METHODS TO INCREASE THE EFFICIENCY OF RAJPHOS (JAMARKHOTRA ROCKPHOSPHATE) IN THE BLACK SOILS OF PALAKKAD DISTRICT FOR RICE

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**Methods to increase the efficiency of Rajphos (Jamarkhotra rockphospahate) in the black soils of Palakkad district for rice**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **"Methods to increase the efficiency of Rajphos (Jamarkhotra rockphospahate) in the black soils of Palakkad district for rice"** is a record of research work done independently by Mr. Vyas, N. G. (98-11-34) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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INTRODUCTION

1. INTRODUCTION

Phosphorus is one of the essential plant nutrients which decides the growth and yield of crops and can be found in all living tissues. The element P has been studied extensively because of the fact that its behaviour in soil plant system is different from other nutrients. The chemical forms of phosphorus and their relative abundance in soils control its uptake and utilisation by crops. Knowledge about the relative abundance of the different chemical forms and their distribution in soil would thus provide a scientific basis for assessing the P requirements of different crops.

Though considerable research work in soil has been carried out in India and abroad, management of P in soil for different crops is still a major problem, owing to the fact that phosphate anion forms a wide array of compounds of low solubility and often of variable chemical composition. This is further complicated in water logged soils by reductive processes that lead to changes in the relative proportions of P compounds. It is the relative abundance particularly of Fe-P fraction in soil which decides the availability of P in waterlogged soils (Al-Abbas and Barbar, 1962). In this context the alkaline rice soils of Palakkad, which are likely to contain a very low Fe-P fraction need prime attention. A thorough knowledge regarding the forms of P in the black cotton soils of Palakkad and its availability in different water regimes continues to be a branch of fruitful research of soil fertility and plant nutrition under the rice farming situations of this locality. According to soil taxonomy, black soils of Palakkad are mainly classified as Ustalfic chromusterts. The black soils of Palakkad district cover an area of 12,000 ha^{-1} and rice is the major crop grown followed by sugarcane, cotton, groundnut, pulses and millets. The soil is poor in fertility and is neutral to alkaline in reaction. The situation is further complicated by the P fixation characteristics of these soils which renders soluble P fraction to unavailable forms thus reducing considerably the flux of soluble phosphorus available to plants. In this context management of P warrants prime attention in the paddy soils of this locality. Till recently, India hardly produced any quality rockphosphate and was depending mainly on imports to sustain phosphate industry. Now the bulk of phosphate rock is obtained from India's most important mine at Udaipur from where mining started in 1969 by the Rajasthan state mines and minerals limited. This indigenous rockphosphate (Rajphos) now plays an important role in catering the needs of the phosphate industry and this has opened up the possibilities for their direct use in the powdered form as a P fertilizer in India. It has been estimated that the mine yields more than 50 million tonnes of phosphate which is suitable for processing into commercial fertilizers besides their direct use as a low grade fertilizer.

Information regarding the use of Rajphos in the neutral to alkaline soils of Kerala is scanty and meagre. The problems of fixation of soluble P can be alleviated to some extent by the use of less soluble forms like rockphosphate in conjunction with acid forming amendments like biofertilizers, iron pyrites and other sulphur compounds. Thus the study was mainly intended to investigate the effect of direct application of rockphosphate in combination with amendments for rice culture as well as to bridges the existing gap in our knowledge of phosphate transformations. This study further adds to the theoretical corpus of knowledge of P transformations in the waterlogged soils, particularly alkaline in nature.

Hence the following major objectives were set for the present investigation.

1. To study the comparative efficacy of Rajphos and Single superphosphate (SSP) for rice in the alkaline soils of Palakkad (Chittoor).
2. To study the effect of acidulated rockphosphate and its efficiency in releasing soluble P.
3. To study the dynamics of P fractions under waterlogged situations derived from SSP and Rajphos mixed with amendments like pyrites and biofertilizers.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1 Effect of water logging on available phosphorus and phosphorus fractions

Katyal and Venkatramayya (1983) reported that the concentration of soil solution phosphorus increased by about 2.5 times more in wet season than in dry season in submerged vertisol. Islam (1970) reported that levels of soil phosphorus first increased and then decreased with time of submergence under rice cropping. With increase in moisture content, Turner and Gilliam (1976) noticed ten fold increase in phosphorus diffusion in the soil system.

Mandal and Khan (1977) in their study on the transformation of fixed phosphorus in soils under waterlogged conditions, reported that the applied phosphorus which was left in the soil in the fixed form after the crop harvest could significantly contribute to the pool of available phosphorus in the succeeding season especially during the initial period of plant growth.

According to Mohanty and Patnaik (1977) submergence increased available phosphorus for 30 days because of reduction of Fe and Mn compounds, and afterwards there was a decrease in precipitation of phosphates. In waterlogged soils, large amount of carbon dioxide and organic acids were formed which would convert insoluble tricalcium phosphate to more soluble di or monocalcium phosphate thereby increasing the phosphorus availability (Mandal, 1979).

According to Boro (1980) continuous submergence of rice was an effective management practice for increasing the efficiency of phosphorus fertilizers. According to Mathews and Jose (1984), flooding the soil resulted in an increase in the content of available phosphorus, which was high in laterite compared to Kari soil. Mathews and Jose (1986) reported that submergence resulted in the release of native phosphorus in rice soils of Kerala. Reduction of free hydrous iron oxide during flooding and liberation of sorbed and co-precipitated phosphorus resulted in a rise in extractable phosphorus (Willet, 1989).

Mahapatra and Patrick (1969) found that waterlogging generally increased Al-P and Fe-P, decreased reductant soluble phosphorus and did not much affect the Ca-P. Jose (1973) reported a decrease in available phosphorus Al-P with increasing periods of incubation. Singh and Bahaman (1976) found that there was an increase in available P, Fe-P and Al-P, decrease in Ca-P and negligible changes for saloid bound phosphorus with the advancement of periods under submergence.

Verma and Thripathi (1982) observed that all the native inorganic phosphorus fractions increased upon waterlogging with the maximum increase of 70.7 per cent in Fe-P. The fractions of P increased upto panicle initiation and then decreased till the stage of harvest (Saravanan *et al.*, 1984).

Minhas and Kick (1974) reported that major part of the added rockphosphate was transformed into watersoluble phosphorus and loosely bound Al-P and Fe-P. Experiments of Singh and Ram (1977) recorded an increase in Fe-P and decrease in Al-P with advancement of the period of incubation. According to Saranganath *et al.* (1977) application of watersoluble and citratesoluble phosphorus to acid soils increased the Al-P and Fe-P fractions whereas application of rockphosphates increased Ca-P. Similar observations were recorded by Menhilal and Mahapatra (1979) and Chandrappa (1990).

According to Dhillon and Dev (1986) the applied phosphorus would be converted into saloid bound phosphorus and Al-P at the initial stages and later to Fe-P with time of incubation.

Kumaraswamy and Sreeramulu (1992) reported the fate of added phosphorus, with the advancement of the stages under incubation, as the transformation of Al-P into Fe-P in soils originally predominant in Fe-P and into Ca-P in the soils originally predominant in Ca-P. Bhatta (1993) found that Mussooriephos application resulted in a higher Ca-P while superphosphate recorded higher Al-P. The P uptake by plants was highly correlated with the amount of Fe-P and not with the amount of other fractions (Singlachar and Samaniego, 1973). Jose (1973) observed a close correlation between labile phosphorus, Al-P and Fe-P. Puranik and Bapat (1977) observed positive correlation between available P, Al-P and Ca-P. Mandal and Khan (1977) found that 60 to 75 per cent of the applied phosphate was fixed as Fe-P, Al-P and Ca-P after the harvest of rice and they stated that these fractions significantly contributed to available phosphorus of the succeeding crop.

Nisha (1995) reported that significant leaching loss of P occurred only in the early periods of rice crop. Prakash and Badrinath (1995) concluded that rockphosphate could be used as potential source of phosphorus and calcium under acidic condition owing to their steady release of P, fairly high Ca content and cost effectiveness. Jose *et al.* (1995) reported that the performance of rockphosphate in acid soils of Kerala was almost equivalent to that of watersoluble phosphatic fertilizer.

Panda (1986) reported that higher available P concentration in soil solution was due to steady dissolution of rockphosphate and reduction of iron and aluminum activity through liming effect of the rockphosphate. Bhatta (1993) reported that there was gradual increase in the available phosphorus content by Mussooriephos with the period for incubation days in an acid soil while for SSP, there was a decline. According to Shivanna *et al.* (1995) Mussooriephos maintained a steady level of P fraction and release throughout the incubation period in acid soils of pH 4.5.

2.2 Effect of Phosphorus on Rice

Panda *et al.* (1995) observed better performance of rice with 30 kg P_2O_5 ha^{-1}. Increasing the dose of P to 60 kg P_2O_5 ha^{-1} in rice produced an additional mean yield of 1,082 kg ha^{-1} over control. Masthan *et al.* (1999) concluded that the application of 60 kg P_2O_5 ha^{-1} to rice in kharif enhanced the production of tillers and panicles m^{-2}, filled grains per panicle, test weight, and seed and straw yields. Pandian (1999) reported that the steady and balanced availability of P increased the nutrient uptake which inturn increased yield and growth attributes of rice.

Rama Rao *et al.* (1992) concluded that phosphorus application at higher levels initiated early tillering and took lesser time for completion of flowering and thus available nutrients were diverted to the production of not only more number of panicles but more number of filled grains per panicles. Gangaiah and Prasad (1999) reported that application of phosphorus along with nitrogen had significant influence on N, P and K uptake in Pusa Basmati. Siddiqui *et al.* (1999) reported that grain yield of medium duration rice varieties under closer spacing (10 x 10 cm) was significantly superior over wider spacing (20x10 cm) with 60 kg P_2O_5 ha^{-1}.

Badrul (1999) reported that the application of phosphorus recorded significant increase in grain yields of rice with increase in P_2O_5 levels from 30 to 90 kg ha^{-1}. Sarkunan *et al.* (1998) observed significantly higher P and S uptake by rice grain with increase in P levels upto 50 mg kg^{-1} soil. Subbian *et al.* (1989) observed that application of phosphorus at higher rate of 90 kg P_2O_5 ha^{-1} could significantly improve the dry matter accumulation in rice.

Sucharitha and Ramachandraboopathi (2000) reported that highest grain and straw yield was obtained with the application of DAP @ 2 kg $cent^{-1}$ to nursery along with one by third of the recommended dose of P might be due to the prolonged supply of P to meet the requirement of rice crop in different growth stages including seedling stage.

Roy and Jha (1987) reported that early application of P enhanced early tillering and such tillers were more productive. They also concluded that there is a trend favouring the basal application of entire quantity of P towards enhanced number of productive tillers per m^2.

2.3 Fractionation of soil phosphorus

Debnath and Hajra (1972) studied the transformation of phosphate by adding water soluble P in five contrasting soils both under field moisture and water logged conditions. The inorganic fractions after 24 hours were recovered in the order of Al-P > Fe-P > Ca-P. On ageing the quantity of Fe-P increased and that of Al-P decreased irrespective of soil characteristics and moisture regimes. On the whole Ca-P did not change much.

Jose (1973) studied the transformation of inorganic P in soils at about field capacity and observed that in soils having pH between 7.0 and 7.5 applied P was transformed to Al-P, Fe-P and Ca-P in almost equal proportions. But in soils with Ca-P as the dominant fraction, a major part of the applied P was recovered as Ca-P. Singlachar and Samaniego (1973) studied the effect of flooding and cropping on the transformation of P and reported that the P added to the acid rice soil was slowly converted to Fe-P.

Singhania and Goswami (1978) investigated transformation of applied P in rice wheat cropping sequence in laterite soils of India and found that P applied to rice increased Al-P, Fe-P and reductant soluble P.

Sarkar *et al.* (1979) reported that MCP and NAP in alluvial, red and laterite soils of Bengal produced mainly colloidal amorphous Fe-P and Al-P which on ageing yielded products like octa-calcium-phosphate, variscite etc., and in some instances potassium and ammonium-taranakites, strengite etc.

Gupta *et al.* (1999) concluded that the increased application of phosphorus would increase the content of total phosphorus and different phosphorus fractions in the soil. The content of different phosphorus fractions as per cent of total phosphorus followed the order occluded P > Fe-P > Ca-P > Al-P.

Sharma *et al.* (1980) conducted an incubation study on the transformation of added P in acid soils of Himachal Pradesh and found that most of the added P was transformed to Al-P, Fe-P and very little to Ca-P at one day interval. The added P which was transformed to Al-P increases upto seven days and later decreases slowly with time upto 90 days. The conversion of added P to Fe-P fraction increases slowly with time upto 90 days and very little was changed to Ca-P even at prolonged time intervals.

Regi and Jose (1985) from lab-incubation studies with Rajasthan rockphosphate, mussoorie rockphosphate and superphosphate, showed that the increase in available P content of laterite and kari soils due to application of P fertilizers did not depend on the solubility of added P fertilizers.

Gu and Wang (1986) on the transformation of superphosphate on the gleyed paddy soils found that P applied to the soil was transformed to Al-P and Fe-P at an early stage and thereafter decreases gradually, Fe-P increases continuously and Ca-P changes little.

Cholitkul and Tyner (1971) stated that in low land rice soils Fe-P was the primary source of labile phosphorus. Minhas and Kick (1974) indicated that major part of added rock phosphate was transformed into water soluble and loosely bound Al-P and Fe-P fractions and becomes available for plant growth. Kothandaraman (1975) reported that Al-P and Fe-P contributed to the pool of available P in acid soils. Uzo *et al.* (1975) reported that Al-P was the most available form of P to plants under upland condition while Fe-P was the major available P source under flooded conditions.

Kanwar and Tripathi (1977) reported that Al-P and Fe-P reactions contributed significantly to Olsen and Bray. Sudhir *et al.* (1987) found that Al-P was the more important fraction contributing towards the availability of P in soil followed by reductant soluble P and saloid P.

Gu and Wang (1986) studied the fate of addition of P carriers in gleying rice soils and found that there was a positive correlation between Olsen-P, Al-P and Fe-P. Agarwal *et al.* (1987) found that Al-P was the most important fraction contributing towards available P followed by reductant soluble P and saloid P. Najeeb and Aiyer (1989) found that available P was positively and significantly correlated with Fe-P, Al-P, Ca-P and saloid-P and negatively and significantly correlated with reductant soluble P and occluded P. Sharma and Verma (2000) reported that Fe-P and Al-P were the most significant P fractions contributing to the total variation in available P, indicating their importance in P nutrition in rice-wheat cropping sequence. They also concluded that reductant-P was the major inorganic P in high rainfall areas.

Richard *et al.* (1995) reported that addition of fertilizer P increases Olsen-P concentration in the 0-15 cm layer of soil in the field and the effect was linear in all trials. Soon (1991) reported that soluble organic fractions form Al or Fe-organic-P compounds. This reaction will decrease the formation of different inorganic fractions of P. Tran *et al.* (1995) reported that long term manure and fertilizer application increased significantly the labile and moderately labile P fractions in soil. They also concluded that P transformations depend on texture of soil. Gupta and Latto (1999) reported that the amount of Al-P, Ca-P and occluded-P increases with soil depth and poor response of rice to phosphorus is due to the predominance of occluded-P on submergence. This study was conducted in mild alkaline soil.

Ravindra and Ananthanarayana (1999) concluded that different inorganic phosphorus fractions are controlled by physiochemical properties of soil and availability of phosphorus is also controlled by the amount of these phosphorus fractions. Sharma and Singh (1999) reported that solubility of calcium, iron and aluminium bound phosphorus increased with increase in temperature of soil, so the availability is also increased.

Bharadwaj *et al.* (2000) observed that the major portion of added phosphorus not utilized by plants were transformed into Al-P followed by Fe-P in sandy loam orchard soils of Himachal Pradesh. Misra and Das (2000) reported that both Bray's and Olsen's P fractions substantially increased in the soil even after the first and third maize crop due to the increased dissolution of added rock phosphate. Anilkumar *et al.* (1999) reported that Al-P fraction showed consistent increase even after 90 days of incubation, whereas Ca-P is decreased. This decrease in Ca-P can be attributed to the conversion of Ca-P into other fractions.

2.4 Effect of micro-organism on rockphosphate solubilisation and phosphorus availability

Gupta *et al.* (1993) assessed the ability of *Bacillus licheniformis* to solubilise inorganic phosphates and low grade Indian rockphosphate in broth culture in a sandy loam soil. The results indicated that *Bacillus licheniformis* was able to solubilise rockphosphate in soil and thus had potential for improving soil phosphorus levels. Kumar and Dube (1993) observed the production of siderophores by phosphate solubilising bacteria which helped in P solubilisation.

Illmer and Schinner (1992) concluded that proton excretion accompanying NH_4^+ assimilation is the most probable explanation of microbial solubilisation of rockphosphate. Illmer *et al.* (1995) have also stated that while *Aspergillus niger* produced citrate, oxalate and gluconate, the other species of phosphate solubilising micro-organisms did not produce any organic acid in detectable amounts.

