SUITABILITY OF ROCKPHOSPHATE FOR DIRECT APPLICATION IN ACID RICE SOILS OF KERALA

By

REGI. P. MATHEWS

THESIS

submitted in partial fulfilment of

the requirement for the degree

Master of Science in Agriculture

Faculty of Agriculture

Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry

COLLEGE OF HORTICULTURE

Vellanikkara - Trichur

1985

DECLARATION

I hereby declare that this thesis entitled "Suitability of rockphosphate for direct application in acid rice soils of Kerala" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any University or Society.

Vellanikkara,
May, 1985.

REGI. P. MATHEWS

ACKNOWLEDGEMENTS

I deem it as a great pleasure to express my esteemed gratitude and unforgettable indebtedness to Dr. A. I. Jose, Professor and Head, Department of Soil Science and Agricultural Chemistry and the Chairman of my Advisory Committee, for his timely and valuable advices, inestimable help and inspiring guidance in accomplishing my attempts and in moulding the thesis by offering constructive criticism. His keen interest and unstinted help in all my attempts have been much beyond his formal obligation as the Chairman of my Advisory Committee and he has been a friend, philosopher and guide in all cases, for which I am greatly thankful to him.

Grateful acknowledgements are also due to Sri. P. V. Prabhakaran, Professor of Agricultural Statistics for his guidance and constant help rendered during the statistical analysis of the data. It is my previlege to thank Dr. (Mrs) P. Padmaja, Professor, Project Co-ordinator (Soils and Agronomy) and Dr. R. Vikraman Nair, Professor, Department of Agronomy, for their valuable suggestions and kind help.

Dr.A.I.JOSE
Professor and Head
Dept. of Soil Science &
Agrl. Chemistry.

College of Horticulture,
Vellanikkara,
May, 1985.

CERTIFICATE

Certified that this thesis entitled "Suitability of rockphosphate for direct application in acid rice soils of Kerala" is a record of research work done by Kum. Regi. P. Mathews under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Dr. A.I. JOSE,
Chairman,
Advisory Committee.

I avail myself of this opportunity to place on record my heartfelt thanks to Dr. Abi Cheeran, Professor, Department of Plant Pathology for the proper footing of my career by offering constant encouragement and sound advises during the course of study.

I owe a great debt to Dr. V. K. Venugopal, Smt. K. C. Marykutty, Sri. K. M. Sathianathan and Sri. C. S. Gopi for their timely help at different periods of my project work. Sincere thanks are also due to all staff members of the department of Soil Science and Agricultural Chemistry for the whole hearted co-operation rendered during this investigation.

Thanks are also due to Dr. P. K. Gopalakrishnan, Associate Dean, College of Horticulture for the necessary facilities provided for the study.

It is with an attitude of gratitude I remember the warm blessings, strenuous help, unfailing support and constant encouragement of my loving parents, brother and sisters which helped me a lot for the successful completion of the research work. I also place on record my thanks to all friends for their help and inspiration.

The award of Junior Research Fellowship by the Rajastan State Minearal Development Corporation during the tenure of the study is gratefully acknowledged.

REGI. P. MATHEWS

CONTENTS

LIST OF TABLES

61 Total residual P after the harvest of second crop

LIST OF ILLUSTRATIONS

Figure No.

INTRODUCTION

INTRODUCTION

Phosphorus is reckoned as the 'key to metabolism' because of its involvement in energy release reactions. It is also needed for proper root development and early maturity of grains. This element should be mainly supplied as fertilizers to plants, as its contribution from atmosphere is nil and that from soil is very less. For a substantial and sustained level of agricultural production, fertilizer consumption per unit of arable land should be sufficiently high. However, the consumption rate of phosphatic fertilizers has not been kept pace with that of nitrogenous fertilizers. One of the reasons for such a growth pattern is the relative high cost of chemically processed phosphatic fertilizers. Direct application of cheap, unprocessed, reactive, ground phosphate rock to the soil has been recognized to be an attempt in this direction. Theoretically such substitution should be possible in acid soils which contain soluble alluminium to complex fluorine that is released from the rockphosphate.

The process, patented in 1843, by which ordinary superphosphate was manufactured by treating rockphosphate with sulphuric acid, gave an efficient source of phosphorus fertilizer which dominated the global market for a long time. However, the world shortage of sulphur and occurrence of high grade rockphosphate deposits in some localized specific pockets of the world, prompted the scientists to discover alternative techniques to produce superphosphate. A concentrated form of superphosphate, namely, triple superphosphate, could be manufactured by treating phosphate rock with phosphoric acid instead of sulphuric acid. Although this technique eliminated the glaring demand of the industry for sulphur, yet it turned out to be an energy and capital intensive process. Thus although over the years, the need of phosphatic fertilizers for crop production has been mounting at an alarming rate, the availability of traditional water soluble sources has been presenting serious problems and constraints. Thus there has been a vigorous search for an alternative, which should be equally effective, easily available and cheaper source of phosphatic fertilizer that can be used in lieu of traditional water soluble materials. Use of reactive ground raw rockphosphates for direct application is a fruitful attempt in this direction.

The total reserve of known phosphate rock in India is estimated to be around 140 million tonnes, of which nearly 70 million tonnes are from Rajastan deposits and 20 million tonnes from Mussoorie syncline of U.P. The reactivity of various deposits will vary depending on their origin. Igneous deposits are highly stable and unreactive, metamorphic ones are less stable, and sedimentary deposits are the least stable. The less stable ones are more reactive and phosphorus in them may become easily available to plants. Among the Indian deposits, those from Rajastan are metamorphic cum sedimentary origin, while Mussoorie deposit is exclusively of sedimentary type. The younger sedimentary apatites are not suitable as a raw material for phosphatic industry, but, are suitable for direct application as a fertilizer to the soil.

Phosphate rocks when applied to the acid soils, get easily acidulated by the soil acidity and phosphorus in them will become easily available to the plants. It has been estimated that acid soils in India comprise about 30 per cent of the total land area. Except a small patch of neutral to alkaline soils of Chittoor, the entire state of Kerala comprises of acid soils of varying intensities of acidity. Direct application of powdered rockphosphates, which is comparatively cheap, to these acid soils has been considered as an economical way of phosphorus supply. Various reports show that the performance of phosphate rocks for crop production is comparable with that of superphosphate.

Removal of phosphorus by the first crop normally does not exceed 10 to 30 per cent of the added phosphorus and the rest stays in the soil (Raychaudari, 1980). This residual effect which refers to the carry over benefit of an application, available to the succeeding crops is a beneficial property of phosphatic fertilizers which will help in the skipping of phosphorus application to the succeeding crops. Although the residual effect of phosphate rock is comparable with that of superphosphate, there can be chances for variation among various rockphosphates depending on their reactivity.

Phosphate ion in soil forms a wide array of compounds with varying solubility. This is further complicated in waterlogged soils by the reductive processes which lead to a change in the relative proportion of these compounds. This proportion will also vary with time. It is the relative abundance of these compounds in the soil which decides the status of available phosphorus. Rice, the major food crop of Kerala, being grown in a flooded condition, a knowledge regarding the transformation of various phosphatic fertilizers under this condition will be essential for evaluating their efficiency. Kuttanad and lateritic alluvium are the two main rice growing tracts of Kerala. The behaviour of the various phosphatic fertilizers in these soils should be known for a bettor phosphatic fertilizer management.

The mode of transformation of various phosphate rocks may vary. Hence the present study was taken up with the following objectives in view.

1) to compare the direct effect of Rajastan rockphosphates supplied by Rajastan State Mineral Development Corporation and Mussoorie rockphosphate supplied by Pyrites Phosphates and Chemicals Ltd. (U.P) with that of superphosphate on nutrient uptake and yield of rice in acid rice soils at different levels of application;
2) to compare the residual effect of above rockphosphates at varying levels with that of the

continuous application of superphosphate;

3) to study the transformation of phosphorus from phosphatic fertilizers in acid rice soils under submerged condition; and

4) to study, whether the costly soluble phosphatic fertilizers can be replaced by the cheap rockphosphates in the acid rice soils of Kerala.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

1. Transformation of phosphorus in soil

Phosphorus in soil occurs in organic and inorganic form but the predominant form is the inorganic one. Fractionation of this inorganic form of phosphorus into its components has a direct bearing on soil fertility. The availability of added phosphorus to the current crop as well as of the residual phosphorus to the succeeding crop depends much on the nature and amount of compounds to which the applied phosphorus is converted.

Fraps in 1906 was among the first to chemically fractionate inorganic soil phosphorus (Hesse, 1971). There were many procedures for phosphorus fractionation, but the commonly used one is that of Chang and Jackson which was later on modified by Peterson and Corey in 1966 (Hesse, 1971). The inorganic forms identified in this procedure include saloid phosphorus, aluminium phosphate, iron phosphate, reductant soluble phosphorus, occluded phosphorus and calcium phosphate. Contribution of these various fractions to available phosphate pool will be different. The proportion of these components will vary with the soil pH and soil characteristics, moisture regime, period of incubation and level of application.

1.1 Effect of pH and soil characteristics

According to Hsu and Jackson (1960) the phosphorus transformation in soil is mainly controlled by pH. It is seen that iron phosphate and aluminium phosphate dominate in acid soils while calcium phosphate dominates in alkaline soils (Cho and Cladwell, 1959; Hsu and Jackson, 1960; Wright and Peech, 1960; Chang and Chu, 1961; Jose, 1973; Talati et al., 1975; Kadeba and Boyle, 1978; Sharma et al., 1980).

Gupta and Nayan (1975) obtained iron phosphate as the dominant fraction in U.P. soils with a pH upto 6.7. Jose (1973) indicated that in red, black and alluvial soils of South India, calcium phosphate dominated over iron and aluminium phosphates in quantity, and increased with increasing pH, while reductant soluble and occluded phosphates decreased with increasing alkalinity and their contents were remarkably low. From a study of the forms of soil phosphorus in Tamil Nadu, Balasubramanian and Raj (1969) proved that calcium phosphate predominated over other phosphorus fractions in black, alluvial and red soils, but occurred in traces in laterite soils where iron and aluminium phosphates predominated. Experiments of Nair and Padmaja (1982) in the rice soils of Kerala found that the added phosphorus was mainly converted into aluminium phosphate and iron phosphate.

Singh and Ram (1977) showed that the conversion of added phosphorus to aluminium phosphate was more pronounced in laterite soil and the conversion to calcium phosphate was low. The slow rate of conversion of added phosphorus into calcium phosphate was due to the acidic reaction of the soil. Kothandaraman and Krishnamoorthy (1977) obtained high amount of iron phosphate, reductant soluble phosphorus and occluded phosphorus in laterite soil.

Bapat et al. (1965) reported that the Vidharbha soils containing sufficiently high amount of free $CaCO_3$ and total CaO were rich in calcium phosphate and soils with less free $CaCO_3$ and total CaO contained considerable amount of iron and aluminium phosphates. Khanna and Datta (1968) studied the distribution of inorganic soil phosphorus in some Indian soils and found that calcium phosphate dominated in all alluvial soils with pH greater than 7, while aluminium and iron phosphates were dominant in acid and red soils.

Debnath and Hajra (1972) in their phosphorus fractionation studies of Bengal soils indicated that, most of the added phosphorus was recovered in the order of Al-P $>$ Fe-P $>$ Ca-P and reductant soluble phosphorus increased in red, laterite and hilly soils with no significant change in alluvial and saline soils. Rao et al. (1972) determined the inorganic phosphorus fractions in black and red soils after treating them separately with ammonium phosphate and superphosphate. In both the soils, Fe-P was more than the other forms.

Chang and Jackson (1958) recognized that in calcareous soils or in soils that had not been much weathered, most of the inorganic phosphorus was present as calcium phosphate. In moderately weathered soils the principal form was that sorbed in iron and aluminium oxide films and as the weathering proceeded an increasing proportion of phosphate occurred inside the iron oxide precipitates. Hsu and Jackson (1960) from a study on Wisconsin soils suggested that in a highly weathered soils with high iron oxide content and high iron activity, the content of iron phosphate was higher compared to other fractions.

Syers et al. (1969) observed that only one-fifth of the total inorganic phosphorus was calcium phosphate where reductant phosphorus was the dominant form in older soils while it was two-third in younger soils. Talati et al. (1975) obtained lower amount of aluminium and iron phosphates in alkaline desert plain soils due to their immaturity. Studies in Kerala by Aiyer and Nair (1979) showed that the content of calcium phosphate was higher in kari soil compared to laterite soil which was more weathered.

1.2 Effect of waterlogging and period of incubation

Waterlogging has a pronounced influence on the transformation of phosphorus. Ponnamperuma (1955) confirmed the observations of many other workers that the solubility of phosphate both in the soil solution and acid extracts increased on submergence. According to Mandal and Khan (1975) continuous waterlogged condition is beneficial for the availability of soil native phosphorus in acid soils.

Chang and Chu (1961) attributed the increased availability to the greater accumulation of iron phosphate in flooded soil and the greater mobility of iron in the reduced condition. Basak and Bhattacharya (1962) stated that the increase in available phosphorus in rice soils was due to the release of phosphate from mineralization of organic phosphorus and the reductive transformation of ferric and aluminium phosphates. Mandal (1964) observed a slight increase in 0.5 N acetic acid extractable phosphorus accompanied by a slight decrease in ferric phosphate as a result of waterlogging, while aluminium and calcium phosphates remained unchanged.

Mahapatra and Patrick (1969) found that waterlogging generally increased aluminium and iron phosphates, decreased reductant soluble phosphates and did not much affect calcium phosphate. When soil was incubated with iron, aluminium and calcium phosphates, they were almost completely recovered in the aluminium and iron phosphate fractions under both optimum and waterlogged moisture regimes. Extractable phosphorus was increased by submergence especially in soils that were richest in iron phosphate. Gupta and Nayan (1975) obtained an increase in iron phosphate content due to waterlogging. Singh and Singh (1975) reported the conversion of added phosphate into iron, aluminium and calcium phosphates during waterlogging.

Many reports showed that the amount of iron and aluminium phosphates enhanced markedly while that of calcium phosphates decreased with the period of incubation (Islam, 1970; Mandal and Khan, 1975; Singh and Bahaman, 1976; Rajakkannu and Ravikumar, 1978).

Jose (1973) in his studies on phosphorus transformation found a decrease in available phosphorus, saloid bound phosphorus and aluminium phosphate with increasing periods of incubation. He also stated that irrespective of the pH of the soil, aluminium phosphate was formed in high amount initially, a part of which was transformed to iron phosphate in soils of relatively low pH and to calcium phosphate in soils originally predominating in calcium phosphate with lapse of time. But the changes in the reductant soluble and occluded forms of phosphorus were negligible.

Islam (1970) found that as a result of waterlogging, level of soluble phosphorus first increased and then decreased with time of submergence. Increase in soluble phosphorus in acid soil was due to a decrease in calcium, ferric and reductant soluble phosphates. Singh and Ram (1976) obtained an increase in iron phosphate and a decrease in aluminium phosphate with time of incubation.

Srivastava and Pathak (1972) reported that the added phosphorus in soil got completely converted into saloid bound phosphorus, aluminium phosphate, iron phosphate and calcium phosphate. But with time, saloid bound phosphorus and aluminium phosphate were gradually converted into iron phosphate. They also found that the recovery as reductant soluble phosphorus and occluded phosphate was nil. Chauhan et al. (1972) obtained increased available phosphorus from added phosphate with advancement of time. They suggested that fixation and release of added phosphorus may occur simultaneously and any increase in available phosphorus at any time may be due to greater rate of mineralization than fixation.

Within 24 hours of incubation Debnath and Hajra (1972) recovered most of the added phosphorus in the order of Al-P $>$ Fe-P $>$ Ca-P. On aging, the quantity of iron phosphate increased and that of aluminium phosphate decreased irrespective of soil characteristics and moisture regimes. But the rate of change of added phosphate to various inorganic fractions was enhanced by higher moisture regimes.

Gupta and Nayan (1972) studied the transformation of inorganic phosphorus at field capacity and waterlogged condition. The amount of reductant soluble phosphorus decreased and that of calcium phosphate and iron phosphate increased with time under both conditions. Aluminium phosphate decreased at field moisture capacity, but its amount slightly increased under waterlogged conditions. Mandal and Chatterjee (1972) showed that the amount of added phosphate fixed as aluminium phosphate gradually increased to a maximum with the advancement of time, followed by a decrease.

Sharma et al. (1980) studied the transformation of added phosphorus and found an increase in aluminium phosphate content upto 7 days and later decreased slowly with time till 90 days. The conversion to iron phosphate fraction increased slowly with time upto 90 days and very little change to calcium phosphate was observed even on prolonged incubation. Experiments of Singh and Ram (1976) on transformation of added water soluble phosphate at two moisture regimes (50 per cent field capacity and waterlogging) recorded an increase in iron phosphate and a decrease in aluminium phosphate with advancement of time and the content of saloid bound phosphorus was negligible.

According to Singh and Bahaman (1976) available phosphorus, iron phosphate and aluminium phosphate increased, calcium phosphate decreased and negligible change for saloid bound phosphorus occurred with period of incubation. Singh and Singh (1975) obtained an increased content of aluminium phosphate at initial stages of waterlogging due to the transformation of calcium phosphate to aluminium phosphate and later its content decreased because of its transformation to iron phosphate. This lead to an increase in iron phosphate in later stages.

Gupta and Nayan (1975) studied the transformation of soil inorganic phosphorus in red soil at field capacity and waterlogged conditions. Iron phosphate decreased at field capacity and increased at waterlogged condition. The amount of aluminium phosphate decreased while reductant soluble phosphorus increased with increase in time under both conditions. Singh and Ram (1977) reported a decrease in available phosphorus with time.

1.3 Influence of various inorganic fractions on available phosphorus and plant growth

The contribution of various inorganic fractions to available phosphorus will vary. Jenkins (1966) and Jose (1973) in their phosphorus uptake studies obtained a very close correlation between labile phosphorus, aluminium phosphate and iron phosphate. Smith (1965) and Talati et al. (1975) reported that none of the inorganic forms of soil phosphorus except aluminium phosphate can serve as an index of phosphorus availability.

In neutral soils of West Bengal, aluminium phosphate was obtained as the major source of phosphorus for jute (Doharey et al., 1980). Puranik and Bapat (1977) observed positive correlation between available phosphorus, aluminium phosphate and calcium phosphate. Sacheti and Saxena (1974) reported that the saloid bound phosphorus and aluminium phosphate significantly correlated with available phosphorus while iron phosphate correlated significantly in a few cases only.

The phosphorus uptake by plants was highly correlated with the amount of iron phosphate but not with the amount of other fractions (Gupta and Singh, 1969; Singlachar and Samaniego, 1973; Singh and Bahaman, 1976). Choudhari et al. (1974) reported the correlation between various inorganic fractions and phosphorus uptake by different crops. Calcium phosphate and aluminium phosphate significantly correlated with the phosphorus uptake of jowar, cowpea and urd, while in maize calcium phosphate and phosphorus uptake was correlated.

Phosphorus uptake was highly correlated with aluminium phosphate and iron phosphate in pine seedlings (Kadeba and Boyle, 1978), in tomato (Datta and Khera, 1969) and in rice (Thakur et al., 1975). Mandal and Khan (1977) obtained 60 to 75 per cent of the applied phosphate in fixed form as aluminium, iron and calcium phosphates after the harvest of rice and they stated that these fractions would significantly contribute to available phosphorus to the succeeding crop. Bapat et al. (1965) reported significant correlation between available phosphorus and calcium phosphate in soils containing high amount of $CaCO_3$, but iron and aluminium phosphates were related to available phosphorus in other soils.

2. Effect of pH on the dissolution of rockphosphate

Soil acidity is the main factor for the dissolution of rockphosphate. Ellis et al. (1955) reported that a soil pH of 6.0 or lower appeared to be necessary for satisfactory utilization of rockphosphate. According to Chu et al. (1962) the break down of rockphosphate into both aluminium and iron phosphate fractions decreased with increasing pH. The percentage recovery of phosphorus added through rockphosphate was low or negligible in calcareous soil, but it was fairly high in acid soils (Zende, 1983).

Singh and Datta (1973) observed that citrate solubility of rockphosphate and pH of the soil were the most important factors governing the phosphorus availability and the particle size of rockphosphate had little effect on solubility at low pH values. The availability of phosphorus from naturally occurring phosphate earths, rockphosphates, and basic slag was more in acid soils (Mandal and Khan, 1972; Motsara and Datta, 1971).

According to Chaudhary and Mishra (1980) transformation of rockphosphate in soil was mainly related to soil acidity and phosphate potential, as these two parameters accounted for 94 per cent of variation in the degree of transformation of rockphosphate. In their experiment, at a pH of 5.4 there was 46 per cent phosphorus transformation, while it was only 6 per cent in a soil with a pH of 6.8 and they obtained an expenential relationship for pH with aluminium phosphate and iron phosphate build up.

The calcium phosphate in rockphosphate gets easily acidulated by the soil acidity and phosphorus in it will become easily available to plants. Thus the ground rockphosphate has been considered as a good source of phosphorus in acid soils due to its easy dissolution (Datta _et al_. 1972; Mandal and Khan, 1972; Patnaik _et al_., 1974; Shau _et al_., 1974; Sarangamath and Shinde, 1977;

Nair, 1978; Kadrekar et al., 1983; Luthra et al., 1983; Natarajan, 1983; Subramanian and Manjunath, 1983).

3. Comparison between phosphorus sources

3.1 Rockphosphate and water soluble phosphate

Varying results were obtained with regard to the suitability of rockphosphate as a fertilizer in comparison to water soluble forms.

Superphosphate could easily be replaced by rockphosphate in acid soils and could become an economical source of phosphorus for plants (Minhas and Kick, 1974; Nair, 1978; Jaggi and Luthra, 1983; Luthra et al., 1983; Subramanian and Manjunath, 1983).

Varadan et al. (1977) found that rockphosphate, dicalcium phosphate and superphosphate did not differ significantly in their effect on grain yield of ragi. Nair and Aiyer (1979) indicated no difference between Mussoorie rockphosphate, superphosphate and factamphos for greengram in Kerala. They also stated that in acid soils of Kerala where paddy responds to phosphorus, both Mussoorie rockphosphate and superphosphate were found to be equally good.

Singh and Datta (1974) observed Udaipur and Mussoorie rockphosphates to be as good as superphosphate in acid soils. Mehrotra (1968) found rockphosphate as effective as superphosphate even under neutral conditions.

According to Shukla (1973) the phosphorus content of rice grain was not significantly affected by different phosphorus sources.

Motsara and Datta (1971) in a series of field experiments conducted on soils, varying in pH, showed that for rice, wheat, maize, pea and potato, differences between yield due to rockphosphate and superphosphate treatments were not significant. In acid laterites of Mangalore, Prasad and Dixit (1976) reported a significant response of rice to the application of rockphosphate, but not with superphosphate at equal phosphorus rates.

The citric acid soluble and insoluble phosphates were either on par or better than water soluble phosphates in low pH soils (Atanisu, 1971). Mandal and Khan (1972) reported that rockphosphate and basic slag were more effective than superphosphate for growing rice in acid soils. Kadrekar and Thalashilkar (1977) also reported the better performance of rockphosphate compared to superphosphate in the paddy soils of Maharashtra.

Patnaik _et al_. (1974); Sarangamath and Shinde (1977) and Nair and Padmaja (1982) from their experiments suggested that rockphosphate could effectively replace water soluble phosphate in rice culture, provided it was applied to the moist soil two weeks before flooding. Sahu _et al_. (1974) reported that by considering both direct and residual effects, North Carolina, Idaho and

Udaipur rockphosphates could be used for fertilizing rice in acid laterites of Orissa. Mehrotra (1968) in his field trials in U.P. concluded that the efficiency of Jordan and Mussoorie rockphosphates was similar to that of superphosphate for wheat.

Contradictory to the above results showing the equality of rockphosphate to water soluble forms as phosphatic fertilizers, Mishra and Gupta (1978) in a greenhouse study obtained lower phosphorus uptake from Mussoorie rockphosphate compared to superphosphate. The relative agronomic effectiveness of Mussoorie rockphosphate was only 66.7 per cent for maize compared to superphosphate.

Experiments of Maloth and Prasad (1976) indicated that rockphosphate was only 50 to 55 per cent as effective as superphosphate with regard to green fodder production. According to Singh _et al_. (1976a) superphosphate far excelled as a phosphatic source to all indigenous rockphosphates. They found that Laccadive, Mussoorie and Udaipur rockphosphates were 67, 66 and 64 per cent effective as that of superphosphate.

In the work of Tiwari _et al_. (1979) the maximum efficiency of rockphosphate as seen from crop response and phosphorus uptake was about 50 per cent as compared to superphosphate.

The effect of superphosphate was superior to rockphosphate in rice (Sarangamath et al., 1975; Ahmad and Jha, 1977; Talashilkar and Patil, 1979) and in wheat (Rana et al., 1975).

3.2 Between rockphosphates

Rockphosphates from different sources will vary depending on the crystallographic properties of the apatite mineral. (Lehr and Mc Clellan, 1972; Banerjee, 1979; Luthra et al., 1983).

Dash et al. (1980) from CRRI, Cuttack compared different rockphosphates namely Kasipatnam, Mussoorie, Udaipur, Mehannagar, Jhamarkotra and Purulia, and found that they were not as efficient as North Carolina rockphosphate which was as good as superphosphate in acid soils. Chaudhary and Mishra (1978) indicated that samples from Mussoorie, Jhambua, and Kasipatnam were more reactive than those from Udaipur and Jordan.

Singh et al. (1976a) studied the order of efficiency of rockphosphates from different sources and found as follows. Laccadive > Mussoorie > Udaipur. Singh and Datta (1974) observed Udaipur and Mussoorie rockphosphates to be as good as superphosphate in acid soils.

Mathur et al. (1979) compared the igneous and sedimentary phosphate rocks of Bihar in acid red loam soil and reported that sedimentary phosphate rocks raised the soil pH and available phosphorus, but igneous ones left more residual phosphorus. Singh and Datta (1976) obtained better phosphorus availability from Mussoorie rockphosphate than from Udaipur or Laccadive deposits in Karnataka soils of varying acidity.

Shinde et al. (1978) in their phosphorus transformation studies indicated that the transformation from North Carolina, Gafsa and Jordan rockphosphates was more than that from Florida rockphosphate.

4. Residual effect of rockphosphate

Only about 10 to 30 per cent of the phosphorus applied to the soil is removed by the first crop and the rest will be remaining in the soil (Khanna and Chaudhary, 1979; Raychaudhari, 1980). Rockphosphates were found to be 93 to 94 per cent as effective as superphosphate as far as their residual value is considered (Singh et al., 1976b; 1979).

Gupta et al. (1983) found that the response of residual rockphosphate was curvilinear and they stated that for better use and efficiency of phosphates in a wheat paddy cropping system, the application of this element should be to the wheat crop and its residual effect could be harvested by the paddy crop. Sahu and Pal (1983) stated that the residue of rockphosphate left after rice harvest had increased the grain and straw yield of the succeeding wheat significantly.

Sharma et al. (1976) compared different phosphorus sources for their direct and residual effect on potato. They found that the direct effect of rockphosphate was not good, but the residual effect was similar to that of superphosphate and monoammonium phosphate. Ramaswamy and Arunachalam (1983) reported that the rockphosphate left more available phosphorus in the soil compared to superphosphate, after the harvest of the first crop.

Khanna and Chaudhary (1979) stated that there was no significant difference in the yield of succeeding crops by different phosphorus sources. Marwaha et al. (1981) had observed the residual effect of rockphosphate to an extent of 48.7 per cent to 74.1 per cent compared to superphosphate for corn. Natarajan et al. (1983) observed that the residual effect of Mussoorie rockphosphate was very effective in acid soils. The higher levels of phosphorus added to the first crop (millet) resulted in conspicuous residual effect in the succeeding crop of blackgram by way of significant increase in yield. Krishnappa et al. (1979) reported that there was an increase in the yield of both ragi grain and straw due to the residual effect of rockphosphate, superphosphate and dicalcium phosphate. Sample et al. (1974) in their experiments on pine seedlings indicated that the residual effect of phosphorus during the first two cropping seasons was mainly depending on the citrate solubility of the added material, while in the third cropping season, differences among various phosphorus sources disappeared.

MATERIALS AND METHODS

MATERIALS AND METHODS

The study consisted of two experiments namely 1) an incubation study with two soils, three sources of phosphate and two levels of P in order to study the transformation of P from the different sources under waterlogged condition

2) a potculture experiment with the same soils, P sources and P levels using rice as a test crop grown continuously for two seasons in order to study the direct and residual effect of added P under rice culture in waterlogged condition

Collection of soil samples

A laterite soil (Kodakara, Trichur district) and a kari soil of Kuttanad alluvium (Karumadi, Alleppey district) which represented two important rice soils of Kerala were collected (0 - 15 cm depth). The soils were dried in shade, powdered, seived and used for incubation and potculture experiment.

INCUBATION STUDY

A laboratory incubation study was carried out with two soils (the laterite and kari), three sources of P namely Rajastan rockphosphate (RRP), Mussoorie rockphosphate (MRP) and superphosphate (SP) and two levels of P (45 and 90 kg P_2O_5/ha) in a completely randomized design with two replications. RRP (100 mesh) was supplied by Rajastan State Mineral Development Corporation, and MRP (100 mesh) was supplied by M/s Pyrites Phosphates and Chemicals Ltd. The analyses of these fertilizers are given in Table 2. The treatment combinations were

Treatment No.	Treatment notation	Forms and levels of P_2O_5, kg/ha	Soil
1	OL	No P (control)	Laterite
2	RRP45L	RRP 45	"
3	RRP90L	RRP 90	"
4	MRP45L	MRP 45	"
5	MRP90L	MRP 90	"
6	SP45L	SP 45	"
7	SP90L	SP 90	"
8	OK	No P (control)	Kari
9	RRP45K	RRP 45	"
10	RRP90K	RRP 90	"
11	MRP45K	MRP 45	"
12	MRP90K	MRP 90	"
13	SP45K	SP 45	"
14	SP90K	SP 90	"
15	SP(45+45)L	SP 45+45 (P was given twice, on the first and ninety-first day of incubation)	Laterite
16	SP(45+45)K	SP 45+45 (P was given twice, on the first and ninety-first day of incubation)	Kari

The last two treatments were included to study the residual effect of rockphosphates applied only once in comparison with the residual effect of SP applied twice, the second application being 90 days after the first application.

1. Experimental Procedure

The soils were weighed (500 g) and transferred into plastic containers of 1 kg capacity. The basic properties of the soils are given in Table 1. The phosphatic fertilizers as per the treatments described above were added and thoroughly mixed with the soil. The soils were continuously waterlogged, maintaining water at the level of 2 cm above the soil and incubated at room temperature (28-31^{o}C) for 180 days. Soil samples were drawn regularly at 15 days interval thorough out the period of incubation for the determination of available P and fractionation of inorganic P.

2. Analytical Procedure

The mechanical analysis of the soils was carried out by the International Pipette method (Piper, 1942). pH was determined using an Elico pH meter in a soil water suspension of 1:2.5 ratio. Specific conductance of the 1:2.5 soil water extract was measured using a conductivity bridge.

The organic carbon content was determined by Walkley and Black method as described by Jackson (1958). Available K was determined flame photometrically in the neutral normal ammonium acetate extract of the soil (Jackson, 1958).

Total elemental analysis of P, K, Ca and Mg was done using diacid ($HClO_4$ and HNO_3 in 1:2 ratio) extract. Total P from this extract was determined by vanadomolybdophosphoric yellow colour method in nitric acid system (Jackson, 1958). Total K was read in an EEL flame photometer. Total Ca and Mg were determined by EDTA titration method (Hesse, 1971). Total N was estimated by Kjeldahl digestion - distillation procedure described by Jackson (1958). Cation exchange capacity of the soil was determined by the method of Peech et al. (1947). Phosphorus fixing capacity of the soil was estimated by the method described by Hesse (1971). Dithionate-citrate bicarbonate extraction method described by Jackson (1975) was used for the determination of free iron oxides in the soil.

Available P of the wet sample was extracted using Bray and Kurtz No.1 and No.2 extractants. For wet analysis, a weighed quantity of wet sample to give 5 g of dry soil was used. The moisture content in each sample was separately estimated immediately on withdrawal of the sample and P was extracted and determined by chlorostannous reduced molybdophosphoric blue colour method in hydrochloric acid system (Jackson, 1958).

Fractionation of P was carried out using the modified procedure of Chang and Jackson (1957) after Peterson and Corey (1966) as described by Hesse (1971).

POTCULTURE EXPERIMENT

A potculture experiment was conducted with two soils, three sources of P and two levels of P using a photoinsensitive variety of rice (Jaya) in order to study the direct and residual effect of RRP and MRP in comparison to SP under conditions of plant growth. The soils, sources of P and levels of P were the same as that described under the incubation study. The experiment was laid out in a completely randomized design with four replications. Rice was grown continuously for two seasons (punja and first crop season from December 1983 to September 1984). The treatment combinations were

Treatment No.	Treatment notation	Forms and levels of P_2O_5, kg/ha	Soil
1	OL	No P (control)	Laterite
2	RRP45L	RRP 45	"
3	RRP90L	RRP 90	"
4	MRP45L	MRP 45	"
5	MRP90L	MRP 90	"
6	SP45L	SP 45	"
7	SP90L	SP 90	"
8	OK	No P (control)	Kari
9	RRP45K	RRP 45	"
10	RRP90K	RRP 90	"
11	MRP45K	MRP 45	"
12	MRP90K	MRP 90	"
13	SP45K	SP 45	"
14	SP90K	SP 90	"

15	SP(45+45)L	SP 45+45 (P was given in both the seasons of crop growth)	Laterite
16	SP(45+45)K	SP 45+45 (P was given in both the seasons of crop growth)	Kari

The residual effect of rockphosphates was assessed by continuing the experiment for the second season without the application of phosphatic fertilizers. However, the last two treatments (T_{15} and T_{16}) received SP both in the first and second crop seasons @ 45 kg P_2O_5/ha in order to compare the residual effect of rockphosphates applied once with that of SP applied twice.

1. Experimental Procedure

Earthen pots of uniform size 33 cm x 32 cm were used for the study. These pots were filled with 20 kg of dried and powdered soil. Sufficient water was added to the pots to wet the soil and to bring out a puddled condition. Application of N, K, lime and organic matter was followed as per the package of practices (90 kg N, 45 kg K_2O, 600 kg lime and 5 t organic matter per ha) recommended by Kerala Agricultural University (Anon, 1982). Phosphorus was added in different forms and levels as per the treatment combinations. These fertilizers were mixed thoroughly with the soil.

Rice seedlings were raised by wet method using the seeds obtained from Regional Rice Research Station, Pattambi.

Seedlings (25 day old) were transplanted at the rate of six hills per pot. Plant protection and other intercultural operations were carried out as per the recommendations of Kerala Agricultural University (Anon, 1982). Standing water was maintained till 15 days before harvest. Soil and plant samples were drawn at 15 days interval for chemical analyses. The grain and straw were harvested at full maturity.

2. Collection of Soil and Plant Samples for Analyses

Soil samples were collected from each pot before transplanting and at 15 days interval in both the seasons of crop growth to study the release of P. The collected soil samples were mixed thoroughly, air dried, ground and passed through 2 mm seive and stored in polythene bags for the determination of available P.

Plant samples were collected from each pot at 15 days interval (shoot and root separately). These samples were dried and ground in a mechanical grinder and preserved in separate containers to study the uptake of nutrients.

3. Analytical Procedure

3.1 Soil Sample

Available P of the air dried sample was extracted by Bray and Kurtz No.1 and No.2 extractants and P in the extract was determined as in the incubation study.

