^{a}	1583^{a}	1500^{a}
T_5	1.55^{defg}	0.21^{a}	1.92^{a}	0.58^{abc}	0.26^{a}	0.12^{a}	1360^{a}	1500^{a}
T_6	1.54^{efg}	0.20^{a}	1.98^{a}	0.54^{abc}	0.22^{a}	0.11^{a}	1367^{a}	1333^{a}
T_7	1.52^{efgh}	0.20^{a}	2.01^{a}	0.41^{bc}	0.16^{a}	0.12^{a}	1537^{a}	1250^{a}
T_8	1.57^{def}	0.21^{a}	1.95^{a}	0.39^{abc}	0.12^{a}	0.12^{a}	1477^{a}	1333^{a}
T_9	1.53^{efg}	0.21^{a}	2.17^{a}	0.47^{abc}	0.22^{a}	0.12^{a}	1023^{a}	1500^{a}
T_{10}	1.49^{fgh}	0.20^{a}	2.18^{a}	0.63^{ab}	0.31^{a}	0.12^{a}	1577^{a}	1500^{a}
T_{11}	1.74^{a}	0.21^{a}	1.88^{a}	0.50^{abc}	0.18^{a}	0.13^{a}	1503^{a}	1666^{a}
T_{12}	1.62^{bcde}	0.21^{a}	1.89^{a}	0.48^{abc}	0.16^{a}	0.11^{a}	1510^{a}	1250^{a}
T_{13}	1.59^{bcde}	0.20^{a}	1.94^{a}	0.70^{a}	0.38^{a}	0.11^{a}	1147^{a}	1166^{a}
T_{14}	1.54^{efg}	0.20^{a}	1.70^{a}	0.51^{abc}	0.24^{a}	0.12^{a}	1247^{a}	1083^{a}
T_{15}	1.58^{cdef}	0.20^{a}	1.97^{a}	0.55^{abc}	0.23^{a}	0.16^{a}	1346^{a}	1166^{a}
T_{16}	1.68^{bcd}	0.21^{a}	1.91^{a}	0.65^{ab}	0.35^{a}	0.14^{a}	1033^{a}	1166^{a}
T_{17}	1.71^{ab}	0.21^{a}	2.20^{a}	0.67^{ab}	0.35^{a}	0.13^{a}	1587^{a}	1166^{a}
T_{18}	1.76^{a}	0.21^{a}	1.95^{a}	0.71^{a}	0.39^{a}	0.13^{a}	1583^{a}	1333^{a}
T_{19}	1.43^{a}	0.18^{a}	1.38^{a}	0.29^{c}	0.11^{a}	0.10^{a}	2260^{a}	1250^{a}
T_{20}	1.46^{gh}	0.19^{a}	1.27^{a}	0.41^{abc}	0.12^{a}	0.10^{a}	1760^{a}	1250^{a}

content was recorded in control for *kole* soil with 1.38 per cent and laterite soil with 1.27 per cent.

Highest concentration of Ca (0.71 per cent) was observed inT_{18} i.e., kole soil treated with 90:67.5:135 kgha^{-1} NPK along with rice straw @ 5 tha^{-1} and which was on par with T_{13}. The lowest concentration of Ca was observed in control for *kole* soil (0.29 per cent). In case of Mg, all treatments were on par. The concentration ranged between 0.11per cent and 0.39 per cent. The highest value was obtained in case of T_{18} (0.39 %) and the lowest was recorded in control for *kole* soil (0.11 %). Concentration of S in all treatments were on par. Concentration varied between 0.10 per cent in case of control for *kole* soil and 0.18 per cent in case of T_2.

A concentration of iron (Fe) in the culm was not significantly influenced by the treatment combinations. However, highest concentration (2260 mgkg^{-1}) was recorded in T_{19} followed by T_{20} and T_{17} (kole soil treated with 90:67.5:135 kgha^{-1}along with pongamia leaves @5 tha^{-1}). The lowest Fe content in the culm was observed in T_9 (1023 mgkg^{-1}). In case of Na, highest concentration was 1666 mgkg^{-1} was recorded in T_{11} and lowest was recorded in T_{14} (1083 mgkg^{-1}).

4.2.2.4 ***Panicle***

The data on the elemental composition panicle are presented in table 4.11.

The concentration of N in flower was highest in T_{17} (1.25 %) and lowest in case of control (*Kole* soil) (0.76 %). In case of P content, the highest value was recorded in T_{17} (0.20 %), while the lowest value of 0.16 per cent was recorded in control (both in *Kole* and laterite soil). Potassium content was highest in T_7 (2.28 per cent) and lowest was obtained in control for *kole* soil with 1.51per cent.

Highest concentration of Ca (1.18 %) was observed in case of T_2 (laterite soil treated with 90:45:45 kgha^{-1} NPK + Pongamia leaves @ 5 tha^{-1}) and lowest concentration was obtained in case of control for *Kole* soil (0.61 %).

Table 4.11. Effect of treatments on elemental composition of flower at flowering

T.No	N%	P%	K%	Ca%	Mg%	S%	Fe (mgkg^{-1})	Na (mgkg^{-1})
T_1	0.89^{fghi}	0.17^{a}	1.67^{ab}	0.86^{abc}	0.45^{ab}	0.08^{ab}	1843^{ab}	1166^{a}
T_2	0.13^{abcd}	0.18^{a}	1.78^{ab}	1.18^{ab}	0.74^{a}	0.09^{ab}	1066^{ab}	1250^{a}
T_3	1.03^{cdef}	0.18^{a}	2.08^{ab}	0.96^{abc}	0.60^{ab}	0.11^{ab}	1206^{ab}	1250^{a}
T_4	0.83^{ghi}	0.18^{a}	1.72^{ab}	1.12^{ab}	0.52^{ab}	0.13^{ab}	1223^{ab}	1166^{a}
T_5	0.94^{efgh}	0.18^{a}	1.90^{ab}	1.14^{ab}	0.74^{a}	0.08^{ab}	1266^{ab}	1500^{a}
T_6	0.92^{efghi}	0.18^{a}	2.01^{ab}	1.14^{ab}	0.74^{a}	0.06^{ab}	1263^{ab}	1333^{a}
T_7	0.90^{fghi}	0.18^{a}	2.28^{a}	1.04^{abc}	0.64^{ab}	0.09^{ab}	1236^{ab}	1416^{a}
T_8	0.98^{defg}	0.19^{a}	2.09^{ab}	0.98^{abc}	0.58^{ab}	0.15^{a}	853^{b}	1583^{a}
T_9	0.92^{efghi}	0.19^{a}	2.14^{ab}	0.90^{abc}	0.50^{ab}	0.11^{ab}	1263^{ab}	1416^{a}
T_{10}	0.86^{ghi}	0.18^{a}	2.02^{ab}	0.98^{abc}	0.58^{ab}	0.12^{ab}	1230^{ab}	1500^{a}
T_{11}	1.22^{ab}	0.18^{a}	1.77^{ab}	0.95^{abc}	0.58^{ab}	0.08^{ab}	853^{b}	1333^{a}
T_{12}	1.04^{cdef}	0.18^{a}	1.59^{b}	0.89^{abc}	0.49^{ab}	0.10^{ab}	1256^{ab}	1333^{a}
T_{13}	0.92^{fghi}	0.18^{a}	1.60^{b}	0.77^{abc}	0.37^{ab}	0.11^{ab}	1256^{ab}	1250^{a}
T_{14}	0.98^{defg}	0.18^{a}	1.76^{ab}	0.96^{abc}	0.56^{ab}	0.10^{ab}	1391^{ab}	1436^{a}
T_{15}	0.94^{efgh}	0.18^{a}	1.71^{ab}	0.84^{abc}	0.44^{ab}	0.12^{ab}	1230^{ab}	1416^{a}
T_{16}	1.08^{bcde}	0.18^{a}	1.69^{ab}	0.89^{abc}	0.49^{ab}	0.08^{ab}	1927^{a}	1333^{a}
T_{17}	1.25^{a}	0.19^{a}	1.66^{b}	1.02^{abc}	0.62^{ab}	0.10^{ab}	1317^{ab}	1416^{a}
T_{18}	1.17^{abc}	0.18^{a}	1.60^{b}	1.06^{abc}	0.66^{ab}	0.11^{ab}	1253^{ab}	1513^{a}
T_{19}	0.76^{i}	0.16^{a}	1.51^{b}	0.61^{c}	0.21^{ab}	0.09^{ab}	1560^{a}	1501^{a}
T_{20}	0.81^{hi}	0.16^{a}	1.62^{b}	0.67^{bc}	0.27^{b}	0.07^{ab}	1640^{a}	1250^{a}

In case of Mg, the highest value was obtained in case of T_6 (0.74 %), which was on par with T2, and T_5.Control (*Kole* soil) recorded the lowest concentration of 0.21 per cent. Concentration of S was highest in case of T_8 (0.15 per cent) and lowest was recorded in case of T_6 (0.06 per cent) followed by control for laterite soil (0.07 %).

Among the micronutrient, highest concentration of Fe was obtained in T_{16} (1927 $mgkg^{-1}$) and lowest concentration was recorded in T_8 (853 $mgkg^{-1}$). With respect to Na concentration, no significant difference was observed between the treatments, however, T8 recorded the highest value of 1583 $mgkg^{-1}$ and the lowest was registered in T_1 and T_4 with 1166 $mgkg^{-1}$.

4.2.3 Elemental composition of rice plant at harvest

At harvest,parts of the rice plants such as leaf blade, leaf sheath, culm and panicles were analyzed separately. The data are presented in table 4.12.4.13,4.14, and 4.15.

4.2.3.1 ***Leaf blade***

Data on the elemental composition of leaf blade at harvest are presented in table 4.12.The concentration of N in leaf blade was highest in case of T_{17} (0.97 %) and lowest was recorded in T_4 (0.89 %). In case of P content, the highest value was recorded in T_{18} (0.21 %), which was on par with T_7 (0.21 %), while the lowest value of 0.09 per cent was recorded in T_5 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}). Potassium (K) content was highest in T_7 (2.17 %) and lowest value was recorded in control for both *kole* and laterite soil with 1.61 and 1.64 per cent, respectively.

Highest concentration of Ca (0.94 %) was observed in case of T_8 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) and lowest concentration was obtained in case of control for laterite soil (0.51 %). In case of Mg, the highest value was obtained in case of T_{17} (0.36 %) and lowest value was observed in control, both *kole* and laterite soil 0.16 and 0.14 per cent

Table 4.12. Effect of treatments on elemental composition of rice leaf blade at harvest.

T.No	N%	P%	K%	Ca%	Mg%	S%	Fe (mgkg^{-1})	Na (mgkg^{-1})
T_1	0.89^{a}	0.17^{abcd}	1.83^{bcd}	0.71^{ab}	0.25^{a}	0.13^{a}	990^{bc}	1000^{a}
T_2	0.92^{abc}	0.16^{abcd}	1.84^{abcd}	0.71^{ab}	0.26^{a}	0.12^{a}	1303^{abc}	583^{bcd}
T_3	0.91^{abc}	0.18^{abc}	1.71^{bcd}	0.65^{ab}	0.28^{a}	0.14^{a}	1150^{abc}	916^{abc}
T_4	0.89^{c}	0.11^{de}	1.68^{cd}	0.81^{ab}	0.21^{a}	0.13^{a}	1040^{ab}	833^{abc}
T_5	0.90^{bc}	0.09^{e}	1.93^{abc}	0.73^{ab}	0.17^{a}	0.14^{a}	676^{c}	750^{abcd}
T_6	0.90^{c}	0.16^{abcd}	1.73^{bcd}	0.79^{b}	0.31^{a}	0.16^{a}	1373^{ab}	750^{abcd}
T_7	0.92^{abc}	0.17^{abcd}	1.76^{bcd}	0.64^{b}	0.33^{a}	0.12^{a}	1117^{abc}	1000^{a}
T_8	0.93^{abc}	0.20^{abc}	2.17^{a}	0.94^{a}	0.30^{a}	0.20^{a}	1333^{ab}	666^{abcd}
T_9	0.93^{abc}	0.20^{abc}	1.86^{abcd}	0.64^{ab}	0.25^{a}	0.15^{a}	943^{bc}	916^{ab}
T_{10}	0.91^{abc}	0.16^{abcd}	1.83^{bcd}	0.71^{ab}	0.19^{a}	0.12^{a}	920^{bc}	916^{ab}
T_{11}	0.92^{abc}	0.17^{abcd}	1.96^{ab}	0.66^{ab}	0.22^{a}	0.14^{a}	1263^{abc}	416^{d}
T_{12}	0.91^{abc}	0.18^{abc}	1.86^{abcd}	0.70^{ab}	0.25^{a}	0.12^{a}	1020^{abc}	583^{bcd}
T_{13}	0.89^{c}	0.14^{cde}	1.75^{bcd}	0.68^{ab}	0.28^{a}	0.12^{a}	1253^{abc}	750^{abcd}
T_{14}	0.90^{bc}	0.15^{bcde}	1.80^{bcd}	0.67^{ab}	0.29^{a}	0.12^{a}	1187^{abc}	750^{abcd}
T_{15}	0.90^{bc}	0.17^{abcd}	1.77^{bcd}	0.63^{ab}	0.29^{a}	0.16^{a}	1087^{abc}	499^{cd}
T_{16}	0.94^{abc}	0.20^{abc}	1.68^{cd}	0.57^{b}	0.26^{a}	0.15^{a}	1280^{abc}	666^{abcd}
T_{17}	0.97^{a}	0.21^{ab}	1.86^{abcd}	0.60^{b}	0.36^{a}	0.16^{a}	1627^{a}	750^{abcd}
T_{18}	0.96^{ab}	0.21^{a}	1.82^{bcd}	0.74^{ab}	0.23^{a}	0.17^{a}	1163^{abc}	916^{ab}
T_{19}	0.91^{abc}	0.15^{bcde}	1.61^{d}	0.53^{b}	0.16^{a}	0.10^{a}	1430^{abc}	830^{abc}
T_{20}	0.90^{c}	0.15^{bcde}	1.64^{d}	0.51^{b}	0.14^{a}	0.11^{a}	1370^{abc}	833^{abc}

respectively. While for S, the highest concentration was in T_8 (0.20 %) and the lowest value was recorded in case of T_{14} (0.12 %).

Micronutrients such as Fe and Na were also estimated. For Fe, the highest values were obtained for T_{17} with 1627 $mgkg^{-1}$. The lowest values were recorded in case of T_5 (676 $mgkg^{-1}$) for Fe. With respect to Na, T_1 i.e., laterite soil treated with 90:45:45 kgha-1 NPK without organics recorded highest concentration of 1000 $mgkg^{-1}$ which is on par with T_7 and the lowest was recorded with T_{11} (416 $mgkg^{-1}$) for Na.

4.2.3.2 ***Leaf sheath***

The data on the effect of various treatments on the elemental composition of leaf sheath are presented in table 4.13.

N concentration of leaf sheath varied between 1.30 per cent in control for *kole* soil (T_{19}) and 1.55 per cent in T_{17}, treated with 90:67.5:135 $kgha^{-1}$ NPK along with Pongamia leaves @ 5 tha^{-1} which was closely followed by T_{18} (1.54 per cent). Plants in control for *kole* soil had lowest concentration of N during harvest 1.30 per cent.

At harvest, the concentration of P was highest in case T_{17} (0.15 %) and lowest was recorded in T_{13} (0.06 %).

The results showed that the concentration of K at harvest in leaf sheath of rice plant ranged between 1.28 per cent and 1.96 per cent. Highest concentration of K was observed in plants from pots treated with T_2 (1.96 %) whereas treated with the lowest concentration of 1.28 per cent was recorded in control (*Kole* soil).

Calcium (Ca) concentration ranged between 0.28 per cent in control (*Kole* soil) and 0.70 per cent in T_8. Ca content was highest (0.70 %) in plants receiving T_8 followed by T_7 (0.69 %). The lowest concentration of Ca (0.28 %) recorded in control (*Kole* soil) followed by control (laterite soil) (0.34 %).

Table 4.13. Effect of treatments on elemental composition of leaf sheath at harvest

T.No	N%	P%	K%	Ca%	Mg%	S%	Fe (mgkg^{-1})	Na (mgkg^{-1})
T_1	1.42^{ef}	0.12^{bc}	1.59^{abc}	0.46^{abc}	0.18^{bc}	0.16^{ab}	1697^{a}	716^{b}
T_2	1.47^{cdef}	0.09^{abcd}	1.96^{abc}	0.46^{abc}	0.16^{c}	0.17^{ab}	1630^{ab}	966^{ab}
T_3	1.45^{cdef}	0.11^{abcd}	1.90^{ab}	0.48^{abc}	0.15^{bc}	0.20^{ab}	1507^{ab}	800^{ab}
T_4	1.42^{ef}	0.084^{bcd}	1.71^{abc}	0.55^{abc}	0.12^{c}	0.17^{ab}	1303^{abc}	716^{b}
T_5	1.45^{cdef}	0.07^{cd}	1.74^{abc}	0.45^{abc}	0.15^{bc}	0.16^{ab}	1153^{abc}	883^{ab}
T_6	1.44^{cdef}	0.07^{cd}	1.59^{abc}	0.57^{abc}	0.21^{abc}	0.21^{ab}	1120^{abc}	966^{ab}
T_7	1.48^{cdef}	0.12^{abc}	1.66^{abc}	0.69^{a}	0.36^{a}	0.17^{ab}	1043^{bc}	883^{ab}
T_8	1.49^{abcd}	0.13^{abc}	1.76^{abc}	0.70^{a}	0.33^{ab}	0.19^{ab}	1130^{abc}	883^{ab}
T_9	1.48^{abcde}	0.12^{abcd}	1.71^{abc}	0.47^{abc}	0.14^{c}	0.18^{ab}	693^{c}	883^{ab}
T_{10}	1.45^{cdef}	0.09^{abcd}	1.53^{abc}	0.45^{abc}	0.13^{c}	0.17^{ab}	1120^{abc}	1216^{a}
T_{11}	1.47^{cdef}	0.08^{bcd}	1.65^{abc}	0.54^{abc}	0.23^{abc}	0.17^{ab}	1120^{abc}	826^{ab}
T_{12}	1.46^{cdef}	0.09^{abcd}	1.57^{abc}	0.60^{abc}	0.27^{abc}	0.16^{ab}	1200^{abc}	1050^{ab}
T_{13}	1.43^{ef}	0.06^{d}	1.43^{bc}	0.58^{abc}	0.24^{abc}	0.15^{ab}	1277^{abc}	783^{ab}
T_{14}	1.45^{cdef}	0.11^{abcd}	1.56^{abc}	0.50^{abc}	0.26^{abc}	0.17^{ab}	1203^{abc}	966^{ab}
T_{15}	1.45^{cdef}	0.12^{abcd}	1.50^{bc}	0.46^{abc}	0.17^{bc}	0.15^{ab}	1007^{bc}	800^{ab}
T_{16}	1.50^{abc}	0.12^{abcd}	1.44^{bc}	0.45^{ab}	0.16^{bc}	0.15^{ab}	1283^{abc}	800^{ab}
T_{17}	1.55^{a}	0.15^{a}	1.71^{abc}	0.65^{ab}	0.18^{bc}	0.17^{ab}	1187^{abc}	800^{ab}
T_{18}	1.54^{ab}	0.14^{ab}	1.52^{abc}	0.60^{abc}	0.16^{bc}	0.21^{a}	1430^{ab}	800^{ab}
T_{19}	1.30^{f}	0.09^{abcd}	1.28^{c}	0.28	0.26^{abc}	0.14^{b}	1751^{abc}	800^{ab}
T_{20}	1.33^{f}	0.09^{abcd}	1.31^{c}	0.34^{bc}	0.20^{abc}	0.13^{b}	1701^{abc}	800^{ab}

In case of Mg also, T_7 showed the highest value of 0.36 per cent and lowest concentration was recorded in T_4 (0.12 %). Sulphur (S) concentration ranged from 0.15 per cent in T_{17} and 0.21 per cent in T_{18}.The lowest concentration was recorded in control for laterite soil (T_{20}) with 0.13 per cent.

In case of Fe, T_1 which received 90:45:45 kgha^{-1} NPK without organics was given highest concentration of Fe (1697 mgkg^{-1}). T_9 recorded the lowest concentration of 693 mgkg^{-1}. Highest concentration of Na was obtained in pot treated with T_{10} (1216 mgkg^{-1}). All other treatments except T_4 and T_1 were on par and were the next best. While the lowest concentration of Na was obtained in T_4 and T_1 with 716 mgkg^{-1}.

4.2.3.3.*Culm*

Concentrations of different elements of culm at harvest are presented in table 4.14.

The highest concentration of N was observed in T2 (1.41 %) and followed by T_5 (1.25 per cent). The lowest concentration of N was obtained in control for laterite soil (0.89 per cent).

At harvest, no significant variation in the concentration of P have been noticed.It varied from 0.10 per cent to 0.16 per cent. Plants treated with T_{18} recorded 0.16 percent followed by T_{10} (0.15 per cent). T_{13} recorded the lowest value with 0.10 per cent. The concentration of K was highest in T_8 (1.93 per cent) and lowest was recorded in control for laterite soil (1.40 per cent).