Banik and Dey (1981) obtained higher levels of available P in soils to which FYM, rockphosphate and PS isolates like *Bacillus, Streptomyces, Penicillium* and *Aspergillus* species were added in a pot culture experiment with jute. Banik *et al.* (1989) tested the effect of inoculation of two strains of phosphorus solubilising bacteria and observed that available phosphorus from rockphosphate increased to a maximum after 30 days of crop growth and declined after 120 days. Mohod *et al.* (1989) reported that the use of P solubilising culture alone or in combination with phosphatic fertilizers in rice increased the root cation exchange capacity, available P in soils and P uptake in rice. From the results of a laboratory experiments conducted to test whether phosphorus dissolving fungi are capable of increasing the amount of available P in calcareous soils treated with rockphosphate or triplesuperphosphate (TSP) and its subsequent uptake by sorghum. Salih *et al.* (1989) reported that *Penicillium* sp. and two *Aspergilus* sp. significantly increased the availability of P in soil during the growing season. The dry matter content and P uptake were better in soil treated with rockphosphate and inoculated with these fungi. Heggo and Barakah (1993) observed that the available P status in a calcareous soil increased significantly through the application of mussooriephos and superphosphate in combination with P dissolving bacteria inoculants.

Rangasamy (1972) reported that phosphobacteria increased plant height, girth, root weight and uptake of phosphorus and potassium at all stages of growth of sorghum. Rasal *et al.* (1988) observed that inoculation with *Aspergillus awamori* increased the availability of phosphorus in the soil leading to a significant improvement in nodulation. Srivastava and Ahlawat (1995) confirmed that seed inoculation with rhizobium or phosphorus solubilising bacteria along or in combination resulted in considerable increased in nodulation, nitrogenase activity, growth, yield and nutrient uptake by cowpea over uninoculated control.

Gaur *et al.* (1980) reported that the response of the crop to bacterial inoculation as equivalent to 50 kg P_2O_5 ha^{-1}. Asea *et al.* (1988) using ^{32}P isotope dilution method found that wheat when inoculated with *Penicillium bilaji* was able to obtain 18 per cent of its phosphorus from sources unavailable to the uninoculated plants and was able to solubilise added rockphosphate. Dry matter production and phosphorus uptake in wheat has been reported to increase under field and green house conditions in response to *Pencillium bilaji* inoculation in the absence of added rockphosphate and addition of rockphosphate resulted in a further increase in the dry matter production (Kucey, 1988). In a field experiment with rice conducted in laterite soil of Maharashtra, Mohod *et al.* (1989) revealed that the use of phosphorus solubilising culture significantly increased the number of grains per panicle, weight of 1000 grains, grain weight per panicle, grain yield, nitrogen uptake and the beneficial effects were greater with rockphosphate than single superphosphate. Gaur (1990) has reported that the grain yield of wheat was significantly increased (3070 kg ha^{-1}) due to inoculation of seed with *Pseudomonas striata*, *Bacillus polymyxa* and *Aspergillus awamori* as compared to uninoculated control (2650 kg ha^{-1}). The phosphorus uptake was also augmented due to the use of inoculants.

Prabhakar and Saraf (1990), Kumar and Agarwal (1993) reported favourable effect of *Penicillium striata* on chickpea. Rachewad *et al.* (1991) has reported that seed inoculation with *Bacillus polymyxa* and 75 kg phosphorus per ha increased the biomass production and phosphorus content in maize grown in phosphorus deficient soil compared to the untreated control. Rathore *et al.* (1992) conducted field trails using lentils inoculated with *Bacillus megatherium* and reported that seed inoculation significantly increased yield over the uninoculated control. Sushama *et al.* (1993) used different sources of phosphorus such as single superphosphate, mussoorie rockphosphate (MRP), partially acidulated rockphosphate and MRP along with phosphorus solubilising fungi in rice and reported that the grain yield was highest with MRP and fungi when applied in conjunction with green manure or farm yard manure. The fertilizer use efficiency was highest for the combination of MRP and fungi with green manure indicating that MRP is a better alternative to other expensive watersoluble phosphate sources for use in coastal laterites. Goos *et al.* (1994) had reported that in the absence of phosphorus fertilization, *Penicillium bilaji* inoculation increased the grain yield in spring wheat by an average of 66 kg ha^{-1}. Hedge and Dwivedi (1994) reported significant effect of inoculation with *Bacillus megatherium* and *Bacillus circulans* in rice and wheat, which was equivalent to yield increase obtained with the use of 50 kg P_2O_5 ha^{-1}.

Hazra (1994) reported that phosphobacterin treated seeds produced 31 per cent yield increase in oats. He also noted that seeds coated with *Bacillus polymyxa* gave higher forage yield than non-bacterised seeds. Kathiresan *et al.* (1995) have reported that soil inoculation with phosphobacterin (10 kg ha^{-1}) increased cane yield and quality, application of 31.5 kg P_2O_5 along with soil inoculation of phosphobacterin gave similar cane yield as the application of 63 kg P_2O_5.

Vaishya *et al.* (1996) has observed that the use of phosphorus solubilising micro-organisms (PSM) along with rockphosphate for Bengalgram in a Vertisol resulted in a significantly higher phosphorus uptake. Shehana (1997) reported that the available P content of soil, plant P content, P uptake, yield attributes and dry matter production in banana were favourably influenced by the use of phosphobacterin along with a lesser amount of P than the present package of practices recommendation.

Thiyageswari and Raniperumal (1999) reported that direct use of even low-grade rockphosphate as fertilizer is feasible in neutral to alkaline soils, if phosphate solubilising microbes are used as inoculants. Takur and Sharma (1988) reported that phosphorus from rock phosphate is solubilised and made into available form by *Azotobacter* during composting.

2.5 Effect of acidulation on rockphosphate

Marwahah (1983) stated that acidulation of rockphosphate increased water soluble phosphorus content in the insoluble rockphosphate. He also concluded that phosphoric acid is the best reagent for acidulation.

Santhy (1999) reported that as the degree of acidulation of rockphosphate increased, the amount of water and citratesoluble phosphorus contents were increased.

Hammond *et al.* (1986) reported that effectiveness of low grade phosphate rocks can be increased by partial acidulation. Phosphate rock is treated with certain amount of acid much less than that required for superphosphate production.

Biswas and Narayanasamy (1995) reported that in the case of sulphuric acid involved acidulation production of $CaSO_4$, it is a cementing agent there by reducing the water and citrate solubility of final product.

Mc Lean and Wheeler (1964) revealed higher recovery efficiency of soluble P from 20 per cent acidulated materials over 100 per cent acidulated materials.

Biswas and Narayanasamy (1998) confirmed that grain yield and total P uptake by wheat were greater with 50 per cent PAPRs than 25 per cent PAPRs. Further increase in the levels of acidulation did not increase the yield and P uptake by wheat significantly.

Singh *et al.* (1999) described that dry blending at 1:1 and wet blending at 2:1 ratios of Mussooriephos and oxalic acid gave grain and straw yield of lentil and wheat crops statistically on par with single superphosphate.

Singh and Rahul (1993) reported that oxalic acid can solubilise insoluble P and also chelated the calcium as calcium oxalate which got stabilised with increasing pH of the medium.

Singh *et al.* (1982) reported that the application of mussooriephos alone decreased yield in comparison to control mainly because Mussooriephos itself refixes a major amount of native P as $CaC0_3$ due to high Ca in the soil.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation is aimed at studying different methods to maximise the availability of P from applied rockphosphate and to assess the chemical transformations of rockphosphate under waterlogged conditions in the blacksoils of Chittoor.

As part of this study, a pot culture experiment was laid out using different sources of P mixed with amendments like iron pyrites and phosphobacterin. Three levels each of SSP and Rajphos *viz.*, 15 kg ha^{-1}, 30 kg ha^{-1} and 45 kg ha^{-1} in combination with four amendments namely 25 per cent acidulation, 50 per cent acidulation, iron pyrites and phosphobacterin were tried with the Package of Practices Recommendations (KAU, 1996) as the control. Thus 30 treatment combinations with one absolute control was tested in the pot experiment.

An incubation study was also carried out in the laboratory using the same soil and treatment combinations. The purpose of this study was to identify the treatment combination and time duration to impart maximum P availability in the soil apart from studying the relative abundance of the P fractions released. The experiment was also to compare and assess the solubility of different forms of P at different levels in combination with solubilising agents and amendments.

3.1 Incubation experiment

A typical black cotton soil of Chittoor (Palakkad) collected for pot culture experiment was used for this study. The soil was powdered and sieved through a two millimetre sieve. The soil was kept water logged after treatment with different forms of P at different levels as per treatment combinations listed below. The rate of dissolution of applied phosphorus in each treatment was studied periodically by determining the available P using Olsen's reagent and phosphorus fractions. The experiment was laid out in a completely randomized design with two replications. The treatment combinations are indicated below.

Treatments

Levels of phosphorus - 3

P_1 - 15 kg ha^{-1} P_2O_5

P_2 - 30 kg ha^{-1} P_2O_5

P_3 - 45 kg ha^{-1} P_2O_5

Forms of phosphorus - 2

F_1 - Rajphos

F_2 - Superphosphate

P- Solubilising material - 5

S_1 - 25 per cent of applied Rajphos in acidulated form

S_2 - 50 per cent of applied Rajphos in acidulated form

S_3 - Iron pyrites ten per cent by weight of Rajphos

S_4 - Iron pyrites 15 per cent by weight of Rajphos

S_5 - Biofertilizers like phosphobacterin as per Package of Practices Recommendations

Nitrogen and potash will be applied uniformly as per Package of Practices Recommendations.

Number of treatments - (6 x 5) + 1 control = 31

T_1 - $F_1P_1S_1$	T_6 - $F_1P_2S_1$	T_{11} - $F_1P_3S_1$
T_2 - $F_1P_1S_2$	T_7 - $F_1P_2S_2$	T_{12} - $F_1P_3S_2$
T_3 - $F_1P_1S_3$	T_8 - $F_1P_2S_3$	T_{13} - $F_1P_3S_3$
T_4 - $F_1P_1S_4$	T_9 - $F_1P_2S_4$	T_{14} - $F_1P_3S_4$
T_5 - $F_1P_1S_5$	T_{10} - $F_1P_2S_5$	T_{15} - $F_1P_3S_5$
T_{16} - $F_2P_1S_1$	T_{21} - $F_2P_2S_1$	T_{26} - $F_2P_3S_1$
T_{17} - $F_2P_1S_2$	T_{22} - $F_2P_2S_2$	T_{27} - $F_2P_3S_2$
T_{18} - $F_2P_1S_3$	T_{23} - $F_2P_2S_3$	T_{28} - $F_2P_3S_3$
T_{19} - $F_2P_1S_4$	T_{24} - $F_2P_2S_4$	T_{29} - $F_2P_3S_4$
T_{20} -$F_2P_1S_5$	T_{25} - $F_2P_2S_5$	T_{30} - $F_2P_3S_5$

T_{31} -$F_0P_0S_0$- Control

The different forms of P at varying levels were acidulated by 50 per cent and 25 per cent as per the procedure outline by UNIDO, 1967. The combinations of rockphosphate and SSP at different levels with ten per cent iron pyrites were made by mechanical mixing on weight basis.

3.1.1 Fractionation of soil P

The fractionation of soil P was carried out by procedures of Chang and Jackson after Peterson and Corey described by Hesse (1976).

3.1.2 Experimental details

The soil was dried, powdered and exactly 500 g of the soil was weighed and transferred into one kilogram plastic container. The P fertilizer was added as per treatments and mixed thoroughly with the soil and water logged with a standing water column maintained at two centimeters above the soil level.

Periodical determination of different P fractions were made from each replication on 1^{st}, 15^{th}, 30^{th}, 45^{th}, 60^{th}, 75^{th} and 90^{th} day. A weighed quantity of moist sample to give one gram of dried soil was used for fractionation studies. A weighed quantity of moist sample to give five grams of dry soil was used for available P determination. The moisture content in each sample was separately determined immediately on withdrawal of the sample and exact quantity of dry soil in each sample was used for the fractionation and the available P computation.

3.2 Pot culture experiment

A pot culture experiment in rice using blacksoils of Chittoor (pH 7.6) was conducted during July-October 2000 by applying different forms of phosphorus at varying P levels. The treatment combinations are detailed below. The experiment was laidout in a Completely Randomised Design (CRD) with two replications.

Treatments

Levels of phosphorus - 3

P_1 - 15 kg ha^{-1} P_2O_5

P_2 - 30 kg ha^{-1} P_2O_5

P_3 - 45 kg ha^{-1} P_2O_5

Forms of phosphorus - 2

F_1 - Rajphos

F_2 - Superphosphate

P- Solubilising material - 5

S_1 - 25 per cent of applied Rajphos in acidulated form

S_2 - 50 per cent of applied Rajphos in acidulated form

S_3 - Iron pyrites ten per cent by weight of Rajphos

S_4 - Iron pyrites 15 per cent by weight of Rajphos

S_5 - Biofertilizers like phosphobacterin as per Package of Practices recommendations

Nitrogen and potash will be applied uniformly as per Package of Practices recommendations.

Number of treatments - (6 x 5) + 1 control = 31

Treatment combinations

T_1 - $F_1P_1S_1$	T_6 - $F_1P_2S_1$	T_{11} - $F_1P_3S_1$
T_2 - $F_1P_1S_2$	T_7 - $F_1P_2S_2$	T_{12} - $F_1P_3S_2$
T_3 - $F_1P_1S_3$	T_8 - $F_1P_2S_3$	T_{13} - $F_1P_3S_3$
T_4 - $F_1P_1S_4$	T_9 - $F_1P_2S_4$	T_{14} - $F_1P_3S_4$
T_5 - $F_1P_1S_5$	T_{10} - $F_1P_2S_5$	T_{15} - $F_1P_3S_5$
T_{16} - $F_2P_1S_1$	T_{21} - $F_2P_2S_1$	T_{26} - $F_2P_3S_1$
T_{17} - $F_2P_1S_2$	T_{22} - $F_2P_2S_2$	T_{27} - $F_2P_3S_2$
T_{18} - $F_2P_1S_3$	T_{23} - $F_2P_2S_3$	T_{28} - $F_2P_3S_3$
T_{19} - $F_2P_1S_4$	T_{24} - $F_2P_2S_4$	T_{29} - $F_2P_3S_4$
T_{20} -$F_2P_1S_5$	T_{25} - $F_2P_2S_5$	T_{30} - $F_2P_3S_5$

T_{31} -$F_0P_0S_0$- Control

Source of N - Urea (46 per cent N)

Source of P - Rajphos (22 per cent P_2O_5)

Source of K - (Muriate of potash) MOP (60 per cent K_2O)

Earthern pots of uniform size of 30 x 32 cm were used for the study. A layer of gravel was placed at the bottom of each pot. Ten kilograms of dried and sieved soil samples were taken in each pot and sufficient water was added to bring the soil to a puddled condition. The fertilizer nitrogen and potassium were added at the rate of 70 kg ha^{-1} and 35 kg ha^{-1} respectively. Phosphorus fertilizers were added at levels and forms as per the treatment combinations outlined above.

Two third of nitrogen, whole of potassium and phosphorus were given as basal dose and the remaining one third of nitrogen was applied at the 45^{th} day after transplantation.

Twenty days old rice seedling of variety Matta Triveni were transplanted @ two hills per pot. The pots were kept free of weeds. The plants were sprayed two times with Ekalux *i.e.* on 15^{th} and 45^{th} day and once with Metacid on the 75^{th} day. Ten days before harvest irrigation was discontinued. The grain and straw were harvested separately at full maturity.

Basic data of the soil selected for study

Table 1. Mechanical analysis

Soil	**Fractions**					**Reference**
Chittoor Soil	Gravel (per cent)	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent)	Piper, 1966
	4.66	11.70	20.55	20.25	47.50	

Table 2. **Chemical analysis**

Parameter	Value
pH	7.6
EC	0.18 dS m^{-1}
CEC	6.80 c mol kg^{-1}
Sesquioxides	9.32 %
Organic carbon	0.63 %
Total Nitrogen	0.081 %
Total P	0.16 %
Total K	0.11 %
Available N	186 kg ha^{-1}
Available P	17.8 kg ha^{-1}
Available K	192 kg ha^{-1}
Exchangeable Ca	2.18 c mol kg^{-1}
Exchangeable Mg	1.80 c mol kg^{-1}

3.2.1 Observations

Observations on growth and yield characters were recorded as per the methods suggested by Gomaz (1972).

3.2.1.1 Height of plants

The height of one plant from each of the pot were measured from ground level to the tip of the highest leaf or the tip of the panicle whichever was longer.

3.2.1.2 Tiller count

The panicles of sampling units were harvested separately and length measured (cm.) from the last node to the tip of panicle. The number of productive tillers were also recorded.

3.2.1.3 Yield of grain and straw

Crop was harvested at full maturity. The threshed weights of straw and grain were recorded separately.