3.2 Plant Sample

For the determination of P and K, a diacid extract was prepared by digesting 1 g of powdered plant sample with perchloric and nitric acid in 1:3 ratio. The P content from this extract was determined colorimetrically by the vanadomolybdophosphoric yellow colour method in nitric acid system (Jackson, 1958). For the determination of K, the extract was diluted and read in an EEL flame photometer. Nitrogen content was determined by the micro-Kjeldahl digestion-distillation method as described by Jackson (1958)

Statistical Analysis of the Data

Statistical analysis of the data was carried out by adopting the standard methods described by Panse and Sukhatme (1967).

Table 1. General characteristics of the soil

Characteristics	Laterite soil	Kari soil
Coarse sand (%)	65.50	5.88
Fine sand (%)	1.30	67.45
Silt (%)	7.66	15.00
Clay (%)	25.54	12.50
pH	5.40	3.10
Electrical conductivity (mmho/cm^3)	0.31	1.90
Organic carbon (%)	1.08	1.82
P fixing capacity (ppm)	333.02	329.60
Free iron oxides (%)	2.65	2.14
Total N (%)	0.063	0.041
Total P (ppm)	887.2	793.4
Total K (%)	0.074	0.071
Total Ca (%)	0.019	0.113
Total Mg (%)	0.028	0.034
Available P (ppm)	4.79	3.84
Available K (ppm)	86.00	79.00
Available Fe (ppm)	221.9	211.08
Cation exchange capacity (me/100g)	12.0	8.00

Table 2 (a) Composition of fertilizers used

	RRP	MRP	SP	Urea	M.O.P.
Total P_2O_5 (%)	20.06	20.31	16.51	--	--
Water soluble P_2O_5 (ppm)	4.992	4.626	158514.88	--	--
Citrate soluble P_2O_5 (ppm)	--	--	11417.02	--	--
Nitrogen (%)	--	--	--	43.5	--
Potassium (K_2O%)	--	--	--	--	56.8

Table 2(b) Inorganic fractions of P fertilizers

Inorganic fractions (ppm)	RRP	MRP	SP
Saloid-P	6.583	5.784	68113.5
Al-P	--	--	188.73
Fe-P	144.08	181.74	3.495
Reductant soluble-P	11.36	127.96	22.59
Occluded-P	16.95	4.69	0.67
Ca-P	57569.4	56660.9	891.51

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

In order to assess the suitability of Rajastan rockphosphate for direct application in acid rice soils of Kerala, a laboratory incubation study and a potculture experiment were conducted the results of which are discussed here under.

INCUBATION STUDY

In this experiment, two acid rice soils of Kerala namely laterite and kari were incubated under submerged condition for a period of 180 days with and without the addition of Rajastan rockphosphate (RRP) Mussoorie rockphosphate (MRP) and superphosphate (SP) at the rate of 45 and 90 kg P_2O_5/ha. Soil samples were collected at fortnightly intervals (numbered as periods 0-12) and analysed for inorganic P fractions and available P.

The laterite soil collected from Kodakara, Trichur district was a sandy clay loam with a pH of 5.4 (Table 1). It contained 2.65 per cent of free iron oxides and 221.9 ppm of available Fe (DTPA extractable). The P fixing capacity of the soil was relatively high (332.04 ppm P). The total P content of the soil was 887.2 ppm of which 73.15 per cent was in inorganic form and the remaining in organic form. The organic carbon content of the soil was 1.08 per cent. Fractionation of inorganic P revealed that out of a total of 648.9 ppm of inorganic P, 270.9 ppm (41.74%) was in the form of Fe-P and 191.9 ppm (29.57%) was in the form of Al-P. Available P content of the soil was low (4.79 ppm for Bray 1 and 15.04 ppm for Bray 2). The relatively low content of organic P in the soil is obviously due to the poor content of organic matter; and the high P fixing capacity is due to the preponderance of free iron and alumina in the soil. This was further evidenced by the larger proportion of iron and aluminium phosphates observed during the fractionation of inorganic P.

The kari soil selected for the study from Karumadi, Alleppey district was a sandy loam which was more acidic (pH 3.1) than the laterite soil (Table 1). Also, it contained 1.82 per cent organic carbon. The P fixing capacity was relatively high (329.6 ppm) and the contents of free iron oxide and available Fe were 2.14 per cent and 211.1 ppm respectively. Out of a total of 793.4 ppm P, 604.1 ppm was in inorganic form which accounted for 76.14 per cent of the total P. Among the inorganic P fractions, Fe-P and Al-P predominated over the others. The content of available P in this soil was relatively poor (3.84 ppm for Bray 1 and 12.64 ppm for Bray 2). As in the case of laterite soil the relatively low content of organic P is due to the low content of organic matter; and the high P fixing capacity of the soil can be attributed to the high content of free iron oxide and alumina in the soil. The content of extractable Fe in kari soil was less than that of laterite soil. Predominance of Fe-P and Al-P among the inorganic P fractions is evidently due to the reactions between soil P and Fe and Al components of the soil.

The incubation of the soil under submerged condition for a period of 180 days has increased the content of inorganic P fractions in the soil due to the mineralization of organic P containing compounds. This increased mineralization was conspicuous especially during the early stages of incubation. On incubation, the total inorganic P content of the laterite soil was increased from 648.9 ppm to 783.3 ppm, the increase being 20.69 per cent whereas the increase in kari soil was from 604.1 ppm to 761.9 ppm, the increase being 26.1 per cent. The increased rate of mineralization of organic P during incubation may be due to the high microbial activity taking place in the soil during the initial period which will be gradually slowed down as a result of decrease in the redox potential of the soil normally anticipated in submerged conditions. Even the rate of interconversion of different inorganic P fractions was high in the early stages of incubation, probably due to the changes in the concentration of phosphate reactive components of the soil as a result of microbial activity during the early stages of incubation.

1. Inorganic fractions of P

1.1 Saloid bound phosphorus

Results on the effect of sources and levels of applied P on the saloid-P content at different periods of incubation in laterite and kari soils of Kerala are presented in Tables 3 to 6 and their analysis of variance in Appendix I. The correlations of saloid-P with other inorganic fractions and available P are given in Tables 21 to 24.

The saloid bound phosphorus (saloid-P) refers to the water soluble and freely exchangeable phosphate of the soil which can be extracted by a neutral salt solution like NH_4Cl. Originally, the saloid-P content of the soil was absolutely nil. But on incubation, even without the addition of phosphatic fertilisers, the saloid-P content of the soil increased to a maximum value of 1.130 and 1.289 ppm in laterite and kari soils respectively (Table 3). The relatively higher content of saloid-P in kari soil was attributed to its low P fixing capacity. The increase in the content of saloid-P was marked in the initial stages of incubation. Chemical and biological changes consequent to flooding may result in a change in the solubility of phosphate containing compounds, mainly due to the conversion of ferric phosphate to ferrous phosphate leading to an increased level of saloid-P in submerged soils.

Table 3. Saloid-P as influenced by the treatments at different periods of incubation, ppm

Treatment		Period of incubation, fortnights												
No.	Notation	0	1	2	3	4	5	6	7	8	9	10	11	12
1	OL	0.000	0.245	0.371	0.589	0.593	0.744	1.121	1.130	1.005	0.948	1.041	0.932	0.825
2	RRP45L	0.000	0.486	0.739	1.202	1.193	1.353	1.463	1.788	1.602	1.464	1.328	1.313	1.318
3	RRP90L	0.000	0.489	0.867	1.175	1.293	1.487	1.788	1.809	1.805	1.680	1.665	1.389	1.358
4	MRP45L	0.000	0.370	0.731	1.187	1.325	1.339	1.604	1.687	1.458	1.548	1.391	1.300	1.358
5	MRP90L	0.000	0.498	0.733	1.204	1.407	1.344	1.787	1.816	1.600	1.659	1.648	1.382	1.300
6	SP45L	0.000	0.745	0.980	1.330	1.488	1.764	1.793	1.830	1.693	1.669	1.655	1.364	1.167
7	SP90L	0.809	0.895	1.099	1.500	1.636	1.773	1.822	2.148	1.745	1.775	1.765	1.374	1.179
8	OK	0.000	0.236	0.426	0.939	0.949	1.103	1.205	1.289	1.073	0.996	0.790	0.761	0.796
9	RRP45K	0.000	0.474	0.940	1.580	1.854	1.983	2.094	2.091	2.091	1.944	1.745	1.653	1.611
10	RRP90K	0.000	0.708	0.935	1.580	1.880	2.137	2.132	2.176	2.110	2.031	1.929	1.792	1.812
11	MRP45K	0.000	0.581	0.685	1.570	1.432	1.836	2.096	1.999	1.988	1.913	1.714	1.695	1.588
12	MRP90K	0.000	0.704	0.934	1.590	1.730	2.003	2.206	2.144	2.181	2.067	1.927	1.097	1.623
13	SP45K	0.481	1.164	1.045	1.850	1.860	2.150	2.194	2.049	2.060	2.054	1.892	1.917	1.599
14	SP90K	0.627	1.419	1.418	2.020	2.131	2.300	2.205	2.051	2.080	2.206	1.903	1.929	1.608
15	SP(45+45)L	0.000	0.745	0.980	1.330	1.488	1.764	1.793	1.835	1.867	1.824	1.675	1.686	1.311
16	SP(45+45)K	0.481	1.164	1.045	1.850	1.860	2.150	2.194	2.211	2.085	2.082	2.045	1.727	1.821

Table 4. Mean values of saloid-P as influenced by sources of P, soils and levels of P application, ppm

Period of incubation, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
0	0.000	0.000	0.479	0.135	0.185	0.080	0.239	0.159
1	0.539	0.531	1.054	0.579	0.837	0.630	0.786	0.708
2	0.870	0.771	1.136	0.858	0.993	0.853	0.998	0.926
3	1.383	1.389	1.673	1.266	1.698	1.451	1.513	1.482
4	1.555	1.445	1.777	1.345	1.830	1.519	1.665	1.592
5	1.739	1.630	1.996	1.509	2.068	1.783	1.794	1.789
6	1.889	1.923	2.003	1.709	2.168	1.892	1.985	1.939
7	1.965	1.939	2.018	1.867	2.081	1.913	2.035	1.974
8	1.901	1.899	1.966	1.720	2.124	1.844	1.999	1.922
9	1.778	1.796	1.949	1.631	2.052	1.783	1.899	1.841
10	1.667	1.670	1.804	1.575	1.851	1.623	1.804	1.713
11	1.536	1.571	1.646	1.353	1.815	1.542	1.626	1.584
12	1.484	1.450	1.388	1.240	1.642	1.407	1.474	1.441
Mean	1.408	1.386	1.607	1.292	1.642	1.409	1.524	1.467

CD(0.05) for periods = 0.1220   CD(0.05) for levels = 0.0478

" " soils = 0.0478   " " soil x period = 0.1720

" " sources = 0.0586   " " source x period = 0.2110

This may be the reason for the positive significant correlation obtained (Table 21 to 23) between saloid-P and Fe-P (r = 0.796**, 0.807**, 0.726** for RRP, MRP and SP respectively). It is interesting to observe that the increase in the mean saloid-P content of the soil by the addition of a water soluble phosphatic fertilizer (SP) at the rate of 90 kg P_2O_5/ha is not more than 1 ppm over control which shows the high degree of reactivity of soluble phosphate in acid rice soils selected for the study (Tables 5 and 6). It is apparent that the applied soluble phosphate has been immediately coverted into insoluble compounds, thus resisting an increase in the level of saloid-P in the soil.

A comparison between the forms of P applied revealed that application of SP resulted in more content of saloid-P (1.607 ppm) compared to rockphosphates in the soil (Table 4). But it should be kept in mind that this significant difference of 0.21 ppm over the two rockphosphates (1.408 and 1.386 ppm for RRP and MRP respectively) is negligible in relation to the total quantity of P added to the soil or total inorganic P contained in the soil. Immediately on addition of P fertilizers, saloid-P was recovered only in treatments receiving SP because of its water solubility (Table 3). A comparison between the rockphosphates revealed that

Table 5. Mean values of inorganic P fractions as influenced by P sources and soil, ppm

Soil	Control (No P)	RRP	MRP	SP	Inorganic P fractions
Laterite	0.734	1.226	1.227	1.424	Saloid-P
Kari	0.804	1.591	1.545	1.790	
Laterite	238.5	263.7	263.2	266.9	Al-P
Kari	236.6	253.4	251.8	255.3	
Laterite	360.4	383.1	380.8	385.7	Fe-P
Kari	336.1	377.9	376.3	379.8	
Laterite	59.05	67.58	68.21	70.24	Reductant
Kari	57.51	61.68	60.76	62.18	soluble-P
Laterite	41.78	47.78	48.51	49.18	Occluded-P
Kari	36.95	44.13	44.17	44.30	
Laterite	44.77	58.54	58.65	59.11	Ca-P
Kari	49.84	69.21	69.38	70.94	
Laterite	9.95	12.69	12.74	12.88	Bray 1
Kari	9.69	16.35	16.36	16.36	
Laterite	27.58	33.42	33.46	33.71	Bray 2
Kari	27.04	35.71	35.81	36.15	

they were on par in respect of their effect on saloid-P content of the soil, probably due to their similar transformation pattern in these soils. Saloid-P at different periods of incubation as influenced by forms of P fertilizers is graphically represented in Fig.1.

Increasing the level of application of P from 45 to 90 kg P_2O_5/ha increased significantly the saloid-P content to the extent of 0.116 ppm (Table 4). Increasing the level of application of RRP, MRP and SP resulted in an increase in the saloid-P content from 1.36 to 1.46 ppm, 1.33 to 1.44 ppm and 1.54 to 1.68 ppm respectively when the effects of soils and periods were pooled (Table 6). This increase of saloid-P content was negligible considering the large amount of P added or P contained in the soil.

Prediction equations were worked out to establish saloid-P(Y) at different periods of incubation (x) from RRP, MRP and SP separately and also for the two soils. In all the cases, the response was found to be quadratic. The equations were

1. For soils
   a) Laterite $Y = -0.297 + 0.482x - 0.028x^2$ $(R^2 = 0.98)$
   b) Kari $Y = -0.259 + 0.575x - 0.034x^2$ $(R^2 = 0.97)$
2. For sources of P
   a) RRP $Y = -0.456 + 0.556x - 0.032x^2$ $(R^2 = 0.98)$
   b) MRP $Y = -0.478 + 0.548x - 0.031x^2$ $(R^2 = 0.98)$
   c) SP $Y = 0.099 + 0.481x - 0.029x^2$ $(R^2 = 0.98)$

FIG: 1. SALOID-P AT DIFFERENT PERIODS OF INCUBATION AS INFLUENCED BY FORMS OF P FERTILIZERS

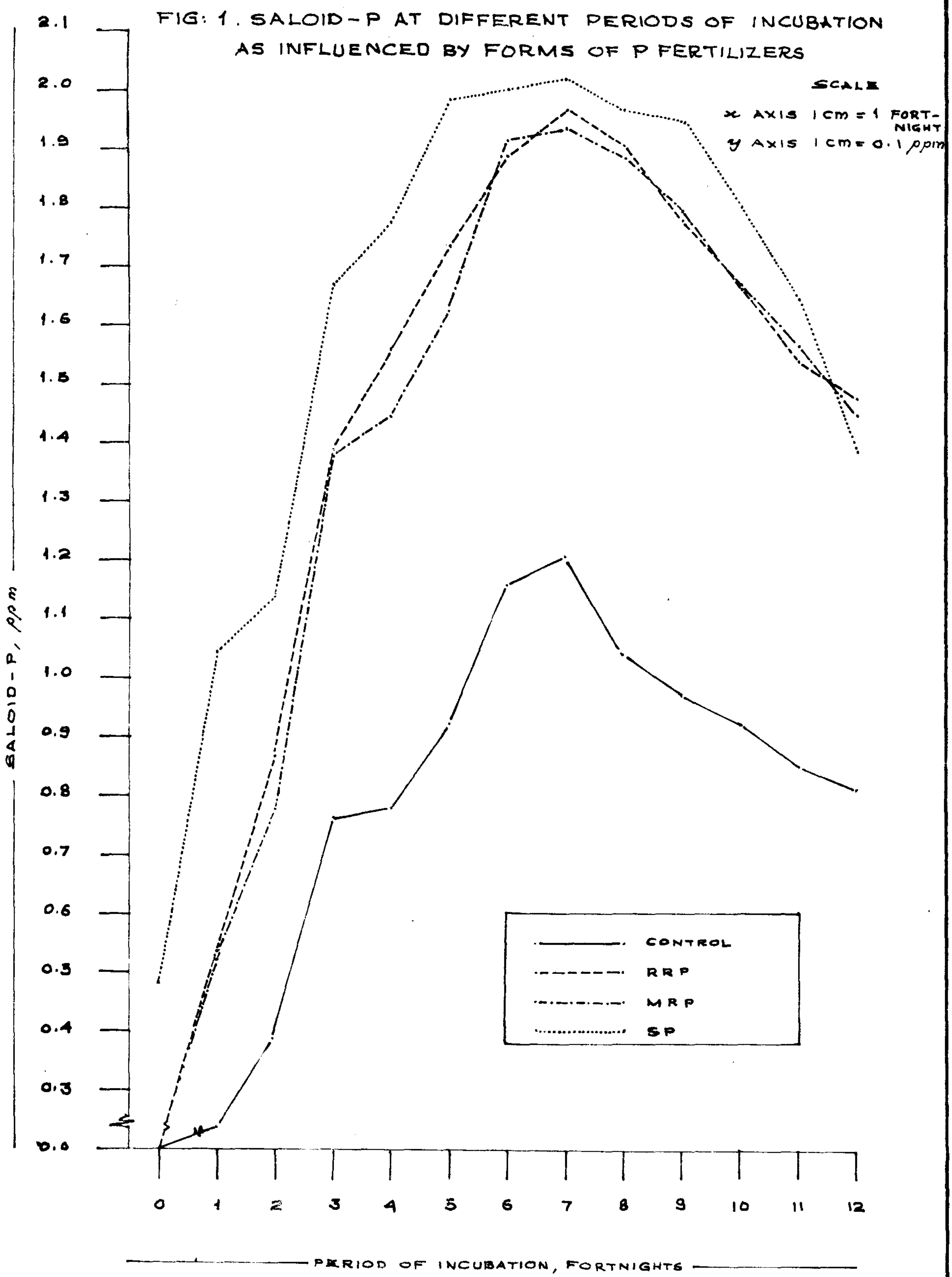


Table 6. Mean values of inorganic P fractions as influenced by levels of P application, ppm

Levels of P_2O_5, kg/ha	Soil		Sources of P			Inorganic P fractions
	Laterite	Kari	RRP	MRP	SP	
45	1.23	1.58	1.36	1.33	1.54	Saloid-P
90	1.35	1.69	1.46	1.44	1.68	
45	261.9	251.0	256.1	254.7	258.5	Al-P
90	267.3	255.9	261.0	260.3	263.7	
45	381.5	376.0	378.9	376.3	380.9	Fe-P
90	384.9	380.0	382.0	380.9	384.5	
45	67.64	60.70	63.96	65.31	62.99	Reductant
90	69.72	62.38	65.98	65.56	66.85	soluble-P
45	47.82	43.57	45.13	45.71	46.25	Occluded-P
90	49.15	44.83	46.77	46.97	47.24	
45	67.68	57.68	61.95	62.57	63.52	Ca-P
90	72.02	59.85	65.81	65.46	66.53	
45	12.27	12.85	14.43	14.45	14.57	Bray 1
90	16.69	16.44	14.62	14.65	14.68	
45	33.40	35.61	34.41	34.53	34.57	Bray 2
90	33.66	35.86	34.72	34.74	34.82	

In general, the mean saloid-P content was maximum during the seventh fortnight irrespective of forms and levels of P, and it was 1.815 ppm more than that of the initial concentration (0.159 ppm). After attaining a maximum of 1.974 ppm, saloid-P gradually decreased to 1.441 ppm in the final stage which was still higher than the initial concentration when the soils, sources and levels of P application were pooled (Table 4). Thus the period of incubation and saloid-P content were positively correlated (Table 24) as revealed by the linear coefficient of correlation ($r = 0.509^{**}$). Initially, the rate of increase in the saloid-P was relatively high, probably due to the high rate of mineralization of organic P and conversion of insoluble phosphatic compounds into more soluble forms. A slight decrease observed in the later periods may be due to the formation of more insoluble secondary minerals which can not be extracted by a neutral salt solution.

There was significant difference between soils with regard to the saloid-P content. Table 4 shows that under fertilized condition, the mean content was significantly higher in kari soil (1.642 ppm) compared to laterite soil (1.292 ppm). Also when no P was added, the concentration was higher in kari soil than in laterite soil, though the difference was not significant (Table 5). The higher content of saloid-P in kari soil in the presence of added P was due to the higher mobilization of added P fertilizers because of its high acidity.

The saloid-P was found to be significantly and positively correlated with available P ($r = 0.887^{**}$ for Bray 1 and $r = 0.881^{**}$ for Bray 2). Saloid bound P being completely water soluble or freely exchangeable, will be fully accounted in the estimation of available P and hence the correlation. This observation is in line with the findings of Sacheti and Saxena (1974) and Nair (1978).

1.2 Aluminium phosphate

Effects of forms and levels of applied P on the content of Al-P at different periods of incubation in laterite and kari soils are presented in Tables 5 to 8 and Appendix I.

In acid soils, one of the major components of inorganic phosphate is Al-P. Originally, the Al-P content was 191.9 ppm in laterite soil and 179.9 ppm in kari soil, which accounted for 29 to 30 per cent of the total inorganic P of these soils (Table 7). Even in the absence of added P, the content of Al-P in the soil increased on incubation and this increase was more pronounced in kari soil. In laterite soil, the increase in Al-P on incubation was 72.8 ppm (37.94%) while it was 89.4 ppm (49.69%) in kari soil (Table 8). The relatively higher rate of increase in Al-P on incubation observed in kari soil can be attributed to its content of organic matter and high acidity.

Table 7. Al-P as influenced by the treatments at different periods of incubation, ppm

Treatment		Period of incubation, fortnights												
No.	Notation	0	1	2	3	4	5	6	7	8	9	10	11	12
1	OL	191.9	207.9	223.6	254.9	242.9	233.5	238.1	237.1	244.7	242.5	255.7	264.7	263.2
2	RRP45L	204.9	220.7	236.4	270.4	262.9	254.4	268.1	267.7	270.2	270.5	281.1	292.1	293.8
3	RRP90L	205.8	229.5	242.5	274.8	270.6	257.7	271.2	274.4	277.2	274.8	292.7	295.9	292.5
4	MRP45L	203.1	224.0	238.4	270.0	262.9	259.4	268.3	265.9	270.8	273.3	272.7	287.6	286.9
5	MRP90L	205.6	231.2	242.8	277.2	267.1	262.3	269.8	271.7	279.1	278.7	289.7	294.5	289.3
6	SP45L	205.6	230.0	239.7	276.6	269.9	266.4	268.9	262.6	276.0	282.0	282.4	286.3	289.5
7	SP90L	206.9	231.7	243.6	282.6	273.7	271.4	273.4	275.9	278.5	289.8	287.2	297.1	292.2
8	OK	179.9	196.3	213.0	242.3	232.5	228.6	233.1	242.8	251.6	256.9	262.8	267.1	269.3
9	RRP45K	194.2	206.3	222.9	259.0	254.1	251.4	256.7	265.2	267.4	268.9	271.0	273.4	275.1
10	RRP90K	197.9	207.4	226.2	262.8	257.4	245.4	265.4	266.1	269.6	275.4	279.6	279.9	284.5
11	MRP45K	193.5	202.8	221.9	256.3	252.6	251.5	256.2	260.6	260.4	265.9	270.4	271.9	275.6
12	MRP90K	197.3	204.0	226.9	262.2	257.6	254.1	265.3	261.9	264.4	271.2	279.4	281.8	285.9
13	SP45K	195.7	209.6	224.7	265.1	254.2	251.2	258.9	261.9	263.8	269.7	271.9	275.9	282.3
14	SP90K	196.6	217.3	228.9	278.4	256.0	253.4	260.2	269.9	270.8	274.8	278.6	283.1	283.9
15	SP(45+45)L	205.6	230.0	239.7	276.6	269.9	266.4	268.9	268.8	278.6	285.4	283.4	274.7	290.6
16	SP(45+45)K	195.7	209.6	224.7	265.1	254.2	251.2	258.9	264.3	266.4	279.7	296.6	281.8	284.4

The increase in the content of Al-P on incubation may be due to the conversion of reductant soluble-P, occluded-P and Ca-P into Al-P and Fe-P as a result of reduction taking place in the soil subsequent to waterlogging. The large amount of free Fe and Al released in soil on incubation would have reacted with the phosphates subsequent to its transformation under reducing conditions. This is evidenced by the decrease in the content of reductant soluble-P, occluded-P and Ca-P observed with increasing period of incubation. It is also possible that the mineralization of organic phosphate would have resulted in an increase in the Al-P content of the soil. Table 5 showed that the mean values of Al-P from RRP, MRP and SP were higher in laterite soil 263.7, 263.2 and 266.9 ppm respectively) compared to kari soil (253.4, 251.8 and 255.3 ppm respectively), probably due to the higher content of free alumina in the laterite soil. Balasubramanian and Raj (1969) and Singh and Ram (1977) also obtained higher amount of Al-P in the laterite soils.

By the addition of phosphatic fertilizers there was a significant increase of 14.7 ppm in the content of Al-P over control during the first period which increased to 20.15 ppm by the twelfth period. This shows that a considerable amount of applied P has been converted into Al-P within a period of 180 days. A gradual decline in

Table 8. Mean values of Al-P as influenced by sources of P, soils and levels of P application, ppm

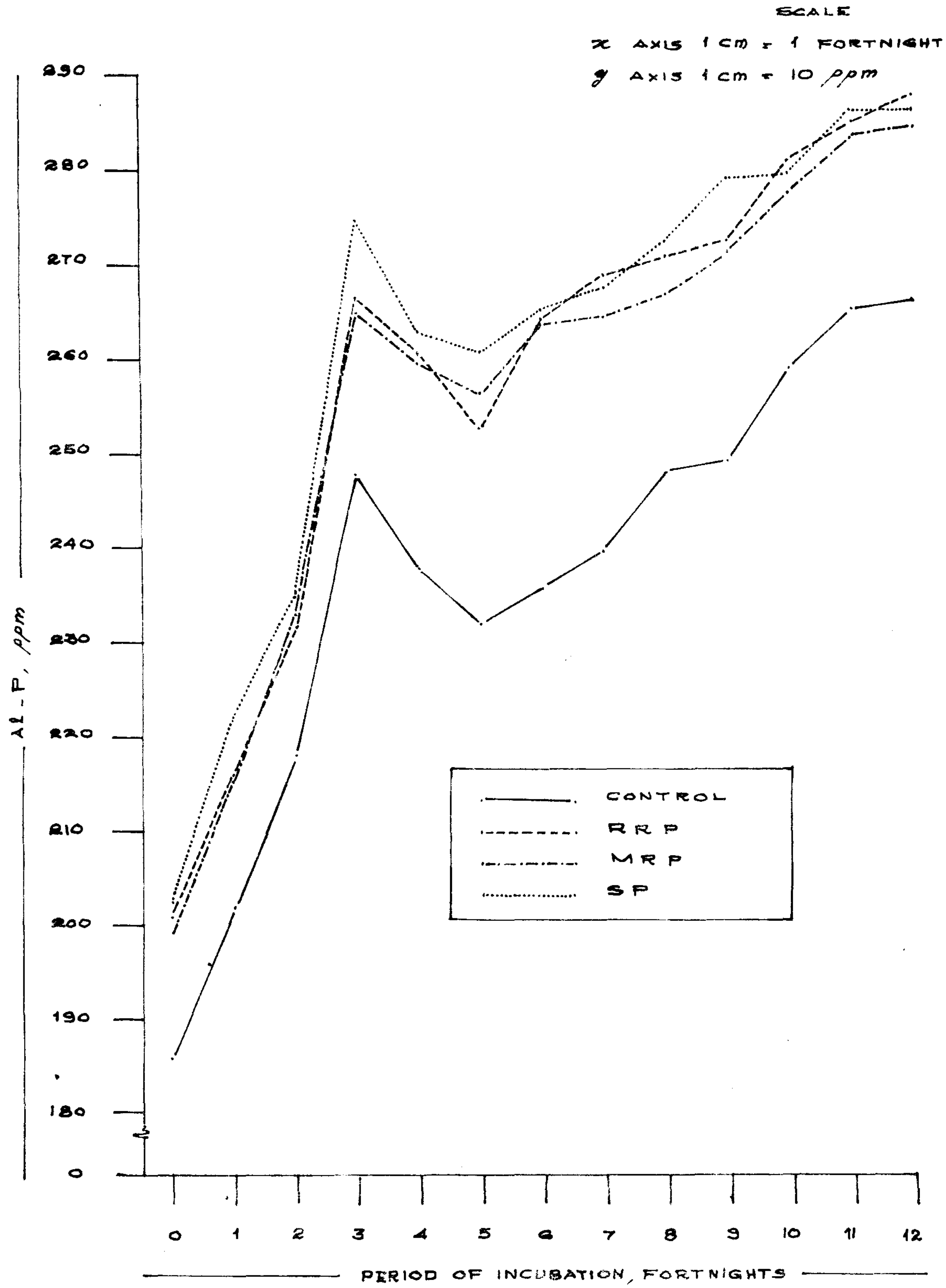
Period of incubation, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
0	200.7	199.9	201.2	205.3	195.8	199.5	201.7	200.6
1	215.9	215.9	222.2	227.8	208.3	215.6	220.5	218.0
2	231.9	232.5	234.2	240.5	225.3	230.6	235.2	232.9
3	266.7	266.4	275.7	275.3	263.9	266.2	272.9	269.6
4	261.2	260.1	263.4	267.8	255.3	259.4	263.7	261.6
5	253.6	256.8	260.6	261.9	252.0	255.7	258.3	256.9
6	265.3	264.9	265.3	269.9	260.4	262.9	267.5	265.2
7	268.3	265.0	267.6	269.7	264.3	263.9	269.9	266.9
8	271.4	267.4	272.3	275.3	265.2	268.1	272.4	270.2
9	272.4	272.2	279.1	278.2	270.9	271.7	277.4	274.6
10	281.1	278.0	280.0	284.3	275.2	274.9	284.5	279.7
11	285.3	283.9	285.6	292.2	277.7	281.2	288.7	284.9
12	287.7	284.4	286.9	291.5	281.2	283.8	288.9	286.4
Mean	258.6	257.5	261.1	264.6	253.5	256.4	261.7	259.0

CD(0.05) for periods = 7.170
" " soils = 2.810
" " levels = 2.810

the formation of Al-P observed during the fourth and fifth periods may be due to the larger proportion of other fractions formed with the advancement of period of incubation. The concentration of Al-P even at the periods of decline was still higher than the initial concentration. Thus the content of Al-P and period of incubation were positively correlated ($r = 0.789^{**}$). This was in confirmity with the observations of Gupta and Nayan (1972), Singh and Bahaman (1976) and Rajakannu and Ravikumar (1978). In general, the increase in the content of Al-P in the soil with increasing period of incubation was represented by a cubic function $Y = 169.4 + 33.51x - 3.84x^2 + 0.152x^3$ ($R^2 = 0.94$).

It was observed that the forms of applied P had little effect in deciding the level of Al-P in the soil. The mean contents of Al-P from RRP, MRP and SP were 258.6, 257.5 and 261.1 ppm respectively (Table 8) i.e., when the three forms of P were compared, the performance of the two rockphosphates was comparable to that of SP with respect to the content of Al-P, though SP contained P in a water soluble form. This phenomenon gives an indication that the dissolution of the tricalcium phosphate in the rockphosphate might have started in the acidic soil environment with the lapse of time. The level of Al-P at different periods of incubation as influenced by forms of P fertilizers is represented in Fig.2.

FIG: 2. Al - P AT DIFFERENT PERIODS OF INCUBATION AS INFLUENCED BY FORMS OF P FERTILIZERS



Increasing level of application of P from 45 to 90 kg P_2O_5/ha increased the content of Al-P to the tune of 5.3 ppm when the sources, soils and periods of incubation were pooled and this increase was found to be significant (Table 8). Also when the soils and sources of P were considered independently, again the Al-P content increased with increasing levels of P application (Table 6).

Aluminium phosphate was found significantly correlated with the available P of the soil (Table 24). The correlation was more intense with Bray 2 ($r = 0.820^{**}$) than with Bray 1 ($r = 0.683^{**}$). Both Bray 1 and 2 extractants contained NH_4F which is a selective extractant for Al compounds. The higher concentration of acid contained in Bray No.2 would have resulted in the higher extraction of Al-P thereby showing better correlation with the available P. Al-P was found positively and significantly correlated with saloid-P ($r = 0.754^{**}$, 0.766^{**}, 0.686^{**} for RRP, MRP and SP respectively) and Fe-P ($r = 0.899^{**}$, 0.909^{**}, 0.902^{**} for RRP, MRP and SP respectively) and negatively correlated with occluded-P ($r = -0.452^{**}$) and reductant soluble-P ($r = -0.407^{**}$).

1.3 Iron phosphate

Influence of various treatments on the Fe-P content of laterite and kari soils at different periods is given in Tables 5, 6, 9 and 10 and their analysis of variance in Appendix I.

Table 9. Fe-P as influenced by the treatments at different periods of incubation, ppm

Treatment		Period of incubation, fortnights												
No.	Notation	0	1	2	3	4	5	6	7	8	9	10	11	12
1	OL	270.9	303.8	343.6	369.5	368.3	378.7	368.4	367.0	374.2	380.5	381.4	390.1	388.4
2	RRP45L	278.4	325.4	367.4	398.6	403.1	401.5	389.5	385.0	392.8	397.4	404.4	408.0	410.4
3	RRP90L	381.5	327.5	370.6	399.2	403.4	398.6	396.9	391.2	296.8	299.9	405.8	412.2	409.4
4	MRP45L	279.5	324.3	368.4	393.5	399.0	399.5	389.9	386.5	386.5	393.2	399.6	401.6	400.8
5	MRP90L	281.4	327.3	370.5	402.6	398.5	406.3	397.3	394.7	392.2	394.9	401.6	410.1	404.0
6	SP45L	279.6	333.5	385.4	395.5	402.4	393.2	391.4	394.7	392.4	399.4	403.4	409.3	409.1
7	SP90L	281.7	338.6	389.1	403.5	406.5	399.5	395.0	400.6	394.6	398.6	408.7	414.9	490.2
8	OK	258.1	283.3	308.5	352.8	344.9	345.5	344.2	337.2	349.9	354.9	351.7	366.5	371.9
9	RRP45K	263.5	303.2	359.2	393.8	392.5	392.1	385.2	383.4	394.1	396.4	403.9	407.7	411.8
10	RRP90K	267.6	309.3	364.7	398.1	401.4	396.9	388.7	388.4	397.2	397.9	407.1	410.4	412.4
11	MRP45K	262.4	303.7	360.5	394.4	391.2	392.2	384.4	378.6	391.5	392.9	401.1	402.4	405.9
12	MRP90K	266.5	307.5	367.7	397.1	397.9	396.4	388.6	388.0	389.6	396.2	402.1	408.6	414.7
13	SP45K	267.6	307.7	371.4	403.1	396.6	393.5	387.9	391.4	388.5	393.9	397.2	408.3	409.2
14	SP90K	270.5	307.6	378.3	407.9	405.9	398.3	388.3	392.2	392.9	395.5	399.6	410.4	410.3
15	SP(45+45)L	279.6	333.5	385.4	395.5	402.4	393.2	296.6	395.6	396.2	398.4	410.8	407.3	410.6
16	SP(45+45)K	267.6	307.7	371.4	403.1	396.6	393.5	389.5	392.6	392.6	395.7	399.8	402.8	408.5

Originally, the content of Fe-P in the two soils (270.9 and 258.1 ppm for laterite and kari soils respectively) accounted for 41 to 43 per cent of the total inorganic P (Table 9). On incubation, without the addition of P, the native Fe-P was increased by 116.5 ppm over the initial concentration, the increase being 44.05 per cent. In general, by the addition of phosphatic fertilizers, irrespective of the forms and levels of P application there was a significant increase of 9.45 ppm in laterite soil and 8.25 ppm in kari soil over the control during the first period, which increased to 19.00 and 38.80 ppm in laterite and kari soils respectively with the advancement of period of incubation. This increase indicated that a major part of the added P was transformed into Fe-P. The rate of increase in Fe-P from the added P with the increasing period of incubation was high in kari soil, probably due to its high acidity. The relatively higher mean values of Fe-P formed from RRP, MRP and SP during incubation in laterite soil as compared to kari soil was obviously due to the high content of free iron oxides and available Fe in the laterite soil (Table 5). Balasubramanian and Raj (1969) and Kothandaraman and Krishnamoorthy (1977) also obtained higher amount of Fe-P in laterite soil.