In case of Ca, the highest value was observed in T_8 (0.94 per cent) and lowest concentration was observed in control for laterite soil (T_{20}) with 0.60 per cent. With respect to Mg, highest value was observed in T_{17} (0.30 per cent) i.e., *Kole* soil treated with 90:67.5:135 kgha^{-1} NPK + Pongamia leaves @ 5 tha^{-1}. The lowest value was observed in control for laterite soil (0.10 per cent). Concentration of sulphur (S) was highest in case of T_6 (0.21 per cent) and lowest in control for both *kole* and laterite soil with 0.13 and 0.12 per cent, respectively.

Table 4.14. Effect of treatments on elemental composition of culm at harvest

T.No	N%	P%	K%	Ca%	Mg%	S%	Fe (mgkg^{-1})	Na (mgkg^{-1})
T_{1}	1.04^{cdef}	0.15^{a}	1.56^{ab}	0.71^{ab}	0.20^{abcd}	0.15^{abcd}	856^{ab}	716^{ab}
T_{2}	1.41^{a}	0.13^{a}	1.81^{ab}	0.81^{ab}	0.20^{abcd}	0.20^{ab}	926^{ab}	633^{b}
T_{3}	1.13^{abc}	0.13^{a}	1.74^{ab}	0.79^{ab}	0.15^{bcd}	0.18^{abc}	826^{ab}	800^{ab}
T_{4}	0.95^{fgh}	0.14^{a}	1.71^{ab}	0.65^{ab}	0.17^{bcd}	0.14^{bcd}	836^{ab}	800^{ab}
T_{5}	1.25^{ab}	0.12^{a}	1.66^{ab}	0.73^{ab}	0.17^{bcd}	0.14^{bcd}	836^{ab}	800^{ab}
T_{6}	0.91^{fg}	0.11^{a}	1.77^{ab}	0.69^{ab}	0.21^{abc}	0.21^{a}	910^{ab}	950^{ab}
T_{7}	0.98^{defg}	0.13^{a}	1.77^{ab}	0.64^{ab}	0.18^{bcd}	0.16^{abcd}	1053^{ab}	833^{ab}
T_{8}	1.13^{abc}	0.14^{a}	1.93^{a}	0.94^{a}	0.18^{bcd}	0.14^{abcd}	886^{ab}	1133^{a}
T_{9}	1.21^{ab}	0.13^{a}	1.74^{ab}	0.74^{ab}	0.20^{abcd}	0.17^{abcd}	858^{ab}	966^{ab}
T_{10}	1.08^{bcde}	0.15^{a}	1.60^{ab}	0.71^{ab}	0.17^{bcd}	0.16^{abcd}	1243^{ab}	1050^{ab}
T_{11}	1.18^{ab}	0.13^{a}	1.80^{ab}	0.81^{ab}	0.22^{abc}	0.18^{abcd}	946^{ab}	883^{ab}
T_{12}	1.10^{bcd}	0.13^{a}	1.75^{ab}	0.70^{ab}	0.18^{bcd}	0.13^{bcd}	980^{ab}	1050^{ab}
T_{13}	1.07^{bcde}	0.10^{a}	1.74^{ab}	0.63^{ab}	0.17^{bcd}	0.15^{abcd}	1210^{ab}	966^{ab}
T_{14}	1.15^{abc}	0.12^{a}	1.59^{ab}	0.68^{ab}	0.14^{bcd}	0.15^{abcd}	1060^{ab}	966^{ab}
T_{15}	1.02^{cdefg}	0.10^{a}	1.60^{ab}	0.65^{ab}	0.24^{ab}	0.14^{bcd}	1143^{ab}	800^{ab}
T_{16}	0.98^{defg}	0.14^{a}	1.52^{ab}	0.67^{ab}	0.21^{abc}	0.16^{abcd}	1037^{ab}	800^{ab}
T_{17}	1.03^{cdefg}	0.15^{a}	1.68^{ab}	0.76^{ab}	0.30^{a}	0.18^{abc}	1097^{ab}	883^{ab}
T_{18}	1.02^{cdefg}	0.16^{a}	1.72^{ab}	0.74^{ab}	0.24^{ab}	0.17^{abcd}	1150^{ab}	883^{ab}
T_{19}	0.92^{fg}	0.11^{a}	1.46^{b}	0.61^{ab}	0.12^{cd}	0.13^{d}	1290^{a}	1050^{ab}
T_{20}	0.89^{g}	0.12^{a}	1.40^{b}	0.60^{b}	0.10^{d}	0.12^{d}	1307^{a}	1050^{ab}

The concentration of Fe in culm at harvest was highest in control of laterite soil (1307 $mgkg^{-1}$) followed by control for *kole* soil (1290 $mgkg^{-1}$). The lowest value was observed in T_3 with 826 $mgkg^{-1}$. For Na, the highest concentration was obtained in T_8 (1133 $mgkg^{-1}$) and lowest in T_2 with 633 $mgkg^{-1}$.

4.2.3.4.*Grains*

The data on the analysis of grain are presented in table 4.15.

The highest concentration of N (2.00 %) was observed in T_2 (laterite soil treated with 90:45:45 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}). The lowest value was recorded in control of laterite soil (T20) (1.42 %). In case of phosphorus content, all treatments were on par. It varied between 0.14 per cent and 0.18 per cent. The highest concentration (0.18 %) was observed in T_8 while lowest (0.14 %) was in T_4. In case of K, the highest concentration was recorded in grain from T_{14} (0.39 %) and the lowest in control of both *kole* and laterite soil each with 0.21 per cent.

Highest content of Ca (0.76 %) was observed in T_{16} and lowest concentration was obtained in control for both *kole* and laterite soils with (0.39 %).

In case of Mg, the highest value was obtained in T_{12} (0.29 %) and the lowest was noticed in control for laterite soil (T_{20}) with 0.09 per cent.All treatments were similar with respect to sulphur content and it varied between 0.09 per cent in control for laterite soil (T_{20}) and 0.16 per cent in T_9.

With respect to Fe, all treatments were on par. The highest value was observed in control for laterite soil with 1130 $mgkg^{-1}$, while the lowest value was noticed in T9 (623 $mgkg^{-1}$). In case of Na, the highest concentration of Na was observed with T_6 and T_{18} each with 800 $mgkg^{-1}$. The lowest value was obtained in control for both *Kole* and laterite soil with 550 $mgkg^{-1}$ each respectively.

Table 4.15. Effect of treatments on nutrient concentration of grain

T.No	N%	P%	K%	Ca%	Mg%	S%	Fe ($mgkg^{-1}$)	Na ($mgkg^{-1}$)
T_{1}	1.67^{defg}	0.17^{a}	0.33^{ab}	0.40^{bc}	0.20^{ab}	0.13^{a}	806^{a}	633^{a}
T_{2}	2.00^{a}	0.16^{a}	0.36^{ab}	0.39^{c}	0.22^{ab}	0.13^{a}	780^{a}	633^{a}
T_{3}	1.77^{bcde}	0.15^{a}	0.34^{ab}	0.42^{bc}	0.16^{ab}	0.11^{a}	906^{a}	633^{a}
T_{4}	1.52^{fgh}	0.14^{a}	0.20^{b}	0.51^{bc}	0.16^{ab}	0.13^{a}	963^{a}	716^{a}
T_{5}	1.81^{abcd}	0.15^{a}	0.33^{ab}	0.45^{bc}	0.21^{ab}	0.11^{a}	956^{a}	633^{a}
T_{6}	1.47^{gh}	01.5^{a}	0.28^{ab}	0.50^{bc}	0.19^{ab}	0.10^{a}	1093^{a}	800^{a}
T_{7}	1.57^{efgh}	0.15^{a}	0.31^{ab}	0.45^{bc}	0.16^{ab}	0.12^{a}	713^{a}	633^{a}
T_{8}	1.93^{ab}	0.18^{a}	0.35^{ab}	0.51^{bc}	0.21^{ab}	0.12^{a}	706^{a}	633^{a}
T_{9}	1.81^{abcd}	0.16^{a}	0.32^{ab}	0.41^{bc}	0.16^{ab}	0.16^{a}	623^{a}	716^{a}
T_{10}	1.48^{gh}	0.17^{a}	0.29^{ab}	0.48^{bc}	0.22^{ab}	0.13^{a}	766^{a}	633^{a}
T_{11}	1.89^{abc}	0.16^{a}	0.35^{ab}	0.56^{b}	0.25^{ab}	0.13^{a}	686^{a}	716^{a}
T_{12}	1.76^{bcdef}	0.15^{a}	0.30^{ab}	0.45^{bc}	0.29^{a}	0.13^{a}	640^{a}	633^{a}
T_{13}	1.71^{cdef}	0.15^{a}	0.31^{ab}	0.46^{bc}	0.18^{ab}	0.11^{a}	783^{a}	633^{a}
T_{14}	1.85^{abcd}	0.17^{a}	0.39^{a}	0.52^{bc}	0.18^{ab}	0.11^{a}	643^{a}	633^{a}
T_{15}	1.64^{defg}	0.17^{a}	0.37^{ab}	0.48^{bc}	0.17^{ab}	0.13^{a}	663^{a}	716^{a}
T_{16}	1.56^{efgh}	0.16^{a}	0.29^{ab}	0.76^{a}	0.16^{ab}	0.13^{a}	843^{a}	633^{a}
T_{17}	1.65^{defg}	0.17^{a}	0.37^{ab}	0.55^{bc}	0.17^{ab}	0.13^{a}	736^{a}	633^{a}
T_{18}	1.64^{defg}	0.18^{a}	0.30^{ab}	0.54^{bc}	0.18^{ab}	0.12^{a}	796^{a}	800^{a}
T_{19}	1.46^{gh}	0.17^{a}	0.21^{b}	0.39^{c}	0.10^{b}	0.98^{a}	1030^{a}	550^{a}
T_{20}	1.42^{h}	0.17^{a}	0.21^{b}	0.39^{c}	0.09^{b}	0.96^{a}	1130^{a}	550^{a}

4.3. EFFECT OF DIFFERENT DOSES OF PHOSPHORUS ON DRY MATTER PRODUCTION AND P CONTENT AT MAXIMUM TILLERING

Concentration of P content in rice plant at highest tillering stage, dry matter production, % Pdff (per cent phosphorus derived from fertilizer), % Pdfs (per cent phosphorus derived from soil), A value and per cent uptake of P applied fertilizer were calculated and presented in table 4.16.

4.3.1 Dry matter production

At maximum tillering, highest dry matter production (1.08 $gpot^{-1}$) was observed in T_2 (laterite soil treated with 90:45:45 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) and T_4 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK without organics). All other treatments except control (both laterite and *kole* soils) were on par. Control (laterite soil) was marginally better than control (*kole* soil), but both were on par, whereas, the lowest value (0.79 $gpot^{-1}$) was recorded in control for *kole* soil.

4.3.2 Phosphorus content

Concentrations of P in rice plant at maximum tillering are presented in table 4.16. All treatments were on par, the highest concentration was observed (0.35 %) in T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) and the lowest (0.30 %) was observed in control (*kole* soil).

4.3.3 Phosphorus uptake

At maximum tillering, the highest P uptake was for T_2 (laterite soil) 90:45:45 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}) (3.48 $mgpot^{-1}$) which was on par with T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) with 3.47 $mgpot^{-1}$, T_1 (laterite soil treated with 90:45:45 $kgha^{-1}$ of NPK without organics) with 3.40 $mgpot^{-1}$and T_9 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) with 3.39 $mgpot^{-1}$. All other

Table 4.16. Effect of treatments on dry matter production P content, total P uptake, % Pdff, %Pdfs, 'A' value and per cent uptake of applied fertilizer at maximum tillering

Sl. No.	Dry matter production (gpot^{-1})	P content (%)	Total P uptake (mgpot^{-1})	% Pdff	% Pdfs	% uptake of applied P fertilizers	\`A\`value* (mgpot^{-1})
1	1.02^{ab}	0.33^{a}	3.40^{a}	6.55^{de}	93.45^{a}	0.74^{cd}	25.40^{a} (622.24)**
2	1.08^{a}	0.32^{a}	3.48^{a}	12.9^{bcd}	87.03^{abc}	0.58^{cd}	22.37^{ab} (474.52)
3	1.03^{ab}	0.30^{a}	3.11^{ab}	14.9^{abcd}	85.09^{abcd}	0.69^{cd}	18.77^{ab} (333.84)
4	1.08^{a}	0.30^{a}	3.28^{ab}	10.8^{bcd}	89.19^{abc}	1.60^{ab}	14.70^{b} (204.56)
5	0.95^{ab}	0.32^{a}	3.03^{ab}	5.84^{de}	94.15^{a}	0.81^{bcd}	20.19^{ab} (387.81)
6	0.97^{ab}	0.33^{a}	3.21^{ab}	7.31^{cde}	92.69^{ab}	1.13^{abcd}	18.27^{ab} (323.16)
7	0.91^{ab}	0.31^{a}	2.82^{ab}	17.27^{ab}	82.73^{cd}	0.75^{cd}	21.92^{ab} (459.13)
8	0.94^{ab}	0.34^{a}	3.27^{ab}	10.19^{bcd}	89.81^{abc}	0.51^{d}	25.09^{a} (604.76)
9	1.00^{ab}	0.34^{a}	3.39^{a}	11.37^{bcd}	88.63^{abc}	0.60^{cd}	26.32^{a} (667.08)
10	0.90^{ab}	0.30^{a}	2.77^{ab}	17.26^{ab}	82.74^{cd}	1.09^{abcd}	15.36^{b} (220.95)
11	0.94^{ab}	0.33^{a}	3.11^{ab}	23.72^{a}	76.28^{d}	1.71^{a}	12.27^{b} (138.59)
12	0.89^{ab}	0.34^{a}	3.05^{ab}	13.71^{bcd}	86.29^{abc}	0.95^{abcd}	17.52^{ab} (293.19)
13	0.98^{ab}	0.32^{a}	3.20^{ab}	6.48^{de}	93.51^{a}	0.98^{abcd}	18.15^{ab} (311.54)
14	0.91^{ab}	0.32^{a}	2.97^{ab}	7.88^{bcde}	92.12^{abc}	1.07^{abcd}	16.68^{ab} (261.86)
15	0.92^{ab}	0.32^{a}	2.95^{ab}	10.20^{bcd}	89.80^{abc}	1.44^{abc}	16.08^{ab} (242.88)
16	0.91^{ab}	0.32^{a}	2.92^{ab}	17.44^{ab}	82.56^{cd}	0.78^{bcd}	18.41^{ab} (321.06)
17	0.98^{ab}	0.35^{a}	3.47^{a}	16.91^{abc}	83.09^{bcd}	0.90^{abcd}	18.40^{ab} (320.72)
18	0.99^{ab}	0.32^{a}	3.26^{ab}	16.61^{abc}	83.39^{bcd}	0.84^{bcd}	18.31^{ab} (335.27)
19	0.79^{b}	0.30^{a}	2.37^{b}	0.00^{e}	100.0^{a}	-	-
20	0.84^{b}	0.31^{a}	2.60^{ab}	0.00^{e}	100.0^{a}	-	-

* Square root transformation is $\sqrt{x} + 0.5$

** Values in parenthesis indicates the original values

treatments except control (*kole* soil) were on par. Control for *kole* soil recorded the lowest P uptake of 2.37 $mgpot^{-1}$.

4.3.4 Per cent phosphorus derived from fertilizer (% Pdff)

Per cent phosphorus derived from fertilizer was highest (23.72 per cent) in T_{11} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) followed by T_{16} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK without organics) (17.44 per cent), T_7 with 17.27 per cent and T_{10} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK without organics) (17.26 %). The lowest per cent Pdff was registered in control (both *kole* and laterite soil) followed by T_5 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) (5.84 per cent) and T_{13} (*kole* soil treated with 90:22.5:90 $kgha^{-1}$ of NPK without organics (6.48 per cent).

4.3.1 Per cent phosphorus derived from soil (%Pdfs)

Per cent phosphorus derived from soil (% Pdfs) was highest in case of control (both *kole* and laterite soil) each recorded 100 per cent, followed by T_5 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) 94.15 per cent, T_{13} (*kole* soil treated with 90:22.5:90 $kgha^{-1}$ NPK without organics) (93.51 %) and T_1 (laterite soil treated with 90:45:45 $kgha^{-1}$ NPK without organics) with 93.45 per cent. The lowest % Pdfs was recorded in T_{11} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) 76.28 per cent followed by T_{16} (82.56 %), T_7 (82.73 %) and T_{10} (82.74 %).

4.3.2 Per cent uptake of applied P fertilizer

At highest tillering, T_{11} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) received the highest value of 1.713 per cent followed by T_4 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK without organics) with 1.607 per cent and T_{15} (*kole* soil treated with 90:22.5:90 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) 1.447 per cent. T_6, T_{10}, T_{12}, T_{13}, T_{14} and T_{17} were on par and were next best. T_2 recorded the lowest value of .58 per cent.

4.3.3 A value

The 'A' value serves as an availability index for either a fertilizer nutrient or a soil nutrient. The availability of soil phosphorus is measured relative to a standard fertilizers source, the accurate 'A' value is obtained when the reaction between the fertilizer standard and the soil phosphorus is minimal or when the labelled carrier is banded.

At maximum tillering, the P availability index, The highest A value (26.32 $mgpot^{-1}$) with laterite soil receiving 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1} (T_9) and laterite soil receiving 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1} (T_8) being on par (25.09 $mgpot^{-1}$). T_{11} recorded the lowest value of 12.27 $mgpot^{-1}$.

4.4. EFFECT OF DIFFERENT DOSES OF PHOSPHORUS ON DRY MATTER, YIELD AND P CONTENT AT FLOWERING

At 50 per cent flowering, different plant parts like leaf blade, leaf sheath, culm and flower were analysed separately. The results are summarized and are presented in table 4.17 to 4.20.

4.4.1 Leaf blade

At 50 per cent flowering, leaf blade were analysed for the 'P' content, plant dry matter production, total P uptake and other radio assay. The results are presented in table 4.17.

4.4.1.1 Dry matter production

At 50 per cent flowering, all treatments were on par. The dry matter production of leaf blade varied between 5.25 $gpot^{-1}$ and 5.86 $gpot^{-1}$. The highest dry matter production (5.86 $gpot^{-1}$) of leaf blade was recorded with T_{12} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}). The lowest value was recorded with T_{11} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1} (5.25 $gpot^{-1}$).

Table 4.17. Effect of treatments on dry matter production, P content, total P uptake, % Pdff,%Pdfs, 'A' value and per cent uptake of applied fertilizer of leaf blade at flowering

Sl. No.	Dry matter production ($gpot^{-1}$)	P content (%)	Total P uptake ($mgpot^{-1}$)	% Pdff	% Pdfs	% uptake of applied P fertilizer	\`A\`value * ($mgpot^{-1}$)
1	5.67^{a}	0.19^{a}	10.95^{abc}	4.86^{bcdef}	95.14^{bcdef}	1.26^{abcd}	30.15^{def} (879.2)**
2	5.61^{a}	0.20^{a}	11.29^{abc}	5.88^{abcde}	94.11^{cdefg}	1.58^{ab}	28.75^{ef} (798.52)
3	5.39^{a}	0.20^{a}	10.87^{abc}	6.81^{abcd}	93.18^{defg}	1.67^{ab}	27.35^{efg} (720.97)
4	5.69^{a}	0.20^{a}	11.60^{abc}	1.56^{fgh}	98.43^{ab}	0.88^{bcd}	44.43^{bcd} (19.30)
5	5.57^{a}	0.19^{a}	10.81^{abc}	0.84^{gh}	99.16^{a}	0.42^{cd}	51.52^{b} (2604.01)
6	5.69^{a}	0.21^{a}	11.97^{ab}	1.06^{gh}	98.94^{a}	0.60^{bcd}	48.60^{bc} (2314.00)
7	5.56^{a}	0.21^{a}	11.98^{ab}	4.22^{cdefg}	95.78^{abcde}	0.78^{bcd}	38.93^{bcd} (1476.90)
8	5.64^{a}	0.22^{a}	12.69^{a}	7.22^{abc}	92.77^{efg}	1.40^{abc}	29.49^{def} (840.8)
9	5.62^{a}	0.21^{a}	12.31^{ab}	8.13^{ab}	91.86^{fg}	1.59^{ab}	27.89^{ef} (778.20)
10	5.29^{a}	0.19^{a}	10.51^{abc}	8.44^{a}	91.56^{g}	2.07^{a}	22.13^{fg} (468.51)
11	5.25^{a}	0.20^{a}	10.54^{abc}	3.76^{defg}	96.24^{abcd}	0.92^{bcd}	36.17^{cdef} (1257.79)
12	5.86^{a}	0.21^{a}	12.56^{a}	0.93^{gh}	99.07^{a}	0.27^{d}	69.78^{a} (4800.81)
13	5.56^{a}	0.19^{a}	10.99^{abc}	3.04^{efgh}	96.96^{abc}	1.63^{ab}	17.82^{g} (300.25)
14	5.78^{a}	0.19^{a}	11.43^{abc}	2.98^{efgh}	97.02^{abc}	1.60^{ab}	26.72^{efg} (714.31)
15	5.34^{a}	0.20^{a}	10.75^{abc}	3.31^{efgh}	96.69^{abc}	1.69^{ab}	26.01^{efg} (650.85)
16	5.37^{a}	0.20^{a}	11.13^{abc}	7.98^{ab}	92.02^{fg}	1.38^{abc}	28.01^{ef} (746.93)
17	5.51^{a}	0.21^{a}	11.82^{abc}	5.18^{abcde}	94.81^{cdefg}	0.94^{bcd}	37.06^{cde} (1336.67)
18	5.43^{a}	0.20^{a}	11.39^{abc}	5.79^{abcde}	94.21^{cdefg}	1.06^{abcd}	35.40^{cde} (1218.08)
19	5.28^{a}	0.17^{a}	8.98^{c}	0.00^{h}	100.0^{a}	-	-
20	5.30^{a}	0.18^{a}	9.54^{bc}	0.00^{h}	100.0^{a}	-	-

* Square root transformation is $\sqrt{x} + 0.5$

** Values in parenthesis indicates the original values

4.4.1.2 Phosphorus content

At 50 per cent flowering, no significant variations in the concentration of P of leaf blade also have been noticed. It varied between 0.17 and 0.22 per cent. T_8 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) recorded 0.22 percent followed by T_9 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) with 0.21 per cent. T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) showed a concentration of 0.21 per cent. Control (*kole* soil) recorded the lowest value of 0.17 per cent.