3.2.1.4 Thousand grains weight

Thousand grains weight of each replication was recorded.

3.2.1.5 Leaf Area Index

LAI was calculated at 45 days after planting and at the time of harvest for each replication. Area of all leaves produced per plant was recorded using a leaf area meter (LICOR Model-3100) and LAI was worked out using the formula suggested by Watson, 1952.

$$LAI = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Land area occupied by plants (cm}^2\text{)}}$$

3.2.1.6 Number of grains per panicle

Number of grains per panicle for each treatment combination was recorded.

3.2.2 Chemical analysis of plant samples

Plant samples from the pot culture experiment on rice were collected for plant analysis.

3.2.2.1 Preparation of plant samples

The grain was winnowed, cleaned and then dried in an air oven at 100^{0}C. Prepared samples were kept in separate labelled bottles. The whole grain samples were used for chemical analysis. The straw samples, which were also similarly dried, were ground in a Wiley mill. The ground samples were also kept in separate labelled bottles. It was used for the determination of N, P, K, Ca and Mg. Standard procedures adopted are given below.

Table 3. Analytical methods followed in plant analysis

Element	Method	Reference
Nitrogen	Microkjeldahl digestion in sulphuric acid and distillation	Jackson, 1973
Phosphorus	Nitric - Perchloric - Sulphuric acid (9:2:1) digestion and colorimetry making use of vanado-molybdo phosphoric yellow colour method	Jackson, 1973
Potassium	Nitric - Perchloric - Sulphuric acid (10:4:1) digestion and flame photometry	Jackson, 1973
Ca, Mg	Nitric - Perchloric - Sulphuric acid digestion and AAS	Piper, 1966

Table 4. Analytical methods followed in soils analysis

Parameter	Method	Reference
Mechanical composition	International pipette method	Piper, 1966
pH	pH meter	Jackson, 1973
EC	Conductivity meter	Jackson, 1973
CEC	Ammonium saturation using neutral normal ammonium acetate	Jackson, 1973
Organic carbon	Walkley and Black Rapid Titration	Walkley and Black, 1934
Available N	Alkaline permanganate	Subbiah and Asija, 1956
Available P	Ascorbic acid reduced-molybdo phosphoric blue colour	Jackson, 1973
Available K	Flame photometry	Jackson, 1973
Exchangeable Ca and Mg	Neutral normal ammonium acetate extraction and AAS	Jackson, 1973
Total nitrogen	Modified microkjeldahl method	Jackson, 1973
Total phosphorus	Vanado molybdo phosphoric yellow colour	Jackson, 1973
Total potassium	Flame photometry	Jackson, 1973

3.3 Statistical analysis of the data

The data of the pot culture experiments and incubation studies were statistically analysed (Panse and Sukhatme, 1967).

RESULTS

4. RESULTS

An investigation was carried out in the Department of Soil Science and Agricultural Chemistry at the College of Agriculture, Vellayani to standardise methods for increasing the efficiency of Rajphos (Jamarkotra rockphosphate) in the black soils of Palakkad district cropped to rice. The study was conducted during July-October, 2000, consisting of a field pot culture and laboratory incubation experiments.

The results of the study are presented here under in Tables 5 to 16.

4.1 Incubation Experiment

4.1.1 Fractionation of soil phosphorus

Data on fractionation of soil phosphorus obtained from the incubation experiment is presented in Tables 5 to 10.

4.1.1.1 Saloid-P

Irrespective of treatments, saloid-P showed an increase with increase in the period of incubation upto the 30th day of incubation and decreased subsequently towards the last sampling. In general an increase which was significant for many treatments (T_{12}, T_{14}, T_{16}, T_{19}, T_{21}, T_{26}, T_{22}, T_{27}, T_{28}, T_{29}, T_{30}) was observed at all stages of incubation at all levels. This trend was

Table 5. Effect of different levels and forms of P on saloid-P fraction on submergence (ppm) (pooled mean value)

Treatments	Forms of P	Levels of P_2O_5 Kg/ha	Period in days						
			0-days	15-days	30-days	45-days	60-days	75-days	90-days
T_1	Rajphos	15	0.72	0.82	0.93	0.79	0.69	0.60	0.58
T_2	”	”	0.74	0.84	0.95	0.81	0.71	0.62	0.61
T_3	”	”	0.70	0.80	0.91	0.76	0.66	0.57	0.55
T_4	”	”	0.73	0.83	0.93	0.80	0.70	0.61	0.60
T_5	”	”	0.72	0.82	0.91	0.76	0.66	0.57	0.55
T_6	Rajphos	30	0.74	0.84	0.95	0.82	0.72	0.63	0.61
T_7	”	”	0.79	0.89	0.99	0.86	0.76	0.67	0.65
T_8	”	”	0.72	0.82	0.92	0.79	0.69	0.60	0.58
T_9	”	”	0.75	0.85	0.95	0.82	0.72	0.63	0.61
T_{10}	”	”	0.73	0.83	0.93	0.80	0.70	0.61	0.60
T_{11}	Rajphos	45	0.81	0.91	0.96	0.88	0.78	0.69	0.67
T_{12}	”	”	0.84	0.96	1.20	0.93	0.83	0.74	0.72
T_{13}	”	”	0.80	0.90	0.95	0.97	0.77	0.68	0.66
T_{14}	”	”	0.83	0.94	0.99	0.91	0.81	0.72	0.70
T_{15}	”	”	0.82	0.91	0.96	0.88	0.78	0.69	0.68
T_{16}	Superphosphate	15	0.86	0.94	1.30	0.91	0.82	0.73	0.71
T_{17}	”	”	0.88	0.97	1.50	0.94	0.84	0.75	0.73
T_{18}	”	”	0.82	0.90	1.20	0.87	0.78	0.69	0.67
T_{19}	”	”	0.87	0.95	1.40	0.92	0.83	0.74	0.70
T_{20}	”	”	0.84	0.92	1.10	0.90	0.80	0.71	0.71
T_{21}	Superphosphate	30	0.88	0.97	1.50	0.90	0.80	0.71	0.69
T_{22}	”	”	0.92	0.94	1.70	0.96	0.88	0.79	0.77
T_{23}	”	”	0.84	0.93	1.50	0.90	0.80	0.71	0.70
T_{24}	”	”	0.90	0.95	1.40	0.92	0.86	0.77	0.75
T_{25}	”	”	0.87	0.90	1.20	0.87	0.83	0.74	0.73
T_{26}	Superphosphate	45	0.92	1.00	1.30	0.97	0.88	0.79	0.78
T_{27}	”	”	0.96	1.30	1.90	0.99	0.92	0.83	0.81
T_{28}	”	”	0.87	0.96	1.40	0.93	0.83	0.74	0.73
T_{29}	”	”	0.94	1.10	1.50	0.98	0.86	0.77	0.75
T_{30}	”	”	0.90	0.99	1.60	0.98	0.90	0.81	0.80
T_{31}			0.80	0.91	1.10	0.90	0.81	0.71	0.62
C.D. at 5% level			0.136	0.320	0.362	0.105	0.118	0.131	0.133

Table 6. Effect of different forms and levels of P on occluded-P fractions on submergence (ppm) (pooled meanvalue)

Treatments	Forms of P	Levels of P_2O_5 Kg/ha	Period in days						
			0-days	15-days	30-days	45-days	60-days	75-days	90-days
T_1	Rajphos	15	8.20	8.70	9.00	8.05	7.05	6.20	6.60
T_2	"	"	8.90	9.20	10.00	8.00	7.00	6.10	6.00
T_3	"	"	5.00	5.50	6.00	4.93	3.93	2.98	2.98
T_4	"	"	7.00	7.30	8.00	6.50	5.50	4.35	4.35
T_5	"	"	6.00	6.50	7.00	5.50	4.50	4.10	4.10
T_6	Rajphos	30	9.30	9.70	10.00	9.10	8.10	7.75	7.75
T_7	"	"	9.70	10.20	11.00	9.23	8.23	7.60	7.80
T_8	"	"	7.00	7.50	8.00	6.45	5.45	5.00	5.00
T_9	"	"	7.93	8.20	9.00	7.10	6.10	5.50	5.50
T_{10}	"	"	6.00	6.50	7.00	5.50	4.50	4.00	4.00
T_{11}	Rajphos	45	11.20	11.60	12.00	10.95	9.95	8.95	8.95
T_{12}	"	"	11.85	12.30	13.00	10.10	10.10	9.65	9.65
T_{13}	"	"	8.00	8.50	9.00	7.40	6.40	5.90	5.90
T_{14}	"	"	9.73	10.40	11.00	9.15	8.15	7.18	7.18
T_{15}	"	"	9.00	9.50	10.00	8.50	7.50	7.00	7.00
T_{16}	Superphosphate	15	11.00	11.20	13.00	10.85	9.85	8.65	8.65
T_{17}	"	"	12.00	13.20	14.00	11.15	10.15	9.25	9.25
T_{18}	"	"	8.50	9.50	10.00	8.00	7.00	6.50	6.50
T_{19}	"	"	11.20	11.70	12.00	10.95	9.95	9.35	9.35
T_{20}	"	"	10.00	10.50	11.00	9.20	8.20	7.50	7.50
T_{21}	Superphosphate	30	14.00	14.30	15.00	12.50	11.50	10.60	10.60
T_{22}	"	"	14.10	15.30	16.00	12.95	11.95	11.50	11.50
T_{23}	"	"	10.10	10.50	11.00	9.40	9.00	8.50	8.50
T_{24}	"	"	13.40	13.80	14.00	11.95	10.95	10.15	10.15
T_{25}	"	"	11.00	11.50	12.00	10.5	9.57	8.40	8.40
T_{26}	Superphosphate	45	14.70	15.20	16.00	13.20	12.20	11.35	11.35
T_{27}	"	"	14.90	16.20	17.00	13.98	12.98	11.50	11.50
T_{28}	"	"	11.00	11.50	12.00	10.90	9.90	9.00	9.00
T_{29}	"	"	14.20	14.70	15.00	13.00	12.00	11.00	11.0
T_{30}	"	"	12.00	12.50	13.00	11.00	10.00	9.00	9.00
T_{31}			10.90	11.30	12.00	10.40	9.40	8.90	8.90
C.D. at 5% level			4.32	5.35	5.0	4.52	3.42	2.93	3.21

applicable to treatments having phosphobacterin inoculation also. The absolute values observed were higher at higher levels of applied P and the same trend was maintained throughout the period of incubation. During the last two observations SSP acidulated with H_2SO_4 retained higher levels of saloid-P compared to other treatments. It is observed from the results that during the third observation significantly higher values were recorded by treatments representing acidulated SSP and the highest value (1.90 ppm) was registered by T_{27}.

4.1.1.2 Occluded-P

A close scrutiny of the data presented in Table 6, clearly indicated a gradual increase in the occluded-P fraction with time of incubation. In the case of treatments with acidulated Rajphos, the occluded-P increased gradually during the first three observations and subsequently decreased and then levelled off to a stable value. On the other hand acidulated SSP and pyrite amended SSP registered higher absolute values during the early periods of incubation and attained maximum during the third observation and gradually decreased to a stable value towards the last observation. The final value obtained was significantly higher than the stable values attained for treatments representing Rajphos. The highest occluded-P value was registered for T_{27} (17 ppm) and the lowest value was recorded for T_3 (6 ppm). Irrespective of the time of

Table 7. Effect of different forms and levels of P on reductant-P fraction on submergence (pooled mean value)

Treatments	Forms of P	Levels of P_2O_5 Kg/ha	Period in days						
			0-days	15-days	30-days	45-days	60-days	75-days	90-days
T_1	Rajphos	15	14	16	15	13	12	10	8
T_2	"	"	16	17	16	14	13	11	9
T_3	"	"	12	14	13	11	10	8	6
T_4	"	"	15	16	15	13	12	10	8
T_5	"	"	14	16	15	13	12	10	8
T_6	Rajphos	30	15	17	16	14	13	11	9
T_7	"	"	17	18	16	14	13	11	9
T_8	"	"	13	15	14	12	11	9	7
T_9	"	"	16	17	16	14	13	11	9
T_{10}	"	"	14	16	15	13	12	10	8
T_{11}	Rajphos	45	16	18	17	15	14	12	10
T_{12}	"	"	19	20	18	16	15	13	11
T_{13}	"	"	14	15	14	12	11	9	7
T_{14}	"	"	18	19	18	16	15	13	11
T_{15}	"	"	15	17	16	14	13	11	9
T_{16}	Superphosphate	15	21	23	22	20	19	17	15
T_{17}	"	"	24	27	25	23	22	20	18
T_{18}	"	"	20	22	20	18	17	15	13
T_{19}	"	"	23	26	24	22	21	19	17
T_{20}	"	"	21	23	22	20	19	17	15
T_{21}	Superphosphate	30	22	25	24	22	21	19	17
T_{22}	"	"	25	28	27	25	24	22	20
T_{23}	"	"	21	24	23	21	20	18	16
T_{24}	"	"	24	27	26	24	23	21	19
T_{25}	"	"	22	25	24	22	21	19	17
T_{26}	Superphosphate	45	23	26	25	23	22	20	18
T_{27}	"	"	26	29	28	26	25	23	21
T_{28}	"	"	22	25	24	22	21	19	17
T_{29}	"	"	25	28	27	25	24	22	20
T_{30}	"	"	23	25	24	22	21	19	17
T_{31}			18	20	18	16	15	13	11
C.D. at 5% level			7.5	8.3	6.7	7.1	8.1	9.2	7.4

observation, treatments T_{21}, T_{22}, T_{24}, T_{25}, T_{26}, T_{27}, T_{28}, T_{29}, T_{30} and T_{31} were on a par.

4.1.1.3 Reductant-P

From the data presented in the Table 7, it is evident that the reductant-P value increased from the first observation to the 15^{th} day of submergence with a subsequent decline towards the last observation. Reductant-P fraction was significantly higher during the second observation with respect to all treatments involving SSP than the corresponding treatments representing Rajphos. This trend was more or less maintained during the subsequent observations also though not statistically significant. Values registered during the last observation were very low in all cases compared to the initial values. Amendment with pyrites and inoculation of phosphobacterin was also effective in increasing the reductant-P fraction and registered values comparable to acidulated phosphate. The treatment T_{27} (29 ppm) recorded the highest value and the lowest value was registered by the treatment T_{13} (14 ppm). In all periods of incubation, the treatments T_7, T_{12} and T_{14} consisting of Rajphos and all the SSP treatments were on a par.

4.1.1.4 Fe-P

Perusal of the data presented in Table 8, reveals an increase in Fe-P fraction upto the fourth observation representing the 45^{th} day of submergence.