Table 10. Mean values of Fe-P as influenced by sources of P, soils and levels of P application, ppm

Period of incubation, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
0	272.7	272.4	274.8	280.3	266.3	271.8	274.8	273.3
1	316.4	315.7	321.8	329.4	306.5	316.3	319.6	317.6
2	365.4	366.7	380.9	375.1	366.9	368.7	373.6	371.0
3	397.4	396.9	402.5	398.8	399.1	396.5	401.4	398.9
4	400.1	396.6	402.8	402.1	397.6	397.5	402.3	399.9
5	397.3	398.6	396.1	399.8	394.9	395.4	399.3	397.3
6	390.1	390.8	390.7	393.3	387.7	388.1	392.9	390.5
7	387.9	386.9	394.7	392.8	386.8	387.3	392.5	389.9
8	395.2	389.9	392.2	392.5	392.4	391.0	393.9	392.4
9	397.9	394.3	396.9	397.2	395.5	395.5	397.1	396.3
10	405.3	401.1	402.2	403.9	401.8	401.6	404.1	402.3
11	409.6	405.3	410.7	409.1	407.9	406.2	410.8	408.5
12	410.9	406.3	409.5	407.1	410.7	407.9	409.9	408.9
Mean	380.5	378.6	382.8	383.2	378.0	378.7	382.5	380.5

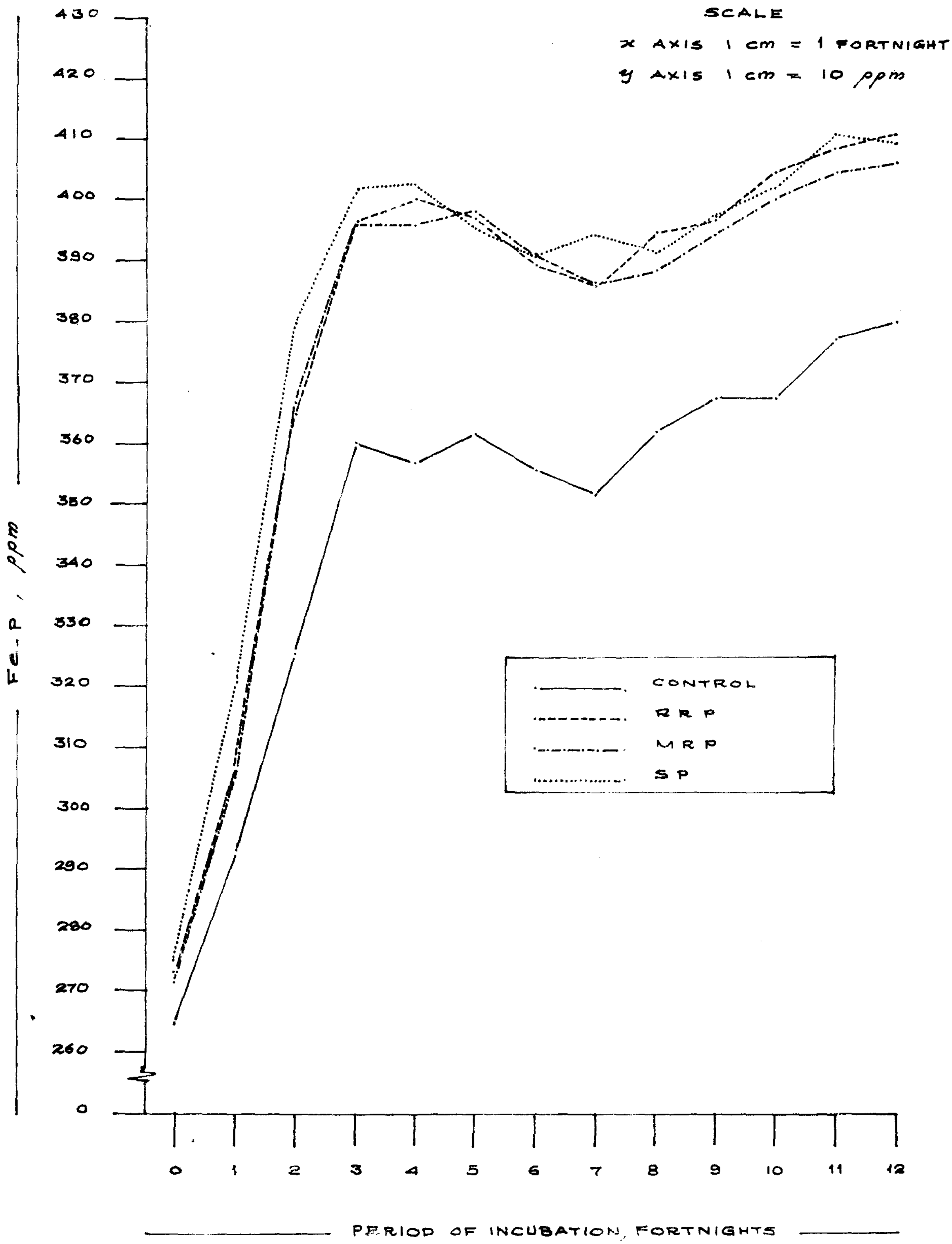
CD(0.05) for periods = 10.00

" " soils = 3.923

Observations revealed that the concentration of Fe-P in the soil was not significantly affected by the variations in the forms and levels of applied P. The mean values of Fe-P formed from RRP, MRP and SP were 380.5, 378.6 and 382.8 ppm respectively when the soils, levels and periods were pooled (Table 10). Effect of forms of P, on the Fe-P content at different periods of incubation is represented in Fig.3. In the acid kari and laterite soils, containing large amount of free Fe and Al, the soluble monocalcium phosphate of SP would have been converted to Fe and Al phosphates. When the rockphosphates were applied, the insoluble tricalcium phosphate got solubilized in these acid soils and the phosphate ions would have reacted with Fe and Al components of the soil, thereby resulting in the formation of Al-P and Fe-P. This explains why irrespective of soluble or insoluble phosphate sources added, the same quantities of Fe-P and Al-P are formed on incubation.

Increasing the levels of P application from 45 to 90 kg P_2O_5/ha increased the content of Fe-P in the soil to the extent of 3.8 ppm when the soils, levels and periods of incubation were pooled (Table 10). When the soils and sources of P were considered separately after pooling the periods, again Fe-P increased with increasing levels of application (Table 6). However, the increase was considerably low, when the total quantity of P added to the soil was considered.

FIG. 3. Fe-P AT DIFFERENT PERIODS OF INCUBATION AS INFLUENCED BY FORMS OF P FERTILIZERS



The Fe-P content (Y) at different periods of incubation (x) from RRP, MRP and SP and in two soils can be predicted from the following equations.

1. For sources of P

   a) RRP

   $$Y = 206.2 + 77.04x - 9.77x^2 + 0.393x^3 \quad (R^2 = 0.96)$$

   b) MRP

   $$\log Y = 2.35 + 0.102x - 0.013x^2 + 0.00053x^3 \quad (R^2 = 0.96)$$

   c) SP

   $$Y = 207.7 + 80.79x - 10.55x^2 + 0.431x^3 \quad (R^2 = 0.94)$$

2. For soils

   a) Laterite

   $$Y = 219.1 + 74.59x - 9.6x^2 + 0.388x^3 \quad (R^2 = 0.96)$$

   b) Kari

   $$Y = 193.2 + 82.8x - 10.62x^2 + 0.430x^3 \quad (R^2 = 0.95)$$

For all the three sources, the peak content of Fe-P was observed during the eleventh and twelfth fortnights in both the soil. Table 10 shows that in general, the mean Fe-P content showed a progressive increase upto the fourth fortnight. At this period, the content was 126.6 ppm more than that of the initial concentration (273.3 ppm).
From fourth fortnight onwards, Fe-P decreased upto the seventh period, and then gradually increased and attained the maximum concentration (408.9 ppm) at the final period which was 49.59 per cent more than the initial concentration. Even in the fifth, sixth and seventh periods, the Fe-P

content was higher than the initial content. The linear coefficient of correlation (r) between Fe-P from three sources and period of incubation was 0.675**, 0.683**, 0.652** for RRP, MRP and SP respectively (Tables 21 to 23).

The rate of change in the concentration of Fe-P was more pronounced during the initial periods of incubation. This was mainly due to the intensive reduction reactions occurring, consequent to flooding. During submergence, a major portion of the reductant soluble and occluded phosphates might have converted into ferrous phosphate. In addition to this process, intensive microbial activity would have released the organically bound phosphates which later get converted into Fe-P. This is supported by the gradual increase in the total inorganic P observed with the advancement of incubation. However, a slight decrease in Fe-P was observed during certain periods of incubation which can be attributed to the conversion of Fe-P to other forms.

As mentioned earlier, Fe-P will contribute much to the pool of available P. The linear coefficient of correlation (r) between Fe-P and available P was found to be 0.761** for Bray 1 and 0.859** for Bray 2 (Table 24). As in the case of Al-P, the higher concentration of acid contained in Bray 2 extractant would have resulted in the higher extraction of Fe-P, thereby showing comparatively higher correlation with the available P. Iron phosphate formed from all the three sources was negatively correlated with reductant soluble-P ($r = -0.398^{**}, -0.401^{**}, -0.305^{**}$ for RRP, MRP and SP respectively) and occluded-P ($r = -0.459^{**}, -0.484^{**}, -0.426^{**}$ for RRP, MRP and SP respectively).

1.4 Reductant soluble phosphorus

Reductant soluble-P as influenced by various treatments in laterite and kari soils is presented in Tables 5, 6, 11 and 12 and their analysis of variance in Appendix I.

Reductant soluble-P refers to that part of inorganic P which is not immediately available to the plants. Chang and Jackson explained the reductant soluble-P as being due to an iron oxide precipitate formed on the surface of iron and aluminium phosphate particles during weathering (Hesse, 1971). Originally, the reductant soluble-P was 73.06 ppm in laterite soil and 67.59 ppm in kari soil which accounted for only 11 to 12 per cent of the total inorganic P (Table 11). The relatively higher content of native reductant soluble-P in the laterite soil compared to kari soil is attributed to its highly weathered and oxic nature with high content of iron oxides. Debnath and Hajra (1972) and Kothandaraman and Krishnamoorthy (1977) also

Table 11. Reductant soluble-P as influenced by the treatments at different periods of incubation, ppm

Treatment		Period of incubation, fortnights												
No.	Notation	0	1	2	3	4	5	6	7	8	9	10	11	12
1	OL	73.06	69.14	63.55	59.30	60.20	59.05	57.97	58.55	57.05	53.85	52.10	51.85	52.05
2	RRP45L	80.35	75.37	69.43	67.00	69.30	69.00	68.68	67.25	63.95	64.55	64.30	54.40	53.05
3	RRP90L	81.00	78.78	71.20	69.60	71.00	68.60	69.75	68.55	66.65	67.90	68.15	57.10	57.35
4	MRP45L	80.28	76.52	70.00	68.80	67.75	67.80	62.55	69.55	64.30	65.25	62.80	54.95	58.90
5	MRP90L	81.22	79.43	70.15	71.30	73.25	72.35	72.30	71.05	65.20	67.05	67.65	56.75	56.40
6	SP45L	80.92	74.62	73.20	74.25	70.85	71.50	68.80	71.45	68.95	65.60	64.75	57.45	59.40
7	SP90L	82.67	79.55	75.10	73.70	75.65	71.85	68.40	72.65	69.95	67.60	67.75	59.35	60.40
8	OK	67.59	64.28	63.05	62.25	57.80	60.60	59.25	59.80	51.50	53.05	51.25	49.40	47.85
9	RRP45K	75.50	72.95	67.45	62.80	63.15	62.40	61.85	58.30	57.70	58.05	55.80	50.75	49.50
10	RRP90K	75.89	74.63	68.40	63.75	64.70	62.45	62.40	59.75	58.20	58.95	57.00	51.35	50.20
11	MRP45K	75.23	72.21	67.95	62.05	62.05	62.40	61.75	57.55	58.05	58.75	56.75	50.25	50.10
12	MRP90K	75.68	75.60	68.65	63.65	63.95	63.10	63.15	57.30	59.10	59.45	57.65	53.05	51.20
13	SP45K	75.88	72.35	68.00	63.15	62.35	63.95	62.75	57.15	58.30	59.15	56.90	52.30	50.50
14	SP90K	76.10	74.80	69.30	63.90	61.95	64.40	63.10	57.95	59.60	60.05	57.95	53.25	51.30
15	SP(45+45)L	80.92	74.62	73.20	74.25	70.85	71.50	68.80	72.00	65.85	64.45	69.00	58.50	61.05
16	SP(45+45)K	75.88	62.35	68.00	63.15	62.35	63.95	62.75	58.15	58.85	59.35	57.20	53.50	50.25

reported the higher content of reductant soluble-P in laterite soil. Table 5 shows that the conversion of added P to reductant soluble-P was also higher in laterite soil (67.58, 68.21 and 70.24 ppm for RRP, MRP and SP respectively) compared to kari soil (61.68, 60.76, 62.18 ppm for RRP, MRP and SP respectively).

By the addition of phosphatic fertilizers, there was a significant increase of 8.07 ppm reductant soluble-P over control, during the first period and with the lapse of time, it increased to a maximum of only 9.78 ppm. This slight increase indicated that the transformation of added P to this fraction was considerably low in the submerged soil because of its reducing environment and it further confirmed the earlier observations that a major part of the added P was converted into a more soluble Al-P and Fe-P in the submerged soil.

Results revealed that the forms of applied P could not influence the concentration of reductant soluble-P in the soil. Influence of sources of P fertilizers on the concentration of this fraction at different periods of incubation is graphically represented in Fig.4. The mean values for reductant soluble-P over control from RRP, MRP, and SP were 11.35, 11.21 and 12.92 ppm respectively when the levels, periods and soils were pooled (Table 12) i.e., by the addition of SP, there was

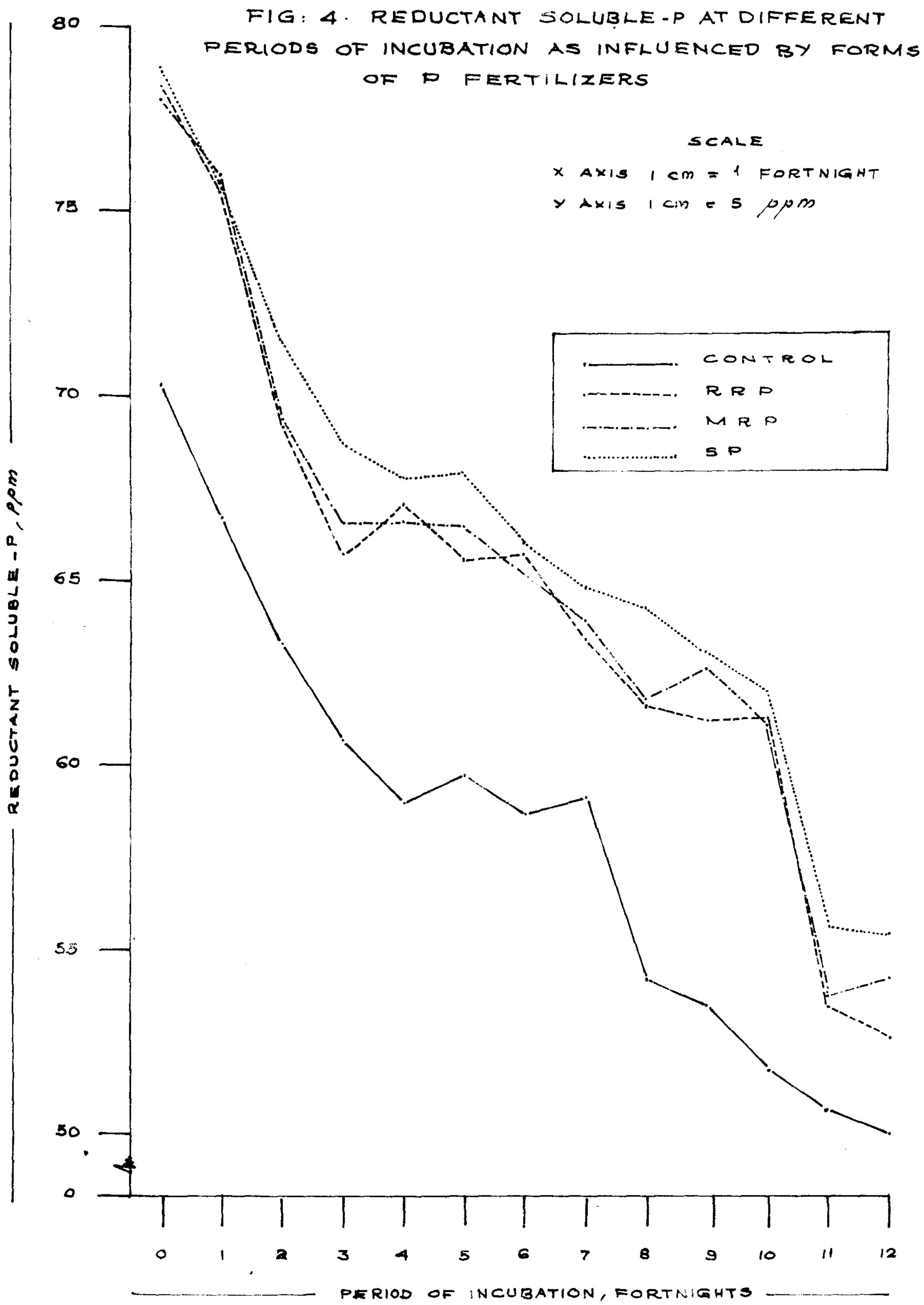


FIG: 4. REDUCTANT SOLUBLE-P AT DIFFERENT PERIODS OF INCUBATION AS INFLUENCED BY FORMS OF P FERTILIZERS
SCALE
X AXIS 1 cm = 1 FORTNIGHT
Y AXIS 1 cm = 5 ppm
CONTROL
RRP
MRP
SP
80
75
70
65
60
55
50
0
REDUCTANT SOLUBLE-P, ppm
0
1
2
3
4
5
6
7
8
9
10
11
12
PERIOD OF INCUBATION, FORTNIGHTS

Table 12. Mean values of reductant soluble-P as influenced by sources of P, soils and levels of P application, ppm

Period of incubation, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
0	78.18	78.13	78.88	81.08	75.70	78.03	78.75	78.39
1	75.41	75.91	75.31	77.35	73.75	73.98	77.12	75.55
2	69.13	69.19	71.40	71.52	68.30	69.35	70.47	69.91
3	65.78	66.45	68.75	70.78	63.21	66.33	67.65	66.99
4	67.03	66.78	67.70	71.29	63.03	65.91	68.41	67.15
5	65.61	66.41	67.93	70.18	63.12	66.18	67.13	66.65
6	65.68	58.28	65.76	68.42	58.06	59.96	66.52	63.24
7	63.43	63.85	64.80	70.05	58.00	63.53	64.52	64.03
8	61.61	61.66	64.20	66.49	58.49	61.88	63.11	62.49
9	61.11	62.60	63.10	65.48	59.06	61.89	62.65	62.27
10	61.31	61.21	61.84	65.90	57.01	60.22	62.69	61.45
11	53.40	53.74	55.54	56.67	51.82	53.35	55.13	54.24
12	52.53	54.15	55.40	57.58	50.47	53.56	54.48	54.03
Mean	64.63	64.49	66.20	68.68	61.54	64.17	66.05	65.11

CD(0.05) for periods = 3.686
" " soils = 1.446
" " levels = 1.446

only 14.54 per cent more reductant soluble-P compared to rockphosphates. The higher contribution of SP in increasing the reductant soluble-P is obviously due to its higher water soluble P content which can easily enter into chemical reactions before the soil gets highly reduced, leading to the conversion of water soluble forms to insoluble stable compounds like reductant soluble-P. In the case of rockphosphates, because of its water insolubility, needed time for its conversion to water soluble form, during which time the soil components might have got reduced to some extent, resulting in the formation of relatively small amount of reductant soluble-P.

Application of P at higher level significantly increased the content of reductant soluble-P to the extent of 1.88 ppm when soils, sources and periods were pooled (Table 12). Increasing the level of application of P from 45 to 90 kg P_2O_5/ha increased the mean reductant soluble-P from 67.64 to 69.72 ppm in laterite soil and from 60.70 to 62.38 ppm in kari soil (Table 6).

Irrespective of soils and levels of P application, the maximum content of reductant soluble-P from all the three sources was recorded during the first period which on incubation get reduced to the extent of 28 to 30 per cent of the initial concentration. A decrease in the content of reductant soluble-P due to incubation was also reported by Mahapatra and Patrick (1969), Islam (1970) and Gupta and Nayan (1972). The rate of decrease in the level of this fraction was more marked during the initial periods of incubation, probably due to the intensive microbial and chemical reactions occurring, consequent to flooding. The decrease in the content of reductant soluble-P (Y) from three sources of P and in two soils with increasing periods of incubation (x) can be predicted by the following equations.

1. For sources of P

   a) RRP $Y = 77.03 - 1.776x$ $(R^2 = 0.90)$

   b) MRP $Y = 76.45 - 1.709x$ $(R^2 = 0.84)$

   c) SP $Y = 77.93 - 1.606x$ $(R^2 = 0.94)$

2. For soils

   a) Laterite $Y = 79.93 - 1.607x$ $(R^2 = 0.87)$

   b) Kari $Y = 1.876 \times 0.013^x$ $(R^2 = 0.91)$

The decrease in the content of this fraction was mainly due to its conversion to other forms. The chemical and biochemical reactions will lead to the transformation of ferric compounds resulting in its conversion to a more soluble Fe-P and Al-P. In a submerged soil, the chances of conversion of other forms to the reductant soluble form are very less compared to the probability of its transformation to other fractions under submerged conditions. In general, the contents of reductant soluble-P and period of incubation were negatively correlated ($r = -0.661^{**}$).

The contribution of reductant soluble-P to available P was nil because of its high stability and hence the negative correlation with available P ($r = -0.273^{**}$, -0.310^{**} for Bray 1 and 2 respectively).

1.5 Occluded phosphorus

Occluded-P as affected by sources and levels of applied P at different periods of incubation in laterite and kari soils are presented in Tables 5, 6, 13 and 14 and their analysis of variance in Appendix I.

The content of native occluded-P in the soil before incubation was 68.15 ppm in laterite soil and 48.05 ppm in kari soil, which represented 7 to 11 per cent of the total inorganic P (Table 13). On incubation, the contribution of this fraction to the total inorganic phosphate pool was reduced to 3 to 5 per cent (32.65 and 27.15 ppm in laterite and kari soils respectively) which confirmed the conversion of occluded-P to other forms. Similar to reductant soluble-P, occluded-P on incubation would also have converted to more soluble forms like Fe-P and Al-P. In general, the rate of decrease in the native occluded-P was 52.09 per cent in laterite soil and 43.49 per cent in kari soil (Table 13). Also, the rate of

Table 13. Occluded-P as influenced by the treatments at different periods of incubation, ppm

Treatment		Period of incubation, fortnights												
No.	Notation	0	1	2	3	4	5	6	7	8	9	10	11	12
1	OL	68.15	55.45	47.10	45.30	43.05	40.50	41.50	34.05	33.00	34.40	32.70	32.65	35.45
2	RRP45L	75.40	56.50	50.95	47.35	46.70	43.70	44.05	43.25	39.95	40.80	38.90	39.75	41.95
3	RRP90L	76.00	59.65	55.10	50.00	48.20	45.65	46.05	45.80	41.35	41.05	40.70	40.95	42.45
4	MRP45L	75.35	57.40	55.40	49.20	47.45	43.85	44.85	45.25	41.25	41.60	39.05	41.05	40.55
5	MRP90L	76.15	60.65	55.95	49.95	49.05	45.90	45.90	46.30	41.85	41.80	40.90	41.35	43.25
6	SP45L	75.95	60.00	54.35	47.90	49.50	44.65	45.60	42.50	42.70	43.60	41.05	42.75	43.20
7	SP90L	76.20	60.45	54.75	49.65	50.25	44.85	47.20	44.50	43.70	44.30	42.45	43.10	43.70
8	OK	48.05	41.65	43.65	41.85	40.55	38.25	34.30	34.25	32.35	32.80	33.45	32.10	27.15
9	RRP45K	53.15	46.55	46.15	48.95	47.35	45.45	40.00	45.90	43.25	40.35	36.90	35.86	34.40
10	RRP90K	54.75	49.90	48.25	48.75	48.70	46.05	39.85	47.45	43.65	42.55	39.45	38.75	35.05
11	MRP45K	53.55	49.20	47.55	49.40	46.65	45.50	39.60	45.10	40.90	40.35	37.45	37.05	33.95
12	MRP90K	55.15	48.40	48.40	49.88	48.25	46.00	45.85	43.30	42.75	42.55	38.15	39.00	34.65
13	SP45K	53.45	43.30	47.95	49.40	47.15	44.55	44.60	43.50	41.45	42.35	38.30	37.60	34.25
14	SP90K	53.75	50.00	47.60	50.10	47.65	45.95	45.75	45.75	41.85	42.50	39.95	37.95	34.30
15	SP(45+45)L	75.95	60.00	54.35	47.90	49.50	44.65	45.60	41.05	43.10	43.60	42.50	42.25	43.35
16	SP(45+45)K	53.45	49.30	47.95	49.40	47.15	44.55	44.60	48.80	43.10	43.50	39.00	38.15	35.00

decrease in this fraction during the first fortnight of incubation was higher in laterite soil for all the three sources (23.28, 22.07 and 20.83 per cent for RRP, MRP and SP respectively). Since the chemical components of the laterite soil exist in a highly oxidized state as compared to that of the kari soil, the degree of reduction caused by incubation will be more intense in laterite soil, thus registering a relatively high rate of decrease in the content of occluded-P formed by the coatings of iron oxide.

Addition of fertilizers significantly increased the content of occluded-P to the tune of 7.69 ppm over control in laterite soil and 5.92 ppm over control in kari soil during the first period. On incubation this was increased to only 8.84 ppm in laterite soil and 7.28 ppm in kari soil. This shows that only a small part of the added P is converted to occluded-P compared to Al-P and Fe-P. Table 5 showed that the mean values of occluded-P from three sources was higher in laterite soil (47.78, 48.51 and 49.18 ppm for RRP, MRP and SP respectively) than in kari soil (44.13, 44.17 and 44.30 ppm for RRP, MRP and SP respectively). The higher content of free iron oxide and alumina in laterite soil may be responsible for its higher content of occluded-P.

The concentration of occluded-P did not vary significantly with the variations in the forms of P added

Table 14. Mean values of occluded-P as influenced by sources of P, soils and levels of P application, ppm

Period of incubation, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
0	64.83	65.05	64.84	75.84	53.97	64.48	65.33	64.98
1	53.15	53.90	54.92	59.10	48.89	53.16	54.83	53.99
2	50.11	51.83	49.93	54.43	46.82	49.50	51.68	50.62
3	48.76	49.60	49.25	49.00	49.41	48.69	49.72	49.20
4	47.74	47.86	48.63	48.53	47.62	47.46	48.68	48.07
5	45.19	45.31	45.00	44.77	45.47	44.61	45.73	45.17
6	42.49	44.04	45.79	45.61	42.60	43.11	45.10	44.10
7	45.60	44.99	44.05	44.59	45.17	44.24	45.52	44.88
8	42.05	41.69	42.43	41.80	42.31	41.58	42.53	42.05
9	41.19	41.58	43.19	42.19	41.78	41.51	42.46	41.98
10	38.99	38.88	40.44	40.50	38.37	38.61	40.26	39.43
11	38.84	39.61	40.35	41.49	37.71	39.02	40.18	39.60
12	38.63	38.10	38.85	42.52	34.43	38.04	38.90	38.47
Mean	45.95	46.34	46.74	48.49	44.20	45.70	46.99	46.35

CD(0.05) for periods = 3.263

" " soils = 1.279

CD(0.05) for levels = 1.279

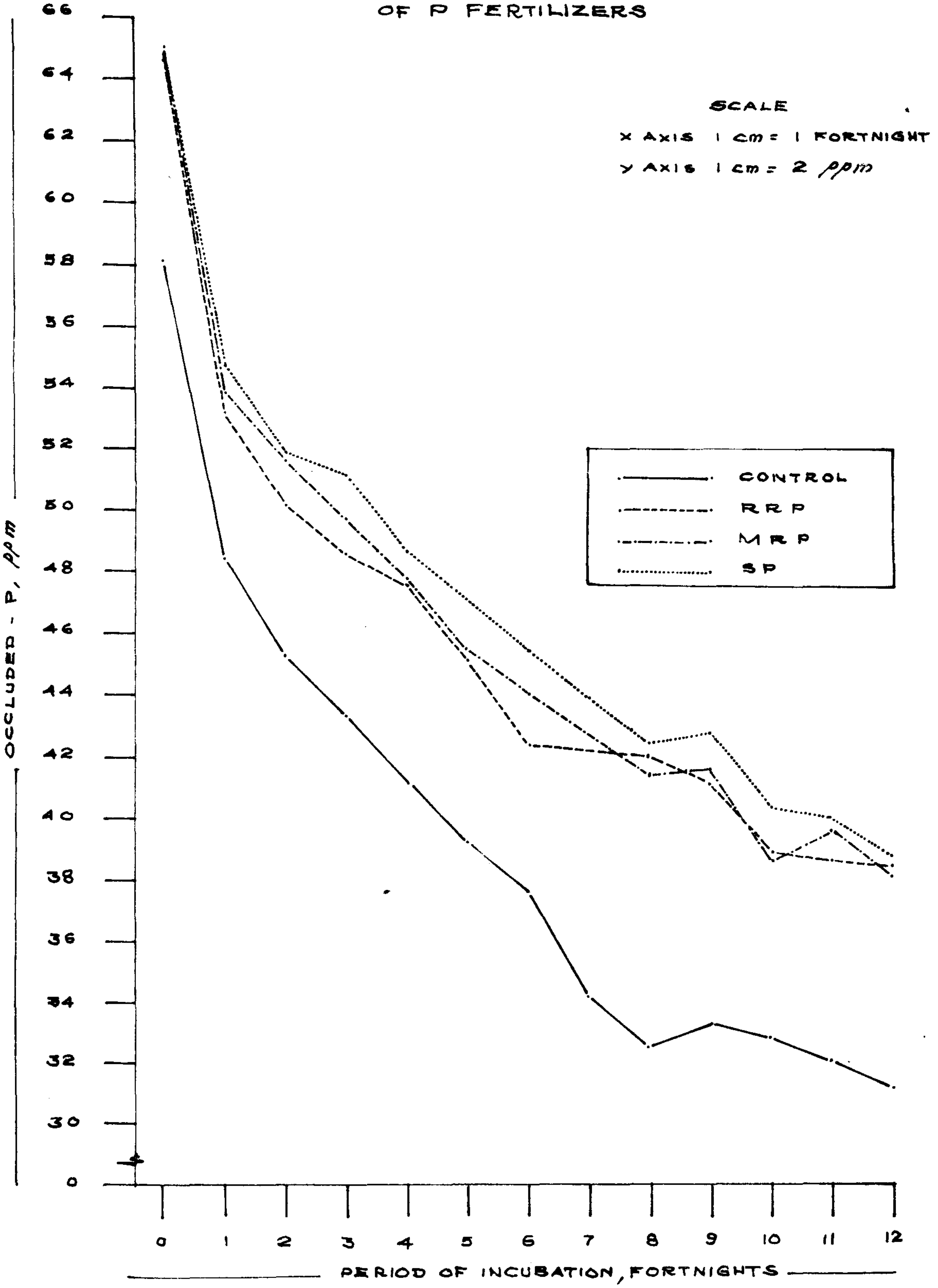
" " soil x period = 4.615

to the soil. The mean values of occluded-P from RRP, MRP and SP were 6.59, 6.98 and 7.38 ppm respectively over control (Table 14) i.e., in general, there was only 8.78 per cent more occluded-P from SP compared to the two rockphosphates. The effect of forms of P fertilizers on the concentration of occluded-P at different periods of incubation was graphically represented in Fig.5. The relatively higher values of occluded-P from SP were because of its high reactivity with soil components due to the higher water soluble P content. However, the increase in the level of occluded-P by the addition of SP did not exceed 1.5 ppm over the two rockphosphates. This indicated that the dissolution of rockphosphates might have started in these acid soils with the advancement of time.

Application of P at higher level increased the content of occluded-P to the extent of 1.29 ppm when the soils, sources and periods were pooled, and this increase was found to be statistically significant. Also, when the soils and sources of P were considered independently, again the occluded-P increased with increasing levels of P application, though the increase was not significant (Table 6).

The decrease in the content of occluded-P with the advancement of time was mainly due to its conversion to other forms. For all the three sources, irrespective

FIG: 5. OCCLUDED-P AT DIFFERENT PERIODS OF INCUBATION AS INFLUENCED BY FORMS OF P FERTILIZERS



of soils and levels of P application, the maximum content of occluded-P was observed during the first period and it was seen to decrease progressively and significantly upto the twelfth fortnight. The linear coefficient of correlation (r) between occluded-P and period of incubation was -0.709^{**}, -0.719^{**}, -0.693^{**} for RRP, MRP and SP respectively. As in the case of reductant soluble-P, the chances of conversion of other fractions to the occluded-P are less compared to the probability of its transformation to other fractions under submerged conditions. The rate of decrease was comparatively higher during the initial periods due to the rapid chemical and biochemical reactions occurring consequent to flooding. The concentration of occluded-P (Y) from different sources of P and in two soils at different periods of incubation (x) can be worked out from the following equations.

1. For sources of P

   a) RRP $Y = 1.765\ x\ -0.0154^{x}$ ($R^2 = 0.87$)

   b) MRP $Y = 1.774\ x\ -0.0163^{x}$ ($R^2 = 0.91$)

   c) SP $Y = 1.768\ x\ -0.0147^{x}$ ($R^2 = 0.87$)

2. For soils

   a) Laterite

   $\log Y = 1.894 - 0.0554x + 0.0027x^2$ ($R^2 = 0.95$)

   b) Kari

   $Y = 53.47 - 1.323x$ ($R^2 = 0.91$)

Occluded-P being an insoluble and stable form can not be extracted by Bray 1 and 2 extractants and this explains its negative correlation (Table 24) with available P (r = -0.269** and -0.386** for Bray 1 and 2 respectively).

1.3 Calcium phosphate

Influence of various treatments on the content of Ca-P at different periods of incubation is presented in Tables 5, 6, 15 and 16 and their analysis of variance in Appendix I.

In the absence of added P, the contribution of Ca-P to the total inorganic P pool was 6.93 per cent in laterite soil (44.95 ppm) and 8.35 per cent in kari soil (50.45 ppm) during the first period, which on incubation was reduced to 5.0 to 5.5 per cent in these soils (Table 15). The relatively low content of this fraction compared to other fractions is evidently due to the unstability of Ca-P in these acid soils.