4.4.1.3 Phosphorus uptake

Total P uptake by leaf blade of rice plant at 50 per cent flowering was observed between 8.90 $mgpot^{-1}$ and 12.69 mg per pot. T_8 i.e.,laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1} recorded the highest uptake of 12.69 mg per pot with was on par with T_{12} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) with 12.56 $mgpot^{-1}$. All other treatments except control were similar. The control (*kole* soil) recorded the lowest uptake of phosphorus (8.98 $mgpot^{-1}$).

4.4.1.4 Per cent phosphorus derived from fertilizer (per cent Pdff)

Per cent phosphorus derived from fertilizer in leaf blade had the highest value in T_{10} (*kole* soil treated with 90:45:45 $kgha^{-1}$ of NPK without organics) (8.13 %) followed by T_9 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ of NPK along with rice straw @ 5 tha^{-1}) with 8.13 per cent and T_{16} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ of NPK without organics) with 7.98 per cent. The lowest % Pdff was recorded with control (both *kole* and laterite soil) with zero per cent followed by T_5 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) 0.84 per cent and T_{12} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) 0.93 per cent.

4.4.1.5 Per cent phosphorus derived from soil (% Pdfs)

Highest percent Pdfs had derived from controls (both in *kole* and laterite soil) with 100 per cent. Which were on par with T_5 (99.16 per cent), T_{12} (99.07 per cent) and

T_6 (98.94 per cent). The lowest value was recorded in T_{10} (*kole* soil treated with 90:45:45 kgha^{-1} of NPK without organics) 91.56 per cent.

4.4.1.6 Per cent uptake of applied P fertilizer

The data are presented in table 4.17.

The per cent uptake of applied fertilizer was highest (2.07 per cent) with T_{10} i.e., *kole* soil treated with 90:45:45 kgha^{-1} NPK without organics followed by T_{15} (*kole* soil treated with 90:22.5:90 kgha^{-1} NPK + rice straw @ 5 tha^{-1}) (1.69 per cent), T_3, T_{13} and T_{14} with 1.60 per cent. The lowest percent uptake of applied fertilizer was recorded with T12 (0.27 per cent).

4.4.1.7 A value

The highest availability of phosphorus (A value) was recorded in T_{12} (69.78 mgpot^{-1}). The lowest A value was observed in T_{13} with 17.82 mgpot^{-1}.

4.4.2 Leaf sheath

4.4.2.1 Dry matter production

Dry matter production of leaf sheath at flowering stage are presented in table 4.18.

With respect to dry matter production of leaf sheath, all treatments were on par. It varied between 3.48 gpot^{-1} and 3.90 gpot^{-1}. Highest dry matter production was obtained in T_{12} (*kole* soil treated with 90:45:45 kgha^{-1} NPK + 5 tha^{-1} rice straw) 3.903 gpot^{-1}. The lowest value was recorded in T_{11} (*kole* soil treated with 90:45:45 kgha^{-1} NPK + 5 tha^{-1} of Pongamia) with 3.487 gpot^{-1}.

4.4.2.2 Phosphorus content

The results are presented in table 4.18.

The concentration of P with respect to all treatments was on par. The highest concentration was obtained in T_{17} (*kole* soil treated with 90:67.5:135 kgha^{-1} NPK +

Table 4.18. Effect of treatments on dry matter production, P content, total P uptake, % Pdff, %Pdfs, 'A' value and per cent uptake of applied fertilizer of leaf sheath at flowering

Sl. No.	Dry matter production (g/pot)	P content (%)	Total P uptake (mgpot^{-1})	%Pdff	% Pdfs	% uptake of applied P fertilizers	'A' value* (mgpot^{-1})
1	3.70^{a}	0.14^{a}	5.47^{ab}	4.39^{cdef}	95.60^{abc}	0.56^{bcde}	28.02^{abc} (757.5)**
2	3.73^{a}	0.15^{a}	5.65^{ab}	6.51^{bcdef}	93.49^{abcd}	0.87^{abcde}	26.07^{abc} (654.3)
3	3.58^{a}	0.14^{a}	5.35^{ab}	12.70^{abcd}	87.30^{bcde}	1.54^{a}	19.61^{cd} (365.5)
4	3.78^{a}	0.14^{a}	5.44^{ab}	0.96^{ef}	99.03^{a}	0.26^{e}	31.77^{abc} (974.8)
5	3.70^{a}	0.14^{a}	5.41^{ab}	2.03^{def}	97.96^{ab}	0.51^{cde}	40.99^{a} (1640.0)
6	3.78^{a}	0.14^{a}	5.42^{ab}	2.44^{def}	97.55^{ab}	0.61^{bcde}	29.81^{abc} (859.2)
7	3.69^{a}	0.14^{a}	5.49^{ab}	14.80^{abc}	85.20^{cde}	0.35^{de}	21.11^{cd} (445.4)
8	3.75^{a}	0.15^{a}	5.88^{a}	17.87^{a}	82.13^{e}	0.65^{bcde}	42.91^{a} (1799.4)
9	3.73^{a}	0.15^{a}	5.83^{a}	14.01^{abc}	85.99^{cde}	0.77^{abcde}	22.86^{bcd} (500.12)
10	3.52^{a}	0.14^{a}	5.20^{ab}	8.32^{abcdef}	91.68^{abcde}	0.99^{abcde}	21.72^{bcd} (450.61)
11	3.48^{a}	0.15^{a}	5.32^{ab}	8.70^{abcdef}	91.30^{abcde}	1.07^{abcde}	22.25^{bcd} (486.75)
12	3.90^{a}	0.14^{a}	5.83^{a}	11.89^{abcde}	88.11^{abcde}	1.59^{a}	18.58^{cd} (326.98)
13	3.69^{a}	0.14^{a}	5.40^{ab}	6.29^{bcdef}	93.71^{abcd}	1.58^{a}	18.46^{cd} (322.70)
14	3.84^{a}	0.15^{a}	5.83^{a}	6.01^{bcdef}	93.99^{abcd}	1.63^{a}	19.01^{cd} (342.70)
15	3.55^{a}	0.14^{a}	5.24^{ab}	4.79^{cdef}	95.21^{abc}	1.17^{abcd}	14.13^{d} (185.91)
16	3.57^{a}	0.14^{a}	5.32^{ab}	16.34^{ab}	83.66^{de}	1.30^{abc}	20.28^{bcd} (391.5)
17	3.66^{a}	0.15^{a}	5.85^{a}	15.55^{bc}	84.45^{de}	1.38^{abc}	20.00^{bcd} (380.6)
18	3.61^{a}	0.14^{a}	5.40^{ab}	17.73^{a}	82.27^{e}	1.57^{a}	20.20^{cd} (388.40)
19	3.51^{a}	0.13^{a}	4.56^{b}	0.00^{f}	100.00^{a}	-	-
20	3.52^{a}	0.13^{a}	4.58^{b}	0.00^{f}	100.00^{a}	-	-

* Square root transformation is $\sqrt{x + 0.5}$

** Values in parenthesis indicates the original values

Pongamia leaves @ 5 tha^{-1}) (0.15 %). The lowest concentration was recorded in control (laterite soil) 0.13 per cent.

4.4.2.2 Phosphorus uptake

Phosphorus uptake by leaf sheath is presented in table 4.18.

Highest uptake of P was observed with T_8 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia @ 5 tha^{-1}) (5.88 $mgpot^{-1}$). It was comparable with T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}), T_9 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}), T_{12} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) being on par. All other treatments except control (both in *kole* and laterite soil) were better and next best. The control (both in *kole* and laterite soil) registered lowest uptake of P of 4.56 $mgpot^{-1}$and 4.58 $mgpot^{-1}$respectively.

4.4.2.3 Per cent Phosphorus derived from fertilizer (% Pdff)

With regard to P in leaf sheath of rice derived from different doses of labelled phosphorus, significant differences were noticed among the treatments (table 4.15). % Pdfff of T_8 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}), recorded highest value (17.87 %), T_{18} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) being on par. T_{16} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ of NPK without organics) recorded 16.34 per cent followed by T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) (16.34 %) and T_9 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) 14.80 per cent. The lowest % Pdff was recorded in control (both in *kole* and laterite soil) with zero per cent followed by T_4 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK without organics) with 0.96 per cent.

4.4.2.4 Per cent Phosphorus derived from soil (% Pdfs)

Control (both *kole* and laterite soil) had highest % Pdfs of 100 per cent, T_4 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK without organics) with 99.03 per cent, being on par. The lowest per cent phosphorus derived from soil was obtained with T_8 (laterite soil treated with 90:67.5:135 kgha^{-1} NPK + Pongamia leaves @ 5 tha^{-1}) (82.13 %), T_{18} (*kole* soil treated with 90:67.5:135 kgha^{-1} NPK + rice straw @ 5 tha^{-1}) with 82.27 per cent being on par.

4.4.2.6 Per cent uptake of applied fertilizer

The results are summarised in table 4.18.

The per cent uptake of applied fertilizer was highest with T_{14} (*kole* soil treated with 90:22.5:90 kgha^{-1} NPK + Pongamia leaves @ 5 tha^{-1}) 1.63 per cent with T_{12} (*kole* soil treated with 90:45:45 kgha^{-1} NPK + rice straw @ 5 tha^{-1}) (1.593 %), T_{13} (*kole* soil treated with 90:22.5:90 kgha^{-1} NPK without organics) 1.58 per cent, T_3 (laterite soil treated with 90:45:45 kgha^{-1} of NPK + rice straw @ 5 tha^{-1}) 1.54 per cent and T_{18} (1.57 %) being on par and the lowest per cent uptake of applied fertilizer was obtained from T_4 with 0.26 per cent.

4.4.2.7 A value

The data on A value given in table 4.18. The highest A value was recorded with laterite soil receiving 90:67.5:135 kgha^{-1} NPK incorporated with Pongamia leaves @ 5 tha^{-1} (T_8) followed by T_5 with 42.91 mgpot^{-1}. The lowest was recorded with T_{15} (14.13 mgpot^{-1}).

4.4.3 Culm

The data on dry matter production, P content, total P uptake, % Pdff, % Pdfs, A value and per cent uptake of applied fertilizer of culm at flowering are given in table 4.19.

4.4.3.1 Dry matter production

The mean data on dry matter production (table 4.19). The result gives that all treatments being on par. The treatment T_{12} (*kole* soil treated with 90:45:45 kgha^{-1} NPK + rice straw @ 5 tha^{-1}) produced highest dry matter production of culm, which is 2.78

Table 4.19. Effect of treatments on Dry matter production, P content, total P uptake, % Pdff, %Pdfs, 'A' value and per cent uptake of applied fertilizer of culm at flowering

Sl. No.	Dry matter production ((gpot^{-1})	P content (%)	Total P uptake (mgpot^{-1})	% Pdff	%Pdfs	% uptake of applied P fertilizers	`A`value * (mgpot^{-1})
1	2.64^{a}	0.20^{a}	5.46^{a}	8.20^{cdef}	91.80^{abc}	1.05^{ab}	23.21^{ab} (516.77)**
2	2.66^{a}	0.21^{a}	5.68^{a}	4.52^{def}	95.47^{ab}	0.58^{c}	32.93^{ab} (1052.0)
3	2.55^{a}	0.21^{a}	5.40^{a}	5.92^{def}	94.08^{ab}	0.73^{abc}	28.08^{a} (760.73)
4	2.70^{a}	0.20^{a}	5.60^{a}	3.58^{ef}	96.42^{a}	0.93^{abc}	25.24^{ab} (612.10)
5	2.64^{a}	0.21^{a}	5.60^{a}	3.90^{ef}	96.09^{a}	0.95^{ab}	26.87^{ab} (695.74)
6	2.70^{a}	0.20^{a}	5.53^{a}	6.83^{cdef}	93.17^{abc}	0.167^{a}	18.73^{b} (332.65)
7	2.63^{a}	0.20^{a}	5.50^{a}	18.61^{a}	81.39^{e}	1.49^{ab}	21.17^{ab} (427.57)
8	2.67^{a}	0.21^{a}	5.84^{a}	17.76^{ab}	82.24^{de}	1.56^{ab}	18.58^{b} (327.21)
9	2.67^{a}	0.21^{a}	5.75^{a}	15.37^{abc}	84.63^{de}	1.33^{ab}	19.79^{b} (372.20)
10	2.51^{a}	0.20^{a}	5.08^{a}	11.38^{abcde}	88.62^{abcde}	1.33^{ab}	19.70^{b} (372.67)
11	2.49^{a}	0.21^{a}	5.27^{a}	9.63^{bcde}	90.36^{abcd}	1.18^{ab}	20.89^{b} (414.9)
12	2.78^{a}	0.21^{a}	5.93^{a}	11.52^{abcde}	88.48^{abcde}	1.59^{a}	19.59^{b} (361.53)
13	2.64^{a}	0.20^{a}	5.38^{a}	4.72^{def}	95.28^{ab}	1.18^{ab}	27.32^{ab} (719.61)
14	2.74^{a}	0.20^{a}	5.67^{a}	4.72^{def}	95.28^{ab}	1.29^{ab}	23.48^{ab} (528.30)
15	2.53^{a}	0.20^{a}	5.30^{a}	4.913^{def}	95.09^{ab}	1.21^{ab}	48.87^{a} (2150.8)
16	2.55^{a}	0.21^{a}	5.38^{a}	10.73^{abcde}	89.27^{abcde}	0.87^{ab}	28.16^{ab} (773.5)
17	2.61^{a}	0.21^{a}	5.73^{a}	12.83^{abcd}	87.17^{bcde}	1.11^{ab}	22.12^{ab} (479.81)
18	2.57^{a}	0.21^{a}	5.56^{a}	8.52^{cdef}	91.48^{abc}	0.75^{abc}	29.11^{ab} (868.6)
19	2.51^{a}	0.18^{a}	4.68^{a}	0.00^{f}	100.00^{a}	-	-
20	2.50^{a}	0.19^{a}	4.78^{a}	0.00^{f}	100.00^{a}	-	-

* Square root transformation is $\sqrt{x} + 0.5$

** Values in parenthesis indicates the original values

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$gpot^{-1}$. The lowest dry matter production of culm was by T_{11} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) with 2.49 $gpot^{-1}$.

4.4.3.2 Phosphorus content

The mean content of phosphorus estimated in culm of rice plant at 50 per cent flowering is given in table 4.19.

In general the different levels of phosphorus application could not impart any significant variation in culm. Hence all treatments were statistically on par. The crop receiving different levels of phosphorus had high content of phosphorus compared to the control (both *kole* and laterite soil). The concentration of P was highest with T_{17} (*kole* soil treated with 99:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) with 0.219 per cent. The lowest was recorded with control (*kole* soil) with 0.187 per cent followed by control (laterite soil) 0.190 per cent.

4.4.3.3 Phosphorus uptake

The data on mean total P uptake ($mgpot^{-1}$) recorded in for culm at 50 per cent flowering is given in table 4.19. At 50 per cent flowering, the uptake of phosphorus in culm was not significantly influenced by treatments. Hence all treatments were on par. The higher uptake of 5.93 $mgpot^{-1}$was recorded by T_{12} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) followed by T_8 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) 5.84 per cent. The control (*kole* soil) recorded the lowest value of 4.68 $mgpot^{-1}$.

4.4.3.4 Per cent phosphorus derived from fertilizer (% Pdff)

The per cent phosphorus derived from fertilizer (% Pdff) is given in table 4.19.

T_7 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK without organics) recorded the highest % Pdff of 18.61 per cent followed by T_8 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) (17.76 %) and T_9 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) with 15.37 per cent. The lowest per cent of zero was recorded with control, both *kole* and laterite followed by T_4 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK without organics) with 3.883 per cent.

4.4.3.5 Per cent phosphorus derived from soil (% Pdfs)

The mean data on % Pdfs is given in table 4.19. The highest % Pdfs was recorded in control (both *kole* and laterite soil) with cent per cent followed by T_4 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ of NPK without organics) 96.42 per cent and T_5 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ of NPK + 5 t/ha Pongamia leaves) 96.09 per cent. The lowest % Pdfs was recorded with T_7 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK without organics) with 81.39 per cent.

4.4.3.6 Per cent uptake of applied fertilizers

The data are presented in table 4.19. The highest per cent uptake of applied fertilizer was obtained in T_6 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ NPK without organics) with 1.66 per cent with T_{12} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) 1.59 per cent being on par. All other treatments except T_3, T_4, T_{18}, T_{16}, T_2 and control being on par and were the next best. T_3, T_{16}, T_{18} were marginally better than T_2 (laterite soil treated with 90:45:45 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}). T_3 recorded the lowest value of 0.73 per cent.

4.4.3.7 A value

The data showed that the plants grown T_{15} gave the highest value of 48.87 $mgpot^{-1}$. the lowest was in T_6 with 18.73.

4.4.4 Flower

The data on dry matter production, P content, total P uptake, % Pdff, % Pdfs, A value and per cent uptake of applied phosphorus from fertilizer of flower are given in table 4.20.

Table 4.20. Effect of treatments on dry matter production, P content, total P uptake, % Pdff, %Pdfs, 'A' value and per cent uptake of applied fertilizer of flower at flowering

Sl. No.	Dry matter production ($gpot^{-1}$)	P content (%)	Total P uptake ($mgpot^{-1}$)	% Pdff	% Pdfs	% uptake of applied Pfertilizers	\`A\`value* ($mgpot^{-1}$)
1	3.86^{a}	0.17^{ab}	6.91^{ab}	8.56^{abcd}	91.43^{abcd}	1.44^{bc}	24.90^{bc} (595.6)**
2	3.89^{a}	0.18^{ab}	7.09^{ab}	7.66^{abcd}	92.34^{abcd}	1.26^{bc}	24.31^{bc} (567.6)
3	3.73^{a}	0.18^{ab}	6.95^{ab}	8.23^{abcd}	91.77^{abcd}	1.36^{bc}	42.43^{a} (1758.6)
4	3.94^{a}	0.18^{ab}	7.11^{ab}	2.90^{de}	97.10^{a}	0.99^{bc}	37.21^{ab} (1348.5)
5	3.86^{a}	0.18^{ab}	6.98^{ab}	3.33^{de}	96.66^{a}	1.04^{bc}	26.39^{abc} (670.3)
6	9.94^{a}	0.18^{ab}	7.35^{ab}	4.55^{cde}	95.45^{ab}	1.60^{bc}	22.89^{bc} (501.6)
7	9.85^{a}	0.18^{ab}	7.11^{ab}	8.79^{abcd}	91.22^{abcd}	1.89^{b}	28.30^{ab} (773.31)
8	3.91^{a}	0.19^{a}	7.51^{ab}	13.66^{a}	86.34^{d}	3.64^{a}	21.74^{bc} (451.2)
9	3.89^{a}	0.19^{a}	7.43^{ab}	10.69^{abc}	89.31^{bcd}	2.48^{ab}	25.36^{abc} (618.15)
10	3.67^{a}	0.18^{ab}	6.65^{ab}	7.25^{abcd}	92.74^{abcd}	1.12^{bc}	24.15^{abc} (559.6)
11	3.63^{a}	0.18^{ab}	6.78^{ab}	6.82^{bcd}	93.18^{abc}	1.09^{bc}	26.79^{abc} (691.4)
12	4.06^{a}	0.18^{ab}	7.63^{ab}	5.01^{bcde}	94.98^{abc}	0.89^{c}	29.05^{ab} (815.2)
13	3.85^{a}	0.18^{ab}	7.08^{ab}	3.85^{de}	96.15^{a}	1.25^{bc}	25.31^{abc} (615.95)
14	4.00^{a}	0.18^{ab}	7.40^{ab}	3.83^{de}	96.17^{a}	1.34^{bc}	24.53^{bc} (577.4)
15	3.70^{a}	0.18^{ab}	6.79^{ab}	7.01^{abcd}	92.99^{abcd}	2.27^{ab}	28.76^{ab} (799.05)
16	3.72^{a}	0.18^{ab}	6.97^{ab}	11.11^{abc}	88.89^{bcd}	1.20^{bc}	23.97^{abc} (525.8)
17	3.82^{a}	0.19^{a}	7.35^{ab}	8.12^{abcd}	91.87^{abcd}	0.90^{bc}	12.17^{c} (136.1)
18	3.76^{a}	0.18^{ab}	7.08^{ab}	11.33^{ab}	88.86^{cd}	1.25^{bc}	23.05^{bc} (507.65)
19	3.66^{a}	0.16^{b}	5.86^{b}	0.00^{e}	100.00^{a}	-	-
20	3.67^{a}	0.16^{b}	5.88^{b}	0.00^{e}	100.00^{a}	-	-

* Square root transformation is $\sqrt{x} + 0.5$

** Values in parenthesis indicates the original values

4.4.4.1 Dry matter production

Dry matter production of flower at 50 per cent flowering are presented in table 4.20. All treatments were on par with respect to dry matter production. Between the treatments, there was no significant difference. It varied between 3.63 $gpot^{-1}$ and 4.06 $gpot^{-1}$. The highest dry matter production of 4.06 g per pot. The highest dry matter production of 4.06 $gpot^{-1}$ was recorded in T_{12} (*kole* soil treated with 90:45:45 $kgha^{-1}$ NPK + rice straw @ 5 tha^{-1}) whereas the lowest dry matter produced by T_{11} (*kole* soil treated with 90:45:45 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}) with 3.63 $gpot^{-1}$.