Table 8. Effect of different levels and forms of P on Fe-P fraction on submergence (ppm) (pooled mean value)

Treatments	Forms of P	Levels of P_2O_5 Kg/ha	Period in days						
			0-days	15-days	30-days	45-days	60-days	75-days	90-days
T_1	Rajphos	15	33	38	44	48	43	37	34
T_2	”	”	36	41	47	51	46	40	37
T_3	”	”	32	37	43	47	42	36	33
T_4	”	”	35	40	46	50	45	39	36
T_5	”	”	33	38	44	48	43	37	34
T_6	Rajphos	30	35	40	46	50	45	39	36
T_7	”	”	38	43	49	53	48	42	39
T_8	”	”	33	38	44	48	43	37	34
T_9	”	”	37	42	48	52	47	41	38
T_{10}	”	”	35	40	46	50	45	39	36
T_{11}	Rajphos	45	42	47	53	57	52	46	43
T_{12}	”	”	45	50	56	60	55	49	46
T_{13}	”	”	40	45	51	55	50	44	41
T_{14}	”	”	44	48	54	58	53	47	44
T_{15}	”	”	41	46	52	56	51	45	42
T_{16}	Superphosphate	15	33	38	44	48	43	37	34
T_{17}	”	”	36	41	47	51	46	40	37
T_{18}	”	”	32	37	43	47	42	36	33
T_{19}	”	”	35	40	46	50	45	39	36
T_{20}	”	”	32	37	43	47	42	36	33
T_{21}	Superphosphate	30	45	50	56	60	55	49	46
T_{22}	”	”	49	54	60	64	59	53	46
T_{23}	”	”	43	48	53	58	52	46	42
T_{24}	”	”	48	53	59	63	58	52	49
T_{25}	”	”	44	49	55	59	54	48	45
T_{26}	Superphosphate	45	51	56	62	66	61	55	52
T_{27}	”	”	55	60	66	70	65	59	56
T_{28}	”	”	50	55	61	65	60	54	51
T_{29}	”	”	53	58	64	68	63	56	54
T_{30}	”	”	51	56	62	66	61	55	52
T_{31}			40	46	53	57	51	45	42
C.D. at 5% level			11.4	11.5	12.4	11.2	13.2	12.8	13.7

Table 9. Effect of levels and forms of P on Al-P fraction on submergence (ppm) (pooled mean value)

Treatments	Forms of P	Levels of P_2O_5 Kg/ha	Period in days						
			0-days	15-days	30-days	45-days	60-days	75-days	90-days
T_1	Rajphos	15	24	29	37	42	35	32	28
T_2	"	"	27	33	41	46	39	36	32
T_3	"	"	21	26	34	39	32	29	25
T_4	"	"	25	31	39	44	37	34	30
T_5	"	"	23	28	36	41	34	31	27
T_6	Rajphos	30	26	31	39	44	37	34	30
T_7	"	"	31	37	45	50	43	40	36
T_8	"	"	24	29	37	42	35	32	28
T_9	"	"	29	34	42	47	41	38	34
T_{10}	"	"	25	30	38	43	36	33	29
T_{11}	Rajphos	45	29	34	42	47	40	37	33
T_{12}	"	"	32	38	46	51	44	41	37
T_{13}	"	"	27	32	40	45	38	35	31
T_{14}	"	"	30	35	43	48	41	38	34
T_{15}	"	"	28	33	41	46	39	36	32
T_{16}	Superphosphate	15	33	39	46	53	44	41	37
T_{17}	"	"	36	42	50	55	48	45	41
T_{18}	"	"	31	36	44	49	42	39	35
T_{19}	"	"	34	39	47	52	45	42	38
T_{20}	"	"	32	37	45	50	43	40	36
T_{21}	Superphosphate	30	35	40	48	53	46	43	39
T_{22}	"	"	39	45	53	58	51	48	44
T_{23}	"	"	34	39	47	52	45	42	38
T_{24}	"	"	37	42	50	55	48	45	41
T_{25}	"	"	35	40	48	53	46	43	39
T_{26}	Superphosphate	45	37	42	50	55	46	43	39
T_{27}	"	"	40	47	55	60	53	50	46
T_{28}	"	"	35	40	48	53	46	43	39
T_{29}	"	"	38	43	51	56	49	46	42
T_{30}	"	"	36	41	49	54	45	42	38
T_{31}			31	38	45	51	44	40	36
C.D. at 5% level			10.5	8.3	9.7	13.3	11.5	10.7	10.4

The treatment T_{27} recorded the highest value (70 ppm) and the lowest value was registered by the treatments T_{18} and T_{20} (47 ppm) on the 45th day of observation. Towards the last three observations a decrease in the Fe-P fraction was noticed and the final values obtained after 90 days were more or less the same as the first observation. The absolute values observed for SSP containing treatments during the fourth observation was comparable to the values recorded for Rajphos applied treatments at all levels of P application. However, with respect to phosphobacterin inoculation, no substantial change could be observed though there was an increase in the Fe-P values with time of incubation, recording maximum values on the 45th day. The treatments T_{12}, T_{14}, T_{16}, T_{17}, T_{18}, T_{19}, T_{20}, T_{21}, T_{22}, T_{24} and T_{25} were on a par.

4.1.1.5 Al-P

Data presented in Table 9, indicated a gradual increase in the Al-P fraction with the period of incubation. Maximum values were recorded during the fourth observation for all the treatments at all levels of P application. Subsequently the values showed a decrease towards the last observation. The absolute values recorded with respect to all the treatments during the last observation were higher than the initial values. Treatments containing SSP invariability registered higher values of Al-P in all the observations at all levels though not significant statistically. The treatment T_{27} representing the highest

Table 10. Effect of different levels and forms of P on Ca-P fraction under submergence (pooled mean value)

Treatments	Forms of P	Levels of P_2O_5 Kg/ha	Period in days						
			0-days	15-days	30-days	45-days	60-days	75-days	90-days
T_1	Rajphos	15	74	78	82	85	86	85	80
T_2	”	”	78	82	86	89	90	89	84
T_3	”	”	72	76	80	83	84	83	78
T_4	”	”	76	80	84	87	88	87	82
T_5	”	”	73	77	81	84	85	84	79
T_6	Rajphos	30	77	82	87	91	92	91	85
T_7	”	”	79	84	89	93	94	93	87
T_8	”	”	75	80	85	89	90	89	83
T_9	”	”	78	83	88	92	93	92	86
T_{10}	”	”	76	81	86	90	91	90	84
T_{11}	Rajphos	45	95	101	107	112	113	112	105
T_{12}	”	”	98	104	110	115	116	115	108
T_{13}	”	”	92	98	104	109	110	109	106
T_{14}	”	”	96	102	108	113	114	113	101
T_{15}	”	”	91	97	103	108	109	108	102
T_{16}	Superphosphate	15	84	89	94	98	100	97	87
T_{17}	”	”	89	94	99	103	105	102	92
T_{18}	”	”	80	85	90	94	96	93	83
T_{19}	”	”	86	91	96	100	102	99	89
T_{20}	”	”	83	88	93	97	99	96	97
T_{21}	Superphosphate	30	95	101	106	111	114	110	99
T_{22}	”	”	98	104	110	115	118	114	103
T_{23}	”	”	91	96	101	106	109	105	94
T_{24}	”	”	96	102	108	113	116	112	101
T_{25}	”	”	92	98	104	109	112	108	97
T_{26}	Superphosphate	45	104	111	118	124	118	123	111
T_{27}	”	”	108	115	127	133	137	132	120
T_{28}	”	”	102	109	116	122	126	121	109
T_{29}	”	”	105	112	119	125	129	124	112
T_{30}	”	”	103	110	117	123	127	122	110
T_{31}			70	76	82	87	88	86	79
C.D. at 5% level			18.4	16.3	22.2	25.7	28.6	26.3	20.7

dose of SSP amended with acid treatment registered the highest value (60 ppm) while the lowest value was observed in the case of T_5 (41 ppm). The effect of pyrite application was not much pronounced in this case though there is a non-significant increase in the values with time. In this case all the SSP treatments were on a par except the control. But in the case of Rajphos treatments only T_{12} and T_{14} were on a par for all periods of incubation.

4.1.1.6 Ca-P

Results of Ca-P fraction are presented in Table 10. All the treatments registered an increase in Ca-P with increase in the period of incubation upto 60^{th} day, values decreased there after towards the last observation. The treatment T_{27} (137 ppm) recorded the highest value and the lowest value was recorded by T_3 (84 ppm). In general treatments containing SSP showed higher values over Rajphos containing treatments in all observations. The final values observed in all treatments were higher than the initial values though not significant statistically. Application of pyrites and phosphobacterin along with P sources increase the Ca-P in all observations compared to the initial values. However treatments receiving acidulation had shown maximum effect in the release of Ca-P. The treatments T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{21}, T_{22}, T_{23}, T_{24}, T_{25}, T_{26}, T_{27}, T_{28}, T_{29} and T_{30} were on a par.

4.2 Pot Culture Experiment

4.2.1 Growth characters

Data on growth characters of the rice crop is presented in Tables 11 and 16.

4.2.1.1 Plant height

The effects of various treatments on various growth characters are evident from the Table 11. A close scrutiny of the data clearly indicates significantly superior effect of the treatment T_{12} (73.2 cm) on plant height. The lowest value was recorded by the treatment T_{18} (63.3 cm). The treatments T_{12} and T_7 (72.8 cm) were on a par. Treatments T_{12} and T_7 represented 50 per cent acidulated Rajphos @ 45 kg ha^{-1} and 30 kg ha^{-1} respectively. Other treatments could not register comparable results with T_{12} and T_7. Results showed statistically significant effect for acidulated rockphosphate on plant height.

4.2.1.2 Number of tillers per plant

Data on tiller count presented in Table 11, indicated significant effects for treatments applied. Treatments T_{12} recorded the maximum number of tillers (14.0) per plant. The lowest value was registered for the treatment T_{18} (9.0). The treatments T_2, T_7, T_{14} and T_{12} were on a par. Hence it is evident that the application of iron pyrites @ 15 per cent (T_{14}) also has given significant effect

Table 11. Effect of different levels and forms of P on the growth characters of rice (pooled mean value)

Treatment	Forms of P	Levels of P_2O_5 Kg/ha	Plant height (cm)	No.of tillers/plant	No.of productive tillers/plant	Panicle length	No.of filled grains	1000 grain weight (gm)
T_1	Rajphos	15	68.3	11.0	8.5	17.7	2044	16.55
T_2	"	"	72.4	13.0	11.0	18.5	2123	16.85
T_3	"	"	65.1	10.5	9.5	16.0	1974	16.20
T_4	"	"	69.2	12.5	10.0	18.0	2055	16.70
T_5	"	"	67.6	10.9	8.0	16.8	1993	16.40
T_6	Rajphos	30	68.0	11.5	9.0	18.0	2032	16.75
T_7	"	"	72.8	13.5	12.0	20.0	2172	17.00
T_8	"	"	67.2	10.0	8.0	17.0	1972	16.25
T_9	"	"	70.1	12.5	11.0	18.8	2067	16.90
T_{10}	"	"	67.8	11.2	8.5	17.8	1992	16.60
T_{11}	Rajphos	45	70.0	12.0	10.0	19.1	2069	16.95
T_{12}	"	"	73.2	14.0	13.0	20.8	2276	17.15
T_{13}	"	"	68.0	10.5	8.5	18.2	2016	16.35
T_{14}	"	"	71.1	13.0	11.0	19.4	2109	17.05
T_{15}	"	"	68.2	11.8	9.0	18.5	2018	16.85
T_{16}	Superphosphate	15	64.0	9.5	8.0	17.0	1981	14.55
T_{17}	"	"	67.0	10.5	8.5	17.7	1988	14.45
T_{18}	"	"	63.3	9.0	6.5	16.2	1972	14.70
T_{19}	"	"	65.4	10.0	8.0	17.2	1987	14.50
T_{20}	"	"	63.5	9.9	8.0	17.0	1980	14.60
T_{21}	Superphosphate	30	64.9	9.5	7.5	17.7	1995	14.98
T_{22}	"	"	67.6	12.5	10.0	18.8	1996	14.95
T_{23}	"	"	64.4	8.5	7.0	17.0	1953	14.85
T_{24}	"	"	66.0	11.5	9.0	17.9	1994	15.05
T_{25}	"	"	64.9	10.0	7.5	17.2	1960	14.80
T_{26}	Superphosphate	45	65.6	10.5	8.5	18.5	2000	15.10
T_{27}		"	68.0	13.0	11.0	18.8	2036	15.20
T_{28}	"	"	64.8	10.0	8.0	18.3	1996	15.05
T_{29}	"	"	66.93	11.0	10.0	18.6	2012	15.41
T_{30}	"	"	65.3	10.8	8.5	18.4	1997	15.15
	"							
T_{31}			67.90	12	10	17.9	2039	15.10
C.D. at 5% level			1.89	1.34	1.43	0.82	132	1.04

on tiller production. All other treatments were on a par and were inferior to T_{12} and T_{14}.

4.2.1.3 Number of productive tillers per plant

More or less the same trend as noticed in the previous case was seen for number of productive tillers with T_{12} (13) registering maximum productive tillers followed by T_7 (12). The lowest value was registered by the treatment T_{18} (6.5).

4.2.1.4 Panicle length

Panicle length recorded also shows the same trend as observed in the case of number of productive tillers. The lowest value was recorded for treatment T_3 (16.0 cm) representing 15 kg ha^{-1} Rajphos amended with ten per cent iron pyrite. The highest value was recorded by the treatment T_{12} (20.8 cm).

4.2.1.5 Number of filled grains

Number of filled grains were also affected by acidulation. On closer analysis, the treatment T_{12} (2276) was found to be superior over the remaining treatments. The treatments T_{23} (1953) received the lowest value for number of filled grains. The treatments T_{12} and T_7 (2172) were on a par. Hence it was clear that the application of SSP @ 30 kg ha^{-1} with ten per cent iron pyrites was the least efficient treatment with respect to number of filled grains. All other treatments were inferior to T_{12} and T_7.

Table 12. Effect of Different levels and forms of P on L. A. I.

Treatment	Forms of P	Levels of P_2O_5 Kg/ha	L.A.I (45 D.A.P)	L.A.I (Harvest)
T_1	Rajphos	15	1.91	1.88
T_2	"	"	1.93	1.91
T_3	"	"	1.90	1.88
T_4	"	"	1.92	1.89
T_5	"	"	1.90	1.88
T_6	Rajphos	30	1.93	1.90
T_7	"	"	1.96	1.94
T_8	"	"	1.91	1.89
T_9	"	"	1.94	1.92
T_{10}	"	"	1.91	1.89
T_{11}	Rajphos	45	2.00	1.98
T_{12}	"	"	2.30	2.00
T_{13}	"	"	1.94	1.89
T_{14}	"	"	2.10	1.99
T_{15}	"	"	1.95	1.91
T_{16}	Superphosphate	15	1.88	1.86
T_{17}	"	"	1.89	1.87
T_{18}	"	"	1.84	1.81
T_{19}	"	"	1.89	1.87
T_{20}	"	"	1.86	1.84
T_{21}	Superphosphate	30	1.90	1.88
T_{22}	"	"	1.93	1.91
T_{23}	"	"	1.85	1.83
T_{24}	"	"	1.91	1.89
T_{25}	"	"	1.89	1.87
T_{26}	Superphosphate	45	1.94	1.91
T_{27}	"	"	1.96	1.93
T_{28}	"	"	1.93	1.90
T_{29}	"	"	1.95	1.92
T_{30}	"	"	1.93	1.90
T_{31}			1.93	1.90
C.D. at 5% level			0.233	0.033

4.2.1.6 Thousand grain weight

Data on thousand grain weight recorded the maximum value (17.15 g) for T_{12} and the lowest value was obtained in the case of T_{22} (14.95 g). The treatments T_1 to T_{15} were on a par.

4.2.2 Leaf Area Index

The effect of various treatments on Leaf Area Index was evident from the Table 12. A close scrutiny of the results reveals the superiority of the treatment T_{12} on LAI at 45 days after planting and at the time of harvest. Irrespective of the treatments LAI showed a decreasing trend from 45 days after planting towards harvest in all the treatment combinations. Data on LAI at 45 days after planting showed maximum value for T_{12} (2.30) and the treatments T_{12} and T_{14} (2.10) were on a par. All other treatments were inferior to the above treatments with respect to LAI. At the time of harvest the treatment T_{12} (2.00) was found to be superior to all other treatments. During both the observations, the lowest value was registered by T_{18} (1.81). Results clearly indicate the positive influence of acidulation and pyrite application in releasing soluble P from Rajphos.

4.2.3 Yield characters

4.2.3.1 Grain yield

Different levels and forms of P were found to influence the grain yield significantly. Data on grain yield was presented in the Table 13. The treatment

Table 13. Effect of different levels and forms of P on yield character (pooled mean value)

Treatment	Forms of P	Levels of P_2O_5 Kg/ha	Grain yield/pot (g)	Straw yield/pot (g)
T_1	Rajphos	15	33.84	38.90
T_2	"	"	35.78	40.80
T_3	"	"	31.98	37.00
T_4	"	"	34.32	39.41
T_5	"	"	32.63	37.69
T_6	Rajphos	30	34.05	40.10
T_7	"	"	36.93	42.15
T_8	"	"	32.05	38.52
T_9	"	"	34.94	40.08
T_{10}	"	"	33.06	39.10
T_{11}	Rajphos	45	35.07	41.10
T_{12}	"	"	39.05	48.05
T_{13}	"	"	32.96	39.98
T_{14}	"	"	35.95	42.06
T_{15}	"	"	34.01	42.01
T_{16}	Superphosphate	15	28.83	34.01
T_{17}	"	"	28.99	34.05
T_{18}	"	"	28.73	33.62
T_{19}	"	"	28.92	34.00
T_{20}	"	"	28.81	33.90
T_{21}	Superphosphate	30	29.90	36.06
T_{22}	"	"	30.01	36.05
T_{23}	"	"	29.01	35.02
T_{24}	"	"	29.90	36.06
T_{25}	"	"	29.85	36.00
T_{26}	Superphosphate	45	30.26	37.15
T_{27}	"	"	31.01	38.15
T_{28}	"	"	30.05	37.05
T_{29}	"	"	30.96	38.00
T_{30}	"	"	30.20	37.20
T_{31}			30.80	37.90
C.D. at 5% level			2.553	5.186

T_{12} (39.05 g) registered maximum yield over the other treatments followed by T_7 (36.93 g). The treatments T_{12} and T_7 were on a par. The lowest grain yield was recorded by the treatment T_{18} (28.73 g). The effect of acidulation was clearly evident from the results.

4.2.3.2 Straw yield

The treatment effects on straw yield are presented in Table 13. Maximum straw yield was obtained from the pots receiving T_{12} (48.05 g) and the lowest value was recorded for the treatment T_{19} (34.0 g). The treatment T_{12} was significantly superior to all other treatments.

4.2.4 Nutrient content of rice grain

Data obtained from different treatments on N, P, K, Ca and Mg was presented in the Table 14.