By the addition of phosphatic fertilizers, there was a significant increase of 19.72 to 20.02 ppm in the content of Ca-P over control during the first period which on incubation changed to 9.5 ppm in laterite soil and 22.4 ppm in kari soil (Table 16). The increase in the Ca-P content of the soil on the addition of fertilisers is due to the fact that all the fertilizers added

Table 15. Ca-P as influenced by the treatments at different periods of incubation, ppm

Treatment		Period of incubation, fortnights												
No.	Notation	0	1	2	3	4	5	6	7	8	9	10	11	12
1	OL	44.95	41.65	44.85	45.65	45.80	43.60	48.55	48.45	46.45	45.25	42.75	43.05	41.00
2	RRP45L	62.55	61.55	62.20	66.75	65.40	60.95	55.25	53.90	53.05	52.25	51.30	49.10	48.15
3	RRP90L	64.10	63.80	66.00	69.15	71.10	61.70	57.95	57.85	57.00	54.30	53.00	53.20	50.60
4	MRP45L	64.10	61.60	61.30	66.00	64.55	60.90	55.40	54.90	54.35	53.25	52.10	51.55	48.40
5	MRP90L	65.60	63.40	66.00	69.00	70.30	61.70	57.65	56.05	55.75	54.20	52.90	52.20	51.95
6	SP45L	65.80	63.05	64.05	69.85	63.85	61.75	55.60	55.45	53.65	52.60	51.90	50.80	50.45
7	SP90L	65.85	65.30	66.55	72.00	69.65	57.95	56.80	56.15	56.75	54.55	53.10	52.65	50.50
8	OK	50.45	49.45	46.85	46.40	55.25	55.55	55.95	54.90	51.00	49.45	46.20	46.00	40.55
9	RRP45K	67.10	63.50	61.35	64.80	75.80	75.55	71.75	73.40	67.65	68.20	63.55	58.75	56.75
10	RRP90K	71.95	66.45	65.80	68.50	82.50	76.60	78.20	79.10	74.15	73.20	68.85	64.35	61.65
11	MRP45K	67.05	63.00	63.20	67.55	74.20	74.30	73.60	74.70	73.10	67.55	61.40	61.45	57.50
12	MRP90K	73.50	65.00	65.15	67.30	81.60	77.45	79.20	79.80	74.35	73.10	66.80	58.85	62.25
13	SP45K	68.95	64.05	66.35	67.55	75.75	71.60	75.65	76.60	68.20	68.70	64.95	64.85	59.45
14	SP90K	74.25	67.30	68.15	69.80	82.35	81.65	80.60	81.30	75.25	73.60	68.60	66.20	62.95
15	SP(45+45)L	65.80	63.05	64.05	69.85	63.85	61.75	55.60	61.40	61.40	57.50	55.60	54.70	52.70
16	SP(45+45)K	68.95	64.05	66.35	67.55	75.75	71.60	75.65	81.60	75.40	72.85	67.50	66.95	62.50

contained P as Ca-P. On incubation, Ca-P gets gradually solubilized and the larger content of free Fe and Al and relatively less amount of Ca in the laterite soil may be responsible for the increased rate of conversion of Ca-P into other forms as compared to kari soil. However, in kari soil due to the higher proportion Ca due to the marine influence, the content of Ca-P was comparatively high (Table 5). This observation was in line with that of Nair (1978).

The mean values of Ca-P formed from RRP, MRP and SP were 16.72, 16.85 and 17.86 ppm respectively over control when the soils, periods and levels were pooled (Table 16). The effect of forms of P fertilizers on the content of Ca-P at different periods of incubation is presented in Fig.6. The nonsignificant difference between sources of P indicated that the degree of water solubility in the added materials was not a critical factor in deciding the concentration of Ca-P in the soil. It also indicated that the stable tricalcium phosphate in the two rockphosphates might have started its dissolution and the released reactive phosphate ions which in turn react with the Fe and Al components in the soil.

It was seen that when the soils, sources and periods were pooled the increasing levels of application of P from 45 to 90 kg P_2O_5/ha increased the mean Ca-P content

FIG: 6. Ca-P AT DIFFERENT PERIODS OF INCUBATION AS INFLUENCED BY FORMS OF P FERTILIZERS

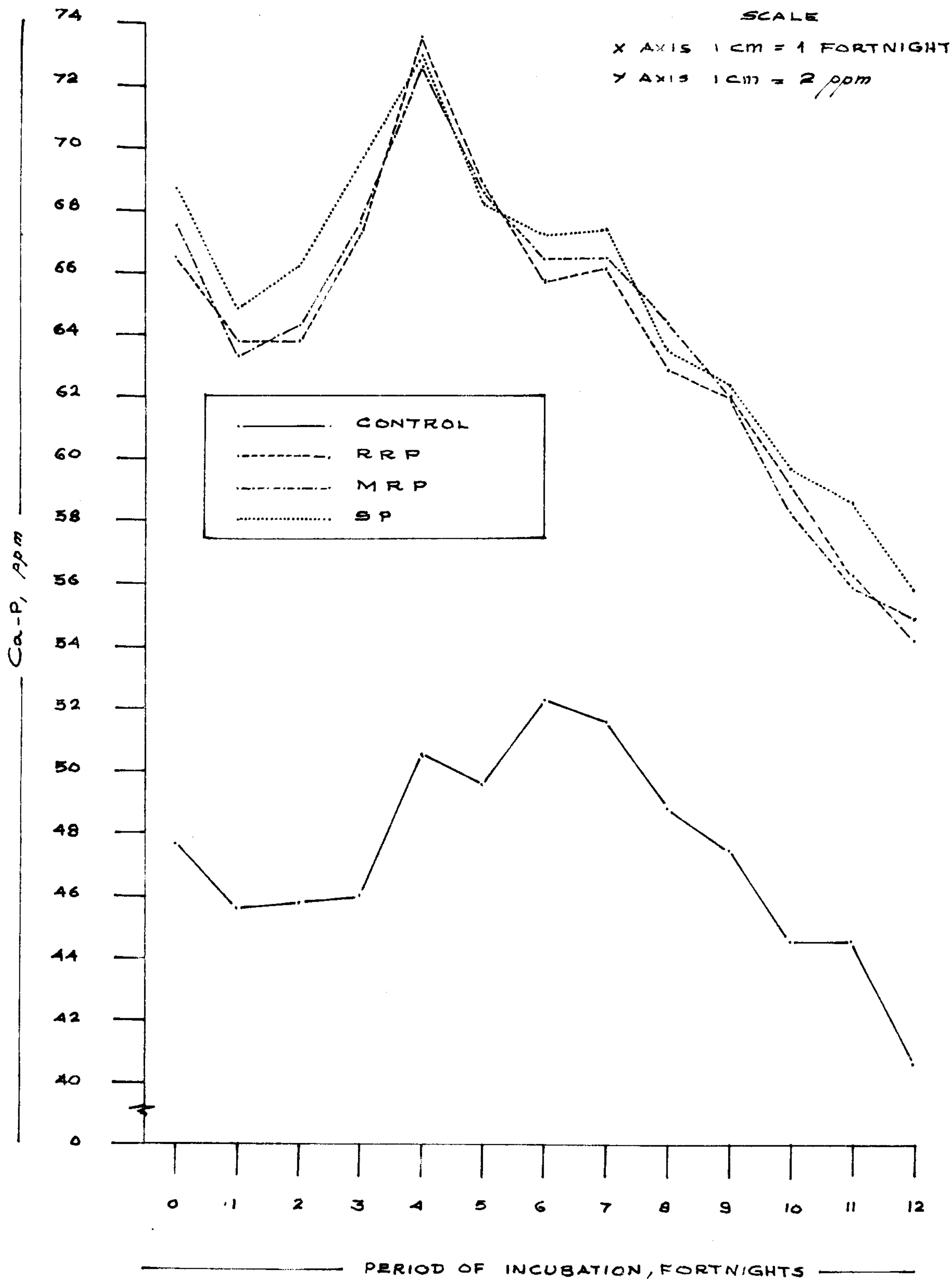


Table 16. Mean values of Ca-P as influenced by sources of P, soils and levels of P application, ppm

Period of incubation, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
0	66.43	67.56	68.71	64.67	70.47	65.93	69.21	67.57
1	63.81	63.25	64.93	63.12	64.88	62.78	65.21	63.99
2	63.83	64.18	66.23	64.35	65.17	63.08	66.43	64.76
3	67.33	67.46	69.80	68.80	67.59	67.09	69.30	68.19
4	73.70	72.60	72.89	67.43	78.69	69.88	76.25	73.06
5	68.70	68.60	68.24	60.83	76.18	67.51	69.50	68.50
6	65.79	66.45	67.19	56.46	76.49	64.55	68.40	66.45
7	66.09	66.36	67.38	55.76	77.48	64.83	68.38	66.60
8	62.96	64.40	63.46	55.09	72.13	61.67	65.55	63.61
9	62.00	62.03	62.34	53.53	70.71	60.41	63.83	62.12
10	59.18	58.29	59.64	52.38	65.68	57.53	60.53	59.03
11	56.31	56.01	58.63	51.56	62.40	56.08	57.88	56.98
12	54.33	55.03	55.84	50.01	60.12	53.48	56.65	55.06
Mean	63.88	64.01	65.02	58.76	69.85	62.68	65.93	64.30

CD(0.05) for periods = 2.930
" " soils = 1.150

CD(0.05) for levels = 1.150
" " soil x period = 4.147

from 62.68 ppm to 65.93 ppm which was found to be statistically significant. When the soils and sources of P were taken separately again the Ca-P increased with increasing levels of application (Table 6).

In general, the three sources of P showed a gradual decrease with increasing periods of incubation though a slight increase was observed during the second, third and fourth fortnights (Table 16). Irrespective of soils, sources and levels of application, the minimum Ca-P was observed during the twelfth fortnight. The following equations were used for the prediction of the concentration of Ca-P (Y) from different sources and in two soils at different periods of incubation (x).

1. For sources of P

a) RRP

$$Y = 61.16 + 3.128x - 0.373x^2 + 0.0068x^3$$

$(R^2 = 0.82)$

b) MRP

$$Y = 62.35 + 2.463x - 0.269x^2 + 0.00679x^3$$

$(R^2 = 0.83)$

c) SP

$$Y = 63.92 + 2.626x - 0.354x^2 + 0.00789x^3$$

$(R^2 = 0.86)$

2. For soils

a) Laterite

$$\log Y = 1.816 + 0.00449x + 0.00199x^2 - 2.042x^3$$

$(R^2 = 0.73)$

b) Kari

$$Y = 60.11 + 4.352x - 0.916x^2 - 0.0407x^3$$
$$(R^2 = 0.89)$$

The rate of decrease in the content of this fraction both in the presence and absence of added P was more pronounced in kari soil due to its high acidity. The general decrease observed in the concentration of Ca-P on incubation is due to its conversion to other forms like Fe-P and Al-P. The content of Ca-P and period of incubation were negatively correlated ($r = -0.233^{*}$).

The relatively low degree of correlation between Ca-P and available P ($r = 0.243^{*}$, 0.291^{**} for Bray 1 and 2 respectively) may be due to the fact that a part of the Ca-P that can be solubilized in the acid soil would have already been converted to Fe-P and Al-P and the remaining Ca-P of the soil may be quite stable to the action of the chemical extractants employed in the estimation of available P. A slightly higher rate of correlation between Ca-P and Bray No.2 extractable P is obviously due to the higher concentration of acid employed in this extractant.

Total inorganic phosphorus

Before incubation, the total inorganic P content of the soil was 648.96 ppm in laterite soil and 604.09 ppm in kari soil, which accounted to 73.15 per cent and

76.14 per cent of the total P. On incubation, it was increased to 88.29 per cent in laterite soil and 96.02 per cent in kari soil. Thus the average rate of increase in the content of native inorganic P with the lapse of time was 23.31 per cent. This increase in the total inorganic P was due to the conversion of organic P into inorganic form and it was observed that the rate of mineralization of organic P was relatively higher in kari soil (83.34%) compared to laterite soil (56.88%).

In general, by the addition of phosphatic fertilisers, there was an increase of 58.79 ppm of inorganic P over control during the first period. When the contribution from added P was deducted, the increase in the inorganic P in the presence of added P accounted to 3.99 per cent of the total native inorganic P. On incubation, this was increased upto 10 per cent of the native inorganic P. This phenomenon indicated that in the presence of added P, the rate of mineralisation of organic P was increased due to the enhanced microbial activity occurring in the presence of added P and this enhanced microbial activity was more pronounced during the initial periods of incubation.

2. Available phosphorus

Effects of various sources and levels of applied P on the available P (Bray 1 and 2) content of the soil at

Table 17. Available P (Bray 1) as influenced by the treatments at different periods of incubation, ppm

Treatment		Period of incubation, fortnights												
No.	Notation	0	1	2	3	4	5	6	7	8	9	10	11	12
1	OL	4.79	5.38	8.74	9.26	14.43	14.18	14.21	11.51	9.84	9.58	9.49	9.69	9.51
2	RRP45L	6.72	8.11	9.11	12.21	15.35	14.13	14.58	14.39	13.99	14.13	13.73	13.57	13.48
3	RRP90L	7.05	7.17	9.46	12.24	15.69	14.45	14.79	14.81	14.44	14.39	13.78	13.71	13.31
4	MRP45L	6.99	8.23	9.29	12.36	15.34	14.23	14.59	14.63	14.23	13.98	13.56	13.52	13.49
5	MRP90L	7.07	8.31	9.31	12.55	15.50	15.01	14.68	14.78	14.45	14.04	13.64	13.80	13.49
6	SP45L	7.61	8.47	9.63	12.49	15.63	13.99	14.65	14.35	14.29	14.20	13.69	14.28	13.61
7	SP90L	7.99	8.53	9.71	12.65	15.68	14.06	14.76	14.56	14.36	14.16	14.13	13.89	13.55
8	OK	3.84	5.27	8.04	10.19	11.43	11.41	11.39	11.31	11.14	10.89	10.79	10.67	10.45
9	RRP45K	7.75	10.14	10.75	15.86	17.49	18.78	18.96	18.86	18.69	18.46	18.26	18.22	17.76
10	RRP90K	8.13	10.22	11.25	15.79	17.77	19.49	19.15	18.75	19.17	17.99	18.33	18.17	18.13
11	MRP45K	7.59	10.08	11.06	15.84	17.63	18.79	19.09	18.71	18.11	18.64	18.27	18.22	18.01
12	MRP90K	8.10	10.16	12.60	15.91	17.75	18.97	19.62	18.99	18.65	18.79	18.31	18.29	18.39
13	SP45K	8.54	10.24	12.48	15.86	17.51	19.02	18.94	18.66	18.44	18.28	18.09	17.93	17.82
14	SP90K	8.89	10.39	12.72	16.27	17.37	19.59	19.03	18.66	18.46	18.35	18.16	17.75	17.81
15	SP(45+45)L	7.61	8.47	9.63	12.49	15.63	13.99	14.65	14.80	14.90	15.30	14.60	14.00	13.60
16	SP(45+45)K	8.54	10.24	12.48	15.86	17.51	19.02	18.94	20.05	20.20	20.55	20.30	18.20	18.00

different periods of incubation in laterite and kari soils are given in Tables 5, 6 and 17 to 20 and their analysis of variance in Appendix I.

The original content of Bray No.1 extractable P is 4.79 ppm in laterite soil and 3.84 ppm in kari soil and this low content of available P in these soils make them to be rated under the class 'low' as per the soil fertility rating norms followed by the soil testing laboratories of the state (Table 17). The low content of available P was mainly attributed to their high P fixing capacity.

Even in the absence of added P, the content of available P (Bray 1 and 2) in the soil increased on incubation and this increase was more pronounced in laterite soil (Table 17 and 19). In laterite soil, the increase in available P on incubation was 9.64 and 20.13 ppm for Bray 1 and 2 respectively, while it was 7.59 and 19.61 ppm respectively for Bray 1 and 2 in kari soil (Table 18 and 20). The increase in the content of available P on incubation may be due to the increased content of saloid-P and enhanced solubility of Fe-P and Al-P brought about by the reduction reactions occurring as a result of flooding.
In addition to this process, mineralization of organic P

Table 18. Mean values of available P (Bray 1) as influenced by sources of P, soils and levels of P application, ppm

Period of incubation, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
0	7.40	7.43	8.25	7.23	8.15	7.53	7.85	7.69
1	9.16	9.19	9.45	8.30	10.22	9.22	9.30	9.26
2	10.89	10.94	11.15	9.45	12.53	10.91	11.08	10.99
3	14.05	14.18	14.35	12.65	15.93	14.12	14.27	14.19
4	16.60	16.54	16.56	15.54	17.59	16.49	16.64	16.57
5	16.70	16.75	16.69	14.33	19.10	16.50	16.93	16.72
6	16.89	16.98	16.86	14.83	19.13	16.82	17.00	16.91
7	16.71	16.78	16.58	14.60	18.78	16.61	16.77	16.69
8	16.56	16.33	16.38	14.28	18.56	16.28	16.57	16.42
9	16.25	16.36	16.23	14.13	18.43	16.26	16.30	16.28
10	16.03	15.89	16.00	13.73	18.21	15.90	16.04	15.97
11	15.94	16.03	15.96	13.83	18.12	16.00	15.95	15.98
12	15.65	15.76	15.65	13.48	17.90	15.63	15.74	15.69
Mean	14.53	14.55	14.62	12.77	16.36	14.48	14.65	14.57

CD(0.05) for periods = 0.829

" " soils = 0.325

" " soil x period = 1.172

would also have contributed to the pool of available P. The relatively higher content of available P in laterite soil was attributed to its higher content of total P and enhanced rate of reduction reactions occurring in the soil due to its highly oxidized nature compared to kari soil.

By the addition of phosphatic fertilizers, there was a significant increase of 2.45 and 4.81 ppm of Bray No.1 and 2 available P in laterite soil and 4.33 and 8.99 ppm available P (Bray 1 and 2) in kari soil over the control (no P) during the first period, which changed to 3.98 ppm (Bray 1) and 8.08 ppm (Bray 2) in laterite soil and 7.54 ppm (Bray 1) and 7.69 ppm (Bray 2) in kari soil with the advancement of period of incubation (Table 18 and 20). This indicated that though the transformation of added P to different inorganic fractions has taken place its contribution to the available phosphate pool is considerably low.

In general, the peak content of available P (Bray 1 and Bray 2) was observed during the sixth and seventh periods of incubation and after attaining the maximum value it tended to decrease upto the twelfth fortnight. But the values at the twelfth period were also higher than the initial concentration. The linear coefficient

Table 19. Available P (Bray 2) as influenced by the treatments at different periods of incubation, ppm

Treatment		Period of incubation, fortnights												
No.	Notation	0	1	2	3	4	5	6	7	8	9	10	11	12
1	OL	15.04	16.34	24.37	27.81	35.17	29.37	30.51	35.04	29.70	29.35	29.01	28.35	28.41
2	RRP45L	19.14	20.87	26.85	32.94	37.61	36.05	37.36	37.45	36.85	37.05	37.05	36.61	36.32
3	RRP90L	19.59	21.01	27.64	32.90	38.37	36.57	37.78	38.52	37.00	37.00	36.65	37.41	36.39
4	MRP45L	19.13	20.59	27.16	33.03	37.61	36.23	37.38	37.92	36.95	37.35	37.10	36.89	36.31
5	MRP90L	19.49	21.38	27.21	33.02	37.89	36.11	37.97	39.35	37.60	36.50	36.25	37.08	36.65
6	SP45L	20.46	21.67	27.32	33.13	38.27	35.68	37.54	37.80	37.05	36.95	37.30	36.93	36.63
7	SP90L	21.26	22.49	27.49	33.52	38.28	35.87	37.38	38.73	37.15	36.75	37.20	37.09	36.61
8	OK	12.64	14.43	20.60	23.84	32.25	30.42	32.01	31.68	30.85	31.30	30.60	30.35	30.33
9	RRP45K	21.06	24.94	29.28	35.68	40.76	38.58	39.99	39.80	38.95	38.95	38.10	38.85	37.56
10	RRP90K	21.26	25.39	29.99	35.52	41.99	39.05	40.19	39.55	39.20	39.05	38.70	38.00	37.97
11	MRP45K	20.69	24.74	29.74	35.66	40.34	38.59	40.27	39.83	39.30	39.75	38.60	38.60	38.20
12	MRP90K	21.21	25.25	30.07	35.44	41.32	38.99	40.53	40.46	39.35	39.20	38.20	38.60	38.46
13	SP45K	22.42	25.09	29.79	35.15	40.77	30.11	39.95	39.36	38.90	38.10	38.20	38.00	37.66
14	SP90K	23.16	25.47	30.36	35.09	41.19	39.24	40.13	49.36	38.55	38.70	37.95	38.10	38.26
15	SP(45+45)L	20.46	21.67	27.32	33.13	38.27	35.68	37.54	38.18	38.45	39.70	37.80	37.61	36.77
16	SP(45+45)K	22.42	25.09	29.79	35.15	40.77	39.11	39.95	40.73	41.45	42.45	41.35	38.30	38.29

Table 20. Mean values of available P (Bray 2) as influenced by sources of P, soils and levels of P application, ppm

Period of incubation, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
0	20.26	20.14	21.84	19.86	21.63	20.50	20.99	20.75
1	23.06	22.96	23.68	21.33	25.12	22.98	23.48	23.23
2	28.45	28.55	28.73	27.27	24.88	28.36	28.79	28.58
3	34.28	34.29	34.34	33.10	35.50	34.26	34.34	34.30
4	39.70	39.30	39.65	38.03	41.08	39.24	39.86	39.55
5	37.53	37.45	37.45	36.05	38.90	37.33	37.62	37.48
6	38.83	39.06	38.73	37.57	40.18	38.75	38.99	38.87
7	38.84	39.40	38.83	38.31	39.73	38.70	39.34	39.02
8	38.00	38.29	37.94	37.12	39.03	38.01	38.14	38.08
9	38.01	38.20	37.61	36.92	38.96	38.02	37.85	37.94
10	37.63	37.54	37.64	36.93	38.28	37.70	37.50	37.60
11	37.71	37.72	37.53	36.98	38.32	37.59	37.71	37.65
12	37.06	37.34	37.08	36.42	37.90	37.08	37.23	37.16
Mean	34.57	34.63	34.69	33.53	35.73	34.51	34.74	34.63

CD(0.05) for periods = 1.896

" " soils = 0.744

of correlation (r) between available-P and period of incubation was 0.474** for Bray 1 and 0.609** for Bray 2 (Table 24). Prediction equations were worked out to establish available P (Bray 1 and 2) at different periods of incubation (x) from RRP, MRP and SP separately and also for the two soils. In all the cases the response was found to be quadratic. The equations were

<u>Bray 1 P</u> (Y_1)

1. For soils

   a) Laterite

   $$Y_1 = 4.823 + 2.355x - 0.135x^2 \quad (R^2 = 0.88)$$

   b) Kari

   $$Y_1 = 5.29 + 3.142x - 0.173x^2 \quad (R^2 = 0.95)$$

2. For fertilizers

   a) RRP

   $$Y_1 = 4.74 + 2.82x - 0.158x^2 \quad (R^2 = 0.94)$$

   b) MRP

   $$Y_1 = 4.83 + 2.799x - 0.156x^2 \quad (R^2 = 0.94)$$

   c) SP

   $$Y_1 = 5.627 + 2.594x - 0.145x^2 \quad (R^2 = 0.93)$$

<u>Bray 2 P</u> (Y_2)

1. For soils

   a) Laterite

   $$Y_2 = 14.51 + 5.353x - 0.292x^2 \quad (R^2 = 0.92)$$

Table 21. Interrelationships of inorganic P fractions and available P during incubation after the addition of RRP

(Correlation coefficients)

	Saloid-P	Period	Fe-P	Al-P	Reductant soluble-P	Occluded-P	Ca-P	Bray 1 P	Bray 2 P
Saloid-P	—	0.550**	0.796**	0.754**	-0.327**	-0.363**	0.229*	0.914**	0.901**
Period		—	0.675**	0.805**	-0.689**	-0.709**	-0.236*	0.479**	0.619**
Fe-P			—	0.899**	-0.398**	-0.459**	0.234*	0.769**	0.864**
Al-P				—	-0.467**	-0.471**	0.169	0.685**	0.825**
Reductant soluble-P					—	0.757**	0.576**	-0.302**	-0.366**
Occluded-P						—	0.417**	-0.281**	-0.408**
Ca-P							—	0.244*	0.284**
Bray 1 P								—	0.895**
Bray 2 P									—

* Significant at 5 per cent level

** Significant at 1 per cent level

b) Kari

$$Y_2 = 17.14 + 5.416x - 0.367x^2 \quad (R^2 = 0.91)$$

2. For fertilizers

a) RRP

$$Y_2 = 15.38 + 5.496x - 0.306x^2 \quad (R^2 = 0.92)$$

b) MRP

$$Y_2 = 15.16 + 5.569x - 0.309x^2 \quad (R^2 = 0.93)$$

c) SP

$$Y_2 = 16.92 + 5.088x - 0.283x^2 \quad (R^2 = 0.91)$$

Observations revealed that the concentration of available P in the soil was not significantly affected by the variations in the forms of applied P (Fig.7). The contents of available P (Bray 1) retained in the laterite soil over control when RRP, MRP and SP were added, were 4.58, 4.60 and 4.67 ppm respectively when the effects of levels and periods of incubation were pooled (Table 5). In kari soil, the contribution from RRP, MRP and SP to the available phosphate pool was 4.84, 4.86 and 4.93 ppm respectively over control (Table 5). These values indicates that whether the phosphatic fertilizer is applied as superphosphate or rockphosphate, its contribution to available phosphate pool remains to be the same.

When the level of P application was at the rate of 45 kg P_2O_5/ha, only 4.68 ppm P was recovered as

FIG: 7. AVAILABLE P (BRAY 1) AT DIFFERENT PERIODS OF INCUBATION AS INFLUENCED BY FORMS OF P FERTILIZERS

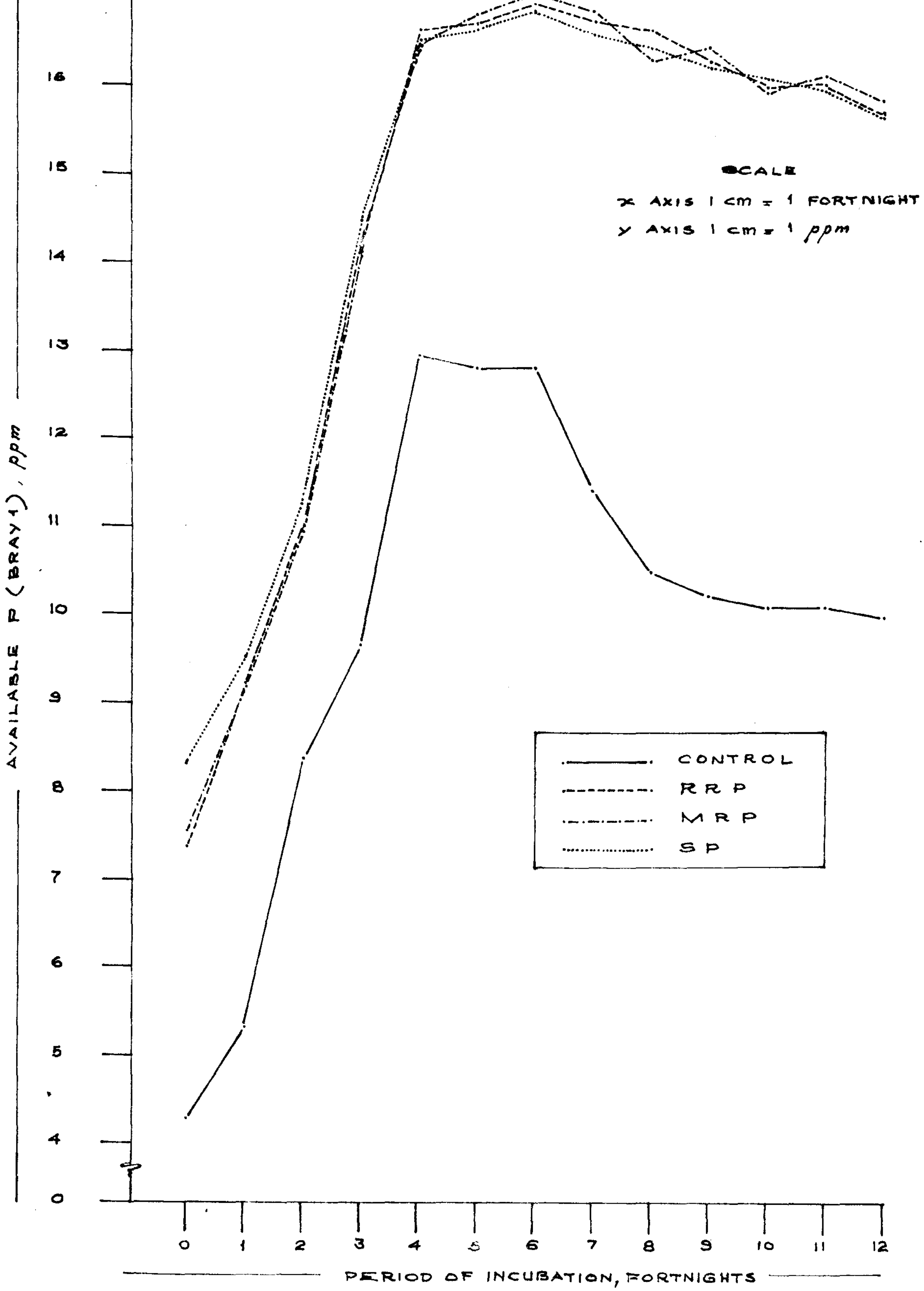


Table 22. Interrelationships of inorganic P fractions and available P during incubation after the addition of MRP

(Correlation coefficients)

	Saloid-P	Period	Fe-P	Al-P	Reductant soluble-P	Occluded-P	Ca-P	Bray 1 P	Bray 2 P
Saloid-P	—	0.577**	0.807**	0.766**	-0.323**	-0.387**	0.214*	0.902**	0.909**
Period		—	0.683**	0.799**	-0.670**	-0.719**	-0.235*	0.478**	0.612**
Fe-P			—	0.909**	-0.401**	-0.484**	0.218*	0.766**	0.865**
Al-P				—	-0.439**	-0.476**	0.172	0.682**	0.819**
Reductant soluble-P					—	0.766**	0.582**	-0.284**	-0.322**
Occluded-P						—	0.435**	-0.282**	-0.401**
Ca-P							—	0.235*	0.282**
Bray 1 P								—	0.905**
Bray 2 P									—

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 23. Interrelationships of inorganic P fractions and available P during incubation after the addition of SP

(Correlation coefficients)

	Saloid-P	Period	Fe-P	Al-P	Reductant soluble-P	Occluded-P	Ca-P	Bray 1 P	Bray 2 P
Saloid-P	—	0.408**	0.726**	0.686**	-0.107	-0.211*	0.389**	0.856**	0.844**
Period		—	0.652**	0.765**	-0.628**	-0.693**	-0.230*	0.464**	0.596**
Fe-P			—	0.902**	-0.305**	-0.426**	0.265**	0.751**	0.851**
Al-P				—	-0.322**	-0.411**	0.236*	0.685**	0.819**
Reductant soluble-P					—	0.765**	0.589**	-0.233*	-0.246*
Occluded-P						—	0.451*	-0.240*	-0.348**
Ca-P							—	0.251*	0.307**
Bray 1 P								—	0.898**
Bray 2 P									—

* Significant at 5 per cent level

** Significant at 1 per cent level

available P (Bray 1) and when the rate of application was increased from 45 kg to 90 kg P_2O_5/ha, the additional increase in the available P recovered was practically nil (0.17 ppm) (Table 18). In general, the increase in the level of application of P increased the available P (Bray 1) content from 12.27 to 12.69 ppm in laterite soil and from 12.85 to 16.44 ppm in kari soil (Table 6). This shows that in the acid soils under study under submerged condition, only a constant level of P out of the P added can be retained in available form and further increase in the rate of application results in the retention of P in the unavailable pool in the soil.

Interrelationships between various inorganic fractions of phosphorus and their contribution to available phosphorus

The direct and indirect effects of various inorganic fractions of P on available P (Bray 1 and 2) from RRP, MRP and SP were brought out by the path analysis. Path analysis showed that saloid-P, Fe-P, Al-P and Ca-P were correlated with the amount of phosphate extracted by Bray 1 and 2 extractants under waterlogged conditions (Tables 25 to 28).