4.4.4.2 Phosphorus content

With regard to phosphorus concentration of flower, highest phosphorus concentration was recorded in T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}) 0.19 per cent, T_8 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}) 0.19 per cent and T_9 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}) 0.19 per cent being on par.

4.4.4.3 Phosphorus uptake

The results are presented in table 4.20. The highest uptake of phosphorus was observed with T_{12} (*kole* soil treated with 90:45:45 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}) with 7.63 $mgpot^{-1}$. All other treatments except control (both in *kole* and laterite soil) were being on par and were the next best. The lowest uptake of phosphorus was observed with control. *Kole* and laterite soil with 5.86 $mgpot^{-1}$ and 5.88 $mgpot^{-1}$ respectively.

4.4.4.4 Per cent phosphorus derived from fertilizer (% Pdff)

The data on per cent phosphorus derived from fertilizer are presented in table 4.20. The highest per cent of phosphorus derived from fertilizer (% Pdff) of culm was obtained from T_8 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}) 13.66 per cent, whereas the lowest was recorded in controls (both in *kole* and laterite soil) with zero per cent, followed by T_4 (laterite soil treated with

90:22.5:90 kg NPK/ha without organics) with 2.90 per cent and T_5 (laterite soil treated with 90:22.5:90 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1}) with 3.33 per cent.

4.4.4.5 Per cent phosphorus derived from soil (% Pdfs)

The data on % Pdfs are presented in table 4.20. The % Pdfs of control (both in *kole* and laterite soil) had highest values of 100 per cent with T_4 (laterite soil treated with 90:22.5:90 kgha^{-1} of NPK without organics) of 97.10 per cent, T_5 (laterite soil treated with 90:22.5:90 kgha^{-1} of NPK + rice straw @ 5 tha^{-1}) of 96.66 per cent, T_{14} (*kole* soil treated with 90:22.5:90 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1}) of 96.17 per cent and T_{14} of 96.15 per cent being on par. The lowest % Pdfs of 88.86 per cent was obtained by T_{18} (*kole* soils treated with 90:67.5:135 kgha^{-1} of NPK + rice straw @ 5 tha^{-1}).

4.4.4.6 Per cent uptake of applied fertilizer

The highest per cent uptake of applied fertilizer was recorded with T_8 (laterite soil treated with 90:67.5:135 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1}) 3.64 per cent followed by T_9 (laterite soil treated with 90:67.5:135 kgha^{-1} of NPK + rice straw @ 5 tha^{-1}) (2.48 %) and T_{15} (*kole* soil treated with 90:22.5:90 kgha^{-1} of NPK + rice straw @ 5 tha^{-1}) with 2.27 per cent. All other treatments except control were being on par and next best control recorded the lowest value of 0.89 per cent was recorded in T_{12}.

4.4.4.7 A value

Highest A value of 42.43 mgpot^{-1}was recorded in laterite soil receiving 90:45:45 kgha^{-1} of NPK without organics organics (T_3) and the lowest was with T_{17} (12.17 mgpot^{-1})

4.4.5 Effect of different doses of phosphorus on dry matter, yield and P content at harvesting

At maturity, samples of straw (leaf blade, leaf sheath, culm separately) and grain were analysed the results are presented in tables 4.21,4.22,4.23,4.24.

4.4.5.1 Leaf blade

Effect of different doses of phosphorus on 'P' content, % Pdff, % Pdfs, A value and per cent uptake of phosphorus from fertilizer of leaf blade at harvest.The data are presented in table 4.21

4.4.5.1.1 Dry matter production

At harvesting, highest culm dry matter was observed in case of T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}) 26.81 $gpot^{-1}$) where as the lowest value was recorded for T_4 (laterite soil treated with 90:22.5: $kgha^{-1}$ of NPK) 10.84 $gpot^{-1}$).

4.4.5.1.2 Phosphorus content

At harvesting, the highest concentration was observed for T_{18} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}) (0.21 %) and the lowest value (0.09 %) was recorded in T_5 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}).

4.4.5.1.3 Phosphorus uptake

At harvesting, highest uptake of P was obtained in T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}) (55.91 $mgpot^{-1}$), while the lowest value was recorded in pots receiving T_4 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ of NPK without organics) (12.42 $mgpot^{-1}$).

4.4.5.1.4 Per cent phosphorus derived from fertiliser (% Pdff)

With regard to % Pdff, all treatments were statistically on par. It varied between zero per cent to 5.70 per cent. The highest % Pdff was observed in T_{12} which received *kole* soil treated with 90:45:45 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1} with 5.70 per cent and the lowest value of zero was observed with control (both in *kole* and laterite soil), T_5 and T_6.

Table 4.21. Effect of treatments on dry matter production, P content, total P uptake, % Pdff, %Pdfs, 'A' value and per cent uptake of applied fertilizer of leaf blade at harvest

Sl. No.	Dry matter production ($gpot^{-1}$)	P content (%)	Total P uptake ($mgpot^{-1}$)	% Pdff	% Pdfs	% uptake of applied P fertilizer	'A' Value* ($mgpot^{-1}$)
1	12.84^{fg}	0.17^{abcd}	22.09^{ghi}	2.23^{a}	97.77^{a}	1.17^{b}	28.84^{bc} (831.76)**
2	15.68^{efg}	0.16^{abc}	26.33^{efgh}	2.00^{a}	97.99^{a}	1.33^{b}	18.85^{ab} (336.8)
3	12.38^{fg}	0.18^{abc}	22.35^{ghi}	1.50^{a}	98.49^{a}	0.73^{b}	17.39^{bc} (302.51)
4	10.84^{g}	0.11^{de}	12.42^{i}	2.36^{a}	97.63^{a}	1.76^{ab}	33.45^{bc} (1086.33)
5	17.01^{cdef}	0.09^{e}	16.45^{hi}	0.00^{b}	100.00^{a}	0.00^{c}	0.50^{c} (0.00)
6	13.17^{fg}	0.16^{abcd}	21.18^{ghi}	0.00^{b}	100.00^{a}	0.00^{c}	0.50^{c} (0.00)
7	15.60^{efg}	0.17^{abcd}	26.47^{efgh}	4.21^{a}	95.78^{a}	1.83^{ab}	52.89^{bc} (2798.0)
8	17.18^{cdef}	0.20^{abc}	34.75^{bcdef}	0.92^{a}	99.07^{a}	0.56^{b}	27.04^{bc} (709.93)
9	14.29^{fg}	0.20^{abc}	28.70^{defg}	1.11^{a}	98.89^{a}	0.49^{b}	87.59^{a} (7585.63)
10	16.99^{cdef}	0.16^{abcd}	28.76^{defg}	3.24^{a}	96.76^{a}	2.41^{ab}	69.66^{ab} (4784.19)
11	24.37^{ab}	0.17^{abcd}	41.29^{bc}	2.25^{a}	97.75^{a}	2.27^{ab}	28.88^{bc} (834.49)
12	13.33^{fg}	0.18^{abc}	24.23^{fgh}	5.70^{a}	94.30^{a}	2.13^{ab}	55.57^{abc} (3033.12)
13	16.79^{def}	0.14^{cde}	24.57^{fgh}	1.64^{a}	98.36^{a}	1.86^{ab}	48.28^{bc} (2283.12)
14	20.83^{bcde}	0.15^{bcde}	31.56^{cdefg}	3.83^{a}	96.17^{a}	5.44^{a}	26.46^{bc} (673.99)
15	22.59^{abc}	0.17^{abcd}	38.42^{bcd}	0.87	98.91^{a}	2.00^{ab}	15.08^{bc} (212.62)
16	17.98^{cdef}	0.20^{abc}	36.32^{bcde}	3.61^{a}	96.38^{a}	1.96^{ab}	27.96^{bc} (754.6)
17	26.81^{a}	0.21^{ab}	55.91^{a}	4.74^{a}	95.26^{a}	4.08^{ab}	24.27^{bc} (565.1)
18	20.64^{bcde}	0.21^{a}	43.87^{b}	5.02^{a}	94.98^{a}	3.34^{ab}	23.04^{bc} (531.2)
19	22.17^{abcd}	0.15^{bcde}	33.25^{cdef}	0.00^{b}	100.00^{a}	-	-
20	23.82^{ab}	0.15^{bcde}	35.73^{bcde}	0.00^{b}	100.00^{a}	-	-

* Square root transformation is $\sqrt{x + 0.5}$

** Values in parenthesis indicates the original values

4.4.5.1.2 Per cent phosphorus derived from soil (% Pdfs)

The % Pdfs of all treatments, no remarkable variations have been noticed. Means all treatments were on par, it varied between 100 per cent and 94.30 per cent. Pots treated with control (both *kole* and laterite soil) recorded highest % Pdfs of 100 per cent with T_6 (laterite soil treated with 90:22.5:90 kgha^{-1} of NPK + rice straw @ 5 tha^{-1}) and T_5 (laterite soil treated with90: 22.5:90 kgha^{-1} of NPK + Pongamia leaves@5tha^{-1}being on par with T_{12} (*kole* soil treated with 90:45:45 kgha^{-1} of NPK + rice straw @ 5 tha^{-1}) registered

4.4.5.1.6 The Per cent uptake of applied fertilizer

Per cent uptake of applied P fertilizer was highest in T_{14} (*kole soil treated with* 90:22.5:90 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1}) 5.440 per cent followed by T_{17}, T_{18}, T_{10}, T_{11}, T_{15} and T_{16} are being on par were ranked next best after T_{14}. T_1, T_2, T_8 were better than control both *kole* and laterite soil. T_5, T_6Control recorded the lowest value of zero with T_5, T_6. Lowest per cent Pdfs (94.30 %).

4.4.5.1.7 A value

The 'A' value index was higher (87.59 mgpot^{-1}) in case of T_9 (laterite soil treated with 90:67.5:135 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1} and the lowest was obtained with T5 and T6 with zero value.

4.4.5.2. Leaf sheath

4.4.5.2.1 Dry matter production

The variations in dry matter production of leaf sheath are presented in table 4.22.

Table 4.22. Effect of treatments on dry matter production, P content, total P uptake, % Pdff, %Pdfs, 'A' value and per cent uptake of applied fertilizer of leaf sheath at harvest

Sl. No.	Dry matter production ($gpot^{-1}$)	P content (%)	Total P uptake ($mgpot^{-1}$)	% Pdff	% Pdfs	%uptakeof applied P fertilizer	'A' value* ($mgpot^{-1}$))
1	9.51^{fg}	0.12^{abc}	12.14^{cdefgh}	0.43^{c}	99.56a	0.13^{ab}	66.54^{a} (4362.2)**
2	11.6^{efg}	0.09^{abcd}	11.14^{defgh}	2.42^{c}	97.57ab	0.78^{ab}	29.66^{b} (850.71)
3	9.18^{fg}	0.11^{abcd}	10.94^{h}	16.26^{ab}	83.74ab	3.29^{ab}	13.28^{bc} (163.54)
4	8.04^{g}	0.08^{bcd}	6.70^{defgh}	0.00^{c}	100.00a	0.00^{b}	0.50^{c} (0.00)
5	12.60^{cdef}	0.07^{cd}	10.18^{gh}	10.55^{abc}	89.45ab	3.79^{ab}	11.67^{bc} (124.92)
6	9.96^{fg}	0.07^{cd}	$7.86^{bcdefgh}$	1.38^{c}	98.62ab	0.76^{ab}	13.38^{bc} (166.03)
7	11.56^{efg}	0.12^{abc}	$14.99^{bcdefgh}$	5.80^{abc}	94.19ab	1.60^{ab}	24.72^{b} (586.92)
8	12.73^{cdef}	0.13^{abc}	$16.46^{bcdefgh}$	6.95^{abc}	93.05ab	1.61^{ab}	23.11^{bc} (511.6)
9	10.59^{fg}	0.12^{abcd}	$13.44^{bcdefgh}$	9.29^{abc}	90.70ab	2.53^{ab}	20.70^{bc} (408.38)
10	12.59^{cdef}	0.09^{abcd}	12.14^{cdefgh}	9.51^{abc}	90.48ab	3.64^{ab}	15.63^{bc} (229.02)
11	18.06^{ab}	0.08^{bcd}	$14.27^{bcdefgh}$	0.55^{c}	99.44a	0.11^{ab}	25.47^{bc} (648.84)
12	9.883^{fg}	0.09^{abcd}	8.77^{efgh}	2.73^{c}	97.26ab	0.63^{ab}	13.16^{bc} (160.45)
13	12.44^{def}	0.06^{d}	8.04^{fgh}	0.53^{c}	99.47a	0.18^{ab}	21.55^{bc} (443.37)
14	15.44^{bcde}	0.11^{abcd}	17.80^{bcd}	5.54^{abc}	94.45ab	4.86^{a}	14.81^{bc} (205.01)
15	16.74^{abc}	0.12^{abcd}	20.20^{bc}	2.48^{c}	91.51ab	2.50^{ab}	20.99^{bc} (420.11)
16	13.33^{cdef}	0.12^{abcd}	16.82^{bcdef}	18.11^{a}	81.89b	3.08^{ab}	26.47^{b} (700.89)
17	19.88^{a}	0.15^{a}	29.83^{a}	4.10^{bc}	95.89ab	1.76^{ab}	26.06^{b} (679.39)
18	15.30^{bcde}	0.14^{ab}	21.98^{b}	5.62^{abc}	94.37ab	1.92^{ab}	26.98^{b} (701.28)
19	16.43^{abcd}	0.08^{abcd}	13.14^{bcdefg}	0.00^{c}	100.00a	-	-
20	17.60^{ab}	0.08^{abcd}	14.08^{bcde}	0.00^{c}	100.00a	-	-

* Square root transformation is $\sqrt{x} + 0.5$

***Values in parenthesis indicates the original values*

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T_{17} i.e.,*kole* soil treated with 90:67.5:135 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1} showed highest dry matter production of 19.88 gpot^{-1} whereas T_4 (laterite soil treated with 90:22.5:90 kgha^{-1} of NPK without organics) recorded the lowest amount of dry matter production of 8.04 gpot^{-1}.

4.4.5.2.2 Phosphorus content

At harvest, 'P' concentration varied between 0.063 per cent (T_{13}, *kole* soil treated with 90:22.5:90 kgha^{-1} of NPK without organics) and 0.15 per cent in T_{17} (*kole* soil treated with 90:67.5:135 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1}). T_{17} recorded the 0.18 per cent followed by T_{18} (*kole* soil treated with 90:67.5:135 kgha^{-1} of NPK + rice straw @ 5 tha^{-1}). T_{13} recorded the lowest value with 0.06 per cent.

4.4.5.2.3 Phosphorus uptake

The results are summarised in table 4.22 the results showed that the total uptake of P of leaf sheath at harvest ranged between 10.94 mgpot^{-1}with T_3 and 29.83 mgpot^{-1}with T_{17}.

4.4.5.2.4 Per cent phosphorus derived from fertilizer

At harvesting, % Pdff of leaf sheath was highest (18.11 %) in plants which received T_{16} (*kole* soil treated with 90:67.5:135 kgha^{-1} of NPK without organics).

A plant treated with T3 (laterite soil treated with 90:45:45 kgha^{-1} of NPK + rice straw @ 5 tha^{-1}) was the next best followed by pots treated with T_5, T_9, T_{10} were on par but the % Pdff was less than that of T_3. T_{17} (*kole* soil treated with 90:67.5:135 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1}). T_{12}, T_{15}, T_6 and T_{11} were still lesser % Pdff and on par where as control (both in *kole* and laterite soil) was lowest (0 %).

4.4.5.2.5 Per cent phosphorus derived from soil (% Pdfs)

The results are presented in table 4.22. At harvest, % Pdfs of leaf sheath in pots treated with control (both *kole* and laterite soil) had highest % Pdfs, with T_4 (laterite soil treated with 90:22.5:90 kgha^{-1} of NPK without organics), T_{13} (*kole* soil treated with

90:22.5:90 kgha^{-1} of NPK without organics) being on par. All other treatments except T_{16} were on par and next best. T_{16} (*kole* soil treated with 90:67.5:135 kgha^{-1} of NPK without organics) recorded the leaf % Pdfs of 9.49 per cent.

4.4.5.2.6 Per cent uptake of applied fertilizer

With regard to per cent uptake of applied fertilizer, T_{14} (*kole* soil treated with 90:22.5:90 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1}) and highest value of 4.860 per cent with followed by all other treatments except controls (both in *kole* and laterite soil) and T_4. Control (*kole* and laterite soil) and T_4 recorded the lowest value (0 %).

4.4.5.2.6 A value

The table 4.22 showed the A value recorded in leaf sheath at harvesting . The highest A value was with laterite soil receiving 90:45:45 kgha^{-1} of NPK without organics (T_1) with 66.54 mgpot^{-1}where as the lowest value of A value was obtained with T_4 with 0.5 mgpot^{-1}.

4.4.5.3 Culm

The results are presented in table 4.23.

4.4.5.3.1 Dry matter production

The highest dry matter production of 15.690 gpot^{-1} was obtained in plants treated with T_{17} (*kole* soil treated with 90:67.5:135 kgha^{-1} of NPK + Pongamia leaves @ 5 tha^{-1}). The lowest dry matter production of 6.343 gpot^{-1} was recorded in T_4 (laterite soil treated with 90:22.5:90 kgha^{-1} of NPK without organics).

4.4.5.3.2 Phosphorus content

No remarkable variation in the concentration of phosphorus have been noticed at harvest in culm. All treatments were statistically similar. It varied between 0.11 per cent and 0.162 per cent. T_{18} (*kole* soil treated with 90:67.5:135 kgha^{-1} NPK + rice straw @ 5 tha^{-1}) recorded 0.16 per cent. Whereas, plants treated with control (*kole* soil) recorded the lowest value with 0.11 per cent.

Table 4.23. Effect of treatments on dry matter production, P content, total P uptake, % Pdff, %Pdfs, 'A' value and per cent uptake of applied fertilizer of culm at harvest

Sl. No.	Dry matter production (gpot^{-1})	P content (%)	Total P uptake (mgpot^{-1}))	% Pdff	% Pdfs	% uptake of applied P fertilizers	'A' value* (mgpot^{-1})
1	7.51^{fg}	0.15^{a}	11.36^{cd}	5.21^{abc}	94.78^{a}	1.41^{b}	18.89^{bc} (338.32)**
2	9.17^{efg}	0.13^{a}	12.12^{bcd}	8.27^{abc}	91.73^{a}	2.40^{b}	15.04^{bc} (211.5)
3	7.24^{fg}	0.13^{a}	9.68^{d}	16.71^{a}	83.29^{a}	3.26^{ab}	17.65^{bc} (294.17)
4	6.34^{g}	0.14^{a}	9.43^{d}	5.00^{abc}	94.99^{a}	1.21^{b}	14.57^{bc} (198.16)
5	9.95^{cdef}	0.12^{a}	12.75^{bcd}	8.76^{abc}	91.23^{a}	2.30^{b}	26.87^{abc} (669.75)
6	7.70^{fg}	0.11^{a}	9.32^{d}	6.47^{abc}	93.53^{a}	1.33^{b}	5.95^{cd} (29.76)
7	9.12^{efg}	0.13^{a}	12.14^{bcd}	14.52^{ab}	85.48^{a}	1.18^{b}	22.68^{abc} (492.25)
8	10.05^{cdef}	0.14^{a}	14.67^{bcd}	15.02^{ab}	84.98^{a}	1.39^{b}	29.77^{ab} (857.21)
9	8.36^{fg}	0.13^{a}	11.59^{bcd}	8.17^{abc}	91.82^{a}	0.78^{b}	44.55^{a} (1940.88)
10	9.94^{cdef}	0.15^{a}	15.68^{abcd}	11.84^{abc}	88.15^{a}	5.18^{ab}	24.10^{abc} (557.09)
11	14.26^{ab}	0.13^{a}	19.02^{abc}	2.76^{bc}	97.24^{a}	1.30^{b}	13.09^{bc} (158.69)
12	7.80^{fg}	0.13^{a}	11.16^{cd}	11.14^{abc}	88.85^{a}	2.92^{ab}	19.92^{abc} (389.63)
13	9.82^{def}	0.15^{a}	9.88^{cd}	7.80^{abc}	92.19^{a}	4.21^{ab}	20.23^{abc} (579.9)
14	12.19^{bcde}	0.12^{a}	15.46^{abcd}	12.12^{abc}	97.88^{a}	8.43^{a}	17.33^{bc} (283.38)
15	13.22^{abc}	0.10^{a}	14.09^{bcd}	10.48^{abc}	89.52^{a}	5.87^{ab}	14.12^{bc} (185.76)
16	10.52^{cdef}	0.14^{a}	15.64^{abcd}	12.27^{abc}	87.73^{a}	2.78^{ab}	16.00^{bc} (240.53)
17	15.69^{a}	0.15^{a}	23.80^{a}	9.86^{abc}	90.13^{a}	4.12^{ab}	15.75^{bc} (248.1)
18	12.08^{bcde}	0.16^{a}	20.61^{ab}	9.92^{abc}	90.07^{a}	3.53^{ab}	17.09^{bc} (275.4)
19	12.97^{abcd}	0.11^{a}	14.27^{bcd}	0.00^{c}	100.00^{a}	-	-
20	13.94^{ab}	0.12^{a}	16.73^{abcd}	0.00^{c}	100.00^{a}	-	-

* Square root transformation is $\sqrt{x} + 0.5$

** Values in parenthesis indicates the original values

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4.4.5.3.1 Phosphorus uptake

The results showed that the uptake of P of culm at harvesting ranged between 9.32 $mgpot^{-1}$and 23.80 $mgpot^{-1}$. The highest uptake of P was recorded in T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}) (23.80 $mgpot^{-1}$). Whereas the lowest uptake of P(9.32 $mgpot^{-1}$) was recorded with T_6 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}).It was comparable with T_4 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ of NPK) (9.43 $mgpot^{-1}$) and T_3 (laterite soil treated with 90:45:45 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}) with 9.68 $mgpot^{-1}$.