4.2.4.1 Nitrogen content

The effect of various treatments on grain nitrogen content is presented in Table 14. The treatment T_{12} (1.10 %) showed maximum grain nitrogen content which was significantly superior to all other treatments receiving SSP as their phosphorus source. The treatments T_1 to T_{15} and T_{27} were on a par. The lowest value was registered by the treatment T_{18} (0.90 %). Acidulation of Rajphos was found to increase significantly the grain nitrogen content.

Table 14. Effect of different forms and levels of P on grain nutrient content (%) (pooled mean value)

Treatment	Forms of P	Levels of P_2O_5 Kg/ha	N	P	K	Ca	Mg
T_1	Rajphos	15	1.02	0.22	0.92	0.71	0.14
T_2	"	"	1.06	0.24	0.94	0.70	0.16
T_3	"	"	1.01	0.20	0.90	0.73	0.13
T_4	"	"	1.03	0.23	0.93	0.71	0.15
T_5	"	"	1.01	0.21	0.91	0.72	0.12
T_6	Rajphos	30	1.04	0.23	0.92	0.74	0.13
T_7	"	"	1.09	0.27	0.98	0.71	0.18
T_8	"	"	1.03	0.22	0.91	0.78	0.14
T_9	"	"	1.07	0.24	0.93	0.73	0.15
T_{10}	"	"	1.03	0.22	0.91	0.78	0.14
T_{11}	Rajphos	45	1.05	0.25	1.10	0.80	0.15
T_{12}	"	"	1.10	0.29	1.60	0.71	0.21
T_{13}	"	"	1.03	0.23	0.97	0.76	0.14
T_{14}	"	"	1.06	0.26	1.20	0.72	0.16
T_{15}	"	"	1.05	0.24	0.99	0.71	0.21
T_{16}	Superphosphate	15	0.93	0.12	0.82	0.67	0.14
T_{17}	"	"	0.95	0.14	0.85	0.68	0.16
T_{18}	"	"	0.90	0.10	0.81	0.66	0.13
T_{19}	"	"	0.93	0.13	0.83	0.64	0.12
T_{20}	"	"	0.91	0.11	0.81	0.66	0.13
T_{21}	Superphosphate	30	0.93	0.13.	0.83	0.69	0.15
T_{22}	"	"	0.96	0.16	0.87	0.70	0.18
T_{23}	"	"	0.91	0.11	0.82	0.67	0.14
T_{24}	"	"	0.94	0.14	0.84	0.66	0.16
T_{25}	"	"	0.92	0.12	0.82	0.65	0.13
T_{26}	Superphosphate	45	0.95	0.14	0.84	0.69	0.16
T_{27}	"	"	0.98	0.18	0.89	0.70	0.21
T_{28}	"	"	0.93	0.12	0.83	0.68	0.15
T_{29}	"	"	0.96	0.15	0.85	0.66	0.17
T_{30}	"	"	0.94	0.13	0.83	0.65	0.14
T_{31}			0.96	0.16	0.87	0.69	0.19
C.D. at 5% level			0.120	0.095	0.395	0.078	0.045

4.2.4.2 Phosphorus content

Phosphorus content of grain was significantly influenced by the treatments. Data on grain phosphorus content is presented in Table 14. The treatment T_{12} (0.29 %) recorded the maximum value and the lowest phosphorus content was registered in the case of T_{18} (0.10 %). The treatments T_1 toT_{15} were on a par. Acidulation of Rajphos was found to be effective in increasing the grain phosphorus content. The treatments receiving SSP was statistically inferior to acidulated Rajphos in this context.

4.2.4.3 Potassium content

The effect of different treatments on grain K content is presented in Table 14. The treatment T_{12} (1.60 %) was the most effective treatment indicating the maximum K value. The lowest grain K content was recorded for the treatments T_{18} and T_{20} (0.81 %). All the other treatments were on a par. Results of these treatments clearly indicated the negative effect of pyrites application and inoculation with phosphobacterin with respect to grain K content.

4.2.4.4 Calcium content

The grain calcium content was very much influenced by the different forms and levels of phosphorus (Table 14). The treatment T_{11} (0.8 %) recorded the highest value and the lowest value was recorded for the treatment T_{19} (0.64 %). The treatments T_6, T_8, T_9, T_{10}, T_{11} and T_{13} were on a par. The treatments with SSP were inferior to the above treatments and invariably registered lower values.

4.2.4.5 Magnesium content

The treatment effects significantly influenced the magnesium content. The treatments T_{12}, T_{15} and T_{27} (0.21 %) indicated the maximum value and the lowest value was recorded by the treatments T_5 and T_{19} (0.12 %). The treatments T_7, T_{12}, T_{15}, T_{22}, T_{29} and T_{31} were on a par.

4.2.5 Nutrient content on rice straw

Results of treatment effects on straw nutrient contents are presented in the Table 15.

4.2.5.1 Nitrogen content

The treatments applied significantly influenced the nitrogen content. The treatment T_{12} (0.98 %) registered the maximum nitrogen content. The lowest value was recorded for the treatment T_{18} (0.80 %). The treatments T_2, T_7, T_{12} and T_{14} were on a par. The data clearly indicated a positive influence of acidulated Rajphos and pyrite amended Rajphos in deciding the nitrogen content of the straw.

Table 15. Effect of different forms and levels of P on straw nutrient content (%) (pooled mean value)

Treatment	Forms of P	Levels of P_2O_5 Kg/ha	N	P	K	Ca	Mg
T_1	Rajphos	15	0.91	0.18	0.90	0.70	0.11
T_2	"	"	0.96	0.20	0.92	0.68	0.14
T_3	"	"	0.90	0.17	0.88	0.71	0.10
T_4	"	"	0.93	0.19	0.91	0.69	0.12
T_5	"	"	0.90	0.17	0.89	0.71	0.10
T_6	Rajphos	30	0.92	0.21	0.91	0.69	0.14
T_7	"	"	0.97	0.24	0.96	0.67	0.16
T_8	"	"	0.91	0.20	0.89	0.74	0.11
T_9	"	"	0.94	0.21	0.92	0.69	0.15
T_{10}	"	"	0.91	0.20	0.90	0.74	0.11
T_{11}	Rajphos	45	0.94	0.23	0.98	0.70	0.13
T_{12}	"	"	0.98	0.26	0.99	0.66	0.18
T_{13}	"	"	0.93	0.21	0.96	0.70	0.14
T_{14}	"	"	0.95	0.23	0.98	0.69	0.15
T_{15}	"	"	0.93	0.22	0.97	0.75	0.12
T_{16}	Superphosphate	15	0.81	0.10	0.81	0.65	0.12
T_{17}	"	"	0.85	0.12	0.84	0.66	0.14
T_{18}	"	"	0.80	0.09	0.80	0.63	0.10
T_{19}	"	"	0.83	0.11	0.82	0.64	0.13
T_{20}	"	"	0.80	0.10	0.80	0.65	0.12
T_{21}	Superphosphate	30	0.82	0.11	0.82	0.67	0.13
T_{22}	"	"	0.86	0.14	0.85	0.68	0.16
T_{23}	"	"	0.81	0.09	0.81	0.64	0.11
T_{24}	"	"	0.84	0.12	0.83	0.65	0.14
T_{25}	"	"	0.81	0.10	0.81	0.65	0.12
T_{26}	Superphosphate	45	0.84	0.12	0.83	0.68	0.14
T_{27}	"	"	0.88	0.16	0.87	0.69	0.18
T_{28}	"	"	0.82	0.10	0.82	0.64	0.12
T_{29}	"	"	0.85	0.13	0.84	0.65	0.15
T_{30}	"	"	082	0.11	0.82	0.67	0.13
T_{31}			0.87.	0.15	0.86	0.68	0.17
C.D. at 5% level			0.032	0.066	0.071	0.052	0.035

4.2.5.2 Phosphorus content

Data on phosphorus content of the straw were presented in the Table 15. It is clearly evident from the data that the straw P content is significantly affected by the treatment effects. The maximum straw P was recorded in the case of T_{12} (0.26 %) and the minimum value was noticed for T_{23} (0.09 %). The treatments T_6, T_7, T_8, T_9, T_{10}, T_{12}, T_{13}, T_{14} and T_{15} were on a par. Acidulation was found to impart maximum positive effect on straw P content.

4.2.5.3 Potassium content

Data on straw K content was presented in the Table 15. Highest K value was obtained for the treatment T_{12} (0.99 %) and the lowest value was registered by the treatment T_{18} (0.80 %). The treatments T_2, T_7, T_{11}, T_{12}, T_{13}, T_{14} and T_{15} were on a par. Acidulation was found to have a significant positive effect on straw K content.

4.2.5.4 Calcium content

The results showed statistically significant effect of treatments on calcium content. The lowest value was recorded by the treatment T_{18} (0.63 %) and the highest value was registered by the treatment T_{15} (0.75 %). The treatment T_1, T_3, T_5, T_8, T_{10}, T_{11}, T_{13} and T_{15} were on a par. Inoculation of Rajphos with phosphobacterin was also found to be effective in increasing the calcium content of the straw.

4.2.5.5 Magnesium content

Data on straw magnesium content is presented in the Table 15. Data presented indicate a significant positive effect on the magnesium content due to treatments. The treatments T_{12} and T_{27} (0.18 %) recorded the maximum values. The lowest value was recorded by the treatment T_{18} (0.10 %). Treatments T_7, T_9, T_{12}, T_{14}, T_{22}, T_{27} and T_{31} were on a par. Pots receiving acidulated Rajphos consistently recorded higher magnesium content of straw compared to the other treatments.

4.2.6 Drymatter production and nutrient uptake

Results on drymatter yield and nutrient uptake are presented in the Table 16.

4.2.6.1 Drymatter production

A close scrutiny of the data clearly indicates significantly superior effect of the treatments on drymatter production. The treatments T_{12} and T_7 were on a par. Other treatments could not register comparable results with T_{12} and T_7. The lowest value on drymatter production was recorded for the treatment T_{18} (72.94 g). Maximum drymatter production was registered for the treatment T_{12} (87.10 g).

The nutrient uptake by the crop receiving different treatments is outlined below.

Table 16. Effect of different levels and forms of P on drymatter production and nutrient uptake (%)

(Pooled mean value)

Treatment	Forms of P	Levels of P_2O_5 Kg/ha	Dry matter production(g)	N	P	K	Ca	Mg
T_1	Rajphos	15	72.74	0.701	0.149	0.661	0.508	0.093
T_2	"	"	76.58	0.754	0.166	0.711	0.527	0.111
T_3	"	"	68.98	0.659	0.129	0.620	0.492	0.075
T_4	"	"	73.73	0.729	0.148	0.696	0.514	0.102
T_5	"	"	70.31	0.668	0.132	0.624	0.501	0.083
T_6	Rajphos	30	74.15	0.722	0.162	0.680	0.532	0.103
T_7	"	"	79.08	0.925	0.200	0.765	0.544	0.133
T_8	"	"	70.57	0.680	0.147	0.640	0.532	0.083
T_9	"	"	75.02	0.753	0.167	0.692	0.524	0.111
T_{10}	"	"	72.16	0.695	0.150	0.647	0.542	0.092
T_{11}	Rajphos	45	76.17	0.820	0.185	0.872	0.539	0.113
T_{12}	"	"	87.10	1.090	0.236	1.249	0.594	0.168
T_{13}	"	"	72.94	0.714	0.162	0.698	0.549	0.093
T_{14}	"	"	77.00	0.794	0.185	0.758	0.544	0.124
T_{15}	"	"	76.02	0.747	0.169	0.794	0.605	0.105
T_{16}	Superphosphate	15	62.81	0.550	0.074	0.517	0.404	0.087
T_{17}	"	"	63.04	0.564	0.087	0.532	0.421	0.093
T_{18}	"	"	62.35	0.526	0.058	0.500	0.394	0.067
T_{19}	"	"	62.92	0.538	0.062	0.528	0.406	0.074
T_{20}	"	"	62.71	0.530	0.061	0.504	0.414	0.080
T_{21}	Superphosphate	30	65.85	0.569	0.077	0.542	0.446	0.090
T_{22}	"	"	66.16	0.598	0.098	0.568	0.455	0.111
T_{23}	"	"	64.02	0.552	0.062	0.520	0.412	0.075
T_{24}	"	"	65.96	0.583	0.084	0.550	0.431	0.097
T_{25}	"	"	64.03	0.551	0.069	0.520	0.412	0.075
T_{26}	Superphosphate	45	67.41	0.605	0.078	0.569	0.440	0.106
T_{27}	"	"	69.16	0.628	0.116	0.606	0.480	0.133
T_{28}	"	"	67.10	0.593	0.073	0.552	0.432	0.86
T_{29}	"	"	68.96	0.613	0.080	0.575	0.471	0.120
T_{30}	"	"	67.40	0.585	0.079	0.555	0.454	0.093
T_{31}			68.70	0.625	0.105	0.592	0.469	0.122
C.D. at 5% level			10.053	0.253	0.038	0.352	0.093	0.042

4.2.6.2 Nitrogen uptake

Data presented in the Table 16, indicated significant effects due to treatments. The treatment T_{12} (1.090 %) recorded the maximum value for nitrogen uptake. The lowest value was indicated for pots receiving treatment T_{18} (0.714 %). The treatments T_{12} and T_7 were on a par. All other treatments were on a par and were inferior to T_{12} and T_7. Hence it is inferred that the application of acidulated Rajphos is imparting a profound influence on the nitrogen uptake by the crop. Treatments receiving pyrite and phosphobacterin were less effective in this context.

4.2.6.3 Phosphorus uptake

More or less the same trend as observed in the previous case was seen for phosphorus uptake with T_{12} (0.236 %) registering the maximum uptake followed by T_7 (0.200 %). The lowest value was observed in the case of the treatment T_{18} (0.058 %).

4.2.6.4 Potassium uptake

The potassium uptake was also affected significantly by treatment effects. Perusal of the data indicated the superiority of T_{12} (1.249 %) over the remaining treatments. The pots receiving T_{18} (0.500 %) showed the lowest value for K uptake. All the treatments except T_{23} and T_{25} were on a par. Treatments receiving pyrite and phosphobacterin along with Rajphos and superphosphate was not very effective when compared to treatments receiving acidulation.

4.2.6.5 Calcium uptake

Data on calcium uptake is presented in the Table 16. Results on calcium uptake indicated the superior effect of phosphobacterin inoculation. Maximum value on Ca-uptake was registered for the treatment T_{15} (0.005 %) and the lower value was recorded for T_{16} (0.404 %). The treatments T_2, T_4, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13} and T_{14} were on a par.

4.2.6.6 Magnesium uptake

Treatments applied significantly influenced the magnesium uptake. The maximum value was obtained for the treatment T_{12} (0.168 %) and the lowest value was recorded for the treatment T_{18} (0.093 %). The treatments T_7, T_{12} and T_{27} were on a par.

DISCUSSION

5. DISCUSSION

5.1 Incubation experiment

The transformations of applied phosphorus under the rice farming situations of Chittoor *Poonthalpadams* were investigated through an incubation experiment and the significance of the relative proportions of the P fractions *viz.*, saloid-P, occluded-P, reductant-P, Al-P and Ca-P obtained at different time intervals are discussed in relation to the soil properties and the pre-treatments the P sources are subjected to.

It is evident from the data presented (Table 5 to 10 and Fig. 5 to 7) that these fractions were significantly influenced consequent to submergence by the various amendments used. As the mineralochemical composition of the soil selected was more or less uniform for all the samples, the observed variations could be attributed to the inherent variations in the P sources selected and the pre treatments given to the source material.

5.1.1 Saloid-P

The observed increase in saloid-P fraction upto the 30^{th} day of incubation is attributed to an expected increase in the ionic swarm consequent to soil reduction and the co-existence of the soluble P fractions with basic cations presumably through co-ordination complexes whose existence is transitory. This mechanism is reasonably active in an alkaline soil with appreciable base exchange capacity. As time advances the transformations of the saloid bound P fraction to other stable fractions are likely to gain momentum. Thus a decline in the concentration of saloid-P is the rule under submerged conditions. As the saloid-P fraction is mainly restricted to the finer colloidal phase of the soil, the subsequent transformations which they are subjected to owing to the higher surface area is very active. As expected, any amendment or process, which leads to an increase in the availability of P from either native or added sources could increase the transformation of this fraction at a faster rate. Hence, enhancement of the dissolution of Rajphos by direct acidulation (Hammond *et al.*, 1986), solubility increase due to indirect acidulation by pyrites application and inoculation with phosphobacterin (Sushama *et al.*, 1993), all have a positive beneficial effect to increase this fraction. The decline in the concentration after a peak is believed to be due to its conversion to other forms or by plant uptake. Thus the present observation is in conformity with the findings of Chaudhary and Mishra (1980), Mandal and Khan (1975) who were observed a similar trend for saloid-P fraction under waterlogged conditions. Higher values observed for saloid-P at higher doses of P fertilizers with amendments could be explained by the increased soluble P and its subsequent transformation to this fraction. As SSP treated with acid contributed maximum soluble P fractions for subsequent conversions, the superiority of T_{27} (1.90 ppm) stands substantiated.