Table 24. Interrelationships of inorganic P fractions and available P during incubation after the addition of different P fertilizers

(Correlation coefficients)

	Saloid-P	Period	Fe-P	Al-P	Reductant soluble-P	Occluded-P	Ca-P	Bray 1 P	Bray 2 P
Saloid-P	—	0.509**	0.772**	0.731**	-0.249*	-0.319**	0.278**	0.887**	0.881**
Period		—	0.669**	0.789**	-0.661**	-0.707**	-0.233*	0.474**	0.609**
Fe-P			—	0.902**	-0.366**	-0.455**	0.239*	0.761**	0.859**
Al-P				—	-0.407**	-0.452**	0.193	0.683**	0.820**
Reductant soluble-P					—	0.761**	0.582**	-0.273**	-0.310**
Occluded-P						—	0.434**	-0.269**	-0.386**
Ca-P							—	0.243*	0.291**
Bray 1 P								—	0.899**
Bray 2 P									—

* Significant at 5 per cent level

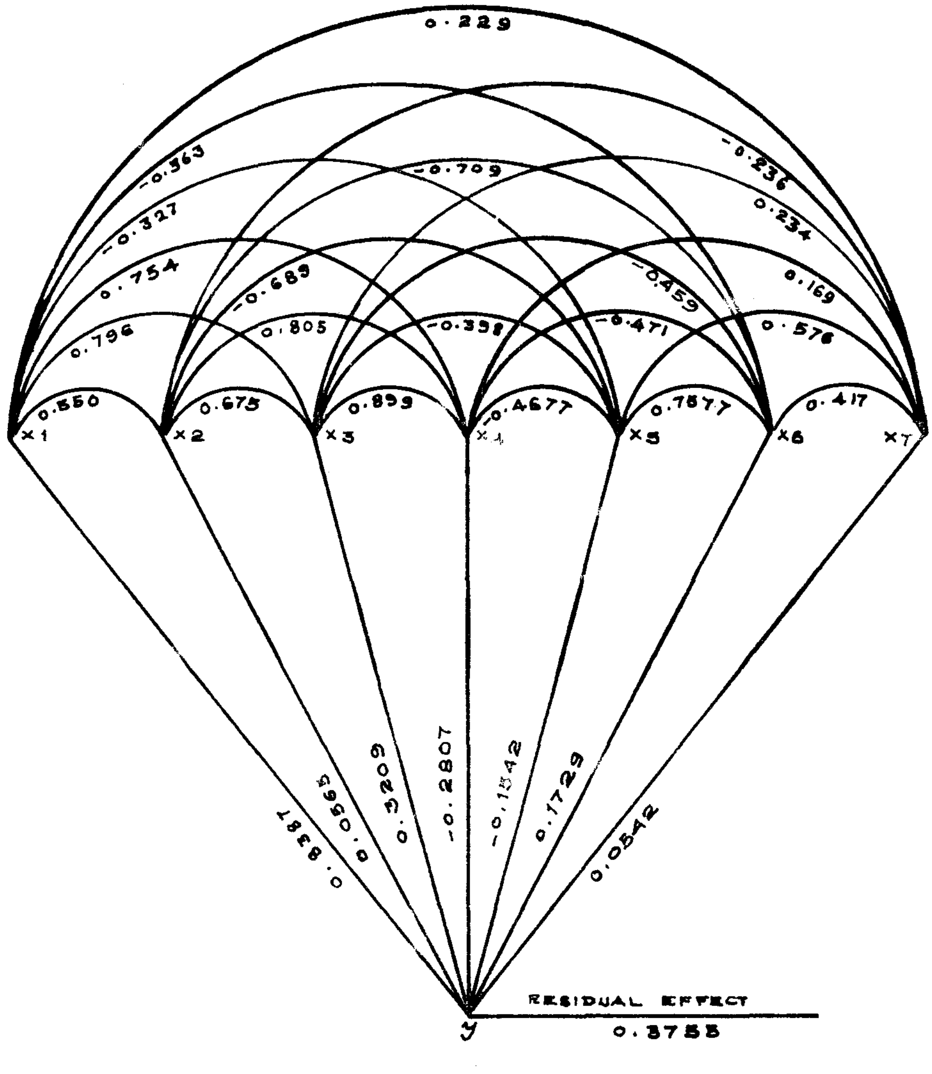
** Significant at 1 per cent level

The maximum correlation values for available P (Bray 1 and 2) were obtained with saloid-P in all the three sources irrespective of their water solubility. The path coefficient analysis (Table 28) revealed that the saloid-P had maximum positive direct effect on available P (0.757 and 0.513 for Bray 1 and Bray 2 respectively). The direct effect of saloid-P on Bray 1 P was 0.839, 0.834, 0.704 for RRP, MRP and SP respectively (Tables 25 to 27). Apart from the highly significant positive direct effect, saloid-P increases the available P by its indirect positive effect through Fe-P, Al-P and Ca-P. These were further confirmed by the higher positive values of linear coefficient of correlation of saloid-P with Fe-P (0.796**, 0.807** and 0.728** for RRP, MRP and SP respectively) and Al-P (0.754**, 0.765** and 0.686** for RRP, MRP and SP respectively). The negative correlation of saloid-P with reductant soluble and occluded-P indicates that the increase in saloid-P is also due to a decrease in reductant soluble and occluded forms of P as a result of reduction consequent to incubation. The highly significant total correlation of saloid-P with available P emphasises its role in determining the available P (Bray 1 and 2). Saloid-P

Table 25. Path coefficient analysis showing direct and indirect effect of inorganic P fraction and period of incubation on available P from RRP

	Saloid-P	Period of incubation	Fe-P	Al-P	Reductant soluble-P	Occluded-P	Ca-P	Total correlation coefficients	Residual effect
					Bray 1				
Saloid-P	0.839	0.031	0.255	0.051	-0.212	-0.063	0.012	0.914	
Period of incubation	0.462	0.056	0.217	0.106	-0.226	-0.123	-0.013	0.479	
Fe-P	0.667	0.038	0.321	-0.252	0.061	-0.079	0.013	0.769	0.376
Al-P	0.633	0.045	0.288	-0.281	0.072	-0.081	0.009	0.685	
Reductant soluble-P	-0.275	-0.039	-0.128	0.131	-0.154	0.131	0.031	-0.302	
Occluded-P	-0.305	-0.039	-0.147	0.132	-0.117	0.173	0.023	-0.281	
Ca-P	0.193	-0.013	0.075	-0.048	-0.089	0.071	0.054	0.244	
					Bray 2				
Saloid-P	0.552	0.041	0.196	0.029	0.036	0.006	0.004	0.901	
Period of incubation	0.304	0.074	0.167	0.031	0.076	0.012	-0.043	0.619	
Fe-P	0.439	0.049	0.247	0.034	0.044	0.008	0.042	0.864	0.338
Al-P	0.417	0.059	0.222	0.038	0.051	0.008	0.031	0.825	
Reductant soluble-P	-0.181	-0.051	-0.098	-0.018	-0.109	-0.013	0.104	-0.366	
Occluded-P	-0.201	-0.052	-0.113	-0.018	-0.083	-0.016	0.075	-0.408	
Ca-P	0.127	-0.017	0.058	0.006	-0.063	-0.007	0.180	0.284	

FIG: 8 PATH DIAGRAM - DIRECT AND INDIRECT EFFECTS OF INORGANIC P FRACTIONS ON AVAILABLE P (BRAY 1) FROM RRP



y = AVAILABLE P	x_4 = Al - P
x_1 = SALOID - P	x_5 = REDUCTANT SOLUBLE P
x_2 = PERIODS OF INCUBATION	x_6 = OCCLUDED P
x_3 = Fe - P	x_7 = Ca - P

as a whole was extracted during the estimation of available P, while only a fraction of other inorganic forms was extracted during estimation. This explains the higher correlation values obtained between saloid-P and available P, though its concentration in the soil was relatively low as compared to the concentration of other fractions.

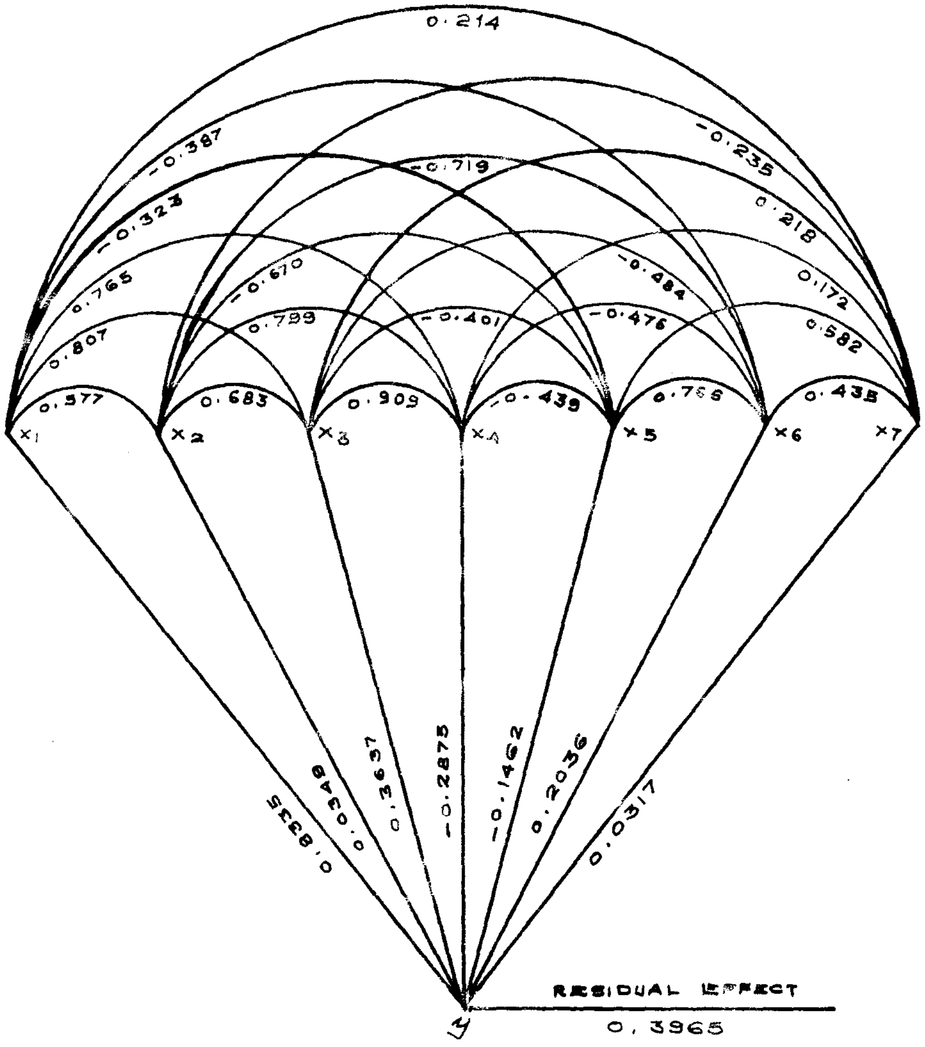
The contribution of Fe-P in deciding the available P (Bray 1 and 2) was mainly due to its indirect positive effect through saloid-P (0.667, 0.673, 0.511 for Bray 1 P from RRP, MRP and SP respectively). The direct effect of Fe-P on available P was also high (0.380, 0.310 for Bray 1 and Bray 2 respectively). The indirect effect of Fe-P through reductant soluble P and occluded-P were negative (Tables 25 to 28). The relatively higher correlation between Fe-P and Al-P (0.902**) may be due to their interconversion.

The direct effect of Ca-P in increasing the available P (Bray 1) was relatively low compared to saloid-P, Fe-P and Al-P. Also irrespective of the forms of added P, the total contribution of Ca-P to available P (Bray 1 and 2) was less as revealed by the correlation coefficients. It was seen that the direct effect of Ca-P was high for Bray 2 P (0.126)

Table 26. Path coefficient analysis showing direct and indirect effect of inorganic P fraction and period of incubation on available P from MRP

	Saloid-P	Period of incubation	Fe-P	Al-P	Reductant soluble-P	Occluded-P	Ca-P	Total correlation coefficients	Residual effect
					Bray 1				
Saloid-P	0.834	0.020	0.293	0.047	-0.220	-0.079	0.007	0.902	
Period of incubation	0.481	0.035	0.248	0.098	-0.229	-0.147	-0.007	0.478	
Fe-P	0.673	0.024	0.364	-0.261	0.059	-0.099	0.007	0.766	
Al-P	0.638	0.028	0.331	-0.288	0.064	-0.097	0.005	0.682	0.397
Reductant soluble-P	-0.269	-0.023	-0.146	0.126	-0.146	0.156	0.019	-0.284	
Occluded-P	-0.323	-0.025	-0.176	0.137	-0.112	0.204	0.014	-0.282	
Ca-P	0.179	-0.008	0.079	-0.049	-0.085	0.089	0.032	0.235	
					Bray 2				
Saloid-P	0.586	0.042	0.234	0.003	0.012	0.003	0.029	0.909	
Period of incubation	0.338	0.074	0.198	0.004	0.025	0.006	-0.032	0.612	
Fe-P	0.472	0.050	0.289	0.004	0.015	0.004	0.029	0.865	
Al-P	0.448	0.059	0.262	0.004	0.017	0.004	0.023	0.819	0.338
Reductant soluble-P	-0.189	-0.049	-0.116	-0.002	-0.038	0.007	0.079	-0.322	
Occluded-P	-0.227	-0.053	-0.140	-0.002	-0.021	-0.009	0.591	-0.401	
Ca-P	0.126	-0.017	0.063	0.008	-0.022	-0.004	0.136	0.282	

FIG: 9. PATH DIAGRAM - DIRECT AND INDIRECT EFFECTS OF INORGANIC P FRACTIONS ON AVAILABLE P (BRAY 1) FROM MRP



y = AVAILABLE P	x_4 = Al_P
x_1 = SALOID_P	x_5 = REDUCTANT SOLUBLE P
x_2 = PERIODS OF INCUBATION	x_6 = OCCLUDED P
x_3 = Fe.P	x_7 = Ca_P

compared to Bray 1 P (0.004). This is due to the higher concentration of acid in the Bray 2 extractant which can extract more Ca-P compared to Bray 1 extractant.

Higher correlation of Al-P with available P was mainly due to its positive indirect effect on increasing the saloid-P. This was further confirmed by the higher values of linear correlation coefficients between saloid-P and Al-P (0.754^{**}, 0.765^{**} and 0.686^{**} for RRP, MRP and SP respectively).

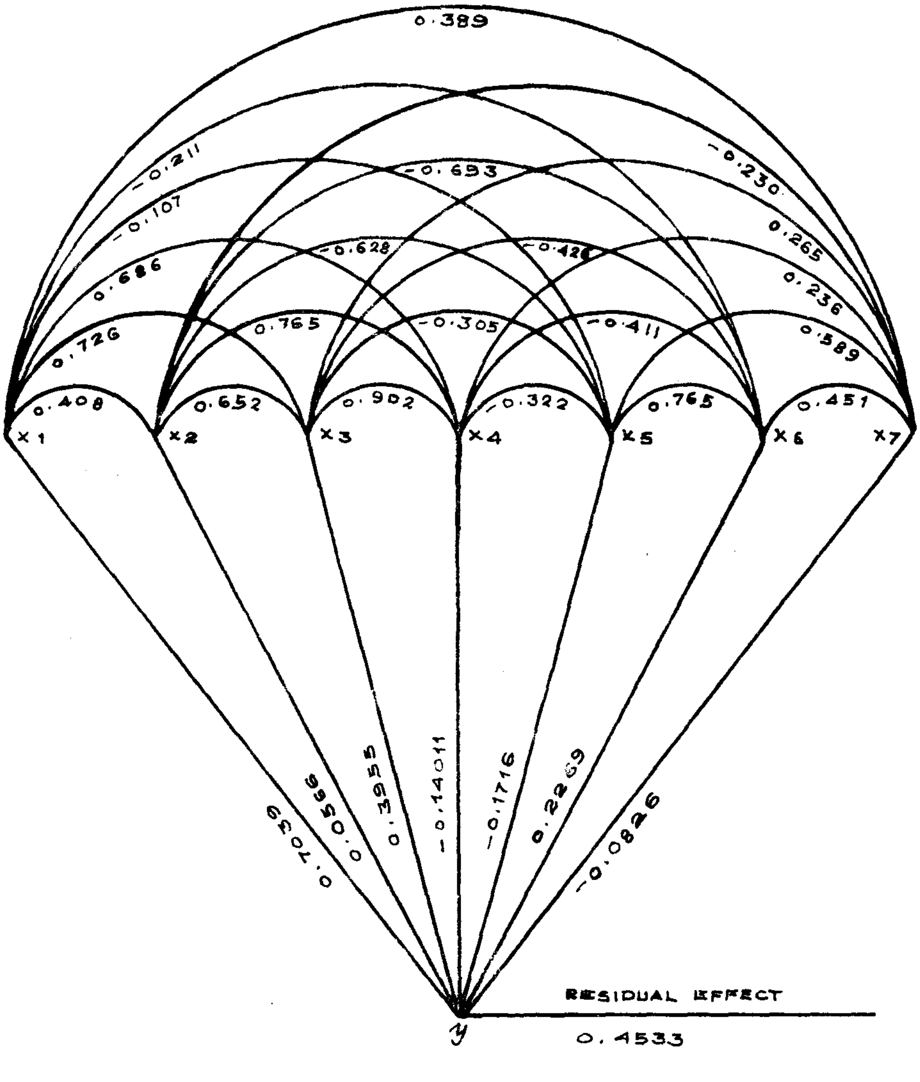
Both reductant soluble and occluded-P contribute little to the pool of available P, mainly due to their indirect negative effect on other inorganic fractions. This was again proved by the negative correlation values obtained between reductant soluble-P and occluded-P with other fractions.

The influence of time or period of incubation on available P and inorganic fractions was also brought out by the path analysis. Irrespective of the forms of P added to the soil, time was positively correlated with available P (Bray 1 and 2). This positive correlation of period of incubation with available P was mainly attributed to its indirect positive effect on saloid-P and Fe-P. Linear coefficient of correlation revealed that the Ca-P, reductant soluble-P

Table 27. Path coefficient analysis showing direct and indirect effect of inorganic P fraction and period of incubation on available P from SP

	Saloid-P	Period of incubation	Fe-P	Al-P	Reductant soluble-P	Occluded-P	Ca-P	Total correlation coefficients	Residual effect
					Bray 1				
Saloid-P	0.704	0.023	0.287	0.018	-0.096	-0.048	-0.032	0.856	
Period of incubation	0.287	0.057	0.258	0.108	-0.107	-0.157	0.019	0.464	
Fe-P	0.511	0.037	0.396	-0.126	0.052	-0.097	-0.022	0.751	
Al-P	0.483	0.043	0.357	-0.140	0.055	-0.093	-0.020	0.685	0.453
Reductant soluble-P	-0.752	-0.036	-0.121	0.045	-0.172	0.174	-0.049	-0.233	
Occluded-P	-0.149	-0.039	-0.168	0.058	-0.131	0.227	-0.373	-0.240	
Ca-P	0.274	-0.013	0.105	-0.033	-0.101	0.102	-0.823	0.251	
					Bray 2				
Saloid-P	0.471	0.055	0.250	0.043	0.004	-0.003	0.024	0.843	
Period of incubation	0.192	0.135	0.225	0.048	0.021	-0.010	-0.014	0.596	
Fe-P	0.342	0.088	0.345	0.056	0.010	-0.006	0.016	0.851	
Al-P	0.323	0.103	0.311	0.062	0.011	-0.006	0.014	0.819	0.395
Reductant soluble-P	-0.050	-0.085	-0.105	-0.020	-0.033	0.113	0.036	-0.246	
Occluded-P	-0.100	-0.009	-0.147	-0.026	-0.025	0.015	0.028	-0.348	
Ca-P	0.184	-0.031	0.091	0.015	-0.019	0.007	0.061	0.307	

FIG: 10. PATH DIAGRAM - DIRECT AND INDIRECT EFFECTS OF INORGANIC P FRACTIONS ON AVAILABLE P (BRAY I) FROM SP



y = AVAILABLE P	x_4 = Al - P
x_1 = SALOID-P	x_5 = REDUCTANT SOLUBLE P
x_2 = PERIODS OF INCUBATION	x_6 = OCCLUDED P
x_3 = Fe - P	x_7 = Ca - P

Table 28. Path coefficient analysis showing direct and indirect effect of inorganic P fraction and period of incubation on available P from different sources of P

	Saloid-P	Period of incubation	Fe-P	Al-P	Reductant soluble-P	Occluded-P	Ca-P	Total correlation coefficients	Residual effect
					Bray 1				
Saloid-P	0.757	0.025	0.294	0.036	-0.167	-0.062	0.001	0.887	
Period of incubation	0.385	0.050	0.255	0.102	-0.180	-0.137	-0.001	0.474	
Fe-P	0.504	0.033	0.380	-0.206	0.057	-0.030	0.001	0.761	
Al-P	-0.553	0.039	0.293	-0.228	0.063	-0.088	0.001	0.683	
Reductant soluble-P	-0.188	-0.033	-0.140	0.093	-0.155	0.148	0.002	-0.272	0.423
Occluded-P	-0.242	-0.035	-0.173	0.103	-0.118	0.194	0.002	-0.269	
Ca-P	0.210	-0.012	0.091	-0.044	-0.090	0.084	0.004	0.243	
					Bray 2				
Saloid-P	0.513	0.050	0.234	0.028	0.015	0.001	0.035	0.881	
Period of incubation	0.261	0.098	0.207	0.030	0.039	0.003	-0.029	0.609	
Fe-P	0.396	0.065	0.310	0.035	0.022	0.002	0.030	0.859	
Al-P	0.375	0.077	0.279	0.038	0.024	0.002	0.024	0.820	0.366
Reductant soluble-P	-0.128	-0.065	-0.113	-0.016	-0.059	-0.522	0.073	-0.310	
Occluded-P	-0.164	-0.070	-0.141	-0.017	-0.045	-0.005	0.055	-0.386	
Ca-P	0.143	-0.023	0.074	0.007	-0.034	-0.190	0.126	0.291	

and occluded-P gradually and progressively decreased with the lapse of time. This phenomenon again indicated that, though the P was added as Ca-P, the contribution of Ca-P to the available phosphate pool was considerably less with the advancement of time because of its transformation to other forms.

The extent of contribution of various inorganic fractions to available P was the same in all the three forms of fertilizers added to the soil as revealed by their path analysis. This indicated that the transformation of RRP, MRP and SP was similar in the two acid soils, though SP contained P in a water soluble form. Thus it was confirmed that the water solubility of P in the added material was not a critical factor in deciding the various inorganic fractions and available P content of the acid soils taken for the study.

Prediction equations were arrived at to estimate the available P from different P sources based on the contents of various inorganic P fractions and period of incubation. The equations are presented below.

1. From RRP

a) Bray 1 P (Y_1)

$$Y_1 = 4.741 + 5.470x_1 + 0.062x_2 + 0.031x_3 - 0.041x_4 - 0.067x_5 + 0.075x_6 + 0.019x_7$$

$(R^2 = 0.86)$

b) Bray 2 P (Y_2)

$$Y_2 = 4.345 + 6.452x_1 + 0.143x_2 + 0.043x_3 + 0.009x_4 - 0.086x_5 - 0.013x_6 + 0.116x_7$$

$(R^2 = 0.89)$

2. From MRP

a) Bray 1 P (Y_1)

$$Y_1 = 3.187 + 5.509x_1 + 0.031x_2 + 0.037x_3 - 0.042x_4 - 0.062x_5 + 0.083x_6 + 0.0116x_7$$

$(R^2 = 0.84)$

b) Bray 2 P (Y_2)

$$Y_2 = 0.422 + 6.969x_1 + 0.144x_2 + 0.053x_3 + 0.0009x_4 - 0.030x_5 - 0.007x_6 + 0.087x_7$$

$(R^2 = 0.89)$

3. From SP

a) Bray 1 P (Y_1)

$$Y_1 = -1.672 + 4.444x_1 - 0.022x_2 + 0.029x_3 + 0.003x_4 - 0.069x_5 + 0.087x_6 - 0.034x_7$$

$(R^2 = 0.80)$

b) Bray 2 P (Y_2)

$$Y_2 = -2.339 + 5.434x_1 + 0.317x_2 + 0.066x_3 - 0.004x_4 - 0.024x_5 + 0.018x_6 + 0.042x_7$$

$$(R^2 = 0.84)$$

x_1 Saloid-P

x_2 Period of incubation

x_3 Fe-P

x_4 Al-P

x_5 Reductant soluble-P

x_6 Occluded-P

x_7 Ca-P

The various inorganic fractions of P along with the Period of incubation contributed to more than 80 per cent of the variability in available P during incubation. Direct and indrect effects of various inorganic P fractions on available P (Bray 1) from RRP, MRP and SP are represented in Fig. 8,9 and 10 respctively.

<u>Effect of continuous application of phosphorus as superphosphate</u>

Two treatments (T_{15} and T_{16}) were incorporated to study the effect of a single application of rockphosphate in comparison with the continuous application of P as SP, on the transformation of inorganic P in soil, the second application being done 90 days after the first application. Observations revealed that the increase in the content of various inorganic fractions and available P by the application of 90 kg P_2O_5/ha as SP twice in two equal doses was not conspicuous compared to the intial and single application of the same quantity of P as rockphosphates and SP. This showed that the effect of two rockphosphates was comparable with that of superphosphate in the acid soils selected for the study and the transformations were comparable whether the phosphatic fertilizers were applied in a single dose initially or in two doses.

POTCULTURE EXPERIMENT

A potculture experiment was conducted in order to assess the direct and residual effect of rockphosphates (RRP and MRP) in comparison with the water soluble superphosphate (SP) in laterite and kari soils of Kerala. The same two soils used in the incubation study were used for the potculture experiment. Phosphatic fertilizers were applied at two levels (45 and 90 kg P_2O_5/ha) and applications of N and K were done uniformily in all the treatments. Soil and plant samples were drawn regularly at 15 days interval to study the release of P from the phosphatic fertilizers and the uptake of major nutrients. The residual effect of rockphosphates was assessed by continuing the experiment for the second season without the application of P fertilizers. However, the last two treatments (T_{15} and T_{16}) received SP both in the first and second crop seasons at the rate of 45 kg P_2O_5/ha in order to compare the residual effect of rockphosphates applied once with that of SP applied twice.

A. <u>First crop</u>

1. Nutrient uptake

1.1 Nitrogen

1.1.1 Nitrogen per cent of straw and root

Table 29. Nitrogen per cent of straw and root as influenced by the treatments at different periods of crop growth (first crop)

Treatment		N% of straw at different periods, fortnights						N% of root at different periods, fortnights					
No.	Notation	1	2	3	4	5	6	1	2	3	4	5	6
1	OL	1.89	3.15	2.73	2.52	1.05	0.55	1.68	2.31	1.85	1.52	0.51	0.29
2	RRP45L	1.19	2.06	2.90	2.35	1.14	0.55	1.89	2.56	2.06	1.73	0.51	0.36
3	RRP90L	2.19	3.45	3.11	2.31	1.14	0.51	1.98	2.77	2.19	1.85	0.59	0.40
4	MRP45L	1.85	3.11	3.03	2.27	1.22	0.46	1.68	2.36	1.93	1.64	0.48	0.34
5	MRP90L	2.02	3.36	3.53	2.26	1.31	0.55	1.81	2.73	2.10	1.93	0.53	0.36
6	SP45L	2.10	3.45	3.19	2.44	1.22	0.46	1.77	2.61	1.98	1.85	0.57	0.38
7	SP90L	2.19	3.53	3.03	2.31	1.22	0.55	1.81	2.65	2.06	1.85	0.55	0.38
8	OK	1.73	2.65	2.31	2.06	1.14	0.21	0.84	1.81	1.68	1.47	0.42	0.27
9	RRP45K	1.93	3.45	3.11	2.52	1.31	0.40	1.31	2.02	1.77	1.56	0.53	0.35
10	RRP90K	1.93	3.70	3.28	2.65	1.47	0.46	1.47	2.06	1.85	1.56	0.53	0.34
11	MRP45K	1.94	3.65	3.36	2.39	1.47	0.44	1.30	2.02	1.77	1.56	0.48	0.27
12	MRP90K	1.93	3.53	3.24	2.94	1.39	0.46	1.39	2.06	1.73	1.56	0.55	0.32
13	SP45K	2.02	3.84	3.49	2.86	1.47	0.55	1.35	2.02	1.81	1.56	0.55	0.32
14	SP90K	2.10	3.95	3.36	2.90	1.58	0.63	1.43	2.10	1.85	1.60	0.55	0.34

Table 30. Mean values of nitrogen per cent of straw and root as influenced by sources of P, soils and levels of P application (first crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				N% of straw				
1	2.041	1.931	2.100	2.075	1.973	1.988	2.060	2.024
2	3.465	3.411	3.690	3.360	3.680	3.440	3.610	3.520
3	3.098	3.160	3.270	3.050	3.310	3.150	3.200	3.180
4	2.457	2.460	2.630	2.320	2.710	2.450	2.580	2.520
5	1.261	1.350	1.370	1.205	1.450	1.280	1.380	1.330
6	0.477	0.477	0.546	0.511	0.490	0.466	0.535	0.500
Mean	2.133	2.132	2.267	2.087	2.269	2.129	2.228	2.179
				N% of root				
1	1.660	1.540	1.590	1.820	0.373	1.547	1.645	1.597
2	2.351	2.290	2.350	2.610	2.040	2.254	2.400	2.328
3	1.960	1.880	1.920	2.050	1.790	1.875	1.966	1.921
4	1.670	1.670	1.710	0.806	1.560	1.639	1.729	1.684
5	0.535	0.509	0.554	0.536	0.529	0.507	0.558	0.533
6	0.358	0.321	0.354	0.370	0.319	0.333	0.355	0.345
Mean	1.423	1.369	1.412	1.532	1.270	1.359	1.442	1.401

N% of straw

CD(0.05) for periods = 0.2680

N% of root

CD(0.05) for periods = 0.2080

Results on the effect of various sources and levels of applied P on N per cent of straw and root at different growth stages in laterite and kari soils are presented in Tables 29 to 32 and their analysis of variance in Appendix II.

Both in the presence and absence of added P, levels of N in the straw and root were maximum during the second period which represented the maximum tillering stage of rice plant (Table 29). During this period, the rate of growth was more as revealed by the increase in the straw yield, compared to other stages which leads to the maximum absorption of nutrients like N. From third period onwards, the level of N tended to decrease. This decrease is due to the increase in the dry matter production with less vigorous nutrient absorption resulting in the dilution of nutrient concentration. The N per cent of the straw and root during the first period showed maximum correlation ($r = 0.550^{**}$) compared to other periods.

In the absence of added P, the mean N per cent of the straw and root was 1.981 and 1.360 respectively in laterite soil and 1.680 and 1.080 respectively in kari soil (Table 32). By the addition of phosphatic fertilizers, these values were increased to 2.087 and 1.532 per cent for straw and root respectively in

Table 31. Mean values of per cent of nutrients, nutrient uptake and available P as influenced by levels of P application (first crop)

Levels of P_2O_5, kg/ha	Soil			Sources of P		
	Laterite	Kari		RRP	MRP	SP
45	2.040	2.220	N% of straw	2.070	2.060	2.250
90	2.130	2.320		2.190	2.190	2.280
45	1.480	1.240	N% of root	1.380	1.310	1.400
90	1.580	1.300		1.470	1.430	1.430
45	0.710	0.730	N uptake by	0.680	0.670	0.800
90	0.760	0.840	straw, g/pot	0.780	0.760	0.860
45	0.086	0.086	P% of straw	0.085	0.081	0.085
90	0.106	0.089		0.086	0.088	1.250
45	0.025	0.033	P% of root	0.026	0.028	0.032
90	0.029	0.034		0.031	0.031	0.033
45	35.83	35.51	P uptake by	35.41	34.16	37.44
90	36.67	40.99	straw, mg/pot	39.08	35.15	42.26
45	2.170	2.840	K% of straw	2.440	2.440	2.640
90	2.220	2.910		2.520	2.480	2.680
45	1.440	1.610	K% of root	1.520	1.510	1.540
90	1.490	1.660		1.580	1.570	1.580
45	0.776	0.010	K uptake by	0.862	0.836	0.987
90	0.826	1.150	straw, g/pot	0.977	0.910	1.070
45	38.05	36.94	Straw yield,	36.96	36.17	39.36
90	39.71	40.75	g/pot	40.63	38.41	41.66
45	4.990	4.010	Available P	4.070	4.430	4.990
90	5.690	5.710	(Bray 1), ppm	4.960	5.020	5.810
45	13.16	15.98	Available P	14.15	14.09	15.47
90	13.96	17.62	(Bray 2), ppm	15.29	15.22	16.87

Table 32. Mean values of per cent of nutrients, nutrient uptake straw yield and available P as influenced by P sources and soil (first crop)

Soil	Control (No P)		RRP	MRP	SP
Laterite	1.981	N% of straw	2.084	2.035	2.138
Kari	1.680		2.183	2.226	2.393
Laterite	1.360	N% of root	1.570	1.490	1.540
Kari	1.080		1.270	1.250	1.290
Laterite	0.667	N uptake by	0.720	0.698	0.785
Kari	0.357	straw, g/pot	0.735	0.730	0.879
Laterite	0.077	P% of straw	0.087	0.082	0.118
Kari	0.054		0.084	0.087	0.092
Laterite	0.015	P% of root	0.025	0.027	0.029
Kari	0.021		0.031	0.033	0.035
Laterite	33.48	P uptake by	37.56	33.95	37.26
Kari	15.62	straw, mg/pot	36.94	35.36	42.45
Laterite	1.090	K% of root	1.480	1.440	1.480
Kari	0.780		1.620	1.640	1.630
Laterite	1.710	K% of straw	2.140	2.150	2.300
Kari	1.630		2.830	2.780	3.010
Laterite	0.687	K uptake by	0.771	0.753	0.879
Kari	0.403	straw, g/pot	0.106	0.993	1.180
Laterite	37.68	Straw yield,	38.83	37.44	40.37
Kari	23.95	g/pot	38.76	37.14	40.65
Laterite	3.600	Available P	4.990	5.450	5.560
Kari	2.210	(Bray 1), ppm	3.850	4.000	5.240
Laterite	11.43	Available P	13.07	13.17	14.44
Kari	10.13	(Bray 2), ppm	16.37	16.14	17.89

laterite soil and 2.269 and 1.270 per cent respectively in kari soil (Table 30). The increase in the level of N in the straw due to the application of P over control accounted to 5.30 and 34.94 per cent in laterite and kari soils respectively. The increase in the level of N in plant by the application of P fertilizers to soil indicated that the N utilization by the plant was limited by the low availability of P and this effect was maximum in the case of kari soil. It was seen that available P (Bray 1 and 2) content during all the periods of plant growth except at the time of harvest was positively correlated with the N per cent of the straw, but maximum correlation was obtained with available P content of the soil during the second period ($r = 0.906^{**}$ and 0.432^{*} for Bray 1 and 2 respectively) and this represented the stage of maximum level of N in the straw and root.

The increase in the level of N in the straw due to the application of RRP, MRP and SP were 0.303, 0.300 and 0.435 per cent respectively over control (Table 30). The slightly higher content of N in the treatments receiving SP was not statistically significant.

Increasing the level of application of RRP, MRP and SP increased the N per cent of the straw from 2.07 to 2.19 per cent, 2.06 to 2.19 per cent and 2.25 to 2.28

Table 33. Uptake of nitrogen and phosphorus by rice straw as influenced by the treatments at different periods of crop growth (first crop)

Treatment		Uptake of N (g/pot) at different periods, fortnights						Uptake of P (mg/pot) at different periods, fortnights					
No.	Notation	1	2	3	4	5	6	1	2	3	4	5	6
1	OL	0.303	0.959	0.926	0.990	0.538	0.284	2.66	13.60	21.25	57.85	53.05	47.45
2	RRP45L	0.332	0.998	1.050	0.943	0.570	0.302	5.33	16.60	24.40	62.20	61.05	54.75
3	RRP90L	0.336	1.152	1.057	1.040	0.610	0.288	5.19	18.45	24.75	57.95	68.90	51.20
4	MRP45L	0.269	0.984	1.030	0.909	0.580	0.246	4.35	18.40	24.80	48.90	60.10	48.45
5	MRP90L	0.311	1.120	1.120	0.916	0.605	0.302	4.37	15.40	24.25	52.75	58.30	47.30
6	SP45L	0.371	1.106	1.210	1.030	0.609	0.267	6.63	18.15	28.15	50.80	65.80	46.20
7	SP90L	0.375	1.202	1.250	1.050	0.652	0.336	6.19	17.70	34.15	58.80	67.70	46.80
8	OK	0.105	0.474	0.530	0.549	0.407	0.080	1.19	7.04	11.87	21.95	23.85	27.85
9	RRP45K	0.241	0.726	1.030	1.103	0.672	0.218	1.66	11.10	22.45	63.45	52.90	49.10
10	RRP90K	0.299	0.961	1.150	1.240	0.882	0.302	4.50	15.30	25.10	68.15	67.80	61.75
11	MRP45K	0.228	0.731	1.080	1.050	0.742	0.242	2.61	10.12	20.30	61.80	55.65	54.55
12	MRP90K	0.297	0.880	1.130	1.400	0.720	0.270	4.04	12.60	26.00	70.55	59.85	46.40
13	SP45K	0.309	1.050	1.290	1.300	0.752	0.325	4.61	24.60	26.45	62.35	56.80	64.80
14	SP90K	0.342	1.180	1.340	1.380	0.889	0.391	6.39	21.70	31.00	73.80	69.55	73.40

per cent respectively when the effects of soils and periods were pooled (Table 31). This showed that the absorption of N by the straw and root could not be increased beyond a certain level, by the application of P.

Linear coefficient of correlation (r) between N per cent of straw at different periods and grain yield revealed that the values for N per cent of straw during the second and third fortnights were maximum correlated with the yield (0.569** and 0.559** for second and third periods respectively).

1.1.2 Uptake of nitrogen by the straw

Effects of various sources and levels of applied P on the uptake of N by the straw at different growth stages in laterite and kari soils are furnished in Tables 31 to 34 and their analysis of variance in Appendix II.

In all the treatments, the uptake of N by the straw was found to increase rapidly upto the third and fourth period and then gradually decreased. This decrease may be due to the translocation of the nutrients to grain from the straw occurring after the fourth period. Both under P treated and control (no P) conditions, the values of N uptake at the time of harvest (0.182 and 0.291 g N/pot for control and P treated pots) were significantly lower than the initial uptake, due to the very low level of N in the straw at the time of harvest (Table 33).