4.4.5.3.2 Per cent phosphorus derived from fertilizer

Data on the per cent phosphorus derived from fertilizer (% Pdff) in culm at harvesting are presented in table 4.23.

The % Pdff was highest in T_3 (laterite soil treated with 90:45:45 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}) (16.71 %), followed by T_8 (laterite soil treated with 90:67.5:135 $kgha^{-1}$ of NPK + rice straw @ 5 tha^{-1}) with 15.02 per cent, and T_7 were on par. T_{11} (*kole* soil treated with 90:45:45 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1}) recorded 2.76per cent where as control (both in *kole* and laterite soil) had the lowest value of zero per cent.

4.4.5.3.3 Per cent phosphorus derived from soil (% Pdfs)

In case of % Pdfs value, all treatments were on par, no remarkable variation has been observed among the treatments. It varied from 83.29 to 97.88 percent in T_{14}.

4.4.5.3.4 Per cent uptake of applied fertilizer

The results showed (table 4.23) that the per cent uptake of applied fertilizer was highest in T_{14} (*kole* soil treated with 90:22.5:90 $kgha^{-1}$ NPK + Pongamia leaves @ 5 tha^{-1}) with 8.43 per cent. The lowest was recorded in T_9 with .78 per cent.

4.4.5.3.5 A value

The results are summarized in table 4.23. The highest A value (44.55 $mgpot^{-1}$) was recorded with plants grown in laterite soil which receiving 90:67.5:135 $kgha^{-1}$ of NPK with rice straw @ 5 tha^{-1} (T_9). Whereas the lowest A value was recorded with T_6 with 5.49 $mgpot^{-1}$.

4.4.5.4 Grain

The results are presented in table 4.24.

4.4.5.4.1 Dry matter production

With respect to dry matter production, the highest value was recorded by T_{17} (*kole* soil treated with 90:67.5:135 $kgha^{-1}$ of NPK + Pongamia leaves @ 5 tha^{-1} (23.15 $gpot^{-1}$) whereas, the lowest was recorded with T_4 (laterite soil treated with 90:22.5:90 $kgha^{-1}$ of NPK without organics) with 9.36 $gpot^{-1}$

4.4.5.4.2 Phosphorus content

In case of P concentration, all treatments were on par. It varied between 0.14 per cent and 0.18 per cent. The highest concentration of P 0.18 per cent was observed in T_8 and the lowest (0.14 %) was from T_4.

4.4.5.4.3 Phosphorus uptake

The highest uptake of P was from T_{17} with 40.27 $mgpot^{-1}$and the lowest was recorded from T_4 (13.2 $mgpot^{-1}$). All other treatments were intermediary one.

4.4.5.4.4 Per cent phosphorus derived from fertilizer

The highest value for percent phosphorus derived from fertilizer (% Pdff) (20.27 per cent) was observed in T_{16} (*kole* soil treated with 90:67.5:90 $kgha^{-1}$ of NPK without organics). It was closely followed by T17 and T_7 with 18.23 and 18.20 per cent,respectively.

Table 4.24. Effect of treatments on dry matter production, P content, total P uptake, % Pdff, %Pdfs, 'A' value and per cent uptake of applied fertilizer of grain at harvest

Sl. No.	Dry matter production ($gpot^{-1}$)	P content (%)	Total P uptake ($mgpot^{-1}$)	% Pdff	% Pdfs	% uptake of applied P fertilizer	'A' value* ($mgpot^{-1}$)
1	11.08^{a}	0.17^{a}	19.58^{fgh}	8.60^{abc}	91.40ab	3.91^{b}	82.34^{ab}(6698.8)**
2	13.54^{fghi}	0.16^{a}	22.28^{efgh}	7.73^{abc}	92.27ab	4.08^{b}	23.97^{c} (551.19)
3	10.69^{hi}	0.15^{a}	16.85^{gh}	10.63^{abc}	89.37ab	4.65^{b}	12.81^{c} (151.68)
4	9.36^{i}	0.14^{a}	13.27^{h}	5.53^{bc}	94.46ab	3.35^{b}	14.58^{c} (198.31)
5	14.68^{defgh}	0.15^{a}	23.37^{fg}	9.24^{abc}	90.75ab	8.50^{b}	20.72^{c} (409.1)
6	11.37^{hi}	0.15^{a}	17.37^{gh}	7.40^{abc}	92.59ab	6.83^{b}	35.62^{bc} (1192.9)
7	13.47^{fghi}	0.15^{a}	20.78^{efgh}	18.20^{ab}	81.80ab	5.44^{b}	97.13^{a} (9338.6)
8	14.83^{defgh}	0.18^{a}	27.45^{bcdef}	12.39^{abc}	87.61ab	5.81^{b}	14.20^{c} (189.990)
9	12.34^{ghi}	0.16^{a}	20.22^{fgh}	12.97^{abc}	87.07ab	3.70^{b}	55.91^{abc} (3071.3)
10	14.67^{defgh}	0.17^{a}	25.40^{cdefg}	7.15^{abc}	92.84ab	3.84^{b}	37.16^{abc} (1344.2)
11	20.06^{abc}	0.16^{a}	32.33^{abcd}	6.58^{abc}	93.42ab	4.85^{b}	17.29^{c} (282.02)
12	11.51^{hi}	0.15^{a}	17.87^{gh}	17.79^{ab}	82.21ab	6.63^{b}	18.30^{c} (317.03)
13	14.50^{efgh}	0.15^{a}	1.95^{efgh}	5.16^{bc}	94.84ab	4.99^{b}	37.07^{abc} (1333.4)
14	17.17^{bcdefg}	0.17^{a}	29.60^{bcde}	13.58^{abc}	86.41ab	18.49^{a}	15.90^{c} (255.9)
15	19.51^{abcd}	0.17^{a}	34.21^{abc}	6.82^{abc}	93.17ab	10.70^{ab}	34.83^{bc} (1127.2)
16	15.53^{cdefgh}	0.16^{a}	24.84^{defg}	20.27^{a}	79.72b	7.68^{b}	17.37^{c} (300.02)
17	23.15^{a}	0.17^{a}	40.27^{a}	18.23^{ab}	81.77ab	11.91^{ab}	25.90^{c} (647.9)
18	17.86^{bcdef}	0.18^{a}	32.55^{abcd}	17.85^{ab}	82.14ab	8.73^{b}	17.91^{c} (306.14)
19	20.57^{ab}	0.17^{a}	35.30^{ab}	0.00^{c}	100.00a	-	-
20	19.14^{abcde}	0.17^{a}	33.34^{abcd}	0.00^{c}	100.00a	-	-

* Square root transformation is $\sqrt{x} + 0.5$

** Values in parenthesis indicates the original values

Highest Per cent phosphorus derived from soil (%Pdfs) with 100 per cent was observed in grain from control followed by T_{13} and T_4 and lowest in T_{16} (*kole* soil treated with 90:67.5:135 kg NPK/ha without organics) with 79.72 per cent.

4.4.5.4.1 Per cent uptake of applied P fertilizer

Per cent uptake of applied P fertilizer was highest with T_{14} (*kole* soil treated with 90:22.5:90 kg NPK/ha + Pongamia leaves @ 5 tha^{-1}) with 18.49 per cent closely followed by T_{17} and T_{15}. The lowest value was obtained in T_4 with 3.35 per cent.

4.4.5.4.6 A value

The data are presented in Table 4.24. The highest A value of grain was recorded inT_7 i.e., laterite soil treated with 90:67.5:135 kgha^{-1} NPK without organics (97.13 mgpot^{-1}). The lowest value was recorded in T_3 with 12.81 mgpot^{-1}.

4.4.5.5 Per cent uptake of applied P fertilizer at harvest (Total)

Per cent uptake of applied P fertilizer was calculated by summing up of the uptakes by all plant parts of rice at harvest. The data are presented in the table 4.25. Significant difference was observed between the treatments.T_{14} i.e., *kole* soil treated with 90:22.5:90 kgha^{-1} of NPK along with Pongamia leaves @5 tha^{-1}was superior to the rest of the treatments with the highest percentage uptake of applied fertilizer (37.22 %).It was followed by T_{17} with same soil and highest fertilizer schedule with pongamia leaves @5 tha^{-1} (21.87 per cent) and T_{15} with 21.08 per cent. The lowest value was recorded in T_4 (laterite soil treated with 90:22.5:90 kgha^{-1} without organics) with 6.32 per cent. But highest uptake of applied P fertilizer (14.11 mgpot^{-1}) was registered in T_{17}, i.e., *kole* soil treated with 90:67.5:135 kgha^{-1} of NPK along with Pongamia leaves @5 tha^{-1} which was superior to the rest of the treatments. It was followed by T_{18} (11.31 mgpot^{-1}). The lowest uptake was in T_4 (1.36 mgpot^{-1}).

Table 4.25 Available phosphorus and iron status of the soil after harvest of rice

T.No	Available P of soil after harvest ($mgkg^{-1}$)	Available Fe of soil after harvest ($mgkg^{-1}$)
T_1	14.2^a	374^a
T_2	15.9^a	384^a
T_3	15.30^a	380^a
T_4	13.80^a	379^a
T_5	15.30^a	384^a
T_6	15.10^a	374^a
T_7	14.90^a	370^a
T_8	16.80^a	380^a
T_9	16.10^a	375^a
T_{10}	11.30^a	427^a
T_{11}	13.90^a	429^a
T_{12}	12.80^a	432^a
T_{13}	11.00^a	430^a
T_{14}	13.10^a	431^a
T_{15}	12.40^a	433^a
T_{16}	14.10^a	424^a
T_{17}	16.70^a	429^a
T_{18}	15.30^a	432^a
T_{19}	13.10^a	435^a
T_{20}	9.80^a	389^a

4.5 AVAILABLE PHOSPHORUS AND IRON STATUS OF THE SOIL AFTER HARVEST OF RICE CROP

Data on the available P and Fe status of the soil are given in table 4.25. With regard to available P status of soil, there was no significant difference between the treatments. However, T_8 recorded the highest available P of 16.8 $mgkg^{-1}$ and control treatment T_{20} and T_{19} had lowest value of 9.8 $mgkg^{-1}$ and 13.1 $mgkg^{-1}$, respectively. In the case of iron content also there was no significant difference between the treatments. In general, iron content was more in kole soil than lateral soil. The Fe content of soil was highest in T_{19} with 435 $mgkg^{-1}$.

Discussion

V. DISCUSSION

One pot culture experiment entitled "Influence of phosphorus on absorption and dynamics of nutrients in rice" was conducted in the Radiotracer Laboratory, College of Horticulture, Kerala agricultural University, Vellanikkara during December 2002 to April 2003. The experiment consisted of 18 treatments with two soil types – kole and laterite, three fertilizer levels and three levels of organics. The results pertaining to the study are discussed below.

Integrated nutrient supply through judicious combination of organic and biological sources along with inorganic fertilizers has a large number of agronomic and environmental benefits over inorganic sources alone and it is a concept that is ecologically sound and leading to sustainable agriculture (Swaminathan, 1987). Since nutrient availability is a major factor in biomass productivity and ecosystem stability a clear understanding of the process contributing to nutrient exchanges in the soils and arriving at an optimum integration of organic and inorganic nutrient sources become necessary. The efficiency of plant biomass synthesis and rate of return of this biomass to the soil ecosystem also controls productivity (Tate, 1987).

5.1 INFLUENCE OF TREATMENTS ON PLANT GROWTH AND RELATED CHARACTERS

Almost all treatments, regardless of inorganics or inorganics in combination with organics such as *Ung (Pongamia glabra)* and rice straw, produced significantly better plants in terms of height and number of tillers as compared to absolute control in *kole* and laterite soil at different stages of the crop growth (Table 4.1). Increase in height is a direct expression of plant growth and is highly related to nutrients taken up by plants. However, in almost all stages of the crop growth, the plant height was more with inorganics in combination with Pongamia leaves compared to inorganics with rice straw alone. This might be due to addition of nutrients by decomposition of Pongamia and rice straw. The concentrations of major nutrients in Pongamia and rice straw are relatively well balanced, but rice straw has less concentration of major nutrients with high and wide C: N ratio compared to Pongamia leaves. Bridgit (1999) reported that the excess amount of iron in the rhizosphere limits rice growth in laterite and *kole* soils. Wider range in tiller production is accompanied by 80 per cent of their conversion to productive tillers. This would appear as an expression of response to favourable additive inputs (Datta, 1981). Whereas heavy tiller production with limited conversion of productive tillers appears to be the expression of dominating influence of unfavourable factors like high acidity, high iron contents in the soil, etc. Musthafa (1995) has found heavy declines of non productive tillers as an unfavourable influence of iron and suggested that it is a mechanism of avoiding excess accumulation of Fe and to shed one kg of Fe, the crop loses 14 kg N and 5 kg P, which inturn leads to absence of response to nitrogen and phosphorus. Thus, it appears that *kole* and laterite soils require ameliorative management to increase rice production. In the present study, highest dose of inorganics in combination with organics could not bring about corresponding increase in grain and straw production indicating the influence of unfavourable factors.

Chlorophyll content *viz.*, chlorophyll '*a*', chlorophyll '*b*' and total chlorophyll are important parameters, which decides the photosynthetic efficiency and ultimately the yield of the crop (Table 4.3 and table 4.4). At panicle initiation stage and at 50 per cent flowering, the chlorophyll '*a*' and total chlorophyll was maximum with T_{11} (Table 4.3). The corresponding yields of this treatments (T_{11}) were high. In other treatments, the low chlorophyll content might due to high iron content in plants. So the data showed that even physiological parameters failed to relate the yield. Absence of relationship of chlorophyll '*a*' to yield may suggest that yield of grain is probably, only the result of translocation of photosynthates to the spikelets from the earlier formed vegetative portions. Jacob (1994) and Musthafa (1995) reported that the entire chlorophyll 'a' get destroyed by flowering of rice grown in laterite soil. Bridgit (1999) reported similar observation in both laterite and *kole* soil. Chlorophyll '*a*' is the precursor of chlorophyll '*b*' and a decline in the level of chlorophyll '*b*' is indicative of instability and stress

(Sindhu, 2002). Leaf sap is considered as a physiological index of crop productivity. Marykutty *et al.* (1992) have reported that leaf sap pH should be around 6.2 for maximum productivity. Results in the present study (Table 4.4) have indicated that laterite soil treated with 90:45:45 kgha^{-1} of NPK without organics, the leaf sap pH was more acidic in both stages *i.e.*, at panicle initiation and at 50 per cent flowering. The higher pH of leaf sap has also reported to be due to non-metabolic accumulation of heavy metals like Fe (Singh, 1970) and also the higher cell sap pH have been identified as an index of physiological malfunctioning and treatment to keep down pH levels of leaf sap have been found to reduce stress of excess content of elements such as Fe and increase the yield (Dungarwal *et al.*, 1974).

5.2 YIELD AND YIELD ATTRIBUTES

The data on the grain and straw yield as influenced by various treatments showed (Table 4.5and table 4.6) that the highest grain yield was observed in T_{11} (*kole* soil treated with 90:45:45 kgha^{-1} of NPK along with 5 tha^{-1} of Pongamia leaves). The straw yield was also significantly higher in T_{11} indicating that there was proper nutrient release into the soil solution and corresponding uptake and utilisation within the plant by efficient use of organic sources *(Pongamia)* when combined with inorganic sources.

Grain yield in rice is a product of number of productive tillers, number of spikelets per panicle, test weight of seeds and fertility percentage. Each of these characters can be influenced by the variations in input sources consequently resulting in yield variation. The yield was highest in T_{11} (*kole* soil treated with 90:45:45 kg NPK/ha with 5 t ha^{-1} of Pongamia leaves) and followed by T_{17} (*kole* soil receiving 90:67.5:135 kg NPK/ha with 5 t ha^{-1} Pongamia leaves). The increase in the yield was mainly due to more number of productive tillers, more spikelets per panicle, high test weight, and low percent of chaff.

Mureta (1969) has reported that the number of florets is the most important parameter in deciding high yield. Thus, the low yield in control of both laterite and *kole* soils, T_3 and T_1 are due to the combined effect of low productive tillers, comparatively less number of spikelets per panicle and high chaff percentage.

5.3 ELEMENTAL COMPOSITION OF RICE PLANT

The variations in plant elemental status due to the effect of treatments are shown in Table (Table 4.7, 4.8,4.9,4.10, 4.11,4.12,4.13,4.14 and 4.15,). The elemental composition of plants is indicative of the amount of available nutrients in the soil.

In all treatments, the nitrogen contents of the plant were reasonably high at maximum tillering, different plant parts at 50 per cent flowering and at harvest., All treatments were on par with respect to N contents of the plants at maximum tillering. The highest concentration of nitrogen was recorded with T_{17} with 3.11 per cent and in T_{18} with 3.01 per cent. But increase in nitrogen content of the plant with higher dose of phosphorus and potassium could be due to the positive interaction between the N, P and K (Tisdale *et al.*, 1997). In plants, receiving Pongamia leaves with inorganic nutrients, the N content was comparatively higher than the pots receiving inorganics alone and inorganics in combination with rice straw. This might be due to rapid decomposition of pongamia leaves leading to the release of organic acids and other nutrients which inturn have enhanced the N uptake. Thus, higher leaf content of N may counteract more effectively iron in laterite and *kole* soils (Bridgit, 1999). The higher grain and straw yield might be due to increased N uptake consequent to reduction of ill effects of Fe toxicity with Pongamia leaves incorporation.

With regard to P content, the control treatment showed the lowest P content at all stages. The maintenance of P at a higher level by treatments involving Pongamia leaves was indicative of the higher bioavailable P content in the Pongamia leaves as well as increase in native available P by dissolving the unavailable form of P by organic acids produced by decomposition of Pongamia leaves. Similar results were reported by Joseph (1994), wherein the uptake of P was seen increased considerably by Sesbania in combination with amophos application. Increased availability of P in Pongamia incorporated treatments have been reported by several scientists (Prabhakar *et al.*, 1972, Hundal *et al.*, 1987, Singh, 1988). The relatively lower concentration of P in rice straw applied pots might be due to slow rate of decomposition of rice straw.

Potassium does not form an integral part of any plant component and its function is catalytic in nature. Potassium content at MT, 50 per cent flowering and at harvest was higher in plants, those received inorganics along with Pongamia leaves than those which received inorganics along with rice straw. (Table 4.7). The low concentration of potassium in rice straw incorporated pots, might be due to the high content of silica in rice straw resulting in the formation of potassium silicate, which renders K unavailable. The low K uptake with rice straw application has been observed by Islam and Saha (1969).

Calcium (Ca) uptake by the crop in Pongamia and rice straw incorporated pots was higher compared to control in all stages and in all parts compared to inorganic alone and control (Table 4.7,4.8,4.9,4.10, 4.11,4.12,4.13,4.14 and 4.15,). This is due to increased content of the element in the plant due to better use efficiency of the nutrient. The low Ca content in no-organic treatments may be due to antagonism between K and divalent cation Ca. It is in conformity with the reports of Muralidharan and Jose (1994). But high Ca content in Pongamia and rice straw incorporated along with inorganics might be due to release of some organic acids which could enhance the Ca uptake by rice plants. It is reported that the absorption of an element is influenced by elemental interactions in the soil (Lindsay, 1979).