5.1.2 Occluded – P

Data on occluded-P fraction clearly indicate a gradual increase with period of submergence. Occluded-P fraction represents the sorption capacity of the soil for phosphorus through adsorption, co-precipitation and occlusion. Though the soil is slightly alkaline, the pedogenic environment in the past had resulted in the accumulation of substantial quantities of inorganic oxides and sesquioxides of iron, aluminium and manganese. Thus the P fraction that could be associated with crystalline and amorphous components through sorption and co-precipitation becomes considerable though they are not chemically bound (Kumaraswamy and Sreeramulu, 1992). Hence the inorganic soil matrix represented by iron, aluminium, manganese components and their physical interaction through a larger surface area would have contributed for a slightly higher value of this fraction. As the solubility of the applied P is increased, the proportionate retention of this soluble fraction as occluded-P also might have increased (Devanath and Hajra, 1972). As the present study has attempted methods and amendments for P solubilisation, it is expected that the interaction of released P with the soil components could increase the occluded-P fraction (Gupta *et al.*, 1999). Further the soil is a typical Vertisol with a reasonably high CEC, clay and sesquioxide content with comparatively higher sorption capacity.

The highest value was recorded in the case of treatment T_{27} (17 ppm) receiving SSP acidulated with H_2SO_4. The rockphosphate acidulated with

H_2SO_4 and amended with pyrite at all levels of P addition might have contributed higher soluble P fractions with time of incubation. The inoculation with phosphobacterin was also effective though the release of P was little slower than the other treatments. Hence it is theoretically sound to believe that all the above treatments could enhance the availability of P and its role to increase the occluded-P through interaction with the inorganic soil components.

5.1.3 Reductant – P

Values on reductant-P fractions show statistical significance with respect to treatment effects. Treatments receiving acidulated phosphate from both sources increased the reductant-P fractions with time of incubation, maximum values were recorded in all cases during the second observation. The easily reducible iron oxides and sesquioxides could readily combine with the soluble phosphates released from the P applied. Since the soil contain appreciable quantities of iron compounds, this fraction increased substantially with the advancement of the time of incubation (Kanwar and Tripathi, 1977). The reductant-P has changed to Fe-P, Al-P and Ca-P and hence a gradual decrease was observed towards the last observation (Mahapathra and Patrick, 1969). Pyrite application and phosphobacterin inoculation also enhanced this fraction though the effect was not much pronounced as in the case of acidulation. Pyrite oxidation to create acidity for the effective solubilisation of rock phosphate was comparatively less significant in this case. As the soil is of recent origin from alluvial deposits, oxides and sesquioxides presented are easily reduced unlike highly senile oxide rich soils. As the soil is continuously submerged subsequent transformations to more active and chemically combined forms like Fe-P, Al-P and Ca-P ultimately decide the existence and stability of this fraction. Since the values reported are intermediate of occluded-P and Ca-P, Fe-P and Al-P, the faster rate at which these fractions are transformed are evident (Singh and Bahaman, 1976). Direct acidulation with H_2SO_4 has substantially increased the P solubility from both the P sources and the solubilised P was immediately made available for reaction with the easily reducible oxides. Thus the treatment T_{27} (29 ppm) representing SSP with maximum acidulation had released the highest level of available P for conversion to reductant-P.

5.1.4 Fe-P

Fe-P values increased drastically due to submergence and recorded maximum values around the fourth observation (Fig. 1). This observed increase is believed to be due to the transformation of the applied P to chemically stable iron phosphates. Though the pH is alkaline, owing to continuous submergence reduction of iron compounds and solubilisation leading to a spurt in the ferrous ion concentration might have initiated the chemical precipitation of colloidal iron phosphates distributed mainly in the finer fractions. Direct conversion from coarser fractions like Ca-P is also expected in alkaline and calcareous soils since Ca-P is concentrated mostly in

Fig. 1. Effect of different levels and forms of P on Fe-P on 45th day of submergence(ppm)

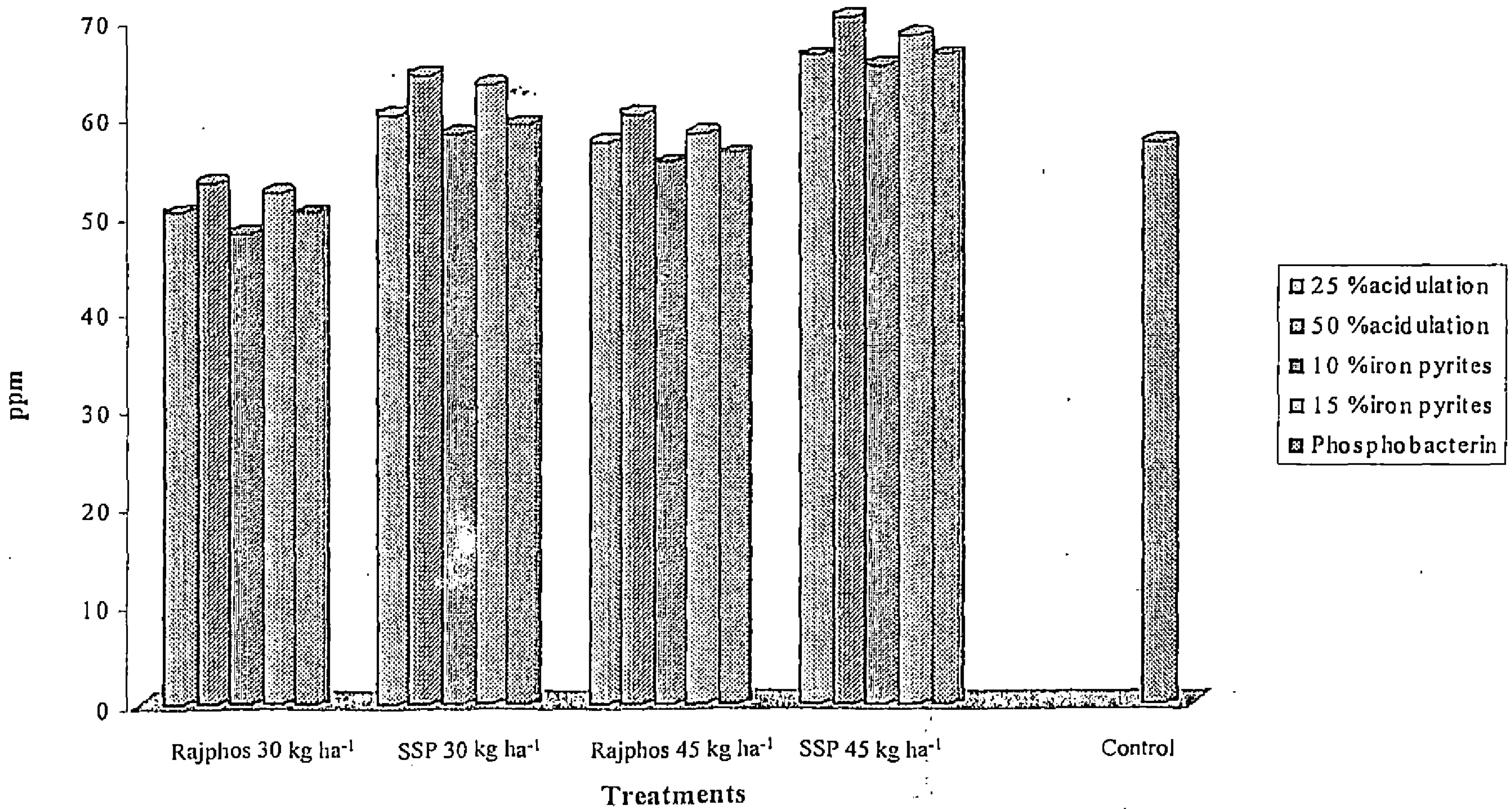
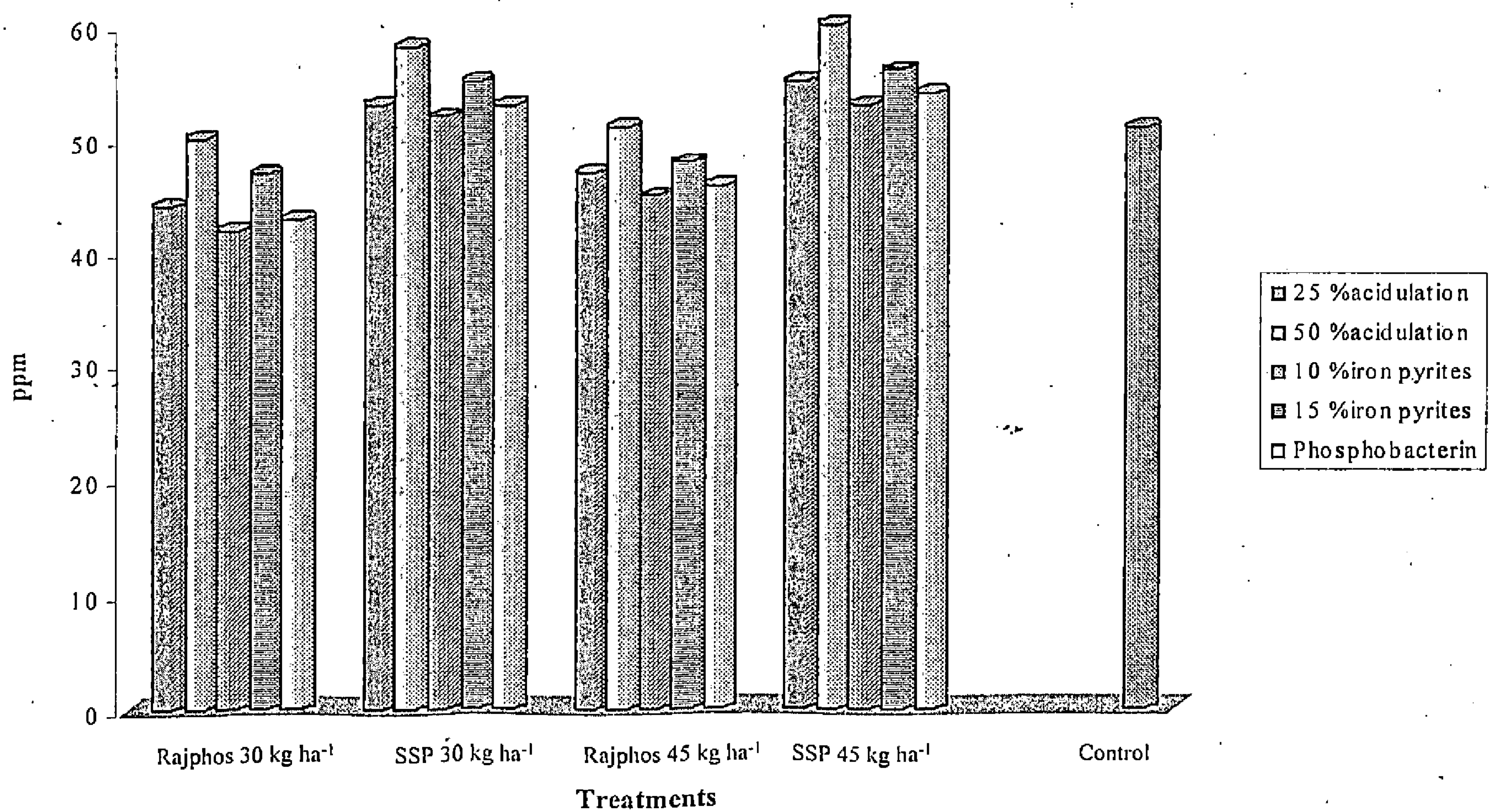


Fig. 2. Effect of different levels and forms of P on Al-P on 45th day of submergence(ppm)



the coarser fraction. Thus the present observation is in conformity with the findings of Mahapathra and Patrick (1969), Singh and Bahaman (1976) and Jose (1973). Acidulation might have remarkably enhanced the solubility of phosphate and solubility of iron oxides both resulting in the formation of Fe-P (Verma and Thripathi, 1982). The highest value was registered for the treatment T_{27} (70 ppm) obtained on the fourth observation. The observed decrease after 45 days of incubation could be attributed to ageing of the precipitated iron phosphate and its conversion to highly insoluble iron compounds of varying complexity (Nair, 1986). As the increased activity of calcium in this soil is higher chances of part of the Fe-P getting converted to Ca-P cannot be ruled out.

5.1.5 Al-P

Al-P fraction of the samples registered an increase with time of incubation upto the fourth observation and declined subsequently for most of the treatments (Fig.2). Treatments receiving acidulation and pyrite application had given higher values compared to phosphobacterin inoculation. The maximum Al-P value was registered for the treatment T_{27} (60 ppm) on the fourth observation. As the soil contain substantial amount of aluminium oxides chiefly distributed in the amorphous form, interaction with soluble phosphates leading to precipitation as Al-P is likely. Though the alkalinity of the soil retard the activity of aluminium in the soil solution, acidity created from the treated rockphosphate and SSP would have considerably enhanced

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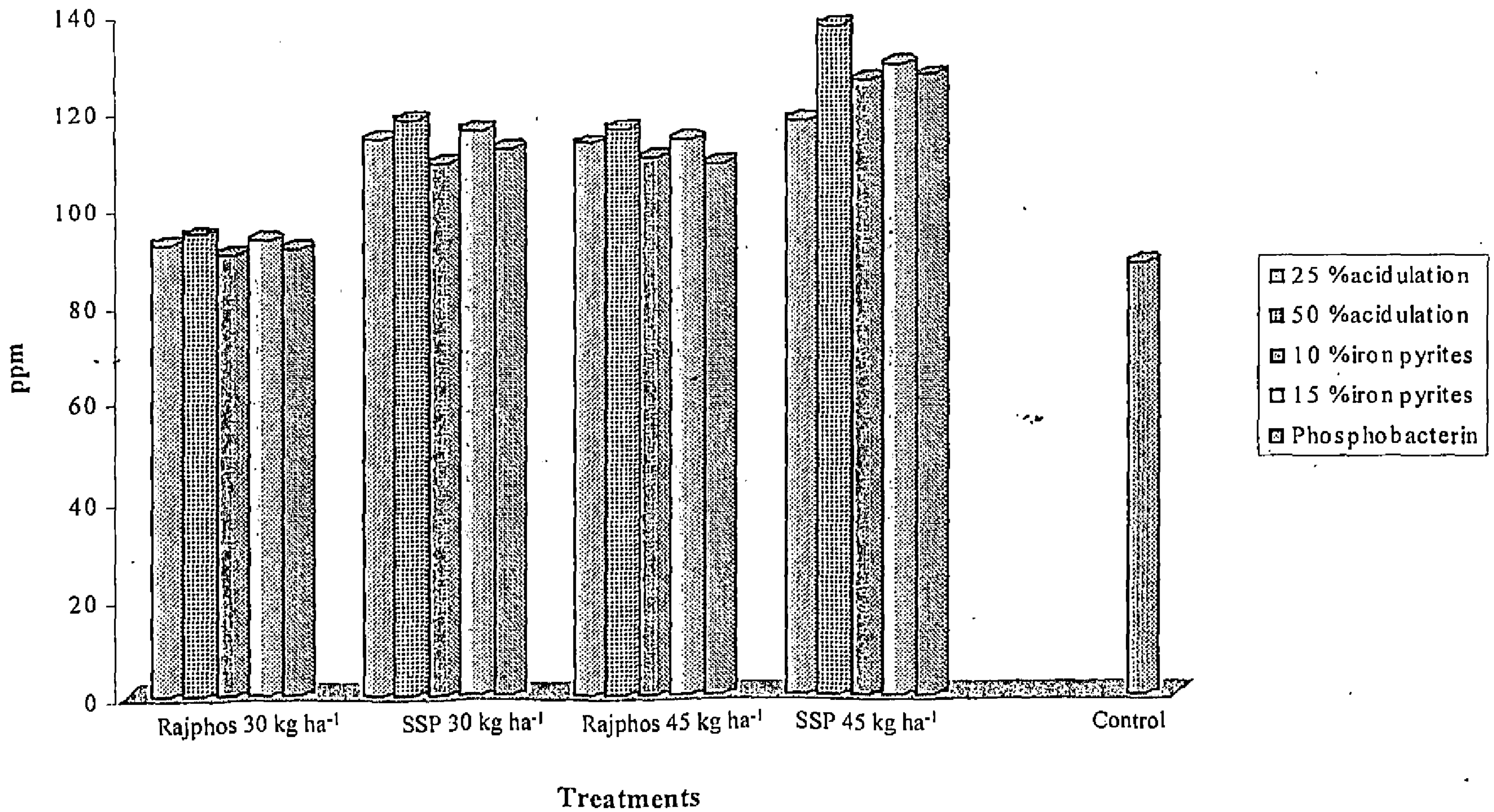
Fig. 3. Effect of different levels and forms of P on Ca-P on 60th day of submergence(ppm)



the rate of formation of Al-P. Further transformations from reductant-P and occluded-P to Al-P was also considerable at least during the earlier phase of the incubation experiment (Gu and Wang, 1986). Hence it is logical to believe that a greater portion of the soluble phosphate released have been converted to Al-P. Increased adsorption of phosphate on clay colloids and subsequent reactions with the aluminosilicates also would have contributed to the pool of Al-P. Subsequent decrease in concentration might be due to its transformation to Fe-P or to mineral forms with low solubility (Ravindra and Ananthanarayana, 1999). This increase in availability of Al-P is in conformity with the findings of Saranganath *et al.* (1977) and Jose (1973). The control treatment receiving no amendments had registered comparatively lower values though the same pattern of change was noticed through out.