When no P was added, the uptake of N in laterite and kari soils was 0.667 and 0.357 g N/pot which on addition of P fertilizers increased to 0.735 and 0.782 g N/pot in laterite and kari soils respectively (Table 32 and 34). The relative increase in the uptake of N due to the application of P in various forms and levels, compared to control was 6.8 per cent in laterite soil and 118.9 per cent in kari soil. When no P was added, the uptake of N in laterite soil was 86.83 per cent more as compared to kari soil, but when P was added, N uptake was 6.44 per cent more in kari soil compared to laterite soil. The higher responsiveness of kari soil to the application of P fertilizers compared to laterite soil may be due to the low content of total native P and available P in kari soil. The general increase in the uptake of N by the straw over control due to the application of P fertilizers is attributed to the increased growth rate of rice occurring in the presence of added P which leads to the increased absorption of nutrients like N. An increase in the uptake of N by straw in the presence of added P was also reported by Ramanathan _et al_. (1979a)

Table 34. Mean values of nitrogen and phosphorus uptake by rice straw as influenced by sources of P, soils and levels of P application (first crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				N uptake (g/pot)				
1	0.302	0.276	0.349	0.332	0.286	0.291	0.307	0.309
2	0.959	0.928	1.140	1.090	0.922	0.932	1.080	1.006
3	1.070	1.090	1.260	1.110	1.170	1.110	1.170	1.140
4	1.080	1.070	1.190	0.979	1.250	1.060	1.170	1.115
5	0.683	0.662	0.725	0.604	0.776	0.654	0.727	0.691
6	0.277	0.264	0.329	0.289	0.291	0.267	0.314	0.291
Mean	0.729	0.715	0.832	0.735	0.782	0.719	0.798	0.759
				P uptake (mg/pot)				
1	4.170	3.840	5.950	5.340	3.970	4.190	5.110	4.650
2	15.36	14.14	19.04	17.45	14.91	15.48	16.88	16.18
3	24.16	23.80	29.94	26.74	25.19	24.42	27.52	25.97
4	62.94	58.50	61.44	55.23	66.68	58.25	63.67	60.96
5	62.66	58.48	64.96	63.64	60.43	58.72	65.35	62.04
6	54.19	49.18	57.80	49.11	58.33	52.98	54.47	53.70
Mean	37.25	34.66	39.85	36.25	38.25	35.67	38.83	37.25

N uptake

CD(0.05) for periods = 0.0890
" " sources = 0.0430
" " levels = 0.0350
" " soil x period = 0.1263

P uptake

CD(0.05) for periods = 6.255

and Reddy and Rao (1983). The content of available P (Bray 2) and N uptake by straw at different stages of plant growth were positively correlated. The available P and N uptake during the third and fourth periods showed maximum correlation ($r = 0.702^{**}$ and 0.731^{**} for third and fourth periods respectively).

The increases in the uptake of N due to the application of RRP, MRP and SP were 0.053, 0.031 and 0.118 g N/pot respectively over control in laterite soil and 0.378, 0.373 and 0.522 g N/pot respectively over control in kari soil (Table 32). In general, the N uptake from treatments receiving SP was 0.11 g N/pot more than the treatments receiving RRP (0.729 g N/pot) and MRP (0.715 g N/pot) and this increase was found to be significant (Table 34). However, the two rockphosphates were on par with regard to the uptake of N by the straw. It was seen that the N per cent and straw yield did not differ significantly with the variations in the forms of P added, though a slight nonsignificant increase was observed in treatments receiving SP. This slight nonconspicuous increase observed in the straw yield and N per cent in the straw due to the application of SP was responsible for its significant increase in the uptake of N by the straw.

Application of P at the rate of 45 kg P_2O_5/ha increased the uptake of N by 0.207 g N/pot and further increase of P application to 90 kg P_2O_5/ha resulted in an increase of 0.079 g N/pot which was found to be significant (Table 34). The increase observed in laterite and kari soils by increasing the level of application of P was 0.050 and 0.110 g N/pot respectively when the effects of periods and fertilizers were pooled (Table 31), the percentage increase being 7.04 and 15.06 respectively. The higher rate of increase observed in kari soil indicates its high responsiveness to P fertilisers.

Uptake of N during all the periods of plant growth was positively correlated with grain yield, but maximum correlation was obtained in the case of N uptake of straw during the second period ($r = 0.553^{**}$).

1.1.3 Uptake of nitrogen by the grain

Influence of various sources and levels of applied P on the uptake of N by the grain in laterite and kari soils are presented in Table 41 and the analysis of variance in Appendix V.

Uptake of N by the grain increased over control due to the application of P in various forms and levels. This was due to the increase in the drymatter production of grain and not because of the increase in the N per cent of the grain.

In the absence of added P, the N per cent in the grain was 1.105 and 1.090 in laterite and kari soils respectively which on the addition of P fertilizers increased to 1.124 and 1.130 per cent respectively.

The uptake of N by the grain in the absence of added P was 0.546 and 0.402 g N/pot in laterite and kari soils respectively i.e., there was 35.82 per cent more N uptake in laterite soil as compared to kari soil.

The increase in the uptake of N by the grain due to the application of P fertilizers was 0.564 and 0.621 g N/pot for laterite and kari soils respectively, the increase being 3.30 and 54.48 per cent respectively. The increase in the uptake of N by the grain in the presence of added P was in conformity with the observations of Reddy and Rao (1983). The higher values of N uptake over control observed in kari soil indicates that it is more responsive to the application of P fertilizers compared to laterite soil. In this soil, among the P treatments, SP at higher level of application (0.719 g N/pot) was found to be significantly superior to other forms and levels of P.

In the case of laterite soil, the P treatments, irrespective of forms and levels, fail to register significant increase in the uptake of N as compared to the control (no P), probably because of the higher supply of native available P occurring under submergence in the laterite soil due to its relatively higher content of total P. However, relatively higher values of N uptake were observed in treatments receiving SP at the rate of 90 kg P_2O_5/ha (0.583 g N/pot) because of the higher supply of available P from SP.

1.1.4 Total uptake of nitrogen

Effect of various treatments on the total uptake of N by rice in laterite and kari soils is presented in Table 41 and the analysis of variance in Appendix V.

In the absence of added P, the total uptake of N by rice was 0.830 and 0.482 g N/pot in laterite and kari soils respectively which on addition of P fertilisers increased to 0.854 and 0.913 g N/pot respectively i.e., by the application of P fertilisers the total uptake of N was increased significantly over control only in kari soil. In laterite soil, the response of P fertilizers in increasing the total uptake of N was not much conspicuous. Though the supply of N was uniform in all the treatments, the growth of plants would have limited by the low level of available P in kari soil and thus the application of P resulted in increased dry matter production and higher uptake of N.

The intensive reduction reactions occurring in laterite soil release comparatively larger quantity of available P from total P. Thus in laterite soil the effect of P fertilizers gets masked because of this increased supply of native available P. Nair and Pisharody (1970) also reported that the laterite soils of Kerala were nonresponsive to the application of P. Results showed that in both the soils N uptake in treatments receiving application of SP at higher level (0.919 and 1.110 g N/pot in laterite and kari soils respectively) was superior to other forms and levels of P due to the higher supply of water soluble P. In kari soil values for total uptake of N from treatments receiving SP at the rate of 45 kg P_2O_5/ha and RRP at the rate of 90 kg P_2O_5/ha were on par. All other treatments consisting of RRP at lower level and MRP at both levels did not differ significantly in increasing the total uptake.

1.2 Phosphorus

1.2.1 Phosphorus per cent of straw and root

Results on the effect of various sources and levels of applied P on the P per cent of straw and root at different growth stages in laterite and kari soils are given in Tables 31, 32, 35 and 36 and their analysis of variance in Appendix II.

Both in the presence and absence of added P, the level of P in the straw and root was maximum during the third and fourth periods which represented the panicle initiation and flowering stages (Table 35). The decrease thereafter observed during the subsequent periods may be attributed to the dilution of nutrient concentration consequent to increase in drymatter production and the translocation of nutrients to the grains.

In the absence of added P, the mean per cent of P in the straw and root was 0.077 and 0.015 respectively in laterite soil and 0.054 and 0.021 respectively in kari soil (Table 32). These values on addition of P fertilisers increased to 0.096 and

Table 35. Phosphorus per cent of straw and root as influenced by the treatments at different periods of crop growth (first crop)

Treatment		P% of straw at different periods, fortnights						P% of root at different periods, fortnights					
No.	Notation	1	2	3	4	5	6	1	2	3	4	5	6
1	OL	0.026	0.051	0.063	0.125	0.109	0.090	0.006	0.019	0.034	0.017	0.007	0.006
2	RRP45L	0.034	0.055	0.068	0.157	0.122	0.099	0.017	0.028	0.038	0.028	0.015	0.011
3	RRP90L	0.034	0.055	0.073	0.134	0.127	0.090	0.024	0.032	0.042	0.036	0.019	0.015
4	MRP45L	0.029	0.059	0.077	0.129	0.120	0.092	0.019	0.028	0.040	0.034	0.019	0.009
5	MRP90L	0.028	0.046	0.065	0.131	0.125	0.086	0.024	0.034	0.044	0.036	0.022	0.017
6	SP45L	0.038	0.057	0.074	0.132	0.122	0.081	0.024	0.034	0.042	0.034	0.019	0.017
7	SP90L	0.036	0.053	0.086	0.129	0.127	0.077	0.027	0.034	0.046	0.036	0.026	0.019
8	OK	0.012	0.038	0.051	0.083	0.067	0.073	0.006	0.032	0.042	0.024	0.017	0.006
9	RRP45K	0.027	0.055	0.068	0.145	0.102	0.090	0.013	0.038	0.047	0.036	0.026	0.017
10	RRP90K	0.034	0.059	0.072	0.145	0.113	0.095	0.017	0.044	0.053	0.038	0.028	0.024
11	MRP45K	0.089	0.051	0.063	0.142	0.110	0.099	0.015	0.040	0.060	0.034	0.024	0.019
12	MRP90K	0.026	0.050	0.074	0.149	0.114	0.081	0.017	0.038	0.060	0.038	0.030	0.017
13	SP45K	0.030	0.068	0.072	0.137	0.112	0.110	0.021	0.046	0.058	0.038	0.032	0.024
14	SP90K	0.038	0.073	0.078	0.157	0.124	0.119	0.019	0.036	0.060	0.038	0.030	0.022

Table 36. Mean values of phosphorus per cent of straw and root as influenced by sources of P, soils and levels of P application (first crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				P% of straw				
1	0.032	0.043	0.036	0.033	0.041	0.041	0.033	0.037
2	0.056	0.051	0.063	0.054	0.059	0.057	0.056	0.056
3	0.069	0.069	0.078	0.141	0.071	0.070	0.142	0.106
4	0.145	0.138	0.139	0.135	0.146	0.140	0.141	0.140
5	0.116	0.117	0.121	0.123	0.112	0.114	0.121	0.118
6	0.093	0.089	0.093	0.087	0.097	0.093	0.091	0.092
Mean	0.085	0.085	0.105	0.096	0.087	0.086	0.097	0.092
				P% of root				
1	0.018	0.019	0.023	0.023	0.017	0.018	0.022	0.019
2	0.036	0.035	0.038	0.032	0.040	0.036	0.036	0.036
3	0.045	0.051	0.014	0.042	0.056	0.048	0.051	0.049
4	0.035	0.036	0.037	0.034	0.037	0.034	0.037	0.036
5	0.022	0.024	0.027	0.020	0.028	0.032	0.026	0.024
6	0.017	0.015	0.021	0.015	0.021	0.016	0.019	0.018
Mean	0.029	0.029	0.033	0.028	0.033	0.029	0.032	0.030

P% of straw

CD(0.05) for periods = 0.0370

P% of root

CD(0.05) for periods = 0.0040
" " soils = 0.0016
" " sources = 0.0019
" " levels = 0.0016
" " soil x period = 0.0057

(0.033%) compared to other treatments which received RRP and MRP (Table 36).

Application of RRP, MRP and SP at higher level increased the P per cent of straw from 0.085 to only 0.086 per cent, 0.081 to 0.088 per cent and 0.085 to 1.250 per cent respectively when the soils and periods of sampling were pooled (Table 31). This increase in level of P in the straw due to the increase in the rate of application of P was not significant. However, the level of P in the root increased significantly to the extent of 0.003 per cent over the lower level, though the increase was low when the total quantity of P added to the soil was considered (Table 36). This shows that in acid soils under submerged condition, only a fraction of the P added can be absorbed by the plant and the rest will be remaining in the soil which can only be used by the succeeding crops.

The highest correlation values for P per cent of straw and grain yield was observed during the fifth period ($r = 0.499^{**}$).

1.2.2 Uptake of phosphorus by the straw

Uptake of P by the straw at different growth stages as influenced by the sources and levels of

0.028 per cent for straw and root respectively in laterite soil and 0.087 and 0.033 per cent respectively in kari soil (Table 36). The contribution of added P in increasing the level of P in the straw was found to be nonsignificant, but the increase in the root was significant over control. The contribution of added P in increasing the level of P in the straw was higher in kari soil (0.034%) compared to laterite soil (0.019%). The lower contribution of applied P in increasing the level of P in the straw in laterite soil was due to the higher native available P. Maximum correlation between available P and P per cent of straw was observed during the third period ($r = 0.759^{**}$).

The mean values of P per cent in the straw due to the application of RRP, MRP and SP were 0.087, 0.082 and 0.118 respectively in laterite soil and 0.084, C.087 and 0.092 respectively in kari soil (Table 32). The higher level of P in the straw receiving SP compared to the rockphosphates was obviously due to the higher available P released from SP, though the increase was not significant. The mean level of P in the root was significantly higher in the treatments which received SP as the source of P applied P in laterite and kari soils is presented in Tables 31 to 34 and their analysis of variance in Appendix II.

When no P was added, the uptake of P by the straw was 33.48 and 15.62 mg P/pot in laterite and kari soils respectively which accounted to 1.890 and 0.984 per cent of the total P contained in these soils (Table 32). The higher uptake of P observed in laterite soil was due to the higher availability of native P in this soil under submergence which in turn leads to the higher absorption of P and drymatter production. Correlations between available P (Bray 2) and uptake of P by the straw during all the periods of sampling were significant and the maximum correlation was obtained during the fourth period ($r = 0.549^{**}$).

When P was added, the uptake was increased to 36.25 and 38.25 mg P/pot in laterite and kari soils respectively which represented 2.03 and 2.39 per cent of the total P in these soils (Table 34). Ramanathan et al. (1978, 1979b), Venkataramaiah (1979) and Reddy and Rao (1983) also observed an increase in the uptake of P by the straw in the presence of added P. The percentage increase in the uptake of P over control due to the addition of P was 8.27 per cent in laterite soil and 144.9 per cent in kari soil. This showed that the uptake of P in the presence of added P was more in kari soil compared to laterite soil. As already mentioned, the level of available P in kari soil was relatively low and therefore the application of P in this soil resulted in increased drymatter production and better utilization of plant nutrients since the limiting factor was eliminated by the addition of P. It is also possible that better mobilization of added P would have happened in kari soil due to the comparatively less amount of Fe and Al and slightly low P fixing capacity as compared to laterite soil

In general, uptake of P by the straw was found to be maximum during the fourth and fifth periods due to the higher level of P in this part during these periods and the higher drymatter production (Table 33). Per cent of P in the straw and P uptake by straw during all the periods of sampling were positively correlated, with the highest correlations during fourth ($r = 0.896^{**}$) and fifth ($r = 0.888^{**}$) periods.

The mean values of uptake of P from treatments receiving RRP MRP and SP were 37.25, 34.66 and

39.85 mg P/pot respectively (Table 34). On an average, the uptake of P by the straw in the treatments receiving rockphosphates was 90.23 per cent of that from SP. From these values it is clear that the uptake of P by straw is not dependent much on the water solubility of P in the added material, but probably on the transformation of added P in the soils. The tricalcium phosphate of rockphosphates might have undergone dissolution in the acidic soil environment, releasing P in an available form similar to that from the water soluble SP.

Results revealed that the uptake of P by the straw was not increasing proportionately with the increase in the level of application of P (Table 31 and 34). This shows that irrespective of the quantity of P added, only a fraction of the P added is utilized by the plants and hence the nonsignificant increase.

Uptake of P during the first and fourth periods of sampling showed highest correlation with yield of grain ($r = 0.467^{*}$ and 0.453^{*} for first and fourth periods respectively).

1.2.3 Uptake of phosphorus by the grain

Results on the effect of sources and levels of applied P on the uptake of P by the grain in laterite and kari soils are presented in Table 41 and the analysis of variance in Appendix V.

It is seen that in both the soils, the forms and levels of added P have little influence in increasing the P per cent of the grain over control (no P) treatment. However, due to the addition of P fertilizers, the uptake of P by the grain was 0.074 g P/pot more than that of the control (0.112 g P/pot) in kari soil, which worked out to 65.63 per cent over control. But in laterite soil, the uptake of P due to the addition of P did not increase conspicuously over control (0.169 g P/pot) due to the higher availability of native P. However, when no P was added, the uptake of P by grain in laterite soil was 50.89 per cent more as compared to kari soil. Thus a significant increase in the uptake of P by the grain over control due to the addition of P fertilizers was observed only in kari soil. In laterite soil, the P treatments irrespective of the forms and levels failed to register significant increase in the uptake of P as compared to the control.

Among the various P treatments, applications of P as SP at both levels and rockphosphates at higher level were on par with regard to the uptake of P by the grain in kari soil, though SP at the rate of 90 kg P_2O_5/ha recorded maximum value (0.208 g P/pot). The two rockphosphates at lower level of application did not differ significantly. In laterite soil also, higher uptake was observed in treatments receiving SP at the rate of 90 kg P_2O_5/ha though the increase was not significant over other treatments. The superiority of SP observed in both the soils is due to the higher immediate availability of P, Ca and S from this form which enhances the absorption of P and also the production of grain.

The significant increase observed in the uptake of P by the grain in kari soil without a significant increase in the P per cent of the grain was obviously due to the higher drymatter production occurring in the presence of added P. Uptake of P by the grain in the absence of added P was 9.52 and 7.06 per cent of that of the total P in laterite and kari soils respectively which on addition of P fertilizers increased to 9.56 and 11.83 per cent in laterite and kari soils respectively.

As in the case of uptake of P by the straw, the uptake of P by the grain also failed to show conspicuous increase with increasing levels of application from 45 to 90 kg P_2O_5/ha.

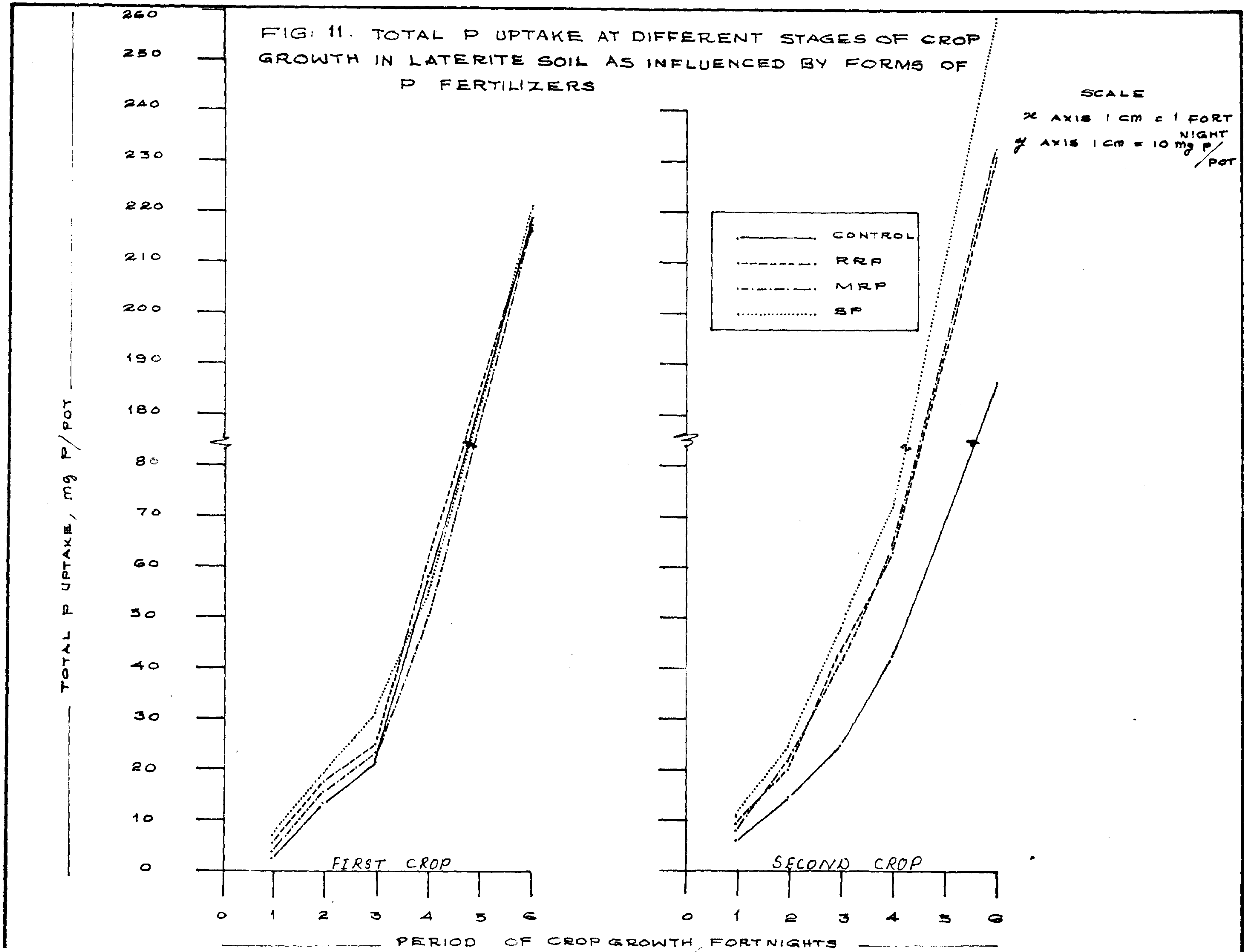


FIG: 11. TOTAL P UPTAKE AT DIFFERENT STAGES OF CROP GROWTH IN LATERITE SOIL AS INFLUENCED BY FORMS OF P FERTILIZERS
SCALE
x AXIS 1 cm = 1 FORTNIGHT
y AXIS 1 cm = 10 mg P/POT
CONTROL
RRP
MRP
SP
TOTAL P UPTAKE, mg P/POT
0
10
20
30
40
50
60
70
80
180
190
200
210
220
230
240
250
260
FIRST CROP
SECOND CROP
0
1
2
3
4
5
6
PERIOD OF CROP GROWTH, FORTNIGHTS

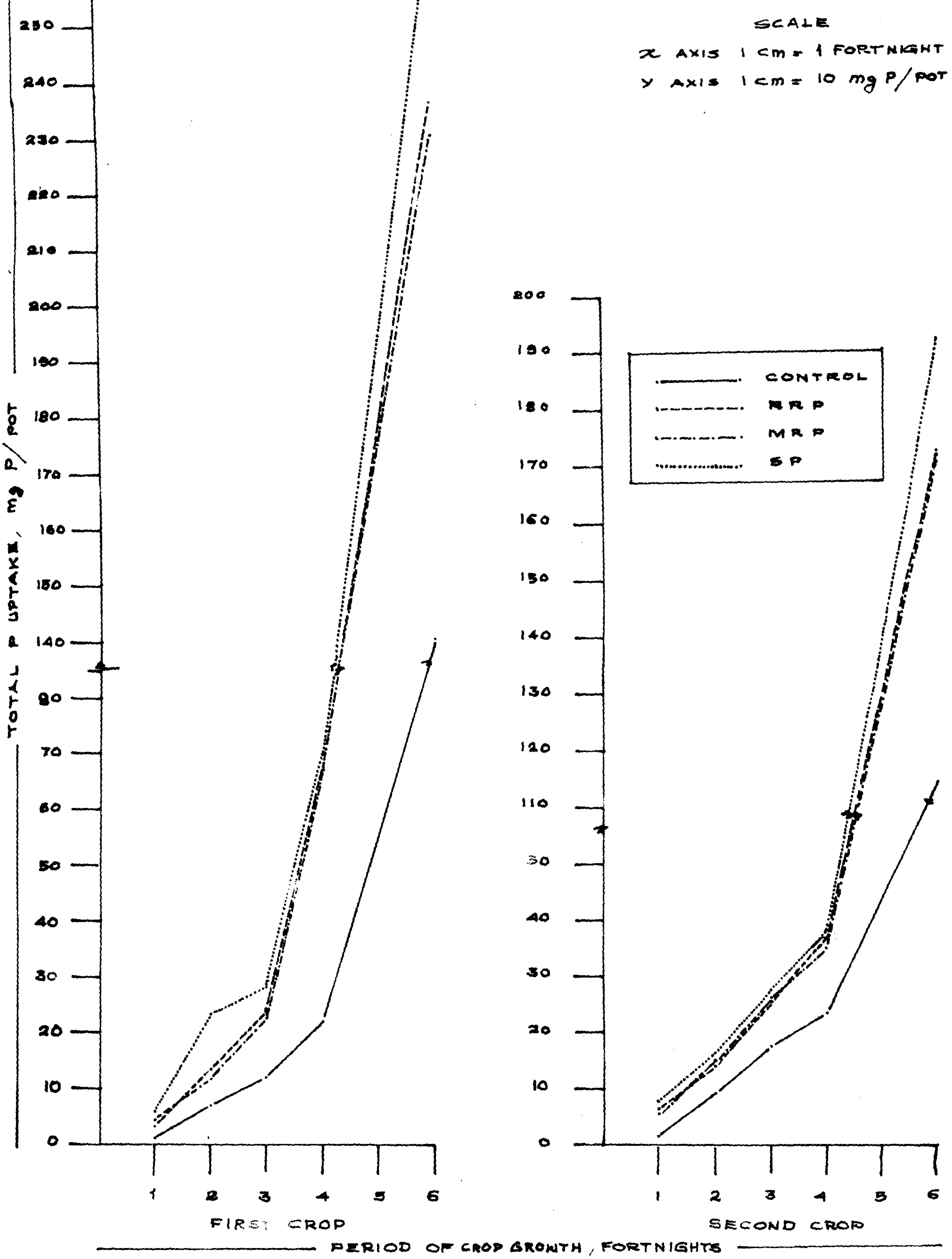
1.2.4 Total uptake of phosphorus

Influence of various sources and levels of applied P on the total uptake of P by rice plant in laterite and kari soils is given in Table 41 and the analysis of variance in Appendix V. Total P uptake as influenced by stages of crop growth, soils and fertilizer treatments is graphically represented in Fig.11, 12 and 13.

The total uptake of P in the absence of added P from laterite soil (216.4 mg P/pot) was higher than that from kari soil (139.9 mg P/pot), the reason being the higher availability of native P under submergence in latorite soil. The total P uptake accounted to 12.09 and 8.73 per cent of the total P in laterite and kari soils respectively.

On addition of P fertilizers, the total uptake was increased from 216.4 mg P/pot to 218.5 mg P/pot in laterite soil and from 139.9 mg P/pot to 243.6 mg P/pot in kari soil which represented 12.21 and 15.21 per cent of the total P in these soils. Higher dry matter production induced by the greater supply of P would have been able to compensate for the lesser concentration of P in the tissues so that the total uptake of P was high in treatments receiving P.

FIG: 12. TOTAL P UPTAKE AT DIFFERENT STAGES OF CROP GROWTH IN KARI SOIL AS INFLUENCED BY FORMS OF P FERTILIZERS



When the percentage increase in the uptake of P due to the addition of P fertilizers over control (no P) was considered, there was 74.17 per cent more total uptake over control in kari soil while in laterite soil the increase was less than 1 per cent. The lower rate of increase in the total P uptake over control due to the addition of P in laterite soil was due to the increased availability of native P.

In both the soils, among the P treatments, application of SP at higher level recorded relatively higher values of total P uptake (221.3 and 280.9 mg P/pot in laterite and kari soils respectively) compared to other treatments though not statistically significant. Results showed that in kari soil the two rockphosphates at higher level of application and SP at lower level of application were on par which indicated that the released P from rockphosphates applied at higher level would be equivalent to the available P from SP at lower level of application. The two rockphosphates did not vary with regard to the total uptake of P. In the case of laterite soil various forms and levels of applied P failed to show significant increase in the total uptake of P over control though the maximum uptake was from SP at higher level of application.

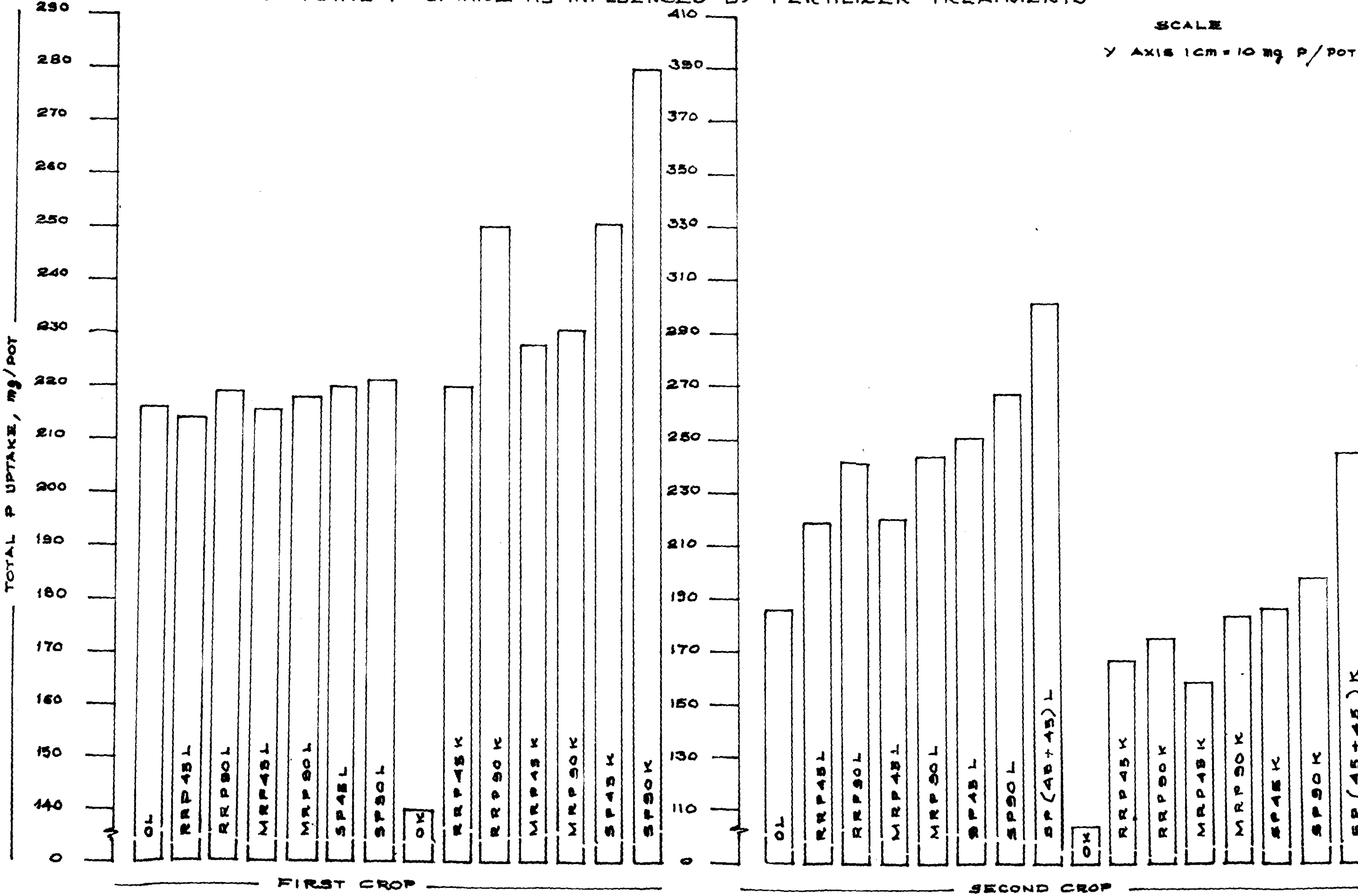


FIG: 13 TOTAL P UPTAKE AS INFLUENCED BY FERTILIZER TREATMENTS

However, in general, the total uptake of P from SP was only 18.42 mg P/pot more than that from two rockphosphates which indicated that the two rockphosphates were 92.43 per cent as efficient as SP in increasing the total uptake of P by rice.

1.3 Potassium

1.3.1 Potassium per cent of straw and root

Potassium per cent of straw and root as influenced by the application of various sources and levels of P in laterite and kari soils is presented in Tables 31, 32, 37 and 38 and their analysis of variance in Appendix II.

Potassium per cent in the straw was relatively higher compared to its level in the root. The level of K in the straw and root was high during the initial stages of growth (Table 37). The decrease observed in the subsequent periods may be due to the higher dry matter production with less vigorous absorption of nutrients leading to the dilution of nutrient concentration.

In the control (no P) treatments, the mean level of K in the straw and root was 1.71 and 1.09 per cent respectively in laterite soil and 1.63 and 0.78 per cent respectively in kari soil which on addition of P

Table 37. Potassium per cent of straw and root as influenced by the treatments at different periods of crop growth (first crop)

Treatment		K% of straw at different periods, fortnights						K% of root at different periods, fortnights					
No.	Notation	1	2	3	4	5	6	1	2	3	4	5	6
1	OL	1.65	2.45	2.83	1.70	0.85	0.78	1.15	1.43	1.80	0.95	0.98	0.78
2	RRP45L	2.10	2.50	3.40	2.05	1.33	1.30	1.60	1.85	1.68	1.38	1.15	1.05
3	RRP90L	2.10	2.75	3.70	2.00	1.23	1.18	1.70	1.95	1.70	1.45	1.23	1.00
4	MRP45L	2.15	2.65	3.50	2.20	1.25	1.10	1.48	1.85	1.55	1.33	1.23	1.03
5	MRP90L	2.15	2.60	3.50	2.13	1.35	1.18	1.63	1.98	1.65	1.40	1.15	1.03
6	SP45L	2.25	2.90	3.40	2.25	1.45	1.33	1.58	2.03	1.70	1.45	1.10	0.98
7	SP90L	2.30	2.90	3.75	2.35	1.48	1.25	1.65	1.98	1.73	1.48	1.18	0.98
8	OK	0.75	2.30	2.43	1.83	1.38	1.08	0.63	0.93	1.03	0.85	0.73	0.58
9	RRP45K	2.70	2.90	3.40	2.78	2.60	2.18	1.78	2.00	2.13	1.58	1.15	0.93
10	RRP90K	2.80	3.20	3.80	2.90	2.53	2.10	1.75	2.08	2.13	1.65	1.30	1.00
11	MRP45K	2.75	3.00	3.40	2.63	2.55	2.13	1.73	2.00	2.13	1.70	1.20	0.93
12	MRP90K	2.85	3.10	3.63	2.60	2.53	2.20	1.73	2.13	2.13	1.68	1.28	1.05
13	SP45K	2.90	3.15	4.00	2.93	2.55	2.15	1.68	2.08	2.10	1.58	1.28	1.00
14	SP90K	2.70	3.50	4.13	2.93	2.58	2.25	1.73	2.10	2.15	1.60	1.30	1.00

Table 38. Mean values of potassium per cent of straw and root as influenced by sources of P, soils and levels of P application (first crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				K% of straw				
1	2.430	2.480	2.540	2.180	2.780	2.480	2.480	2.480
2	2.840	2.840	3.210	2.720	3.210	2.920	3.010	2.960
3	3.580	3.510	3.820	3.540	3.730	3.520	3.750	3.640
4	2.430	2.390	2.620	2.160	2.790	2.470	2.490	2.480
5	1.920	1.920	2.010	1.350	2.550	1.950	1.950	1.950
6	1.690	1.650	1.740	1.220	2.170	1.690	1.690	1.690
Mean	2.480	2.430	2.660	2.190	2.870	2.510	2.560	2.530
				K% of root				
1	1.710	1.640	1.660	1.600	1.730	1.640	1.690	1.670
2	1.970	1.990	2.040	1.940	2.060	1.970	2.030	2.000
3	1.910	1.860	1.920	1.670	2.130	1.880	1.910	1.890
4	1.510	1.530	1.540	1.410	1.640	1.500	1.550	1.530
5	1.210	1.210	1.210	1.170	1.250	1.180	1.240	1.210
6	0.994	1.060	0.990	1.010	0.980	0.980	1.010	0.996
Mean	1.550	1.540	1.560	1.470	1.630	1.530	1.570	1.550

K% of straw		K% of root	
CD(0.05) for periods	= 0.2090	CD(0.05) for periods	= 0.0707
" " soils	= 0.0820	" " soils	= 0.0278
" " sources	= 0.1002	" " levels	= 0.0278
" " soil x period	= 0.2950	" " soil x period	= 0.1001

fertilizers increased significantly to 2.19 and 1.47 per cent respectively in laterite soil and 2.87 and 1.63 per cent respectively in kari soil (Tables 32 and 38). This increase in the level of K in the straw due to the addition of phosphatic fertilizers was 28.07 per cent in laterite soil and 76.07 per cent in kari soil i.e., in the presence of added P, the level of K in the straw and root was significantly higher in kari soil compared to laterite soil due to the better utilisation of added P in kari soil because of its low native available P. But in the absence of added P, the level of K was more in laterite soil due to the higher supply of native P. The increased growth rate of plants in the presence of added P resulted in a higher absorption of nutrients. Also the extended root growth in the presence of added P would have helped the absorption of nutrients more effectively. In addition, the Ca contained in the phosphatic fertilizers also would have contributed to the increased growth of plants in P treated pots, thus resulting in a higher absorption of nutrients.