Content of Mg also showed differences with treatments. At maximum tillering stage (Table 4.7), plants receiving high potassium 135 $kgha^{-1}$ *i.e.*, T_7 and T_{16} (*i.e.*, 90:67.5:135 kg NPK without organics) showed lower Mg content. This was possibly by high concentration of potassium in soil, which antagonised the uptake of Mg.

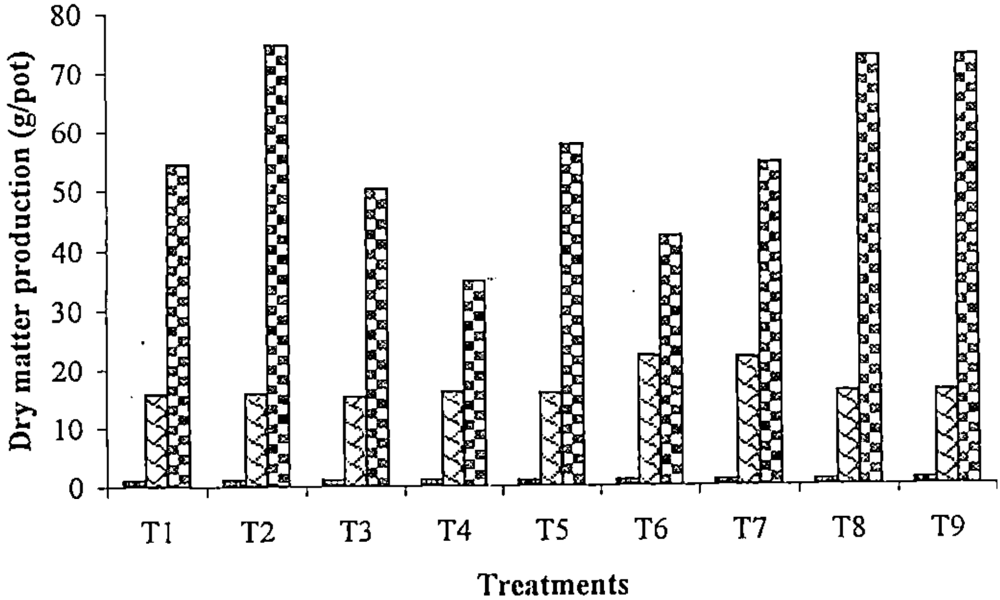

Fig. 1a . Effect of treatments on dry matter production of rice in laterite soil at different intervals

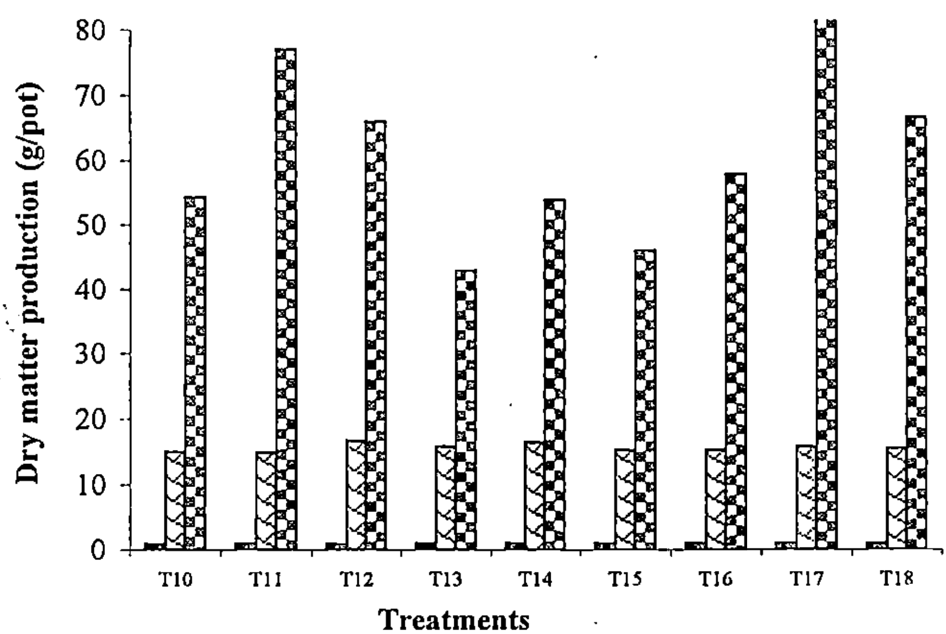

Fig. 1b . Effect of treatments on dry matter production of rice in kole soil at different intervals

The sulphur content of plants showed little variation with treatments. At maximum tillering stage (Table 4.6). The content of S was higher in treatments Pongamia and rice straw applied along with inorganic fertilizers. In control irrespective of the parts and stages of the growth sulphur content was low. This is because of the reaction of sulphur with iron in the soil and plant, which resulted in the decreased availability. So in control, the plant content of iron was higher which limited the availability of sulphur to the crop.

The content of iron in plants at maximum tillering was high in all treatments, but in later stages there was reduction in iron content (Table 4.7). Higher doses of P and K without organics increased iron content of plant at maximum tillering stage, whereas the treatments consisting of inorganics with rice straw application and Pongamia application decreased the iron content in plants. The influence of K and rice straw in decreasing Fe content through mutual competition has been well established (Singh and Singh, 1990, Lakshmikanthan, 2000). Bridgit (1999) also reported that the higher availability of Fe in soil and its excessive accumulation in plants is suspected to be one of the reasons for low fertilizer response resulting in low rice yield in Kerala. Iron is also reported to be inhibiting K uptake by rice plants.

5.4 EFFECT OF LABELLED PHOSPHATIC FERTILIZERS WITH ORGANICS ON THE UTILIZATION OF THE APPLIED AND NATIVE SOIL PHOSPHORUS

5.4.1 Dry matter production

The dry matter productions of rice at different stages are depicted in figure. 1a and 1b.

At maximum tillering stage, the dry matter accumulation was slow. This might be due to low light interception in early stages. The dry matter production was maximum with T_2 which received 90:45:45 kgha^{-1} of NPK along with Pongamia leaves@ 5 t ha^{-1} which is comparable with all other treatments receiving Pongamia leaves.

Increase in dry matter production is an expression of plant growth, which in turn is indirectly related to nutrient taken up by the plants. However, in all most all stages, the dry matter production was maximum with inorganic in combination with Pongamia leaves compared to inorganic with rice straw.

The increase in dry matter production in Pongamia leaves incorporated with inorganic fertilizers might be due to addition of nutrients due to decomposition of Pongamia leaves, increased the availability of fertilizer, soil phosphorus due to release of P from insoluble Fe and Al phosphates. This inturn might be due to complexing effect of organic compounds and improved physical condition of the soil. The concentration of major nutrients in Pongamia leaves and rice straw is well balanced, but rice straw has less concentration of major nutrients compared to Pongamia leaves. Sadanandan *et al.* (1980) reported that the dry matter production of paddy was increased with increased levels of P application along with organics in different soil. The excess amount of iron in the rhizosphere of rice limits rice growth in laterite and *kole* soils (Bridgit, 1999).

5.4.2 Phosphorus uptake

Phosphorus uptake by the crop increased considerably by *ung (Pongamia glabra)* leaves along with NPK fertilizers followed by NPK fertilizers along with rice straw. At maximum tillering stage, the maximum uptake of P was obtained with T_8 and T_{12} (Table 4.6) At harvest also; the grain had the highest concentration of P of 0.184 per cent in T_8 of laterite soil, and in T_{18} of *kole* soil with 0.182 per cent. This increased availability of P due to incorporation of organics. Walunjkar and Acharya (1955) observed an increase in total phosphorus as a result of application of super phosphate in conjunction with FYM and compost. The greater responses of phosphatic fertilizers when applied with organics might be attributed to multiple factors such as complexing of organic compounds and release of organic acids.

Readily available P in fertilizer might remain in safe custody of organic molecules by absorption and adsorption and thus its unavailable forms would be

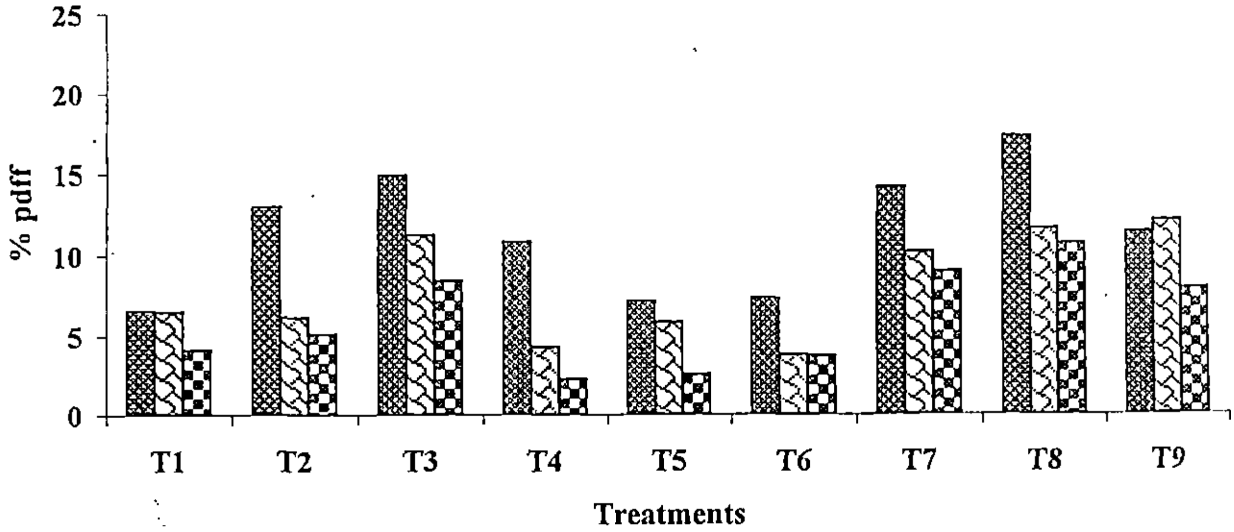

Fig. 2a . Effect of treatments on per cent phosphorus derived from fertilizer (% pdff) in laterite soil at different intervals

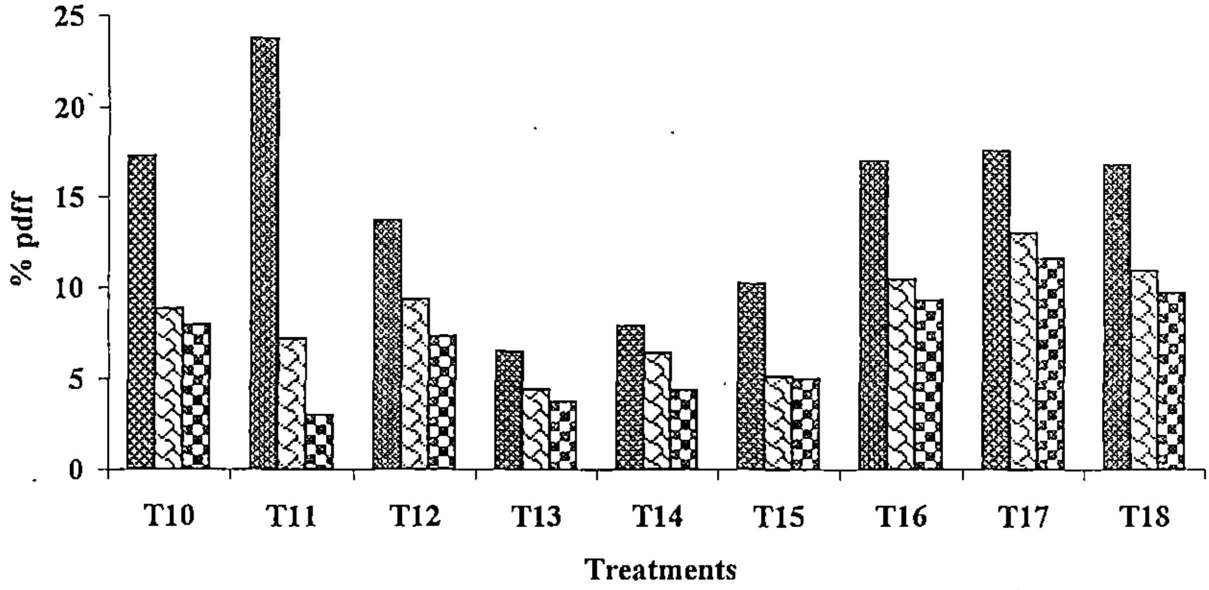

Fig. 2b . Effect of treatments on per cent phosphorus derived from fertilizer (% pdff) in kole soil at different intervals prevented (Russsel, 1964). Organic anions formed during organic matter decomposition such as citrates, tartarates and oxalates might release phosphate ions by exchange and would make it more available to the crops (Tisdale *et al*, 1997). Apart from that, decaying organic matter form a complex on iron and aluminium compounds, which prevent the reaction with soluble phosphate compounds with iron and aluminium (Brady, 2001).

5.4.3 Percent phosphorus derived from fertilizer (%Pdff)

With regard to P in rice derived from labelled single super phosphate, significant differences were noticed in all the intervals, (Table 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23 and 4.24 and figure 2a and 2b).

Phosphorus in plants derived from labelled single super phosphate showed a decreasing trend from maximum tillering to harvesting stage. At the maximum tillering stage, maximum % Pdff was with T_{11} having *kole* soil treated with 90: 45:45 $kgha^{-1}$ of NPK along with Pongamia leaves @ 5 tha^{-1} and in laterite soil T_7 recorded the maximum % Pdff .The per cent Pdff was low at harvest with different parts compared to maximum tillering. (Figure. 3a and 3b). It was revealed by the present study that there was a decrease in % Pdff with advancement in stages of crop growth. The decrease in % Pdff would directly indicate that the absorption of P by the rice crop from the fertilizer source was of greater magnitude at the early stage and decreased gradually with advancement in the crop growth. This might probably be due to the conversion of easily soluble form of P to difficultly available forms with passage of time. The conversion of easily soluble form of P to difficultly available forms in submerged soil was reported by several workers, (Ponnamperuma, 1972; Patrick *et al.*, 1985 and Joseph, 1994). Maximum % Pdff was showed by the treatment of P along with organics, which suggest that addition of organics or green manure should be considered for its long term rather than of short term benefit as far as phosphorus availability is concerned.

5.4.4 Percent phosphorus derived from soil (%Pdfs)

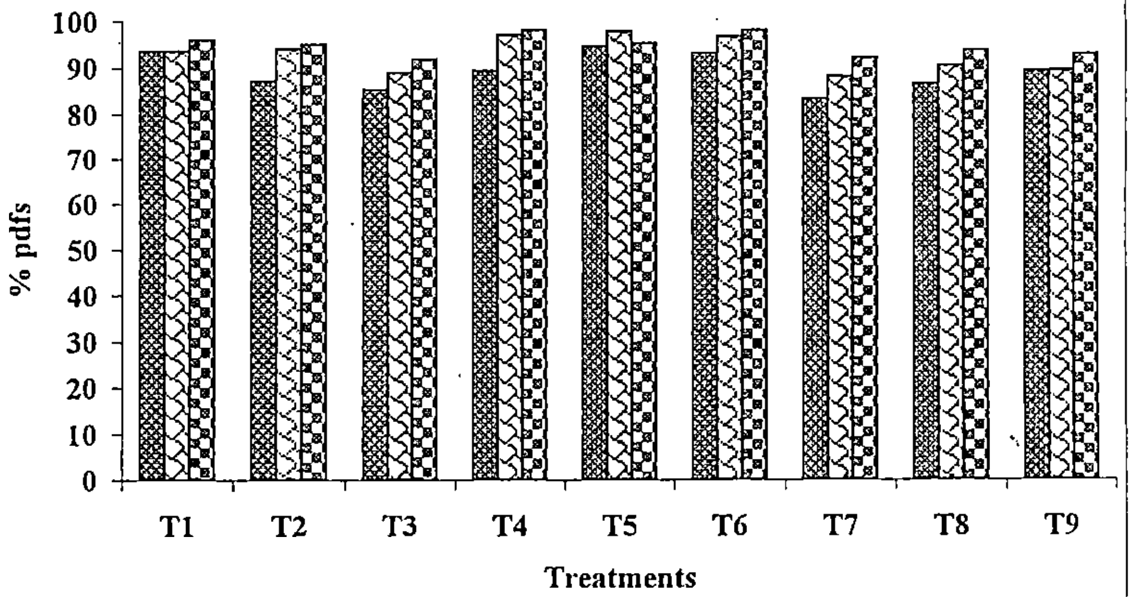

Fig. 3a . Effect of treatments on per cent phosphorus derived from soil (% pdfs) in laterite soil at different intervals

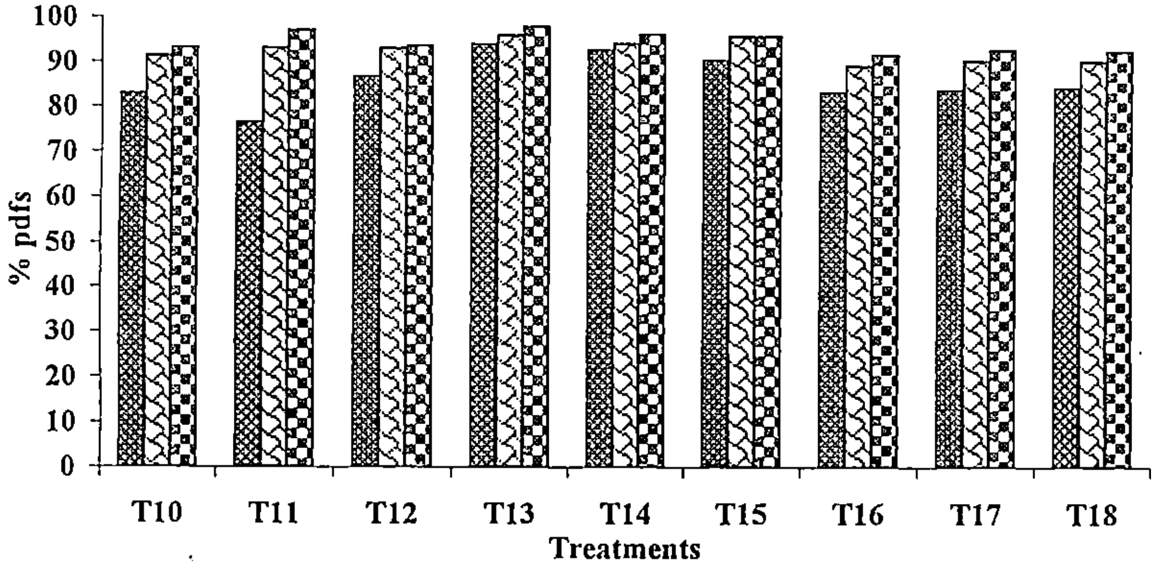

Fig. 3b . Effect of treatments on per cent phosphorus derived from soil (% pdfs) in kole soil at different intervals

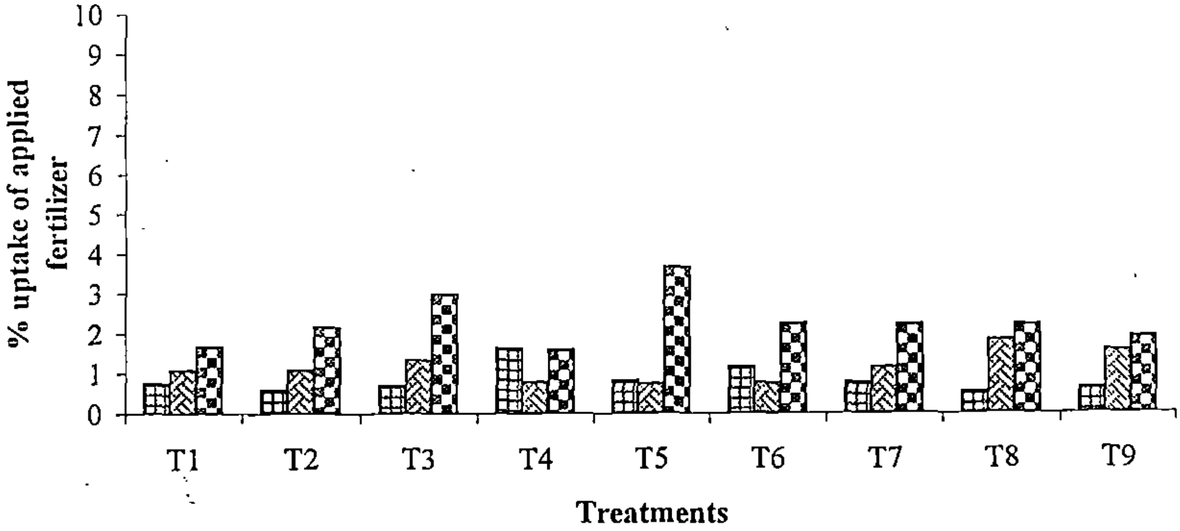

Fig. 4a. Effect of treatments on per cent uptake of applied P fertilizer in laterite soil at different intervals

Maximum tillering **50% flowering** **Harvest**

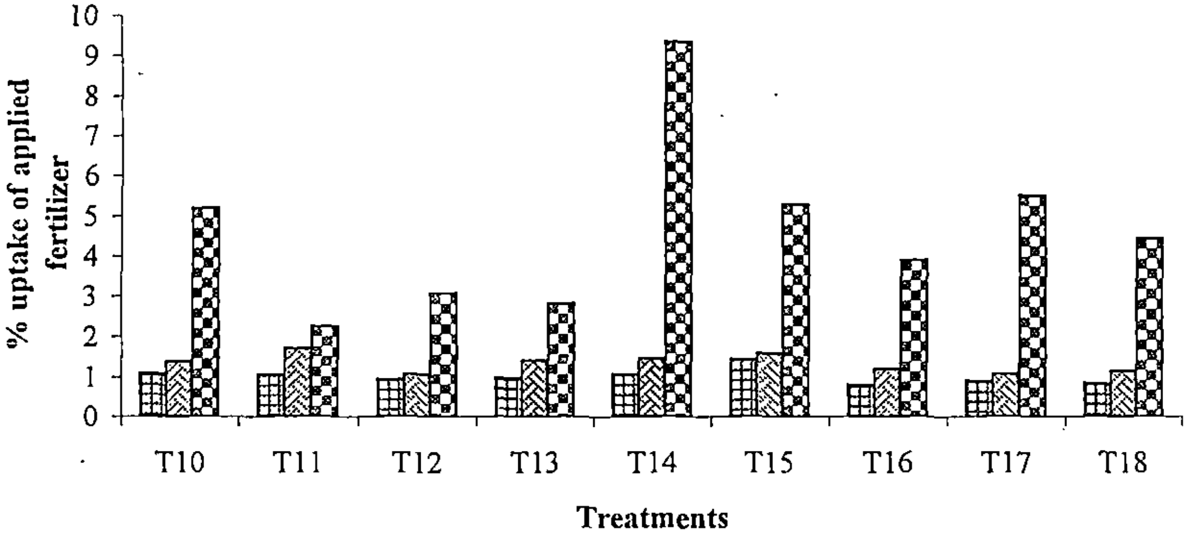

Fig.4b . Effect of treatments on per cent uptake of applied fertilizer in kole soil at different intervals

Maximum tillering **50% flowering** **Harvest**

In case of phosphorus derived from soil (% Pdfs) is presented in table (Table 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23 and 4.24) and the average % Pdfs at different intervals are depicted in figure 3a and 3b. There was significant difference between most of the treatments in all stages. Phosphorus in plants derived from soil showed an increasing trend from maximum tillering to harvesting stage. This might be due to availability of phosphorus to rice plant from native soil phosphorus on submergence and the release of various of organic acids by organics might have contributed towards the solublization of soil native phosphorus. Choudhury and Maitra (2001) reported that the release of these organic acids from organics have some positive effect on the solubilzation of native soil phosphorus or reduced the fixation of P.