5.1.6 Ca-P

Ca-P fractions registered the highest values throughout the period of incubation as compared to other fractions of phosphorus (Fig. 3). As the soil contain a relatively higher percentage of exchangeable calcium, conversion of soluble phosphorus derived from the P sources to Ca-P stands substantiated. The maximum value was registered for the treatment T_{27} (137 ppm) on the fifth observation. As Ca is one of the dominant cations in this soil, transformations from other fractions like Fe-P and Al-P to calcium also might have increased the Ca-P pool (Kumaraswamy and Sreeramulu, 1992). Since Ca-P is concentrated in the coarser colloidal fractions of the soil loss through leaching, adsorption and co-precipitation from the soil solution is also very low. Al-Abbas and Barber (1962), Batta (1993) and Nisha (1995) also reported similar reactions for Ca-P transformations in soils. The present finding is thus in conformity with the reports of Gupta *et al.* (1999), Anilkumar *et al.* (1999) and Jose (1973). The increased solubility leading to a higher availability of soluble P to interact with calcium ions was further mediated through treatments like acidulation and pyrite application. Direct acidulation is found to be more effective than pyrite application in controlling the Ca-P flux of the soil. Phosphobacterin inoculation though technically sound is the least effective in this case.

5.2 Pot culture experiment

5.2.1 Biometric observations

From the results of the biometric observations (Table 11), it is clear that the treatments have got significant effect on number of tillers per plant. The highest number of tillers per plant was recorded for the treatment T_{12} (14) followed by T_2, T_7, T_{14} and T_{12}, all these treatments were on a par. This could be attributed to the higher P availability for the crop from the above treatments. Source of plant nutrients and extend of nutrient availability decide the tiller number of rice plant in many cases (Masthan *et al.*, 1999). Phosphorus availability is maximized through acidulation with sulphuric acid converting insoluble tricalciumphosphate to watersoluble monocalcium phosphate. Phosphorus has a major role to increase the vegetative growth in rice through enhanced root proliferation and the associated increase in the uptake of nutrients. This is in conformity with earlier finding of Rama Rao *et al.* (1992).

The number of productive tillers per plant indicated that the highest values are recorded for the treatments T_{12} (13) and T_7 (12), these treatments were on a par. From the results it could be noted that Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation give higher number of productive tillers per plant which were on a par with Rajphos @ 30 kg ha^{-1} receiving 50 per cent acidulation. This is again followed by Rajphos @ 30 kg ha^{-1} with phosphobacterin (11) and Rajphos @ 45 kg ha^{-1} with phosphobacterin (11) treatments. The solubilisation effect on applied rockphosphate was increased through different amendments like sulphuric acid, pyrites and phosphobacterin inoculation with an increase in the available P status. The acidity created by sulphuric acid and phosphobacterin causes the conversion of unavailable tricalcic form to dicalcic and monocalcic P forms and there by P availability is increased. So maximum productive tiller count could be obtained for the above mentioned treatments. This is in agreement with the earlier findings of Masthan *et al.* (1999), Pandian (1999) and Roy and Jha (1987).

Result of plant height indicated that maximum value is obtained for the treatment T_{12} (73.2 cm). The treatments T_{12} and T_7 were on a par. The maximum plant height was obtained for T_{12} *ie*., Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation followed by Rajphos @ 30 kg ha^{-1} with 50 per cent acidulation. From this observation it could be noted that in neutral to alkaline soils the acidulated forms of Rajphos performs well when compared with other treatments. The soluble phosphate from SSP might have combined with native soil calcium and formed calcium-P in the soil (Saranganath, 1977) thus reducing the available P pool considerably. This is in conformity with earlier works of Gupta and Ram (1971) and Hooffmann and Barber (1971).

Results of panicle length show that the treatment T_{12} (20.8 cm) recorded highest panicle length. The highest value was obtained for T_{12}, which was Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation. It could be noted from the results that Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation, Rajphos @ 30 kg ha^{-1} with 50 per cent acidulation, Rajphos @ 45 kg ha^{-1} with phosphobacterin and Rajphos @ 30 kg ha^{-1} with 25 per cent acidulation perform equally well in giving highest panicle length. From the results it is evident that the effect of SSP is not much pronounced compared to the above treatments. Release of soluble P from treatments receiving amendments is gradual and is sustained by the acidity created in the soil, while the chances of fixation of the soluble P released from the SSP is more and the process is faster. This is in agreement with the findings of Pandian (1999) Hammond *et al*. (1986) and Mc Lean and Wheeler (1964).

From the results it could be noted that Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation give maximum number of filled grains which were on a par with Rajphos @ 30 kg ha^{-1} receiving 50 per cent acidulation. Thus it is obvious that the P released from the treatment T_7 is able to maintain the available P status of the soil to cater the requirement of the crop. A higher additional rate above this dose is not beneficial to the crop. This is in conformity with earlier findings of Singh *et al.* (1987).

Results of thousand grain weight indicated that treatment T_{12} (17.15 g) recorded maximum value. From the results it could be noted that treatment receiving Rajphos @ 30 kg $ha^{-1}$with 50 per cent acidulation is able to impart the same effect as Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation does in the field. Hence the lower dose of Rajphos is more economical and could reduce the cost of cultivation substantially. Solubilisation of rockphosphate by the acidity created with sulphuric acid addition has been reported by many workers (Santhy, 1999; Kanabo and Gilkes, 1987).

5.2.2 Leaf area index (LAI)

The effect of various treatments on Leaf Area Index was evident from the Table 12. A close scrutiny of the results reveals the superiority of the treatment T_{12} on LAI at 45 days after planting and at the time of harvest. Irrespective of the treatments LAI showed a decreasing trend from 45 days after planting towards harvest in all the treatment combinations. Data on LAI at 45 days after planting showed maximum value for T_{12} (2.30) and the treatments T_{12} and T_{14} (2.10) were on a par. All other treatments were inferior to the above treatments with respect to LAI. At the time of harvest the treatment T_{12} (2.00) was found to be superior to all other treatments. During both the observations, the lowest value was registered by T_{18} (1.81). Leaf area is simple and appropriate measure of plant's photosynthetic potential (Watson, 1952). Results clearly indicate the positive influence of acidulation and pyrite application in releasing soluble P from Rajphos.

5.2.3 Grain and straw yield

Effect of different forms and levels of P on grain and straw was found to be significant. The treatments receiving acidulation were found to release sufficient P from added rockphosphate to meet the requirement of the crop. However the highest yield was noticed for both straw and grain in the case of T_{12}. This reported beneficial effect could be attributed to the dissolution of rockphosphate by the acidity created through acidulation (Marwahah, 1983). Even the lowest dose of 15 kg rockphophate with 50 per cent acidulation (T_2) could release soluble P sufficient to meet the crop requirement. Thus the effect of acidulation and its performance in alkaline soil selected for the study stands substantiated.

5.2.4 Nutrient content of grain

The results of different forms and levels of P on grain nutrient content *ie.* N, P, K, Ca and Mg are presented in the Table 14. Maximum N content of grain was obtained for the treatment T_{12} (1.10 %) followed by T_8 (1.09 %)

which were on a par. From the results it is clear that the highest N content of grains is registered for pots receiving Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation followed by Rajphos @ 30 kg ha^{-1} with 50 per cent acidulation. From the results it is evident that acidulation of Rajphos enhance the availability of P in the soil and thereby uptake and utilization of N by plant is enhanced. This might have resulted in an increased in the grain yield and N content. Increase in grain yield and N content consequent to higher dose of P have been reported by many workers (Gangaiah and Prasad, 1999; Ramaswamy, 1981).

Result of P content of grain showed the same trend as in the case of nitrogen. Treatment T_{12} (0.29 %) recorded maximum phosphorus content. It is clear that Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation and Rajphos @ 30 kg ha^{-1} with 50 per cent acidulation and Rajphos with phosphobacterin treatments enhance availability of translocation of P to grains. As the total uptake of P by the plant was increased, the relative proportion of the P to the grains also was increased subsequently. Further the acidity maintained by the treatments resulted in a sustained release of P from the added sources during the active growth stage of the crop. Thus the observed increased in P content of the grain stands substantiated. Similar results have been reported by Vaishya *et al.* (1996) and Salih *et al.* (1989).

Uptake of K, Ca and Mg also was influenced by the treatments significantly. Increase in the available P caused by the treatment effects might have resulted in a higher uptake and utilization of P by the plants. Enhanced P utilization might have increased the uptake of other nutrient like K, Ca and Mg. Since the biomass accumulation due to higher P availability was increased significantly. Further the soil was fertilized with K as per POP recommendations. The exchangeable K, Ca and Mg status of the soil used for the study was also higher (Padmaja *et al.*, 1994) and this maintained a higher level of these available nutrients in the soil solution. Hence the inherently higher soil status coupled with a higher P and N availability resulted in the higher uptake of these nutrients.

5.2.5 Nutrient content of straw

The straw nutrient contents presented in the Table 15, follows the same trend as in the case of grain nutrient contents. Maximum amount of nitrogen was recorded for the treatment T_{12} (0.98 %) which represents Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation. The acidulation might have increased the solubility of applied rockphosphate, thereby increasing P flux of the soil which in turn increase the uptake of P. Increase in the uptake of P by the crop indirectly increased nitrogen uptake due to the positive N-P interactions (Gangaiah and Prasad, 1999).

The treatment T_{12} (0.26 %) recorded maximum P content in harvested straw. The highest straw P content obtained with the application of acidulated rockphosphate at higher level might be due to a prolonged and steady supply of P to meet the requirement of the crop at the different growth stages

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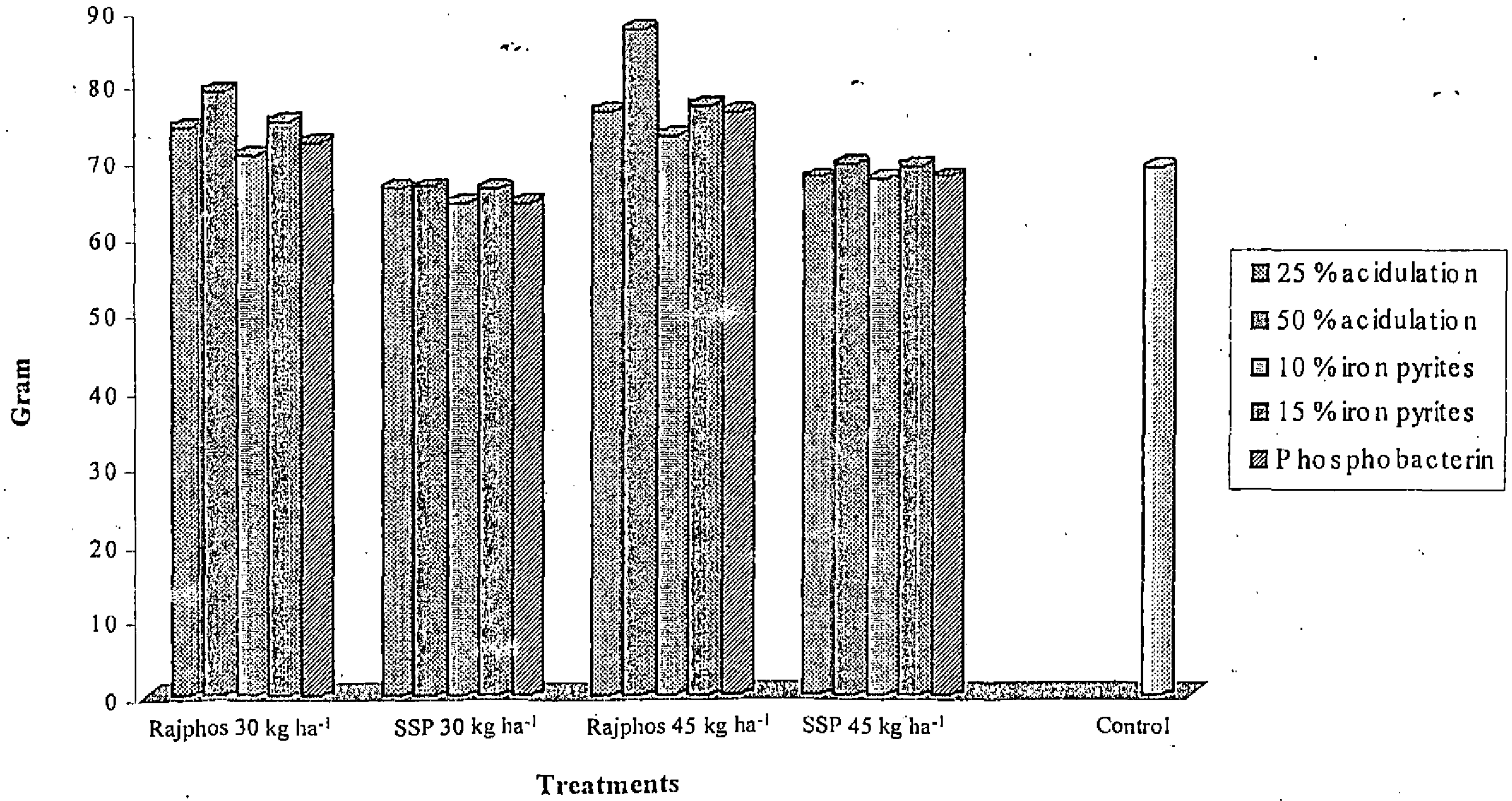
Fig. 4. Effect of different levels and forms of P on drymatter production (g)



(Sucharitha and Ramachandrabhoopathi, 2000). The result of straw K content is presented in the Table 8. The highest value was recorded for the treatment T_{12} (1.30 %), receiving Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation. This might be due to the increased dissolution of rockphosphate by acidulation leading to the higher P availability (Marwahah, 1983), that indirectly increase the uptake of soil potassium by the rice crop through positive P-K interactions. This is again in conformity with the findings of Gangaiah and Prasad (1999). The Ca and Mg content of straw also show the same trend as in the case of grain Ca and Mg content.

5.2.6 Drymatter yield and nutrient uptake

A close scrutiny of data presented in Table 16, clearly indicates the superiority of the treatment T_{12} over other treatments in deciding the total dry matter production and the uptake of plant nutrients (Fig. 4 to 7). As this treatment represents Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation by sulphuric acid, reconversion of the tricalcic form of phosphorus to dicalcic and monocalcic forms available to the plants is indicated. Thus the available soil P pool is enhanced drastically and the plant uptake increased substantially. The change in soil reaction associated with acidulation to a near neutral condition also might have influence favourably the uptake of plant nutrients. Thus compensation for the deficient nutrient phosphorus through acidulated rockphosphate coupled with an assured supply of other nutrients from the added fertilizers as per Package of Practices

Fig. 5. Effect of different levels and forms of P on nitrogen uptake (%)