The mean level of K in the straw in treatments receiving RRP, MRP and SP was 2.48, 2.43 and 2.66 per cent respectively and it was seen that the SP increased the K per cent in the straw significantly over the two rockphosphates (Table 38). But the level of K in the root did not vary significantly with variations in the forms of P added to the soil (Table 38).

As in the case of N, the level of K in the straw failed to register conspicuous increase with increasing levels of P application (Tables 31 and 38).

Level of K in the straw during the third period of sampling showed maximum correlation with grain yield ($r = 0.542^{**}$) compared to other periods.

1.3.2 Uptake of potassium by the straw

Effects of various sources and levels of applied P on the uptake of K by the straw at different growth stages in laterite and kari soils are given in Tables 31, 32, 39 and 40 and their analysis of variance in Appendix II.

Both in the presence and absence of added P, the uptake of K was maximum during the third and fourth periods which represented the stages of maximum accumulation of K in this part (Table 39). From fifth period onwards, the K uptake by the straw tended to decrease, probably due to the translocation of nutrients to the grain from the straw.

In the absence of added P, the uptake of K by straw was 0.687 g K/pot in laterite soil and increased the K per cent in the straw significantly over the two rockphosphates (Table 38). But the level of K in the root did not vary significantly with variations in the forms of P added to the soil (Table 38).

As in the case of N, the level of K in the straw failed to register conspicuous increase with increasing levels of P application (Tables 31 and 38).

Level of K in the straw during the third period of sampling showed maximum correlation with grain yield ($r = 0.542^{**}$) compared to other periods.

1.3.2 Uptake of potassium by the straw

Effects of various sources and levels of applied P on the uptake of K by the straw at different growth stages in laterite and kari soils are given in Tables 31, 32, 39 and 40 and their analysis of variance in Appendix II.

Both in the presence and absence of added P, the uptake of K was maximum during the third and fourth periods which represented the stages of maximum accumulation of K in this part (Table 39). From fifth period onwards, the K uptake by the straw tended to decrease, probably due to the translocation of nutrients to the grain from the straw.

In the absence of added P, the uptake of K by straw was 0.687 g K/pot in laterite soil and

Table 39. Uptake of potassium by the rice straw and straw yield as influenced by the treatments at different periods of crop growth (first crop)

Treatment		Uptake of K (g/pot) at different periods, fortnights						Yield of straw (g/pot) at different periods, fortnights					
No.	Notation	1	2	3	4	5	6	1	2	3	4	5	6
1	OL	0.284	0.727	1.112	0.823	0.580	0.596	14.97	30.60	34.00	40.00	49.00	55.50
2	RRP45L	0.328	0.764	1.220	0.820	0.665	0.717	15.58	30.50	36.00	40.00	50.00	55.13
3	RRP90L	0.321	0.921	1.260	0.900	0.660	0.673	15.30	33.50	34.50	45.00	53.50	57.00
4	MRP45L	0.319	0.838	1.190	0.878	0.594	0.586	14.70	31.50	34.00	40.00	47.50	53.25
5	MRP90L	0.332	0.864	1.295	0.867	0.628	0.651	15.45	33.30	37.00	40.75	46.50	55.40
6	SP45L	0.389	0.929	1.292	0.948	0.726	0.763	17.40	32.00	38.00	42.00	50.00	57.50
7	SP90L	0.394	0.986	1.500	1.069	0.789	0.763	17.20	34.00	40.00	45.50	53.50	62.50
8	OK	0.047	0.413	0.560	0.483	0.497	0.419	6.20	18.00	23.00	26.50	36.00	38.90
9	RRP45K	0.339	0.609	1.130	1.219	1.340	1.190	12.60	21.00	33.00	43.60	57.50	54.60
10	RRP90K	0.584	0.826	1.330	1.370	1.520	1.370	15.50	26.00	35.00	47.00	60.00	65.25
11	MRP45K	0.329	0.600	1.090	1.170	1.290	1.160	11.75	20.00	32.00	44.30	50.50	54.60
12	MRP90K	0.431	0.772	1.270	1.240	1.310	1.270	15.40	25.00	35.00	47.60	52.00	57.50
13	SP45K	0.443	0.974	1.480	1.330	1.301	1.280	15.25	27.50	37.00	45.50	51.00	59.30
14	SP90K	0.480	1.050	1.650	1.400	1.460	1.390	16.30	30.00	40.00	47.50	56.50	62.00

0.403 g K/pot in kari soil which on addition of P fertilizers increased to 0.801 and 1.080 g K/pot in laterite and kari soils respectively (Tables 32 and 40). This increase indicated that the P fertilizers had a direct effect in increasing the K utilization power of the plant and this effect was more pronounced in kari soil due to the higher mobilization of added P. Increased supply of P enhanced the vegetative growth which would have resulted in a higher requirement of other nutrients like K. Though the supply of K was uniform, the higher demand for this nutrient and extended root growth induced by P, would have resulted in a significantly higher K uptake in the presence of added P. Venkataramaiah (1979) also observed an increase in the uptake of K by the straw in the presence of added P.

The increases in the uptake of K due to the application of RRP, MRP and SP were 0.374, 0.328 and 0.485 g K/pot respectively over control which showed that the rockphosphate in general was only 72.37 per cent as efficient as SP in increasing the uptake of K by the straw (Table 40). The significantly higher efficiency of SP is definitely due to the higher immediate availability of Ca and P. Application of P at the rate of 45 kg P_2O_5/ha increased the uptake

Table 40. Mean values of potassium uptake by straw and straw yield as influenced by sources of P, soils and levels of P application (first crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				K uptake by straw (g/pot)				
1	0.393	0.353	0.415	0.347	0.427	0.358	0.416	0.387
2	0.779	0.768	0.985	0.883	0.805	0.786	0.903	0.844
3	1.240	1.210	1.480	1.290	1.320	1.234	1.380	1.309
4	1.080	1.040	1.190	0.913	1.290	1.060	1.140	1.099
5	1.040	0.956	1.070	0.677	1.368	0.986	1.060	1.022
6	0.987	0.916	1.050	0.692	1.280	0.948	1.020	0.984
Mean	0.919	0.873	1.030	0.801	1.080	0.895	0.987	0.941
				Straw yield (g/pot)				
1	14.73	14.31	16.49	15.90	14.45	14.53	15.82	15.18
2	27.75	27.46	30.88	32.47	24.92	27.08	30.30	28.69
3	34.63	34.50	38.75	36.58	35.33	35.00	36.92	35.96
4	43.91	43.16	45.13	42.21	45.92	42.56	45.56	44.06
5	53.75	49.13	52.75	50.17	53.58	50.08	53.67	51.88
6	58.00	55.19	59.06	55.96	58.88	55.73	59.11	57.42
Mean	38.79	37.29	40.51	38.88	38.85	37.49	40.23	38.87

K uptake

CD(0.05) for	periods	= 0.0771
" "	soils	= 0.0302
" "	sources	= 0.0370
" "	levels	= 0.0302
" "	soil x period	= 0.1090

Straw yield

CD(0.05) for	periods	= 3.687
" "	levels	= 1.446
" "	soil x period	= 5.214

of K by 0.350 g K/pot and further increase of P application to 90 kg P_2O_5/ha resulted in a significant increase of 0.092 g K/pot. When the soils and sources of P were taken separately, again the K uptake by straw increased with increasing levels of application of P, though not statistically significant (Table 31). Uptake of K by the straw during the second period showed maximum correlation with grain yield ($r = 0.499^{**}$).

1.3.3 Uptake of potassium by the grain

Uptake of K by the grain as affected by the variations in the sources and levels of applied P in laterite and kari soils is presented in Table 41 and the analysis of variance in Appendix V.

The per cent of K in the grain in the absence of added P was 0.150 and 0.158 in laterite and kari soils respectively which on addition of P fertilizers increased to 0.186 and 0.177 per cent in these soils. Thus, a significant increase in the level of K in the grain over control due to the addition of P fertilizers was observed only in kari soil. In this soil, SP at both levels and rockphosphates at higher levels did not differ significantly in increasing the K per cent of the grain though SP registered relatively higher values. However the two rockphosphates at lower level of application were on par with that of the control (no P) treatment in increasing the level of K in the grain. In laterite soil also, relatively higher K per cent was observed in treatments receiving SP at higher level of application (0.198).

Application of P fertilizers, significantly increased the uptake of K by the grain over control to the extent of 0.041 and 0.980 g K/pot in laterite and kari soils respectively i.e., the uptake of K in the presence of added P was 41.84 per cent more in kari soil compared to laterite soil. The higher values of K uptake observed in kari soil in the presence of added P was obviously due to the higher dissolution of added P in this soil leading to the release of Ca which in turn increased the absorption of K.

In kari soil, among the various P treatments, SP at both levels and RRP at higher level were on par, though SP registered relatively higher value. Application of MRP at both rates and RRP at the lower rate did not differ significantly in increasing the uptake of K by the grain. In the case of laterite soil, SP and RRP at the rates of 90 kg P_2O_5/ha increased the uptake of K compared to all the other treatments which were on par with that of control (no P).

In general, the two rockphosphates increased 85.72 per cent of the uptake of K produced by the application of SP as the source of P. The superiority of SP over the two rockphosphates is due to the higher immediate availability of Ca and P. Higher level of application of P increased the uptake of K by the grain though the increase was not in proportion to the added P.

1.3.4 Total uptake of potassium

Total uptake of K as influenced by various treatments is presented in Table 41 and the analysis of variance in Appendix V.

When no P was added, the total uptake was 40.55 per cent more in laterite soil (0.669 g K/pot) compared to kari soil (0.476 g K/pot). By the application of P fertilizers, the total uptake of K by rice increased significantly over control to the extent of 0.123 and 0.897 g K/pot in laterite and kari soils respectively. Though the application of K was done uniformly in all the treatments, the growth of plants would have been limited by the low level of available P in the soil, and so the application of P resulted in an increased dry matter production and higher uptake of K.

In kari soil, SP at the higher level of application was significantly superior to other treatments and in laterite soil, the levels of application of SP were on par and significantly superior to rockphosphates at both levels of application. In both the soils, the two rockphosphates did not vary much which indicated that their transformation patern was similar in these two soils. In general, the total uptake of K in treatments receiving rockphosphates was 86.55 and 92.46 per cent of those receiving SP in laterite and kari soils respectively. The increase in the total uptake of K with increasing levels of application of P was not pronounced.

2. Yield of straw and grain

2.1 Yield of straw

Effects of various sources and levels of applied P on the yield of straw at different stages of crop growth in laterite and kari soils are given in Tables 31, 32, 39 and 40 and their analysis of variance in Appendix II.

In all the treatments, the rate of increase in the straw yield was maximum during the second fortnight (88.99 per cent) which represented the maximum tillering stage (Table 39). Further increase was relatively low due to the less vigorous absorption of nutrients leading to the reduced rate of dry matter production.

Table 32 shows that in the absence of added P, the mean straw yield from laterite soil (37.68 g/pot) was 63.56 per cent more than that from kari soil (23.95 g/pot). But when P fertilizers were added, straw yield was significantly increased to 38.88 and 38.85 g/pot in laterite and kari soils respectively (Table 40) i.e., the straw yield in laterite soil was increased by 1.2 g/pot due to the addition of P fertilizers, while the increase in kari soil was 14.9 g /pot which accounted to 61.65 per cent more than that of control. Because of the higher supply of native P in laterite soil the nutrient uptake and dry matter production were not limited and so the effect of P fertilizers in increasing the straw yield was not pronounced in laterite soil. However, in kari soil, P is found to be a limiting factor and the nutrient uptake and dry matter production were hindered in the absence of sufficient quantity of P. So in kari soil, the effect of P fertilization was more pronounced with regard to the increase in the straw yield.

The increase in the straw yield over control due to the addition of SP (9.695 g/pot) was 2.47 g/pot more than the two rockphosphates (7.225 g/pot) and the increase was not found to be significant (Table 40). This showed that the two rockphosphates in general was 74.52 per cent as effective as SP in increasing the straw yield. The superiority of SP over the two rockphosphates was due to the higher immediate availability of P and other nutrients like Ca and S which in turn increase the nutrient absorption and dry matter production.

Application of P at the rate of 45 kg P_2O_5/ha increased the straw yield to the extent of 21.66 per cent of that of control and further increase to 90 kg P_2O_5/ha caused 41.05 per cent increase in straw yield over the lower level. Also when the soils and sources of P were considered independently again the straw yield increased with increasing levels of application (Table 31). This increase in straw yield with increasing levels of application of P was obviously due to the increase in the content of available P.

2.2 Yield of grain

Influence of various treatments on the yield of grain is presented in Table 41 and Fig.14 and the analysis of variance in Appendix V. The relationships of grain yield with nutrient uptake and available P in soil at the time of harvest are given in Table 44.

Grain yield in the absence of added P from laterite soil (49.42 g/pot) was higher than that from kari soil (36.79 g/pot), the reason being the higher growth rate and dry matter production due to the higher availability of native P under submergence in laterite soil. On addition of P fertilizers, the grain yield was increased to 50.17 g/pot in laterite soil and 54.97 g/pot in kari soil. When the percentage increase in the yield of grain due to the addition of P fertilizers over control (no P) was considered there was 49.42 per cent more yield over control in kari soil while in laterite soil the increase was only 1.52 per cent. Thus in the case of laterite soil, the P treatments irrespective of forms and levels, failed to register significant increase in the yield of grain as compared to control due to the unrestricted growth and dry matter production occurring in the presence of an unlimited supply of native available P. However, in kari soil, P was

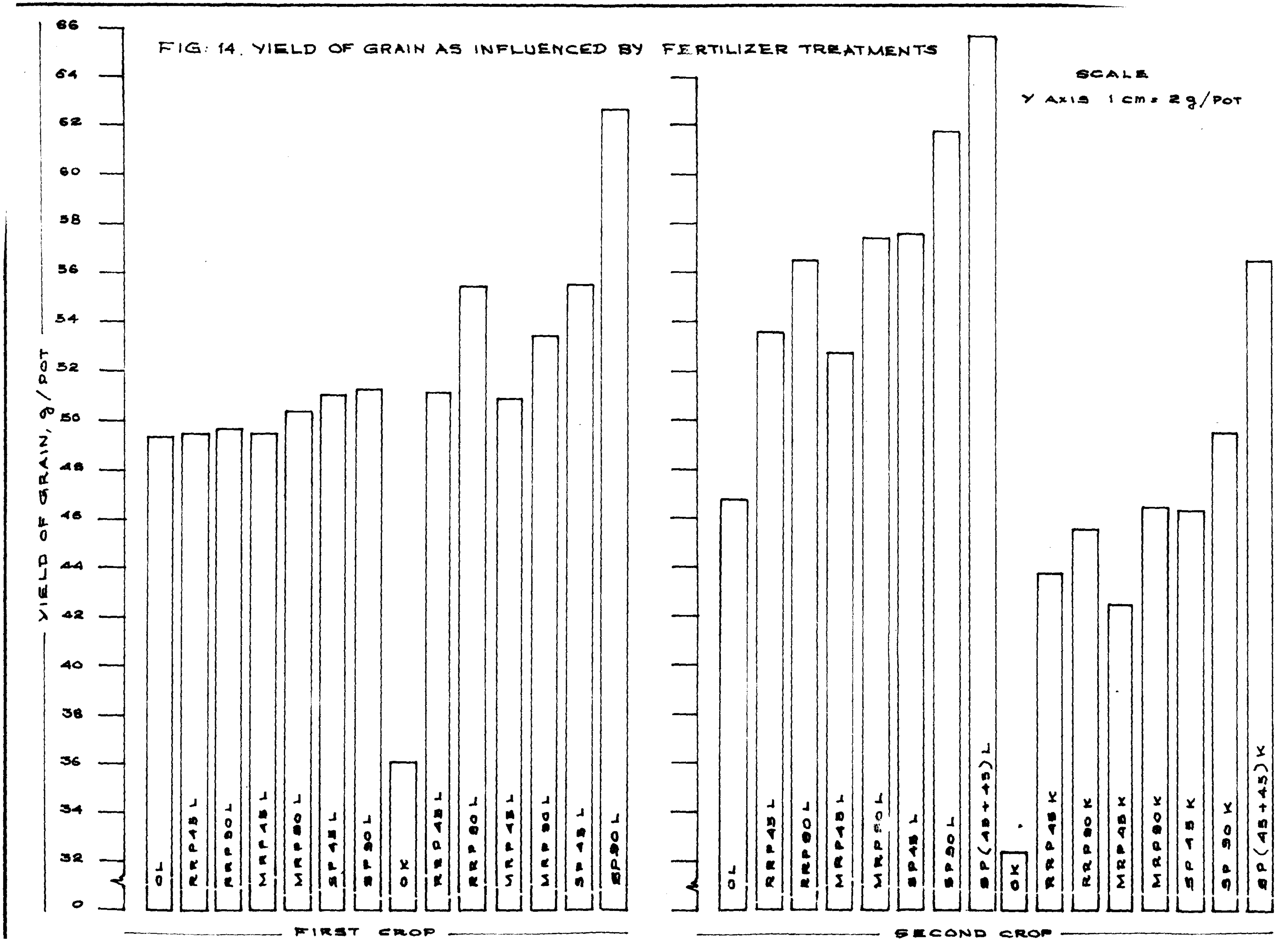


FIG: 14. YIELD OF GRAIN AS INFLUENCED BY FERTILIZER TREATMENTS
SCALE
Y AXIS 1 cm = 2 g/POT
YIELD OF GRAIN, g/POT
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
0
OL
RRP45L
RRP90L
MRP45L
MRP90L
SP45L
SP90L
OK
RRP45L
RRP90L
MRP45L
MRP90L
SP45L
SP90L
OL
RRP45L
RRP90L
MRP45L
MRP90L
SP45L
SP90L
SP(45+45)L
OK
RRP45K
RRP90K
MRP45K
MRP90K
SP45K
SP90K
SP(45+45)K
FIRST CROP
SECOND CROP

Table 41. Grain yield, nutrient per cent and uptake by grain and total uptake of nutrients as influenced by various treatments (first crop)

Treatment		Yield of grain, g/pot	Per cent of nutrients			Uptake of nutrients g/pot			Total uptake of nutrients		
No.	Notation		N	P	K	N	P	K	N g/pot	P mg/pot	K g/pot
1	OL	49.42	1.105	0.337	0.150	0.546	0.169	0.074	0.830	216.4	0.669
2	RRP45L	49.44	1.115	0.323	0.175	0.551	0.160	0.087	0.853	214.3	0.804
3	RRP90L	49.62	1.120	0.328	0.190	0.556	0.168	0.098	0.844	219.2	0.770
4	MRP45L	49.40	1.120	0.341	0.180	0.553	0.169	0.089	0.799	216.9	0.700
5	MRP90L	50.35	1.120	0.341	0.185	0.565	0.172	0.093	0.867	218.8	0.744
6	SP45L	51.04	1.130	0.341	0.190	0.577	0.174	0.097	0.844	220.2	0.862
7	SP90L	51.15	1.140	0.341	0.198	0.583	0.175	0.107	0.919	221.3	0.869
8	0K	36.79	1.090	0.305	0.158	0.402	0.112	0.057	0.482	139.9	0.476
9	RRP45K	51.70	1.120	0.332	0.165	0.579	0.172	0.085	0.797	220.6	1.274
10	RRP90K	55.38	1.130	0.341	0.175	0.626	0.189	0.098	0.928	250.3	1.468
11	MRP45K	50.91	1.120	0.341	0.170	0.570	0.174	0.087	0.812	228.6	1.247
12	MRP90K	53.71	1.130	0.342	0.175	0.608	0.184	0.094	0.878	230.4	1.359
13	SP45K	55.42	1.130	0.337	0.185	0.625	0.186	0.103	0.956	250.8	1.377
14	SP90K	62.67	1.150	0.337	0.193	0.719	0.208	0.121	1.110	280.9	1.514
CD(0.05)		5.306	N.S	N.S	0.0266	0.0631	0.0266	0.0239	0.1989	32.56	0.0438

found to be a limiting factor which hindered the nutrient uptake leading to the reduced rate of dry matter production and hence the addition of P fertilizers had resulted in an significant increase in the yield of grain in this soil.

In both the soils, among the P treatments, application of SP at higher level recorded relatively higher values of grain yield compared to other treatments though the increase was statistically significant only in kari soil. Results showed that the two rockphosphates at both the levels of application and SP at lower level of application were on par in kari soil which indicated that the available P released from rockphosphates at the higher level of application was equivalent to the available P from SP at lower level of application in increasing the yield of grain. However, the two rockphosphates did not vary with regard to the yield of grain. In general, the grain yield by the application of SP was increased to the extent of 3.86 per cent over the two rockphosphates in laterite soil and 11.56 per cent in kari soil. Thus, in general, the two rockphosphates was 93.18 per cent as efficient as SP in increasing the yield of grain in these acid soils under study.

3. Available phosphorus

Contents of available P (Bray 1 and 2) as affected by various sources and levels of applied P in laterite and kari soils are presented in Tables 31, 32, 42 and 43 and the analysis of variance in Appendix IV.

In general, both in the presence and absence of added P, the content of available P (Bray 1 and 2) decreased with the advancement of crop growth. The maximum content of available P was observed during the first fortnight of sampling and then gradually decreased upto the time of harvest (Table 42). Higher level of available P observed during the first fortnight of sampling was due to the release of large quantity of available P due to flooding from the native P in addition to that from the added P, and at the same time the absorption of P by the plant was relatively low during this period. The decrease observed in the subsequent periods is due to the absorption of P by the plant.

Originally (before transplanting) the content of available P (air dried soil) was 2.77 (Bray 1) and 11.30 (Bray 2) ppm in laterite soil and 2.54 (Bray 1) and 8.03 (Bray 2) ppm in kari soil which on addition of P fertilizers increased to 4.42 (Bray 1) and

Table 42. Available P (ppm) of air dried soil as influenced by the treatments at different periods of crop growth (first crop)

Treatment		Available P (Bray 1) at different periods, fortnights							Available P (Bray 2) at different periods, fortnights						
No.	Notation	0	1	2	3	4	5	6	0	1	2	3	4	5	6
1	OL	2.77	6.41	4.12	3.37	2.97	3.05	2.53	11.30	17.88	15.22	13.04	9.96	7.32	5.32
2	RRP45L	3.98	6.15	5.51	4.24	4.28	4.04	3.85	11.75	18.76	17.55	15.08	10.83	8.85	6.46
3	RRP90L	4.06	8.92	6.79	5.23	4.47	4.19	4.25	12.19	20.20	19.01	15.37	10.84	9.33	6.78
4	MRP45L	3.37	8.62	6.82	3.77	4.55	4.42	4.53	12.04	19.05	17.48	14.96	10.83	8.54	6.34
5	MRP90L	4.37	9.17	8.16	4.94	4.90	4.36	4.38	12.51	20.64	19.26	15.77	10.84	10.21	5.91
6	SP45L	5.06	7.17	5.80	4.76	4.66	4.59	4.58	14.03	19.79	20.40	16.17	11.64	10.10	5.80
7	SP90L	5.68	8.29	6.10	7.09	4.95	4.11	4.51	16.78	21.77	18.89	16.63	12.58	9.89	7.87
8	OK	2.54	3.35	2.56	1.93	1.68	1.95	1.50	8.03	16.01	11.87	12.12	9.75	7.42	5.70
9	RRP45K	3.52	5.94	4.10	3.09	2.86	2.85	2.64	14.97	23.62	20.13	17.40	12.37	11.01	9.19
10	RRP90K	3.98	6.38	4.57	3.58	3.65	3.56	3.27	15.32	25.91	21.19	19.13	14.66	13.17	10.07
11	MRP45K	3.28	6.89	4.95	2.74	2.59	2.84	2.72	14.07	23.48	20.18	17.52	12.39	11.26	9.11
12	MRP90K	3.28	7.45	5.61	3.49	3.38	3.48	3.32	15.21	25.99	20.98	18.45	14.21	13.34	9.74
13	SP45K	4.65	7.44	7.21	3.50	3.57	3.56	3.38	18.08	25.66	21.58	19.53	15.91	9.97	8.00
14	SP90K	5.30	9.88	9.55	4.93	3.63	3.52	3.28	18.99	27.52	22.27	21.42	17.51	12.94	11.13

Table 43. Mean values of available P (Bray 1 and 2) as influenced by sources of P, soils and levels of P application, ppm (first crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				Available P (Bray 1), ppm				
0	3.89	3.57	5.17	4.42	4.00	3.98	4.44	4.21
1	6.85	8.03	8.19	8.05	7.33	7.03	8.35	7.69
2	5.24	6.38	7.16	6.53	5.99	5.73	6.79	6.26
3	4.03	3.73	5.07	5.00	3.56	3.68	4.88	4.28
4	3.81	3.85	4.20	4.63	3.28	3.75	4.16	3.96
5	3.66	3.77	4.07	4.36	3.29	3.72	3.95	3.83
6	3.50	3.74	3.93	4.35	3.09	3.62	3.83	3.72
Mean	4.43	4.73	5.39	5.34	4.36	4.50	5.20	4.85
				Available P (Bray 2), ppm				
0	13.55	13.46	16.97	13.21	16.10	14.15	15.16	14.66
1	22.14	22.29	23.95	20.22	25.37	21.93	23.66	22.79
2	19.48	19.48	20.49	18.57	21.07	19.37	20.66	19.82
3	16.74	16.67	18.44	15.66	18.91	16.78	17.79	17.28
4	12.17	12.07	14.41	11.26	14.51	12.33	13.44	12.88
5	10.59	10.84	10.73	9.49	11.95	9.95	11.48	10.72
6	8.37	7.77	8.19	6.50	9.70	7.48	8.75	8.11
Mean	14.72	14.65	16.17	13.56	16.79	14.57	15.79	15.18

Bray 1

CD(0.05) for periods = 0.6694
" " soils = 0.2626
" " sources = 0.3216
" " levels = 0.6694

Bray 2

CD(0.05) for periods = 1.395
" " soils = 0.5473
" " levels = 0.5473
" " sources = 0.6703

4.00 (Bray 1) ppm in laterite and kari soils respectively (Tables 42 and 43). The mean available P contents in the control treatments in laterite and kari soils during the period of plant growth were 3.60 and 2.21 ppm respectively i.e., the laterite soil contained 61.31 per cent more Bray 1 P than that of kari soil (Table 32). This significantly higher content of available P in laterite soil was due to the higher availability of native P released after the intensive reduction reactions occurring in the laterite soil. However, the rate of increase in the available P due to the addition of P fertilisers over control was high in kari soil compared to laterite soil due to the higher dissolution of added P in kari soil.

The mean contents of available P (Bray 1) from RRP, MRP and SP were 1.525, 1.825 and 2.480 ppm respectively over control which showed that the two rockphosphates in general were only 67.54 per cent as efficient as SP with regard to the content of available P (Table 43). This indicates that major part of P from rockphosphates was remaining in an unavailable form for the first crop and this remaining P can be utilized by the succeeding crops.

Table 44. Interrelationships of nutrient per cent, nutrient uptake, grain yield and available P at the time of harvest (first crop)

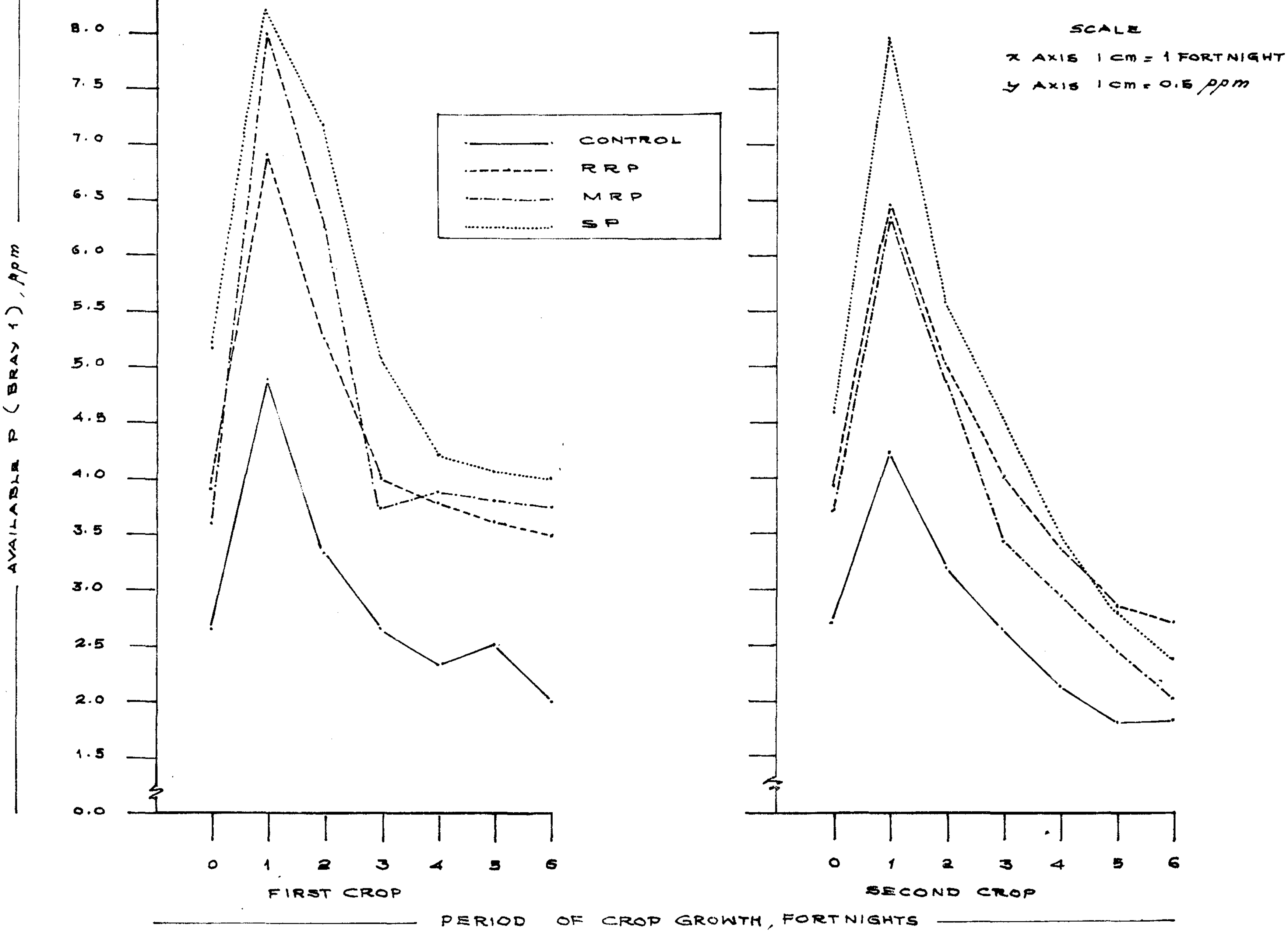
(coefficients of linear correlation)

	N% of straw	P% of straw	K% of straw	N uptake by straw	P uptake by straw	K uptake by straw	Bray 1	Bray 2	Yield of grain
N% of straw	--	-0.106	-0.037	0.764**	0.043	0.067	0.114	0.196	0.514**
P% of straw		--	0.335	0.245	0.872**	0.346	-0.118	0.411*	-0.141
K% of straw			--	0.208	0.479**	0.959**	-0.206	0.714**	0.280
N uptake by straw				--	0.492**	0.369	0.145	0.417*	0.464*
P uptake by straw					--	0.574**	0.121	0.543**	0.106
K uptake by straw						--	-0.140	0.729**	0.318
Bray 1 P							--	-0.314	0.291
Bray 2 P								--	0.451*
Yield of grain									--

** Significant at 1 per cent level

* Significant at 5 per cent level

FIG: 15. AVAILABLE P (BRAY 1) AS INFLUENCED BY FORMS OF P FERTILIZERS



Available P (Bray 1) as influenced by forms of P fertilizers is graphically represented in Fig.15.

Significant increase in available P (Bray 1 and 2) was observed when the addition of P fertilizers was increased to 90 kg P_2O_5/ha from 45 kg P_2O_5/ha. The increase in Bray 1 P observed by increasing the level of application was 0.70 and 1.70 ppm in laterite and kari soils respectively (Table 31). In general increasing the level of application increased the available P (Bray 1 and 2) to the extent of 11.97 per cent over the lower level.

Linear coefficient of correlation between available P (Bray 2) and yield of grain revealed that the contents of available P during all periods of sampling were positively correlated with grain yield, but maximum correlation was obtained with the available P content of the second period ($r = 0.626^{**}$). Relatively higher correlation values for grain yield was obtained with Bray 2 P compared to Bray 1 P during all periods of sampling.

B. Second Crop

The residual effect of the two rockphosphates in comparison with that of superphosphate was assessed by studying the nutrient uptake and yield (straw and grain) of the second crop.

1. Nutrient uptake

1.1 Nitrogen

1.1.1 Uptake of nitrogen by the straw

Results on the effect of various sources and levels of applied P on the uptake of N by the straw at different periods of crop growth in laterite and kari soils are presented in Tables 45 to 50 and their analysis of variance in Appendix III.