5.4.5 Percentage uptake of applied fertilizer

The percentage uptakes of applied fertilizer of rice at different stages with parts are given in tables 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23 and 4.24) and the averages are depicted in figure 4a and 4b as per different stages with respect to soils. There was a significant difference between the treatments. The per cent uptake of P from labelled single super phosphate was showing as increasing trend from maximum tillering to harvesting stage in all treatments. In all stages and also in all parts, organics along with NPK gave maximum per cent uptake of applied fertilizer. At maximum tillering stage, *kole* soil receiving 90:45:45 $kgha^{-1}$ of NPK along with Pongamia leaves @ 5 tha^{-1} (T_1) had the highest per cent uptake of applied fertilizer and also at harvest, *kole* soil receiving 90:22.5:90 $kgha^{-1}$ of NPK along with Pongamia leaves @ 5 tha^{-1} (T_{14}) was superior one compared to other treatments. And the average percent uptake of applied fertilizer was given in figure 5a and 5b. There also, the treatment received NPK along with organics such as Pongamia and rice straw gave highest values. This might be due to organics on decomposition release organic acids, which regulate the availability of phosphorus from applied fertilizer by preventing the formation of unavailable form of Fe-P and Al-P.

Joseph (1994) reported similarly as when amophous applied along with sesbania green manure, the percent uptake of applied fertilizer was in increasing trend through out the period of crop growth. Hashimoto and Tasuji (1973) also reported that 10 to 15 per cent of P recovery of P added through labelled rock phosphate by the maize crop. And also, the percentage uptake of applied fertilizer showed a decreasing trend with the increasing level of applied fertilizer phosphorus from 22.5 $kgha^{-1}$ to 67.5 $kgha^{-1}$. At 22.5 $kgha^{-1}$ of P level, there might be enough competition between the plants to take up P from limited P supply leading to higher utilization of applied P.But still higher level of phosphorus dose such as 67.5 $kgha^{-1}$ did not lead to proportionate increase in the uptake of applied P causing lower utilization compared to 22.5 kg level.The level of phosphorus @ 45 $kgha^{-1}$ was in between these two. Similar results were reported by Dravid and Goswami (1988), Singh *et al* (1994) and Joseph (1994).

5.4.6 A value

A value *i.e.* P availability index at different stages of rice growth is presented in tables 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23 and 4.24. At maximum tillering stage, highest A value was with T_1 of laterite soil and leaf sheath of rice at 50 per cent flowering, T_5 of laterite soil had maximum A value. All treatments were getting different A value. Actually, A value is constant for a specific soil, crop and growing situation (Vose, 1980). But in present investigation A value was different with different treatments In experiments where the labelled fertilizer standard is banded in the soil, the magnitude of the A value can be expected to change with time owing to the continual expansion of the plant root system (IAEA, 1976).

5.4.7 AVAILABLE PHOSPHORUS AND IRON STATUS OF THE SOIL AFTER HARVEST OF RICE CROP

The available P and available Fe of the soil after the harvest of rice (Table 4.25) showed no significant difference between treatments.

In laterite soil, application of 67.5 $kgha^{-1}$ of phosphorus along with Pongamia leaves @ 5 tha^{-1} registered higher concentration of phosphorus in soil. It was seen that in pots where phosphorus was applied alone, the values were much lower than that in pots where organics with phosphatic fertilizers.

Higher dry matter production obtained by the combined application of organics along with inorganic fertilizer might have caused higher amounts of P absorption by the crop, and hence have lead to the consequent decrease in the phosphorus content of the soil.

During decomposition process of organic residue, through large amount of P might be released into the soil (Nagarajah *et al.*, 1986). The crop uptake might have caused its subsequent depletion from the soil. The uptake of P has been found to be higher from organics along with inorganic fertilizer treatments and this resulted in the lower available content of these elements in the soil at the post harvest stage. The low available P content of the soil where only inorganic phosphorus fertilizer was applied might be due to the depletion of the nutrients from the soil.

Post harvest status of available iron content in soil revealed higher available value in control (both *kole* and laterite soil) compared to other treatments.This might be due to submergence. Ponnamperuma (1972) also reported that when a soil is flooded, iron (III) oxides are reduced and large amount of Fe^{2+} ions are brought into solution. The concentration of Fe^{2+} ions in reduced soils ranged from 0.07 to 6600 $mgkg^{-1}$. The increase in water-soluble Fe^{2+} ions is an important benefit of flooding Fe deficient rice soil. It is not only eliminates iron deficiency in such soil but also depresses manganese toxicity in acid soil (Ponnamperuma, *et al.*, 1955). The treatments consisting of organics along with inorganic fertilizers comparatively showed low iron content than control. This might be due to precipitation or complexation reaction of Fe^{2+} with organic compounds resulting in disappearance of Fe^{2+} from the soil. The influence of K and rice straw in decreasing Fe content through mutual competitions has been well established (Singh and Singh, 1990 and Lakhsmikanthan, 2000).

Summary

VI. SUMMARY

A pot culture experiment was carried out during the *punja* season, December 2002 to April 2003 at the Radiotracer Laboratory, College of Horticulture, Kerala Agricultural University, Vellanikkara, to work out the efficiency of applied phosphatic fertilizer, to asses the contribution of phosphorus release from labelled phosphatic fertilizer to the P nutrition of rice and to study the effect of Pongamia and rice straw on the utilization of applied and native soil phosphorus. The important observations made and the conclusions drawn from them are presented here.

Growth, yield and elemental composition of rice

During the early stages of growth, the treatment having 90:67.5:135 $kgha^{-1}$ NPK along with Pongamia leaves @5 tha^{-1} in *kole* soil (T_{17}) recorded the highest plant height and tiller number while in the later stages, plant height and tiller number were more in the treatment receiving 90:45:45 $kgha^{-1}$of NPK along with Pongamia leaves @5 tha^{-1} in *kole* soil (T_{11}).

In case of Chlorophyll content, Chlorophyll 'a' and total chlorophyll were highest in T_{11} *ie*., *kole* soil treated with 90:45:45 $kgha^{-1}$ NPK along with Pongamia leaves @5 tha^{-1} at panicle initiation stage and at 50 per cent flowering.

The cell sap was more acidic in treatments with pongamia in both laterite and kole soil at panicle initiation stage and at 50 per cent flowering with a favourablel p^{H} of 6.26 in T_{11}

Among the yield attributing characters, number of productive tillers and number of spikelets per panicle showed significant increase in kole soil treated with 90:45:45 $kgha^{-1}$ NPK along with Pongamia leaves @5 tha^{-1} (T_{11}). Highest grain and straw yield were also recorded in T_{11}.

The fertilizer schedule of 90:45:45 $kgha^{-1}$ NPK along with Pongamia leaves @5tha^{-1}gave the highest plant content of N (3.20 %) in laterite soil (T_2) and 3.11 per cent in *kole* soil (T_{11}). Plant content of phosphorus and potassium were highest in treatments having inorganics in conjunction with Pongamia at all stages of growth.

Iron content in plants was found to be reduced with advancement in crop growth stages. Treatment with the highest fertilizer schedule of 90:67.5:135 $kgha^{-1}$ NPK along with Pongamia @5 tha^{-1} (T_{17}) recorded the lowest iron content at maximum tillering while the same treatment retained higher iron content compared to other treatments at harvest.

Effect of organics on the labelled phosphatic fertilizer

Percent phosphorus derived from fertilizer (%Pdff) had highest value at maximum tillering stage and thereafter it decreased. T_{11} recorded the highest %Pdff of 23.72 at maximum tillering stage. When the applications of inorganics with and without organics are compared in laterite and kole soil, application of single super phosphate with organics always gave highest %Pdff than with single super phosphate alone. Laterite soil treated with 90: 67.5: 135 $kgha^{-1}$ NPK along with Pongamia leaves @ 5 tha^{-1} obtained 10.68 %Pdff and the same treatment in *kole* soil had 12.96per cent of %Pdff at harvest.

Percent phosphorus derived from soil (%Pdfs) was low at maximum tillering and thereafter it increased upto harvest. At maximum tillering, laterite soil treated with 90:22.5:90 $kgha^{-1}$ NPK with pongamia @5 tha^{-1} (T_5) gave the highest %Pdfs of 94.15per cent followed by the same fertilizer schedule without organics in *kole* soil (T_{13}) with 93.51per cent. At 50per cent flowering and at harvest, both soils treated with 90:22.5:90 $kgha^{-1}$ of NPK with or without organics recorded more %Pdfs.

Percent uptake of applied P fertilizer by the plant had an increasing trend from maximum tillering to harvest, but with a declining trend with the increasing levels of phosphorus from 22.5 $kgha^{-1}$to 67.5 $kgha^{-1}$. *Kole* soil treated with 90:22.5:90 $kgha^{-1}$ NPK along with Pongamia leaves @5 tha^{-1} (T_{14}) recorded 37.22 per cent.

The available P and available Fe content of soil after harvest of rice crop showed variations between the treatments. Laterite soil treated with 90:67.5:135 $kgha^{-1}$ of NPK along with Pongamia leaves @ 5 tha^{-1} (T_8) registered highest concentration of available P of 16.8 $mgkg^{-1}$ followed by the same treatment in *kole* soil with 16.7 $mgkg^{-1}$. Available iron content of soil after harvest was more in treatments having Pongamia in laterite soil while it was more in rice straw applied treatments in *kole* soil.

Conclusion

From the results, the organics-Pongamia and rice straw in conjunction with inorganics always led to consistent supply of nutrients resulting in enhanced yield in both *kole* and laterite soil.

Though Pongamia along with inorganics is an ideal fertilizer schedule for rice crop in terms of yield, when the cost of incorporation of Pongamia is considered, rice straw along with inorganics is more profitable and convenient.

The inorganics met with the initial P requirement of the crop while organics enabled the slow and steady release of unavailable and slowly available fractions of P in the later stages of the crop growth.

The percentage P uptake was always highest in the treatment with Pongamia plus lowest dose of P while % Pdff was highest with Pongamia plus medium dose of P (*ie.* Present recommendation) indicating that enhancing the P dose further is not advantageous to the crop.

References

REFERENCES

Agarwal, S., Singh, T.A. and Bharadwaj, V. 1987. Inorganic soil phosphorus fractions and available phosphorus as affected by long-term fertilization and cropping pattern in Nainital Tarai. *J. Indian Soc. Soil Sci.* 35: 25-28

Alakh, M.S. and Dev, G. 1978. Interaction effect of calcium and sulphur on the growth and nutrient composition of alfalfa (*Medicago sativa* (L.) Pers) using 35 S. *Pl. Soil* 50: 125-134

Alexander, D., Sadanandan, N. and Sasidhar, V.K. 1973. Effect of graded doses of nitrogen and phosphorus on the available phosphorus status of soil during various growth stages of rice. *Agric. Res. J. Kerala* 12: 11-13

Basak, U.K. and Dravid, M.S. 1992. Influence of P-Mg-Zn and moisture on growth and utilization of applied P by rice and wheat. *J. Nuclear Agric. Biol.* 21: 35-40

Battacharya, K.K. and Chatterjee, B.N. 1978. Growth of rice as influenced by phosphorus. *Indian J. agric. Res.* 48: 589-597

Beltran, R., Aceredo, J., Gonzalez, W., Migerel, J., Ceop, S.N. and Hernandez, P. 1982. A study on the effect of rate of P_2O_5 on the yield and yield components of rice. Soils and Fertilizer. *Abstract:* 653

Bhattacharya, D. and Das, B. 1975. Mobilization of iron in soil and its influence on phosphorus availability through the chelating effects of aqueous extracts of some green manuring plant materials. *J. Indian Chem. Soc.* 52: 726-729

Blake, G.R. 1965. *Bulk-Density - Core Method: Methods of Soil Analysis Part I.* American Society of Agronomy, Madision, USA. p.420

Bouldin, D.R. and Black, C.A. 1960. Fertilizer evaluation. Use of ^{32}P labelled fertilizers. *Soil Sci. Soc. Amer. Proc.* 24: 491-496

Bradley, J., Vimpany, I. and Nicholus, P.J. 1984. Effects of water logging and subsequent drainage of a pasture soil on phosphate sorption, extractable phosphate and oxalate-extractable iron. *Aust. J. Soil Res.* 22: 455-461

Brady, N.C. 2001. *The Nature and Properties of Soils.* Tenth edition. Prentice - Hall of India Pvt. Ltd, New Delhi. p.427

Bridgit, T.K. 1999. Nutritional balance analysis for productivity improvement of rice in iron rich lateritic alluvium. Ph.D. thesis, Kerala Agricultural University, Thrissur, India. p.374

Chadrasekaran, N. 1989. Comparative effect of Mussoorie phos and super phosphate on soil properties, yield and quality of rice and succeeding black gram. M.Sc. (Ag.) thesis, Tamil Nadu Agricultural University, Coimbatore, p.286

Chaudhury, J. and Maitra, D.N. 2001. Crop yield and phosphate availability as affected by split application of phosphatic fertilizer. *J. Nuclear Agric. Biol*.36:143-147

Cheng, K.K and Bray, R.H. 1951. Determination of Calcium and Magnesium in soils and plant materials. *Soil Sci.* 8:449-458

Choudhary, M.Y., Ali, S., Zaman, W. and Altamas, S.U. 1978. Effect of Phosphorus and Zinc sulphate on yield and protein content in rice grains. *Indian J. Agric. Chem.* 11: 69-76

De Datta, S.K. 1981. *Principles and Practices of Rice Production.* John Willey and Sons, New York. p.411

De Datta, S.K. 1983. Phosphorus requirements and phosphorus fertilization of lowland rice. *Proceedings of the third International Congress on Phosphorus Compounds, April 24-26, 1982* (eds. Cheng, T., Jhon, K.P., and Yu, T.S). Brussels, Belgium. Institute Monotial du phosphate, Caseblanca, Morocco, pp.401-421

De Datta, S.K. ! Moomow, J.C., Racho, V.V. and Simsiman, G.V. 1966. Phosphorus supplying capacity of lowland rice soils. *Soil Sci. Soc. Amer. Proc.* 30: 613-617

Dayanand, S., Kamath, M.B. and Goswami, N.N. 1976. Effect of lime and phosphate on the uptake and utilization of phosphorus by rice in acid laterite soils. *J. Nuclear Agric. Biol.* 5: 61-64

Deshpande, A.W., Kumbhar, D.D. and Daftarar, S.Y. 1988. Rock phosphate with green manure and FYM as P sources for rice-based cropping system on laterite soils. *J. Maharashtra Agric. Univ.* 13: 10-11

Dravid, M.S. and Goswami, N.K. 1988. Tracer studies on the decomposition of P32 tagged organic matter and nutrient availability relationships in soils. *J. Nuclear. Agric. Biol.*17: 270-279

Dravid, M.S., Rishi, A.K. and Goswami, N.N. 1976. Efficiency of different rock phosphates in acid soils using ^{32}P as a tracer. *J. Nuclear. Agric. Biol.* 5: 32-34

Dungawal, H.S., Mathew, P.M. and Singh, H. 1974. Comparative efficiency of sulphuric acid foliar spray in the prevention of chlorosis in corn (*Zea maize*). *Pl. Soil* 51: 207-216

Fujiwara, A. 1964. Specific role of N, P and K in the metabolism of the rice plant. *Mineral Nutrition of the Rice Plant.* (eds. Khumbhar G.T. and Daftarar, S.Y) IRRI, Oxford and IBH Publishing Co., Calcutta. pp. 318-320

Gosh, G. 1985. Availability of phosphorus in rice soils of Nagaland. *J.Nuclear Agric.Biol.*14: 32-33

Goswami, N.N. and Banerjee, N.K. 1978. Phosphorus potassium and other macro elements. *Soils and Rice.* IRRI, Manila, Phillipines. pp:561-580

Gues, D.J.G. 1954. Means of increasing rice production. *Principles and Practices of rice growing* (eds. Chatterjee, B.N and Maitis, S.). Oxford and IBH publishing Co. New Delhi. pp.168-201

Hart, M.G.R. 1961. A turbidometric method determining elemental sulphur. *Analyst* 86:472-475

Hashimotto, Y. and Tasuji, T.J. 1973. Release of phosphorus from labelled rock phosphate to rice crop. *Soil Manure* 43:203-207

Hundal, H.S., Biswas, C.R. and Vig, A.C. 1987. The utilization of P by rice from different ^{32}P labelled green manures. *Biol. Wastes* 22: 97-105

Hundal, H.S., Dhillon, N.S. and Dev, G. 1992. Contributions of different green manures to P nutrition of rice. *J. Indian Soc. Soil Sci.* 40: 76-81

IAEA. 1976. Technical report series No 171, *Tracer Manual on Crops and Soils.* International Atomic Energy Agency, Vienna, p.277

Islam, A. and Saha, R.C. 1969. Effect of rice straw on the chemical composition of rice plants. *Pl. Soil* 30: 446-45

Ivanov, P. 1975. Reaction of the water-soluble phosphorus in chernozem and green forest soils. *Pochrozn Agrokhim* 10: 30-34

Jackson, M.L. 1973 *Soil chemical analysis*. Prentice-Hall of India Private Limited., New Delhi.p327

Jagadeesan, M., Janakiraman, M., Guruswamy, N. and Palanisamy. 1986. Studies on the relative efficiency of phosphate carriers for rice in acid soils. *Rock Phosphate in Agriculture* (eds. Kothandaraman, G.V., Manickam, T.S. and Natarajan, K.).Proceedings of the national symposium on Rock phosphate in Agriculture,1985. Tamil Nadu Agricultural University, Coimbatore. pp. 58-65

Jocob, B. 1994. Effect of incorporation of crop residues on productivity of succeeding rice crop. M.Sc. (Ag.) thesis, Kerala Agricultural University. Thrissur. p.88

Joseph, P. 1994. Utilization of phosphorus from green manure by rice. M.Sc. (Ag.) thesis, Kerala Agricultural University, Vellanikkara, Thrissur. p.62

Kalita, M.C. and Baroove, S.R. 1994. Effect of phosphorus on some important rice varieties of Assam. *A. agric. Res.* 15: 297-300

Kalyanikutty, T.K. and Morachan, Y.G. 1974. Influence of N, P, K on growth, yield and composition of rice varieties differing in inherent yield potentials. *Madras agric. J.* 61: 239-244

Karuppaiah, V.K.R. and Thangamuthu, G.S. 1986. Study on the efficiency of phosphorus forms in combination with organic manures in low land rice. *Rock Phosphate in Agriculture* (eds. G.V. Kothandaraman, T.S. Manickan, K. Natarajan.) Proceedings of the national symposium on Rock phosphate in Agriculture, 1985. Tamil Nadu Agricultural University, Coimbatore. pp. 209-213

KAU. 2003. *Package of Practices Recommendations Crops-2003.* Directorate of Extension, Kerala Agricultural University, Thrissur, Kerala. p.274.