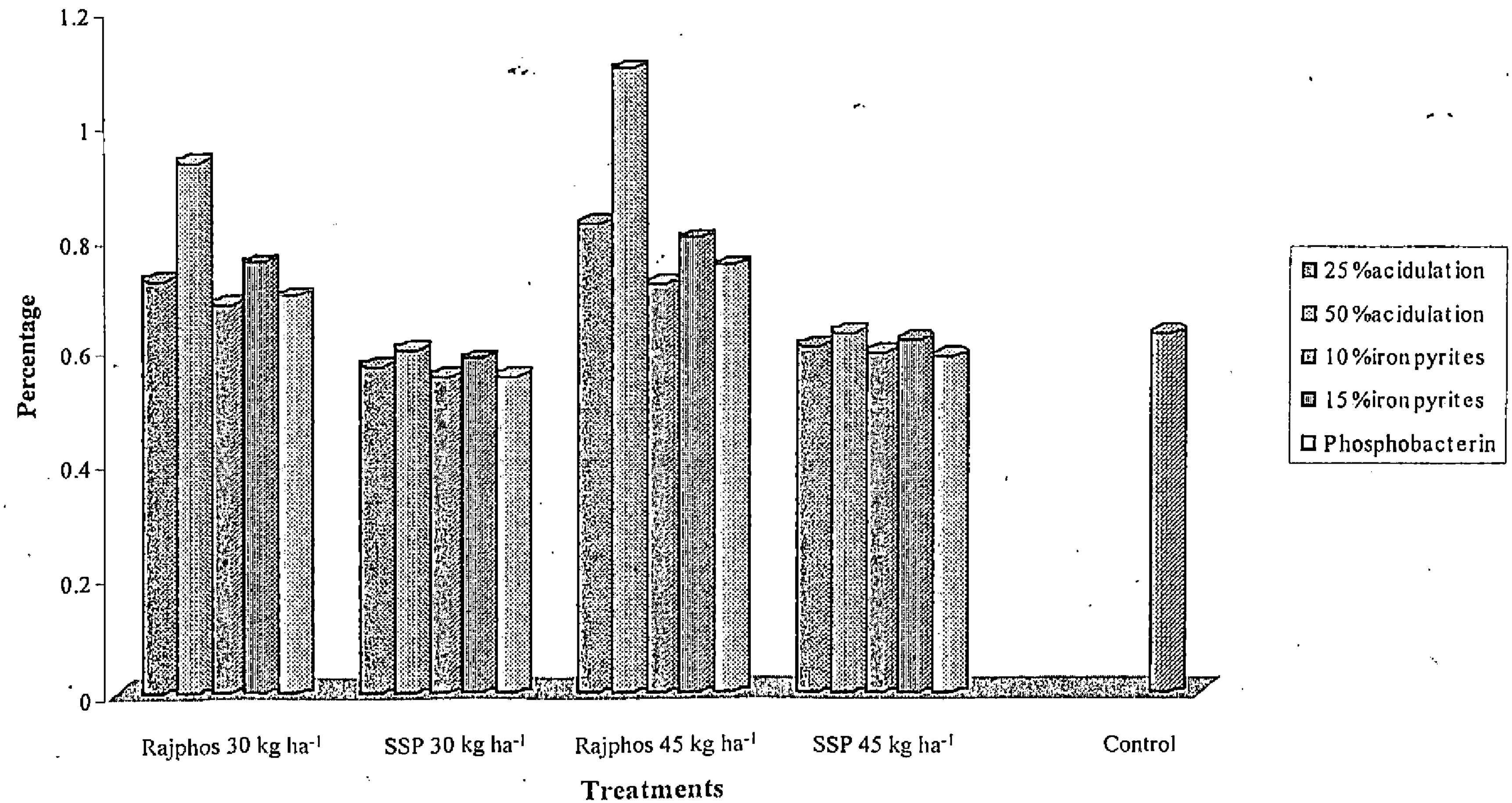


Fig. 6. Effect of different levels and forms of P on phosphorus uptake (%)

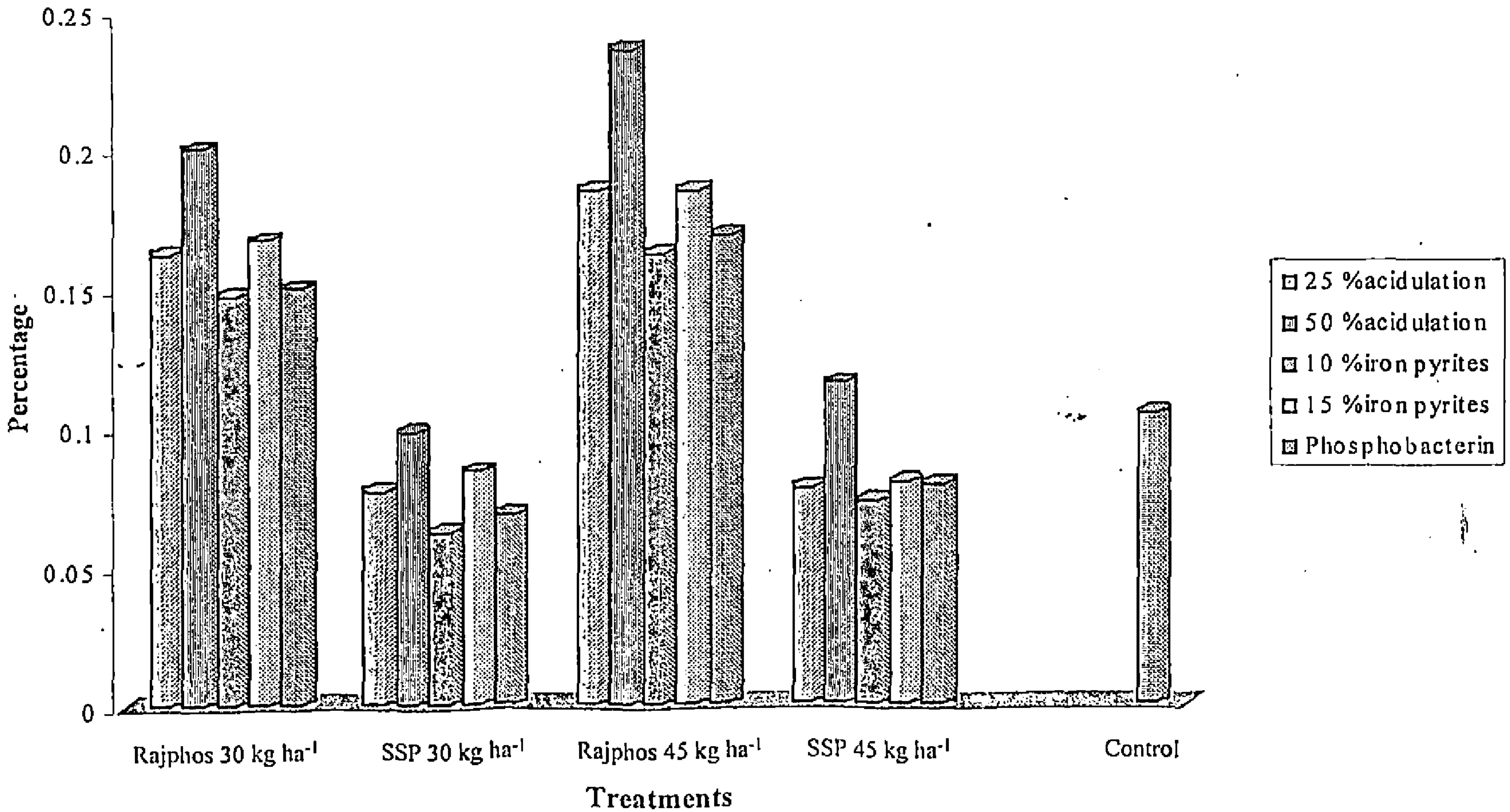
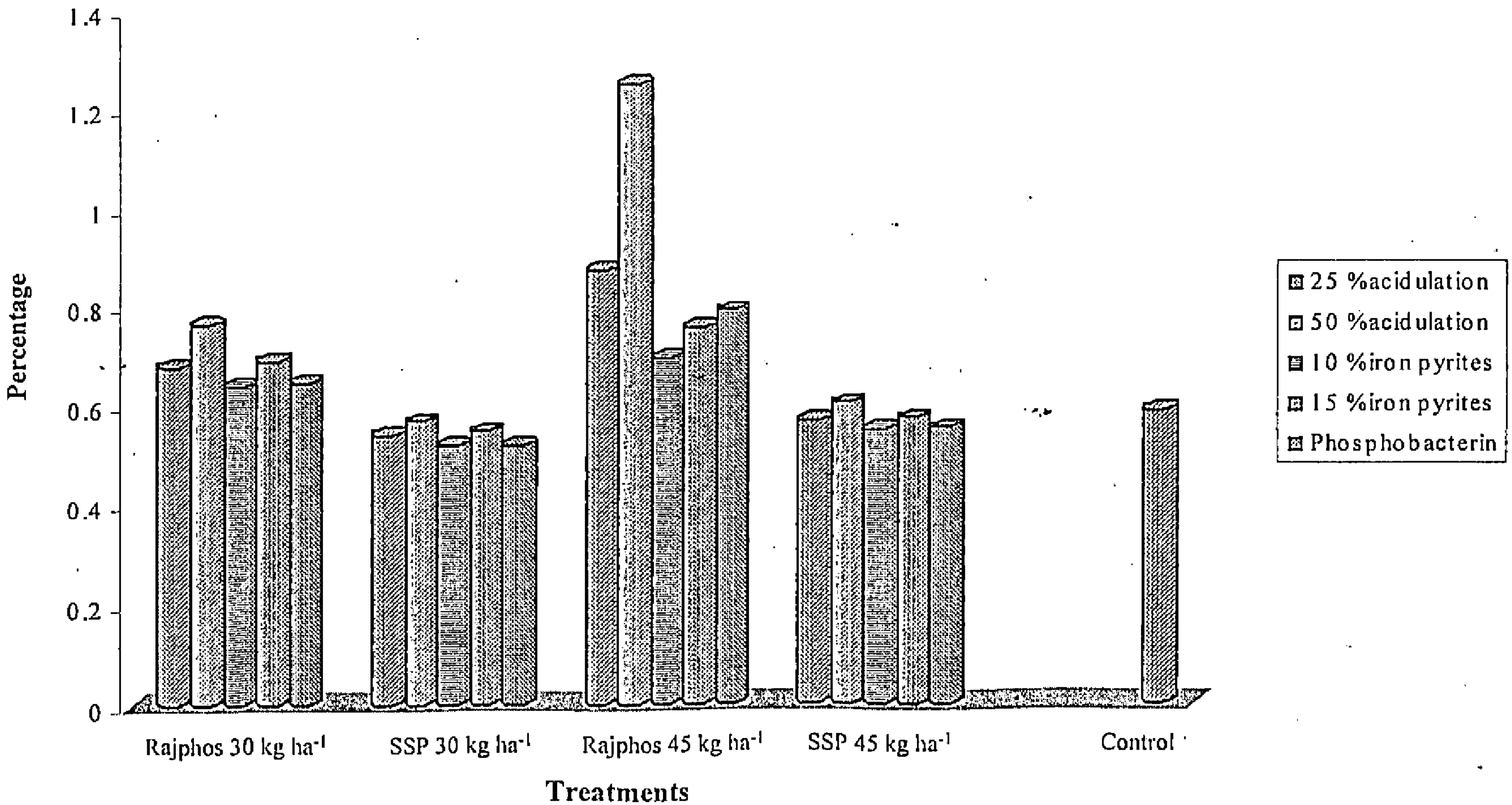


Fig. 7. Effect of different levels and forms of P on potassium uptake (%)



recommendations had resulted in a higher biomass production and nutrient uptake. Though the other amendments applied along with Rajphos was also effective in creating acidity through pyrite oxidation and bacterial solubilisation, the effect was not as pronounced as in the case of direct acidulation. The observed yield decline in the case of treatments receiving SSP might be attributed to the faster reversion of soluble P to insoluble tricalcic forms. This conversion is further accentuated by the native calcium content. The treatment T_7 consisting 30 kg Rajphos with 50 per cent acidulation was also comparable to T_{12} and produced higher dry matter production, which was on par with T_{12}.

It is thus clear from the results that even at a lower dose of Rajphos if acidulation is given Rajphos can perform well as an excellent P source to cater the demand of rice crop for P nutrition. All other treatments performed more or less equally and were on a par with the control. Hence it is evident from the results that the relative efficacy of the highest for direct acidulation with respect to its performance in the field.

A critical study of basic data pertaining to the soil used for the study also indicated a relatively higher status with respect to available K, Ca and Mg though the P status was low. Hence an assured supply of available P is expected to increase the uptake of all other nutrients through a favourable nutrient ratios. Thus the observed increase in uptake of nutrients and higher dry matter production in this pot culture study stands substantiated. Similar increase in total drymatter production and nutrient uptake in rice consequent to rock phosphate application was reported by (Rama Rao *et al.*, 1992; Rabindra, 1995).

SUMMARY

SUMMARY

The salient findings of the study conducted are summarised below.

Incubation experiment showed an increase in saloid-P fraction upto 30^{th} day which decreased subsequently with the advancement of time. Enhancement of the dissolution of Rajphos by direct acidulation, solubility increase due to indirect acidity created by the use of pyrite application and inoculation with phosphobacterin, all have positive beneficial effects. Higher values of saloid-P fraction was observed at higher dose of P addition with amendments.

Occluded-P fraction clearly indicated a gradual increase with period of submergence. Highest value was recorded in the case of treatment T_{27}. Rock phosphate acidulated with sulphuric acid and amended with pyrites at all levels of P addition increased this fraction. Inoculation with phosphobacterin was also effective, though the release of P was slightly slower than the other treatments.

Incubation experiment showed that the treatments have got significant effect on Fe-P fraction. During the first four observations the highest value was obtained for the treatment receiving SSP @ 45 kg ha^{-1} acidulated with sulphuric acid, pyrite and phosphobacterium. Above 45 days of incubation a decline in Fe-P was noticed which stabilized towards the last observation.

The treatments and periods of incubation have significant effect on Al-P fraction. Maximum values were recorded during the 4^{th} observation for all treatments at all levels of P application. Subsequently, values showed a decrease towards the last observation. Treatments containing SSP invariably registered higher values of Al-P at all levels. All the treatments show an increase in Al-P level upto the 45^{th} day and then stabilized at the 90^{th} day of incubation. The highest value was recorded by the treatment T_{27} representing SSP 45 kg amended with sulphuric acid.

The reductant-P fraction showed an increase from zero days to 15^{th} day of submergence and decreased thereafter. Reductant-P fraction was significantly higher during the second observation with respect to all treatment involving SSP than the corresponding treatments representing Rajphos. The maximum value was recorded by treatment T_{27}.

Irrespective of treatments and levels of P, Ca-P registered an increase with period of incubation and the highest value was obtained at 60^{th} day of submergence.

Total number of tillers and productive tillers both increased in treatments receiving Rajphos @ 45 kg ha^{-1} amended with acidulation and pyrite application at all levels.

In the case of 1000 grain weight highest value was obtained for treatments receiving acidulated Rajphos at 45 kg ha^{-1} followed by Rajphos 45 kg ha^{-1} with phosphobacterin.

The maximum value for LAI was recorded for the treatment T_{12} comprising Rajphos application @ 45 kg ha^{-1} with 50 per cent acidulation.

Both the straw and grain yield increased significantly due to treatment effects. The treatment T_{12} registered the highest values for both grain and straw yield.

The contents of N, P and K in both grain and straw recorded the highest value for plants receiving the treatment T_{12}. The treatment T_{18} recorded the highest value for both the grain and straw calcium content. The treatments T_{12} and T_{27} registered the highest value for both the grain and straw magnesium content.

Treatments consisting of Rajphos 45 kg ha^{-1} and 30 kg ha^{-1} with 50 and 25 per cent acidulation respectively recorded significantly higher values for total dry matter production and uptake of N, P and K. The highest calcium uptake is recorded by the treatment T_{15} and the treatment T_{12} registered highest magnesium uptake.

The study reveals the effectiveness of rockphosphate like Rajphos even in the neutral to alkaline soils of Kerala provided acidulation is resorted to for solubilising the insoluble P forms.

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METHODS TO INCREASE THE EFFICIENCY OF RAJPHOS (JAMARKHOTRA ROCKPHOSPHATE) IN THE BLACK SOILS OF PALAKKAD DISTRICT FOR RICE

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ABSTRACT

There has been considerable interest in studying the efficiency of rockphosphate for direct application to the soil in the rice farming situations of Kerala, particularly tapping the iron – to – magnet type of relationship between rockphosphate and acid soils. However no work has been done in the neutral to alkaline soils of Kerala located in the Chittoor Taluk of Palakkad District to utilize the potential of rockphosphate. These soils are inherently poor in phosphorus and the situation is furthur complicated by the high P fixation capacity. Problems of fixation of soluble P can be alleviated to some extent by the use of less soluble forms like rockphosphate in conjunction with acid forming amendments like iron pyrites, sulphuric acid and P solubilising micro organisms.

A study was undertaken to investigate the effect of direct application of rockphosphate in combination with amendments for rice in the Department of Soil Science and Agricultural Chemistry at the College of Agriculture, Vellayani. There were two experiments, an incubation study to investigate the relative efficacy of various amendments in releasing soluble P from rockphosphate and a pot culture experiment to study the comparative efficiency of rockphosphate with amendments.

Incubation experiment shows an increase in P fractions like saloid-P, occluded-P, reductant-P, Fe-P, Al-P and Ca-P upto 45 days which decreased subsequently with the advancement of time. The values stabilized towards the last observation at around 90 days of incubation which was higher than the initial starting values. Rock phosphate acidulated with sulphuric acid and amended with pyrite at all levels of P addition increased P fractions. Inoculation of phosphobacterin was also effective though the release of P was slightly lower than treatment with chemical amendments.

In the pot culture experiment growth and yield character of crop were significantly influenced by treatments receiving rockphosphate amended with direct acidulation and pyrite application at all levels. Rajphos @ 45 kg ha^{-1} with 50 per cent acidulation was found to be on par with the treatment receiving Rajphos @ 30 kg ha^{-1} with 50 per cent acidulation. Rajphos treated with acid perform equally well as SSP and the results were comparable. The grain and straw yield and uptake of plant nutrients were significantly superior for treatment consisting of acidulated rockphosphate. Chemical amendment like iron pyrite and microbial inoculation with phosphobacterin was also found to be efficient but the effect was not significant statistically.

The study reveals the effectiveness of rockphosphate like Rajphos even in the neutral to alkaline soils of Kerala provided acidulation is resorted to for solubilising the insoluble P forms.