Krishnappa, M. 1988. Transformation and availability of applied phosphorus in different stages in Alfisols of Mudigere. (eds. Krishnamurthy, K., Rao. B and Badrinath, A) *Proceedings of a Seminar on the use of Rock phosphate in West Coast Soils,1987.* University of Agricultural Sciences, Bangalore, India, pp.32-38

Kumaraswamy, K. and Ramulu, U.S.S. 1991. Relative contribution of inorganic P fraction to the labile P status of soils and uptake by rice. *J. Indian Soc. Soil Sci.* 39: 308-315

Kurumthottical, S.T. 1982. Dynamics and residual effects of permanent manurial experiment of rice. M.Sc. (Ag.) thesis, Kerala Agricultural University, Vellanikkara, Thrissur, India. p.151

Lakshmikanthan, K. 2000. Efficacy of silicon and potassium in the amelioration of iron in rice culture. M.Sc. (Ag.) thesis, Kerala Agricultural University, Vellanikkara, Thrissur, India. p 242

Lal, M. and Mahapatra, I.C. 1979. Phosphate transformation under continuous submergence in rice-barley rotation. *J. Indian Soc. Soil Sci.* 27: 375-382

Latchanna, A., Narsimhulu, H. and Satyanarayanan, V. 1989. Effect of rates and sources of phosphorus on wetland rice. *Indian J. Agron.* 34: 243-245

Lindsay, W.L. 1979. *Chronical Equilibria in Soil.* John Willey and Sons, New York. p.449

Mahapatra, I.C. and Patrick, W.H. 1969. Inorganic phosphate transformation in waterlogged soils. *Soil Sci.* 107: 281-288

Majumdar, D.K. 1971. Effect of sowing time and fertilizers on yield attributes and yield of rice (*Oryza sativa L.). Indian J. Agron.* 16: 6-9

Mandal, L.N. and Khan, S.K. 1975. Influence of soil moisture regimes on transformation of inorganic phosphorus in rice soils. *J. Indian Soc. Soil Sci.* 23: 31-37

Mandal, L.N. and Mandal, K.C. 1973. Influences of organic matter and lime on the transformation of applied phosphate in acidic lowland rice soils. *J. Indian Soc. Soil Sci.* 21: 57-62

Marawaha, B.C. and Kanwar, B.S. 1981. Utilization of ground rock P as a direct fertilizer. J. *Indian Soc. Soil Sci.* 21: 47-59

Marykutty, K.C. 1986. Factors governing response of rice to liming in Kerala soils. Ph.D. thesis, Kerala Agricultural University, Vellanikkara, Thrissur, India. p.308

Marykutty, K.C., Potty, N.N., Anilakumar, K. and Bridgit, T.K. 1992. Stress influence of nutrient ratios on rice productivity. Proceedings of the national seminar on Plant Physiology, June 15-18,1991(eds.Singh.H., Mathur,A.K and Khan,L) Maharastra Agriculture University, Maharastra. pp.169-180

Mathews, R.P. and Jose, A.I. 1984. Effect of submergence on inorganic phosphorus fractions and available phosphorus in two acid rice soils of Kerala. *Agric. Res. J. Kerala* 22: 107-112

Mathur, B.S., Sarkar, A.K. and Mishra, A. 1980. Release of nitrogen and phosphorus from compost charged with rock phosphate. *J. Indian Soc. Soil Sci.* 28: 206-212

Meelu, O.P. and Morris, R.A. 1984. Integrated management of plant nutrients in rich and rice based cropping systems. *Fert. News* 29: 65-75

Mohanty, S.K. and Mandal, C.N. 1989. Transformation and budgeting of N. P and K in soils for rice cultivation. *Oryza* 26: 213-231

Muralidharan, P. and Jose, A.I. 1994. Effect of micronutrients on the uptake of N, P and K in rice. *J. Trop. Agric.* 32: 137-141

Mureta,Y. 1969. *Physiological aspects of rice yield.* Second edition, Prentice-Hall of India private limited, New Delhi. p. 289

Musthafa, K. 1995. Productivity of semi-dry rice under simultaneous in situ green manuring. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur. p.223

Nagarajah, S., Nene, H.U. and Alberto, M.C.R. 1989. Effect of sesbania azolla and rice straw incorporation on the kinetics of NH_4, K, Fe, Mo, Zn and P in some flooded soils. *Pl. Soil* 116: 37-48

Nagarajah, S., Robielos, M.C.G. and Neue, H.U,. 1986. Effect of incorporation sesbania,azolla and rice soil.*International seminar on Azolla and its impacts on rice growing areas in Asia, 12-16 August 1985*.(eds.Peter,T.V and Albert,P) IRRI Manila, Philippines. pp: 241-265

Nair, K.H and Aiyer, R.S. 1988. Phosphorus uptake and use efficiency of monocalcium phosphate and tricalcium phosphate by rice in the acid soils of Kerala. *Proceedings of a seminar on the use of roce phosphate in West coast soils, 22-26 April 1987* (eds. K.Krishnamurthy, K. Balakrishna Rao, Badrinath). University of Agricultural Sciences. Bangalore, pp.102-116

Nair, R.R., Pillai, C.R., Pisharody, P.N. and Gopalakrishnan, R. 1972. Response of rice to graded dose of Phosphorus in connection with magnesium and spartin. *Indian J. Agron.*17: 317-320

Pandey, S.K. and Sinha, M.N. 1987. Effect of labeled isotopic phosphorus with organics on rice yield. *J. Nuclear Agric. Biol.* 16:35

Panse, V.G and Sukhatme, P.V. 1978 *Statistical Methods for Agriculture Workers*. Third edition, Indian Council of Agriculture Research, New Delhi.p.347

Pareek, R.P. and Gaur, A.C. 1973. Release of phosphate from tricalcium phosphate and rock phosphate from organic acids. *Curr. Sci.* 42: 278-279

Pargan, K.S., Chillar, R.K. and Bhumbla, D.R. 1980. Effect of levels of phosphorus and zinc and their residual effect on wheat in sodic soils. *Indian J. Agron.* 25: 514-515

Patel, M.S., Patil, R.G., Zalawadia, W. and Sutaria, G.S. 1992. Effect of phosphorus, moisture and organic matter on phosphorus availability and its fractions in a calcareous clay soil at different incubation periods. *J. Indian Soc. Soil Sci.* 40: 705-710

Patrick, W.H, Mikkelson, D.S. and Wells. B.R. 1985. *Plant Nutrition Behaviour in Flooded Soil: Fertilizer Use and Technology,* Third edition, Soil science society of America, Madision, Wisconsin, p.228.

Patrick, W.H. and Mahapatra, I.C. 1968. Transformation and availability to rice of nitrogen and phosphorus in water logged soils. *Adv. Agron.* 20: 323-359

Perumal R. and Varadarajan, S. 1967. Efficiency of organic and inorganic forms of P on growth and yield of paddy crop. *Madras Agric. J.* 54: 580-586

Pillai, K.G.K., Suseela, Devi, L., Nanjappa, H.V. and Manure, G.R. 1986. Relative efficiency of different sources of phosphorus on cereal based crop sequences. *International Seminar on Rock phosphates in Agriculture, August 23-24, 1985* (eds. Kandasamy O.S. and Balasubramanium T.N.). Tamil Nadu Agricultural University, Coimbatore. pp.18-30

Piper, C.S. 1950. Soils *and Plant Analysis*. Hanse Publishers, Bombay, p.368

Ponnamperuma, F.N. 1972. The chemistry of submerged soils. *Adv. Agron.* 24: 29-96

Ponnemperuma, F.N., Bradfield, R. and Peech, M. 1955. Physiological diseases of rice attributable to iron toxicity. *Nature* 175: 265-298

Prabhakar, A.S., Patil, S.V. and Krishnamoorthy, K. 1972. Influence of organic manures, ammoniacal and nitrate nitrogen on the availability of soil and applied phosphorus. *J. Indian Soc. Soil Sci.* 20: 413-415

Ramankutty, N.N. and Padmaja, P. 1972. Utilization of phosphates in rice soils. *Agri. Res. J. Kerala* 10: 106-111

Ramasami, S. and Vimal, O.P. 1975. Effect of chemically processed bone meal alone and in combination with organic material on plant growth in Rice-Wheat rotation in an alluvial soil. *J. Nuclear Agric. Biol.* 4: 88-90

Rao, K.V.P. and Kumar, K. 1994. Response of rice varieties to P nutrition in an acid alfisol. *Ann. Agric. Res.* 15: 493-494

Rastogi, A.K., Mahajan, J.P. and Sinha, S.B. 1981. Phosphorus utilization by three rice varieties at different stages of growth in a vertisol. *J. Nuclear Agric. Biol.* 10: 48-57

Ru-kun, L., Bai-fan, L. and Ching-Kwei, L. 1982. Phosphorus management for submerged soil. *Proceedings of International Congress on Soil Science, November 15-19,1981* (eds. Mishra, A.N. and Rao, R.S.). Indian Society of Soil Science, New Delhi, pp.1407-1410

Russel, E.W. 1964. *Soil Conditions and Plant Growth.* The English Language Book Society and Green Co., London, p.480

Sadanandan, A.K., Dash, R.N., Mohanty, S.K. and Patnaik, S. 1982. Transformation and availability of added P in different soils in relation to soil moisture and time of application. *J. Nuclear Agric. Biol.* 11: 7-11

Sadanandan, A.K., Mohanty, S.K., Patnaik, S. and Mistry, K.B. 1980. ^{32}P tracer studies on the efficiency of ammonium nitrate phosphate and polyphosphates for growing rice on different soil types. *J. Nuclear Agric. Biol.* 9: 135-138

Sarkar,D and Sarkar, M.C. 1982. Efficiency of Mussoorie rock phosphate for rice in acid soils of Assam. *J. Indian Soc. Soil Sci.* 30: 48-52

Seng, V., Bell, R.W., Willet, I.R. and Nesbitt, H.J. 1999. Phosphorus nutrition of rice in relation to floodiing and temporary loss of soil-water saturation in the low land soils of Combodia. *Pl. Soil.* 207: 121-132

Sindhu, 2002. Effect of nutrient interrelations on productivity of rice in laterite soil. M.Sc.(Ag.) thesis, Kerala Agricultural University,Vellanikkara, Thrissur. p.190

Singh, A.L. 1970. Effect of sulphur in preventing the occurrence of chlorosis in peas. *Agron. J.* 62: 708-711

Singh, D. and Singh, M. 1990. Effect of phosphorus and number of seedlings per hill on growth, yield and yield attributes of rice cultivars. *Crop Res.* 3: 279-280

Singh, P., Datta, O.M and Deo, P. 1994. Effects of P and K on crop yields and soil fertility under rice-rice cropping system. *J. Nuclear. Agric. Biol.*23: 283-288

Singh, P.K., Panigrahi, B.C. and Satapatty, K.B. 1981. Comparitive efficiency of azolla, blue green algae and other organic manures in relation to N and P availability in a flooded rice soil. *Pl. Soil* 62: 35-44

Singh, R., Dubey, S.N. and Srivastava, S.K. 1985. Direct, residual and cumulative response of rice to phosphorus, potassium and farmyard manure. *Indian J. Agron.* 30: 145-149

Singh, R.S. and Dixit, N.K. 1983. Transformation of inorganic phosphorus in soils growing rice. *J. Indian Soc. Soil Sci.* 31: 298-301

Singh, S. and Patiram.S. 1977. Changes in solubility of phosphorus and its availability to rice plant in waterlogged soil. *J. Indian Soc. Soil Sci.* 25: 129-133

Singh, Y. 1988. Availability, transformation and solubility relations of applied phosphorus in calcareous soils in relation to P nutrition.M.Sc.(Ag.) thesis, Punjab Agricultural University,Ludhiana.p.121

Singh,Y. and Beauchamp, E.G. 1986. Nitrogen mineralization and nitrifier activity in limed and urea treated soils. *Plant Anal.*7: 1369-1381

Singh, Y. Singh, B and Khind, C.S. 1992. Nutrient transformation in soils amended with green manures. *Adv. Soil Sci.* 20: 237-309

Singhania, R.A. and Goswami, N.N. 1978. Transformation of applied phosphorus under simulated condition of growing rice and wheat in a sequence. *J. Indian Soc. Soil Sci.* 26: 193-197

Singhania, R.A., Oommen, P.K. and Goswami, N.N. 1976. Transformation of applied phosphorus in neutral to alkaline alluvial and red soils. *J. Nuclear Agric. Biol.* 5: 81-83

Sinha, S.B., Rastogi, A.K. and Mahajan, J.P. 1980. Uptake of fertilizer phosphorus by three rice varieties in a vertisol. *J. Nuclear Agric. Biol.* 9: 139-140

Sreekantan, L. and Palaniappan, S.P. 1990. Radiotracer studies on P use efficiency in rice based cropping system.*J.Agron.Crop Sci.* 165. 14-18

Subbiah, P. 1991. Effect of levels and sources of phosphorus on yield and nutrient uptake of rice (*Oryza sativa*). *Indian J. Agron.* 36: 230-232

Suseelan, P., George, C.M. and Sreedharan, C. 1978. Effect of phosphorus and lime application on rice variety IR-8. *Agric. Res. J. Kerala* 16: 240-241

Swaminathan, M.S. 1987. The role of green manure in rice farming systems. *International symposium on sustainable agriculture 2-4 May 2000* (eds. Bradfield, R and Peech, M), IRRI, Manila, Philippines. pp.25-29

Tate, L. 1987. *Soil Organic Matter - Biological and Ecological Effects*. John Wiley and Sons, New York. p.284

Tisdale, S.L., Nelson, W.L., Beaton, J.D and Havlin, J.L. 1997. *Soil fertility and fertilizer*, Fifth edition, Prentice-Hall of India private limited, New Delhi. p. 476

Tomar, N.K. and Tekchand.D. 1992. Effect of soil properties on the transformation of phosphorus in acid soils. *J. Indian Soc. Soil Sci.* 40: 257-267

Tripathi, D. and Minhas, R.S. 1991. Influence of fertilizer phosphorus and farm yard manure on transformation of inorganic phosphate. *J. Indian Soc. Soil Sci.* 39: 472-476

Verma, L.P., Warsi, A.S. and Yadav, D.S. 1989. Mussorie phos - a source of phosphorus for rice in eastern Uttar Pradesh. *Indian Fmg.* 39: 23-24

Vose, P.B. 1980. Introduction to Nuclear Techniques in Agronomy and Plant Biology, Pergamon press, New York, p.594

Wahid, P.A, Kamalam, N.V and Shankar, S.J. 1985. Determination of phosphorus-32 in wet digested plant leaves by Cerenkov counting. *Int. J.appl. Rad. Isot* 36:323-364

Walanjkar, W.G and Acharya, C.N. 1955. Organics influence on availability of phosphours in laterite soil. *J.Indian Soc. Soil* Sci. 3:71-78

Walkley, A. and Black,C.A. 1934. An examination of Degtjareff method for determining Soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci* 37: 29-39

Watanabe, F.S and Olsen, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and NaHco3 extracts from soil.*Proc.Sopil Sci Soc.Am.*29: 677-678

Willet, I.R. 1979. The effects of flooding for rice culture on soil chemical properties and subsequent maize growth. *Pl. Soil*. 52: 373-383

Willet, I.R. 1985. The effects of flooding for rice culture on soil chemical properties and subsequent maize growth. *Pl. Soil*, 52:373-383.

Willet, I.R. 1986. Causes and prediction of changes in extractable phosphorus during flooding. *Aust. J. Soil Res.* 27: 45-54

Yoshida,S, Forno,A.S., Cook,H.J and Gomez,A.K. 1972 *Laboratory manual on physiological studies*,IRRI,Manila,p.178

Appendices

Appendix 1. Weekly weather data during the cropping period

Standard Weeks	Temperature (°C)			Relative humidity (%)		Wind speed	Sun Shine	Rainfall (mm)	Evaporation (mm/week)
	Maximum	Minimum	Mean	Morning	Evening	(Km/hr)	(Hrs/day)		
December 49	32.14	23.22	27.69	73.14	52.71	9.55	7.58	0.00	41.64
50	32.08	24.14	28.11	69.28	49.86	11.82	9.38	0.00	41.63
51	31.17	21.08	26.63	69.00	38.58	8.47	8.02	0.00	45.65
52	32.51	20.53	26.53	74.37	36.50	4.12	9.26	0.00	41.70
January 1	32.96	22.40	27.65	66.32	38.20	9.96	8.60	0.00	48.70
2	32.44	23.90	28.15	63.20	37.20	10.00	8.90	0.00	57.90
3	32.44	23.60	28.00	62.00	37.00	10.20	9.10	0.00	62.90
4	34.62	22.00	28.30	72.54	26.50	6.90	9.99	0.00	48.10
5	33.96	22.60	28.25	77.45	39.80	5.40	8.70	23.60	38.50
February 6	34.82	23.70	29.28	77.45	38.52	7.00	9.80	0.20	44.70
7	35.75	24.20	29.95	80.45	42.00	4.90	9.80	2.90	37.90
8	35.16	23.70	29.40	78.65	47.00	3.70	9.20	65.40	37.10
9	33.85	23.30	28.55	91.23	53.61	3.20	8.70	70.00	31.80
March 10	35.23	24.20	29.70	84.56	38.21	4.00	8.80	0.00	40.00
11	34.82	23.40	29.50	88.23	42.20	4.00	8.20	83.40	36.10
12	34.46	24.90	28.80	80.23	49.85	4.20	8.70	10.40	38.20
13	34.12	24.90	29.50	92.35	59.23	2.70	8.10	1.00	33.20
April 14	33.68	25.00	29.25	86.23	63.25	2.80	6.10	6.80	27.60
15	34.46	25.10	29.70	87.49	56.23	2.80	7.90	5.80	37.50
16	34.90	25.00	30.00	88.46	58.00	3.10	8.10	.0.70	35.20
17	35.40	25.7	30.20	81.56	56.23	4.10	8.20	10.50	42.00
18	33.80	24.70	29.25	84.23	58.56	3.90	5.90	7.20	34.20

INFLUENCE OF PHOSPHORUS ON ABSORPTION AND DYNAMICS OF NUTRIENTS IN RICE

By

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ABSTRACT OF THE THESIS

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ABSTRACT

A pot culture experiment on the "Influence of phosphorus on absorption and dynamics of nutrients in rice" was conducted during December 2002 to April 2003 at the Radiotracer Laboratory, College of Horticulture, Kerala Agricultural University, Vellanikkara.

The distribution pattern, content-effectiveness relations of phosphorus on rice productivity in relation to soil types, nutritional levels and the role of organics were investigated in the present study

Plant height, tiller number, productive tillers,filled spikelets per panicle,grain and straw yield showed significant increase in kole soil treated with 90:45:45 kgha^{-1} NPK along with Pongamia leaves @ 5 tha^{-1} (T_{11}).

Chlorophyll 'a' and total chlorophyll were highest in T_{11} having kole soil treated with 90:45:45 kgha^{-1} NPK along with Pongamia leaves @5 tha^{-1} at panicle initiation and at 50 per cent flowering. A favourable cell sap pH was also noticed inT_{11}.

T_{11} gave highest plant content of N in both laterite and kole soil. P and K contents were also more in treatments having inorganics with Pongamia. Iron content of rice plants decreased with advancement in the stages of growth.

Percent phosphorus derived from fertilizer (%Pdff) had highest value at maximum tillering and thereafter it decreased. %Pdff was increased with increasing levels of Phosphorus application. When the applications of inorganics with and without organics are compared in laterite and kole soil, application of single super phosphate with organics always gave highest %Pdff than with single super phosphate alone. Laterite soil treated with 90: 67.5: 135 kgha^{-1} NPK along with Pongamia leaves @ 5 tha^{-1} (T_8) obtained 10.68 % Pdff and the same treatment in kole soil had 12.96% of %Pdff at harvest.

%Pdfs was low at maximum tillering and thereafter increased up to harvest. At maximum tillering, laterite soil treated with 90:45:45 $kgha^{-1}$ NPK without organics (T_1) gave highest %Pdfs of 93.45% and the kole soil treated with 90:22.5:90 $kgha^{-1}$ NPK without organics (T_{13}) gave highest %Pdfs of 93.51% .At 50% flowering and at harvest in both soils treated with 90:22.5:90 $kgha^{-1}$ of NPK with or witnout organics recorded highest %Pdfs. Per cent uptake of applied P fertilizer by the plant also had an increasing trend from maximum tillering to harvest. But it was decreasing with respect to increase in levels of phosphorus from 22.5 $kgha^{-1}$to 67.5 $kgha^{-1}$.

Laterite soil treated with 90:67.5:135 $kgha^{-1}$ of NPK along with Pongamia leaves @ 5 tha^{-1} (T_8) registered highest concentration of available P of 16.8 $mgkg^{-1}$ followed by the same treatment in kole soil with 16.7 $mgkg^{-1}$. Available iron content of soil after harvest was more in treatments having Pongamia in laterite soil while it was more with rice straw applied treatments in kole soil

The present study indicate that organics-Pongamia and rice straw in conjunction with inorganics enable consistent supply of phosphorus for achieving enhanced grain and straw yield in both laterite and kole soil.Though Pongamia along with inorganics is an ideal fertilizer schedule for rice crop in terms of yield. when the cost of incorporation of Pongamia is considered, rice straw along with inorganics is more profitable and convenient.