By the addition of P fertilizers the N per cent in the straw increased from 2.24 to 2.39 in laterite soil and from 1.59 to 1.75 per cent in kari soil (Table 46 and 48). Both in the P treated and control (no P) conditions, the uptake of N by the straw was higher in laterite soil compared to kari soil, probably due to the release of relatively larger amount of native available P formed, in addition to the added P, consequent to the intensive reduction reactions occurring in the laterite soil on flooding. The N uptake by the straw in the control (no P)

Table 45. Nitrogen per cent of straw and root as influenced by the treatments at different periods of crop growth (second crop)

Treatment No.	Treatment Notation	N% of straw at different periods, fortnights 1	2	3	4	5	6	N% of root at different periods, fortnights 1	2	3	4	5	6
1	OL	2.02	3.32	3.32	2.27	1.60	0.93	1.52	1.64	1.47	1.10	0.93	0.26
2	RRP45L	2.15	3.45	3.40	2.48	1.67	1.01	1.56	1.77	1.56	1.18	1.01	0.51
3	RRP90L	2.18	3.45	3.43	2.52	1.68	1.05	1.60	1.81	1.64	1.26	1.14	0.51
4	MRP45L	2.14	3.49	3.40	2.44	1.62	0.97	1.55	1.72	1.51	1.09	1.14	0.42
5	MRP90L	2.23	3.53	3.43	2.56	1.68	1.55	1.60	1.85	1.64	1.30	1.12	0.46
6	SP45L	2.14	3.45	3.40	2.52	1.68	1.01	1.60	1.77	1.68	1.35	1.22	0.51
7	SP90L	2.23	3.49	3.45	2.56	1.64	1.01	1.56	1.76	1.68	1.31	1.14	0.51
8	OK	1.77	2.06	1.89	1.75	1.31	0.76	1.35	1.52	1.35	1.05	0.76	0.17
9	RRP45K	1.85	2.19	2.01	1.77	1.52	0.84	1.43	1.64	1.43	1.10	0.84	0.26
10	RRP90K	1.87	2.14	2.06	1.85	1.56	0.93	1.47	1.63	1.52	1.14	0.89	0.34
11	MRP45K	1.89	2.15	2.06	1.83	1.47	0.86	1.43	1.68	1.47	1.14	0.80	0.30
12	MRP90K	1.92	2.19	2.02	1.85	1.60	0.97	1.50	1.60	1.47	1.09	0.84	0.38
13	SP45K	1.94	2.23	2.06	1.89	1.64	0.97	1.51	1.72	1.52	1.14	0.88	0.30
14	SP90K	1.89	2.19	2.02	1.94	1.64	1.39	1.52	1.68	1.52	1.18	0.93	0.34
15	SP(45+45)L	2.17	3.02	2.68	2.49	1.81	1.18	1.55	1.85	1.79	1.43	1.22	0.59
16	SP(45+45)K	2.07	2.31	2.10	1.91	1.68	1.13	1.60	1.85	1.68	1.51	1.35	0.88

Table 46. Mean values of nitrogen per cent of straw and root as influenced by sources of P, soils and levels of P application (second crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				N% of straw				
1	2.01	2.04	2.05	2.18	2.89	2.02	2.05	2.03
2	2.81	2.84	2.84	3.47	2.19	2.82	2.83	2.83
3	2.72	2.73	2.73	3.42	2.04	2.72	2.73	2.73
4	2.15	2.17	2.23	2.51	1.85	2.15	2.21	2.18
5	1.61	1.59	1.65	1.66	1.57	1.60	1.63	1.61
6	0.96	1.09	1.09	1.10	0.99	0.94	1.15	1.04
Mean	2.04	2.08	2.10	2.39	1.75	2.04	2.10	2.07
				N% of root				
1	1.51	1.52	1.54	1.57	1.48	1.51	1.50	1.53
2	1.72	1.71	1.73	1.78	1.67	1.72	1.73	1.72
3	1.54	1.52	1.59	1.62	1.49	1.53	1.58	1.55
4	1.16	1.15	1.24	1.25	1.13	1.16	1.21	1.19
5	0.97	0.97	1.04	1.12	0.86	0.98	1.01	0.99
6	0.37	0.39	0.41	0.46	0.32	0.36	0.42	0.39
Mean	1.21	1.21	1.26	1.30	1.16	1.21	1.25	1.23

N% of straw

CD(0.05) for periods = 0.2190
" " soils = 0.0860
" " soil x period = 0.3096

N% of root

CD(0.05) for periods = 0.1550
" " soils = 0.0607

treatment was 0.673 and 0.348 g N/pot in laterite and kari soils respectively which on addition of P fertilisers increased to 0.909 and 0.542 g N/pot in these soils (Table 48 and 50). The rate of increase in the uptake of N over control due to the addition of P fertilisers was 35.07 per cent in laterite soil and 55.75 per cent in kari soil. However, the contribution of added P in increasing the uptake of N in laterite soil (0.236 g N/pot) was 21.65 per cent more than that of kari soil (0.194 g N/pot).

Uptake of N from RRP, MRP and SP was 0.181, 0.191 and 0.273 g N/pot respectively over control which showed that the superphosphate was 46.77 per cent more efficient than the two rockphosphates in increasing the N uptake by the straw, though N per cent in the straw and root did not increase significantly due to the addition of SP compared to the two rockphosphates (Table 46 and 50). In treatments receiving SP, the dry matter production has been increased thereby registering high values for N uptake in spite of low N per cent of the straw.

The maximum uptake of N in all the treatments was observed during the third and fourth periods. From fourth period onwards it tended to decrease and attained the minimum value at the time of harvest

Table 47. Mean values of per cent of nutrients, nutrient uptake and available P as influenced by levels of P application (second crop)

Levels of P_2O_5, kg/ha	Soil			Sources of P		
	Laterite	Kari		PRP	MRP	SP
45	2.350	1.730	N% of straw	2.030	2.020	2.080
90	2.420	1.780		2.060	2.130	2.120
45	1.280	1.140	N% of root	1.180	1.190	1.260
90	1.320	1.170		1.250	1.240	1.260
45	0.851	0.510	N uptake by straw, g/pot	0.654	0.639	0.747
90	0.969	0.529		0.729	0.764	0.821
45	0.098	0.076	P% of straw	0.087	0.086	0.088
90	0.102	0.075		0.088	0.087	0.091
45	0.029	0.030	P% of root	0.029	0.028	0.032
90	0.030	0.034		0.033	0.032	0.032
45	41.56	25.64	P uptake by straw, mg/pot	32.19	31.62	36.99
90	47.57	27.36		35.67	36.68	40.04
45	2.860	2.540	K% of straw	2.670	2.680	2.760
90	2.890	2.570		2.730	2.690	2.780
45	1.330	1.130	K% of root	1.190	1.190	1.290
90	1.390	1.210		1.290	1.810	1.320
45	1.090	0.778	K uptake by straw, g/pot	0.899	0.882	1.030
90	1.230	0.849		1.003	1.010	1.104
45	39.37	31.72	Straw yield, g/pot	34.61	38.89	38.15
90	43.52	34.12		37.51	38.38	40.56
45	4.240	3.220	Available P (Bray 1), ppm	3.680	3.360	4.150
90	5.410	3.360		4.350	4.030	4.770
45	12.53	9.320	Available P (Bray 2), ppm	10.76	10.52	11.43
90	13.01	9.480		10.80	11.63	11.49

(Table 49). Application of P at higher level significantly increased the mean uptake of N to the extent of 0.091 g N/pot when soils, sources and different growth stages were pooled (Table 50). But N per cent of straw and root did not increase significantly with increasing levels of application of P (Table 45, 46 and 47). The increase in the uptake of N due to the increase in the level of application was 37.57 per cent, obviously due to the increase in the available P content of the soil which in turn enhances the dry matter production. Available P (Bray 1) and N uptake at different periods of crop growth were positively correlated with maximum correlation during the first fortnight ($r = 0.796^{**}$).

When the contribution of native P and P added initially at the rate of 45 kg P_2O_5/ha in increasing the uptake of N by the straw was deducted, the contribution of second application of SP at the rate of 45 kg P_2O_5/ha was 0.040 g N/pot in laterite soil and 0.109 g N/pot in kari soil (Table 49). Results revealed that in laterite soil twice the application of SP was only 2.85 per cent more efficient than the application of the same quantity of P initially (for first crop) as rockphosphates. In the case of

Table 48. Mean values of nutrient per cent and uptake, straw yield and available P as influenced by P sources and soil (second crop)

Soil	Control (No P)		RRP	MRP	SP
Laterite	2.240	N% of straw	2.370	2.420	2.380
Kari	1.590		1.710	1.730	1.810
Laterite	1.150	N% of root	1.280	1.280	1.340
Kari	1.030		1.140	1.140	1.180
Laterite	0.673	N uptake by straw, g/pot	0.871	0.885	0.974
Kari	0.348		0.513	0.518	0.594
Laterite	0.083	P% of straw	0.099	0.098	0.103
Kari	0.064		0.075	0.075	0.076
Laterite	0.016	P% of root	0.030	0.029	0.030
Kari	0.013		0.033	0.030	0.030
Laterite	29.84	P uptake by straw, mg/pot	42.26	42.54	48.89
Kari	16.78		25.59	25.75	28.14
Laterite	2.370	K% of straw	2.840	2.830	2.960
Kari	2.300		2.550	2.530	2.580
Laterite	1.220	K% of root	1.350	1.340	1.390
Kari	1.030		1.140	1.160	1.270
Laterite	0.757	K uptake by straw, g/pot	1.106	1.109	1.277
Kari	0.519		0.795	0.787	0.859
Laterite	33.12	Straw yield, g/pot	39.89	40.25	44.22
Kari	24.09		32.24	32.02	34.49
Laterite	3.470	Available P (Bray 1), ppm	4.830	4.240	5.420
Kari	1.970		3.190	3.160	3.510
Laterite	5.530	Available P (Bray 2), ppm	12.43	12.95	13.07
Kari	4.340		9.13	9.21	9.86

Table 49. Uptake of nitrogen and phosphorus by rice straw as influenced by the treatments at different periods of crop growth (second crop)

Treatment		Uptake of N (g/pot) at different periods, fortnights						Uptake of P (mg/pot) at different periods, fortnights					
No.	Notation	1	2	3	4	5	6	1	2	3	4	5	6
1	OL	0.252	0.747	0.982	0.862	0.718	0.475	5.90	15.10	25.20	43.35	44.10	45.50
2	RRP45L	0.343	0.895	1.224	1.060	0.833	0.578	8.28	19.10	41.25	58.60	58.50	53.70
3	RRP90L	0.413	1.080	1.340	1.190	0.921	0.637	9.83	22.20	46.30	67.50	64.20	57.80
4	MRP45L	0.335	0.907	1.140	1.040	0.805	0.552	7.84	19.15	38.20	58.90	54.65	52.75
5	MRP90L	0.440	1.090	1.390	1.280	0.950	0.690	9.84	23.95	46.20	70.10	68.90	61.20
6	SP45L	0.392	1.030	1.350	1.230	0.965	0.633	9.42	23.20	43.50	68.10	70.80	62.95
7	SP90L	0.446	1.190	1.510	1.290	0.987	0.661	11.00	26.20	52.35	76.95	75.25	65.70
8	OK	0.102	0.350	0.475	0.479	0.420	0.277	1.79	9.34	17.50	23.50	23.60	24.95
9	RRP45K	0.241	0.437	0.580	0.622	0.629	0.408	5.79	12.90	24.60	34.50	35.30	33.80
10	RRP90K	0.273	0.471	0.645	0.703	0.690	0.455	6.53	13.45	26.60	38.50	38.80	36.40
11	MRP45K	0.229	0.451	0.604	0.622	0.596	0.394	5.93	13.15	25.45	34.80	36.05	33.20
12	MRP90K	0.270	0.513	0.645	0.711	0.698	0.487	5.75	14.70	26.00	36.05	30.90	39.05
13	SP45K	0.291	0.534	0.622	0.711	0.729	0.486	6.25	15.55	26.75	36.05	42.40	39.05
14	SP90K	0.282	0.526	0.634	0.763	0.806	0.745	6.13	15.35	26.10	40.20	42.70	41.30
15	SP(45+45)L	0.469	1.116	1.195	1.234	1.683	0.742	10.92	24.48	44.10	66.33	64.62	63.19
16	SP(45+45)K	0.350	0.578	0.702	0.834	0.884	0.679	10.62	17.50	32.60	45.50	57.85	51.30

Table 50. Mean values of nitrogen and phosphorus uptake by rice straw as influenced by sources of P, soils and levels of P application (second crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				N uptake (g/pot)				
1	0.317	0.318	0.353	0.395	0.264	0.305	0.354	0.329
2	0.705	0.739	0.819	1.021	0.489	0.709	0.800	0.755
3	0.947	0.946	1.029	1.330	0.621	0.919	1.080	0.974
4	0.896	0.914	0.999	1.180	0.688	0.881	0.989	0.935
5	0.768	0.762	0.872	0.902	0.691	0.759	0.842	0.800
6	0.519	0.530	0.621	0.625	0.496	0.508	0.612	0.560
Mean	0.692	0.702	0.784	0.909	0.542	0.680	0.771	0.726
				P uptake (mg/pot)				
1	7.600	7.340	8.190	9.370	6.060	7.250	8.180	7.710
2	16.91	17.74	20.08	22.30	14.18	17.18	19.31	18.24
3	34.69	33.96	37.18	44.63	25.92	33.29	37.26	35.28
4	49.76	49.95	55.26	66.63	36.68	48.48	54.84	51.66
5	49.19	49.49	57.79	65.29	39.02	49.61	54.70	52.15
6	45.43	46.40	52.61	59.17	37.13	45.81	50.48	48.15
Mean	33.93	34.15	38.52	44.57	26.49	33.60	37.46	35.53

N uptake

CD(0.05) for periods = 0.0689
" " soils = 0.0270
" " sources = 0.0331
" " levels = 0.0270
" " soil x period = 0.0975

P uptake

CD(0.05) for periods = 4.250
" " soils = 1.668
" " sources = 2.043
" " levels = 1.668
" " soil x period = 6.015

kari soil, application of SP at the rate of 90 kg P_2O_5/ha in two equal doses was 22.76 and 7.19 per cent more efficient than the application of same quantity of P as rockphosphates and SP initially respectively. The higher efficiency of added phosphatic fertilisers applied initially in laterite soil irrespective of their water solubility indicates that the residual effect of the initially applied P was more pronounced in this soil compared to kari soil due to the lesser utilization of added P in the first crop. Better performance of the treatments receiving SP twice was attributed to the higher immediate availability of P and Ca which enhanced the plant growth. Uptake of N by the straw was positively and significantly correlated with the yield of straw and grain. Uptake of N by straw during the fifth period showed maximum correlation with the yield of straw and grain ($r = 0.787^{**}$ and 0.767^{**} for straw and grain respectively). Uptake of N by straw during the fourth period showed maximum correlation with the uptake of N by grain ($r = 0.855^{**}$).

1.1.2 Uptake of nitrogen by the grain

Uptake of N by the grain as affected by various sources and levels of applied P in laterite and kari soils is presented in Table 57 and their analysis of variance in Appendix V.

In both the soils, in the absence of added P, the uptake of N by the grain was more during the first crop season compared to the second crop season because the rate of release of native P was more during the initial periods of submergence compared to the subsequent periods. However, when P was added, the uptake was more during the first crop season in kari soil and during the second crop season in laterite soil. The lower response of added P during the second crop season in kari soil may be due to the lesser availability of P from the added P during this period. The released P from the added P might have been absorbed by the first crop leaving only a small quantity of available P for the second crop.

In the second crop, application of fertilizers in various forms and levels significantly increased the uptake of N by the grain from 0.534 g N/pot to 0.663 g N/pot in laterite soil, the increase being 24.16 per cent and from 0.360 g N/pot to 0.522 g N/pot in kari soil, the increase being 45 per cent. This significant increase in the uptake of N in both the soils in the absence of a significant increase in the N per cent of grain was mainly due to the higher yield of grain induced by the added P. In general, the contribution of added P in increasing the uptake of N over control was 0.129 g N/pot in laterite soil and 0.162 g N/pot in kari soil. In general, available P (Bray 1) content during the fourth period of sampling showed highest correlation with uptake of N by the grain ($r = 0.829^{**}$).

In both the soils, treatments T_{15} and T_{16} which received P twice as SP recorded relatively higher uptake of N compared to other treatments though the increase was significant only in kari soil. The differences between the initially applied P treatments were not pronounced in both the soils though higher uptake values were recorded by treatments receiving SP (0.704 and 0.549 g N/pot in laterite and kari soils respectively). Per cent of N was also higher in treatments receiving SP. This shows that in the second crop also, SP was found to be a better source of P with regard to the increase in the uptake of N compared to the rockphosphates. Application of SP increased the uptake of N by the grain to the extent of 0.052 g N/pot over the two rockphosphates (0.575 g N/pot).

When the percentage efficiency of a single application of 90 kg P_2O_5/ha (for the first crop) was compared with twice the application of the same quantity of P as SP (for both the crops), it was found that in laterite soil, twice the application was 17.91 per cent more efficient than the single application of the same quantity as rockphosphates and 7.37 per cent more efficient than the single application as SP. In kari soil, application of P twice as SP was 42.01 per cent more efficient than the single application of the same quantity of P. The higher efficiency of the repeated application in kari soil compared to laterite soil was due to the lower supply of native available P and that from added P in kari soil during the second crop season. The released P would have been utilized by the first crop itself leaving only a meagre amount of available P for the second crop.

Linear coefficient of correlation (r) between N uptake by grain and the grain yield was 0.994^{**}.

1.1.3 Total uptake of nitrogen

Total uptake of N as influenced by various treatments is given in Table 57 and the analysis of variance in Appendix V.

In the absence of added P, the total uptake of N was 58.39 per cent more in laterite soil (1.009 g N/pot) compared to kari soil (0.637 g N/pot) probable reason being the increased supply of native available P.

In P treated pots, the total uptake was increased to 1.246 g N/pot in laterite soil and 1.018 g N/pot in kari soil, the increase being 23.49 and 59.76 per cent over control in these soils. Thus the contribution of added P in increasing the total uptake was more pronounced in kari soil, because this soil is highly deficient in available P compared to laterite soil.

In both the soils, the total uptake of N was relatively higher in treatments receiving P twice for the first and second crops (T_{15} and T_{16}) compared to all other treatments, though the difference was significant only in kari soil. The higher uptake observed in treatments T_{15} and T_{16} may be due to the higher immediate availability of P from SP applied to the second crop. Among the P treatments which received P only once, SP applied at higher level gave significantly higher values of total uptake of N in kari soil (1.593 g N/pot). Other treatments consisting of SP at lower level of application and the two rockphosphates at both the levels were on par. However, in laterite soil due to the preponderance of native available P, the added P failed to show significant effect over control in increasing the total uptake of N though SP at higher level recorded maximum value (1.529 g N/pot).

1.2 Phosphorus

1.2.1 Uptake of phosphorus by the straw

Results on the effect of various sources and levels of applied P on the uptake of P by the rice straw at different stages of crop growth in laterite and kari soils are presented in Tables 47 to 52 and their analysis of variance in Appendix III.

Addition of P fertilizers significantly increased the per cent of P in the straw from 0.074 to 0.890 and in the root from 0.015 to 0.031 (Table 48 and 52). On addition of P fertilizers, the uptake of P was significantly increased to 44.57 and 26.49 mg P/pot in laterite and kari soils respectively which accounted to 2.49 and 1.65 per cent of the total P in these soils (Table 50). The lower contribution of initially applied P in increasing the uptake of P in kari soil was due to the higher absorption of P released from the added P by the first crop leaving only a small quantity of available P in the soil for the second crop. Uptake of P by straw showed positive correlation with the content of available P (Bray 1) during all the sampling periods the maximum correlation being obtained during the third period ($r = 0.535^{**}$).

Table 51. Phosphorus per cent of straw and root as influenced by the treatments at different periods of crop growth (second crop)

Treatment		P% of straw at different periods, fortnights						P% of root at different periods, fortnights					
No.	Notation	1	2	3	4	5	6	1	2	3	4	5	6
1	OL	0.047	0.066	0.085	0.114	0.099	0.089	0.010	0.020	0.030	0.015	0.010	0.008
2	RRP45L	0.052	0.077	0.114	0.137	0.116	0.093	0.023	0.035	0.041	0.029	0.021	0.018
3	RRP90L	0.052	0.075	0.119	0.144	0.116	0.095	0.027	0.039	0.044	0.034	0.026	0.020
4	MRP45L	0.050	0.077	0.112	0.137	0.110	0.092	0.021	0.033	0.041	0.031	0.023	0.016
5	MRP90L	0.050	0.077	0.114	0.139	0.121	0.101	0.026	0.037	0.044	0.034	0.020	0.013
6	SP45L	0.052	0.077	0.110	0.140	0.123	0.101	0.033	0.038	0.044	0.034	0.022	0.012
7	SP90L	0.055	0.077	0.119	0.152	0.125	0.102	0.030	0.045	0.045	0.034	0.016	0.010
8	OK	0.031	0.055	0.070	0.086	0.073	0.068	0.005	0.013	0.025	0.015	0.010	0.010
9	RRP45K	0.045	0.064	0.085	0.097	0.085	0.070	0.033	0.039	0.045	0.029	0.021	0.016
10	RRP90K	0.044	0.061	0.085	0.100	0.088	0.073	0.036	0.045	0.048	0.033	0.025	0.020
11	MRP45K	0.041	0.062	0.087	0.101	0.089	0.073	0.026	0.036	0.043	0.025	0.018	0.015
12	MRP90K	0.041	0.063	0.081	0.093	0.089	0.077	0.035	0.046	0.050	0.033	0.023	0.020
13	SP45K	0.041	0.064	0.087	0.095	0.095	0.077	0.030	0.045	0.050	0.035	0.022	0.016
14	SP90K	0.041	0.064	0.083	0.102	0.087	0.077	0.029	0.046	0.050	0.035	0.023	0.018
15	SP(45+45)L	0.051	0.066	0.099	0.134	0.108	0.102	0.033	0.046	0.048	0.035	0.021	0.013
16	SP(45+45)K	0.063	0.070	0.098	0.104	0.109	0.085	0.038	0.048	0.053	0.036	0.027	0.021

Table 52. Mean values of phosphorus per cent of straw and root as influenced by sources of P, soils and levels of P application (second crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				P% of straw				
1	0.048	0.046	0.048	0.052	0.043	0.047	0.047	0.047
2	0.069	0.069	0.071	0.077	0.063	0.070	0.069	0.069
3	0.101	0.099	0.099	0.115	0.085	0.099	0.101	0.099
4	0.119	0.118	0.122	0.142	0.098	0.118	0.122	0.120
5	0.102	0.102	0.108	0.119	0.089	0.103	0.105	0.104
6	0.083	0.086	0.089	0.097	0.075	0.085	0.088	0.086
Mean	0.087	0.087	0.089	0.101	0.076	0.087	0.089	0.088
				P% of root				
1	0.030	0.028	0.031	0.027	0.032	0.028	0.031	0.029
2	0.039	0.038	0.044	0.038	0.043	0.038	0.043	0.041
3	0.045	0.045	0.047	0.044	0.048	0.044	0.047	0.046
4	0.031	0.031	0.035	0.033	0.032	0.031	0.034	0.032
5	0.024	0.021	0.021	0.022	0.022	0.022	0.020	0.022
6	0.019	0.016	0.014	0.015	0.018	0.016	0.017	0.016
Mean	0.031	0.030	0.032	0.029	0.033	0.030	0.032	0.031

P% of straw

CD(0.05) for periods = 0.0079
" " soils = 0.0031
" " sourcesXperiod= 0.0079

P% of root

CD(0.05) for periods = 0.0029
" " soils = 0.0044
" " levels = 0.00114

The uptake of P from the initially applied RRP, MRP and SP was 10.62, 10.84 and 15.21 mg P/pot over control which showed that the two rockphosphates were 70.55 per cent as efficient as the SP (Table 50). The significantly higher efficiency of SP was attributed to its higher supply of water soluble P and other plant nutrients like Ca and S which enhance the uptake of P by increasing the dry matter production. The P per cent of straw and root did not vary significantly with the variations in the sources of P added (Table 52).

In laterite soil, application of 90 kg P_2O_5/ha in two equal doses during first and second crop seasons resulted in an increase in the uptake of P to the extent of only 0.14 per cent over the application of the same quantity of P as rockphosphates initially. But addition of SP at higher level in a single dose was 12.05 per cent more efficient than the repeated application. In the case of kari soil, application of SP in two doses during the first and second crop seasons was 37.74 and 25.28 per cent more efficient than the initial application of the same quantity of P as rockphosphates and SP respectively. This shows that the residual effects of initially applied P was less in kari soil because of the higher absorption of P by the first crop evidenced by the 24.47 per cent more uptake of P by the straw in the presence of added P during the first crop season in kari soil.

Uptake of P was maximum during the fourth and fifth periods of sampling which represented the stage of maximum accumulation of P in the straw (Table 49 and 51). The decrease observed at the sixth period may be due to the translocation of P to the grain. Increasing the level of application of P from 45 to 90 kg P_2O_5/ha increased the uptake of P to the extent of 3.86 mg P/pot when soils, sources and period of incubation were pooled (Table 50). When the three sources of P were considered independently the increase in the uptake of P observed due to an increase in the level of application was from 32.19 to 35.67 mg P/pot for RRP, from 31.62 to 36.68 mg P/pot for MRP and from 36.99 to 40.04 mg P/pot for SP (Table 47). Uptake of P by the straw during the fourth period showed maximum correlation with the yield of straw and grain ($r = 0.574^{**}$ and 0.554^{**} for straw and grain yield respectively)

1.2.2 Uptake of phosphorus by the grain

Uptake of P by the grain as influenced by various treatments in laterite and kari soils is presented in

Table 57 and the analysis of variance in Appendix V.

Phosphorus uptake by the grain increased significantly over control due to the addition of P fertilizers, though the P per cent did not show significant increase over control. This increase in the uptake of P in the absence of a significant increase in the P per cent was obviously due to the increased grain yield in the presence of added P.

When no P was added, the uptake of P by the grain was 0.142 and 0.090 g P/pot in laterite and kari soils respectively which on addition of P fertilizers increased to 0.182 and 0.141 g P/pot in these soils, the percentage increase over control being 28.17 and 56.66 in laterite and kari soils respectively. Available P content during the second period was maximum correlated with the uptake of P by the grain ($r = 0.405^{*}$).

In both the soils, among the initially applied P treatments, SP at both levels of application was found to be significantly better compared to other forms and levels. The two rockphosphates did not vary significantly with regard to the uptake of P by the grain. This indicates that the transformation of these two forms of P is similar in the two soils under study though they are of different origin. Results revealed that two applications of P as SP at the rate of 45 kg P_2O_5/ha for the first and second crop seasons was superior to the application of the same quantity of P initially for the first crop only as SP or rockphosphates, probably due to the higher immediate availability of P from the second dose.

Linear coefficient of correlation between P uptake by grain and grain yield was not found to be significant.

1.2.3 Total uptake of phosphorus

Influence of various treatments on the total uptake of P in laterite and kari soils is presented in Table 57 and the analysis of variance in Appendix V. Total P uptake as influenced by stages of crop growth, soils and fertiliser treatments is graphically represented in Fig.11, 12 and 13.

When the uptakes of P during the first and second crop seasons were compared, it was seen that in both the soils, in the absence of added P, the total uptake was more during the first crop season compared to the second crop. Also, in the presence of added P, total uptake was found to be more during the first crop season in kari soil. But in laterite soil total uptake was more in second crop season. The higher total uptake of P in both the soils during the first crop season compared to the second crop season in the absence of added P is attributed to the increased supply of native available P during the initial periods of flooding which enhances the absorption of P. The better performance of added P during the second crop season in laterite soil was due to the lesser absorption of P from the added P during the first crop because of the higher supply of native available P. This was further confirmed by the nonconspicuous increase in the total uptake of P over control during the first crop season in laterite soil due to the addition of P.

In the control (no P) conditions, the total uptake was 187.3 and 114.9 mg P/pot in laterite and kari soils respectively i.e., even in the second crop season, the contribution of native P in increasing the total P uptake was 63.01 per cent more in laterite soil compared to kari soil. The total uptake of P in the absence of added P accounted to 10.56 and 7.24 per cent of the total P in laterite and kari soils respectively. On addition of P fertilizers the uptake was increased to 240.93 and 197.40 mg P/pot in laterite and kari soils respectively which represented 13.47 and 12.33 per cent of the total P in these soils. This shows that the total P uptake by the rice plant was comparatively less when the total quantity of P in these soils was considered.

In both the soils among the initially applied P treatments, SP applied at higher level recorded significantly higher uptake values (268.7 and 198.3 mg P/pot in laterite and kari soils respectively) compared to the other treatments, probable reason may be the higher supply of available P and other nutrients like Ca and S from SP which enhances the dry matter production and absorption of P leading to the higher total uptake of P. In general the two rockphosphates were 89.38 per cent as efficient as SP in increasing the total uptake of P by rice. Results revealed that the total uptake of P from the two rockphosphates did not differ conspicuously because of their similar transformation or dissolution pattern in the acid soils under study irrespective of their origin.

In both the soils, application of P separately for each crop was found to be significantly superior to the addition of P only for the first crop because of the higher supply of P from the second dose.

Addition of P as SP in two equal doses was 12.73 and 23.45 per cent more efficient than the addition of the same quantity of P in a single dose as SP in laterite and kari soils respectively. Application of P in two doses during the first and second crop season as SP was 24.65 and 36.19 per cent more efficient than the single application of the same quantity of P as rockphosphates in laterite and kari soils respectively.

1.3 Potassium

1.3.1 Uptake of potassium by the straw

Effects of various treatments on the uptake of K by the straw at different growth stages in laterite and kari soils are given in Tables 47, 48 and 53 to 56 and the analysis of variance in Appendix III.

In the absence of added P, the uptake of K by the straw was 45.86 per cent more in laterite soil compared to kari soil because of the higher absorption of K and dry matter production induced by the higher native available P in laterite soil compared to the kari soil (Table 48). On addition of P fertilizers, the K uptake was significantly increased to the extent of 0.403 and 0.294 g K/pot over control in laterite and kari soils respectively (Table 56)

Table 53. Potassium per cent of straw and root as influenced by the treatments at different periods of crop growth (second crop)

Treatment		K% of straw at different periods, fortnights						K% of root at different periods, fortnights					
No.	Notation	1	2	3	4	5	6	1	2	3	4	5	6
1	OL	2.62	2.80	2.90	2.60	2.40	0.87	1.45	1.55	1.35	1.15	1.00	0.80
2	RRP45L	2.68	2.90	3.30	3.15	2.83	1.85	1.50	1.70	1.50	1.23	1.05	0.90
3	RRP90L	2.85	2.93	3.63	3.25	2.88	1.90	1.65	1.80	1.58	1.33	1.08	0.90
4	MRP45L	2.80	2.85	3.53	3.23	2.80	1.78	1.53	1.60	1.55	1.18	1.00	0.83
5	MRP90L	2.70	2.88	3.50	3.25	2.80	1.85	1.70	1.80	1.55	1.30	1.15	0.95
6	SP45L	2.80	2.93	4.05	3.35	2.85	1.80	1.68	1.78	1.55	1.30	1.14	0.95
7	SP90L	2.80	2.90	3.55	3.28	2.73	1.88	1.73	1.85	1.63	1.30	1.05	0.88
8	OK	2.45	2.70	2.75	2.65	2.35	0.92	1.15	1.35	1.15	0.98	0.95	0.73
9	RRP45K	2.55	2.80	2.93	2.75	2.48	1.75	1.30	1.48	1.23	1.05	0.80	0.65
10	RRP90K	2.60	2.85	2.90	2.80	2.40	1.85	1.38	1.60	1.33	1.13	0.95	0.90
11	MRP45K	2.53	2.78	2.93	2.85	2.35	1.70	1.33	1.55	1.15	1.05	0.90	0.70
12	MRP90K	2.55	2.80	2.85	2.90	2.40	1.75	1.38	1.63	1.38	1.15	0.95	0.80
13	SP45K	2.60	2.85	2.85	2.90	2.45	1.75	1.35	1.65	1.38	1.08	0.90	0.78
14	SP90K	2.63	2.85	2.95	2.90	2.40	1.85	1.43	1.70	1.40	1.13	0.95	0.80
15	SP(45+45)L	2.51	2.88	3.22	3.28	2.36	1.95	1.83	1.93	1.73	1.25	1.00	0.98
16	SP(45+45)K	2.70	2.95	2.93	2.95	1.80	2.00	1.55	1.80	1.48	1.18	0.95	0.85

Table 54. Mean values of potassium per cent of straw and root as influenced by sources of P, soils and levels of P application (second crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				K% of straw				
1	2.660	2.640	2.710	2.770	2.580	2.670	2.680	2.670
2	2.870	2.830	2.890	2.900	2.820	2.850	2.880	2.860
3	3.190	3.200	3.460	3.670	2.900	3.260	3.300	3.280
4	2.990	3.060	3.130	3.270	2.850	3.040	3.080	3.060
5	2.640	2.590	2.630	2.830	2.410	2.600	2.610	2.620
6	1.640	1.770	1.810	1.840	1.780	1.770	1.840	1.810
Mean	2.690	2.680	2.770	2.880	2.550	2.700	2.730	2.720
				K% of root				
1	1.460	1.480	1.540	1.630	1.360	1.450	1.540	1.490
2	1.640	1.640	1.740	1.750	1.600	1.630	1.730	1.680
3	1.410	1.410	1.480	1.560	1.310	1.390	1.480	1.430
4	1.180	1.160	1.190	1.270	1.090	1.150	1.220	1.180
5	0.970	0.990	1.010	1.080	0.904	0.960	1.020	0.990
6	0.810	0.820	0.850	0.900	0.750	0.800	0.850	0.830
Mean	1.240	1.250	1.300	1.360	1.170	1.230	1.310	1.270

K% of straw

CD(0.05) for periods = 0.2260
" " soils = 0.0885
" " soil x period = 0.3190

K% of root

CD(0.05) for periods = 0.0806
" " soils = 0.0316
" " levels = 0.0316

i.e., the contribution of added P in increasing the K uptake was 37.07 per cent more in laterite soil compared to kari soil because of the lesser absorption of P from the added P by the first crop in laterite soil due to the higher supply of native P. The mean level of K in the straw and root from all the three sources was also higher in laterite soil compared to kari soil (Table 48).

The mean uptake of K by the initially applied RRP, MRP and SP was 0.313, 0.310 and 0.432 g K/pot respectively over control (Table 56). The significantly higher superiority of SP over the two rockphosphates may be due to the higher immediate availability of Ca and P from SP. The released Ca may replace K in the exchange complex releasing it into the soil solution which can enhance the absorption of K. The per cent of K in the straw and root was also higher in treatments receiving SP (2.77 and 1.30 for straw and root respectively) compared to other treatments, though the differences were not significant (Table 54).

In both the soils, applications of P twice as SP during the first crop and second crop seasons was found to be better in increasing the uptake of K by the straw than the single application of the same

Table 55. Uptake of potassium by the rice straw and straw yield as influenced by the treatments at different periods of crop growth (second crop)

Treatment		Uptake of K (g/pot) at different periods, fortnights						Yield of straw (g/pot) at different periods, fortnights					
No.	Notation	1	2	3	4	5	6	1	2	3	4	5	6
1	OL	0.327	0.629	0.858	0.983	1.080	0.667	12.50	22.50	29.60	37.78	45.10	51.16
2	RRP45L	0.436	0.753	1.190	1.350	1.420	1.060	16.00	26.00	36.00	42.85	50.20	57.30
3	RRP90L	0.519	0.862	1.420	1.530	1.580	1.160	18.89	29.50	39.12	47.10	54.92	60.85
4	MRP45L	0.437	0.741	1.190	1.370	1.390	1.010	15.63	26.00	33.63	42.55	49.71	56.79
5	MRP90L	0.532	0.891	1.420	1.630	1.580	1.130	19.70	31.00	40.60	50.10	56.40	60.90
6	SP45L	0.511	0.879	1.610	1.640	1.640	1.120	18.25	30.00	39.60	48.74	57.50	62.10
7	SP90L	0.566	1.003	1.760	1.710	1.690	1.220	20.00	34.00	43.90	50.50	60.13	65.90
8	OK	0.140	0.458	0.705	0.727	0.758	0.330	5.73	17.00	25.08	27.48	32.30	36.90
9	RRP45K	0.331	0.460	0.844	0.966	1.030	0.846	13.00	20.00	28.90	35.16	41.60	48.40
10	RRP90K	0.379	0.627	0.906	1.070	1.070	0.920	14.59	22.00	31.25	38.14	44.23	49.60
11	MRP45K	0.305	0.583	0.856	0.974	0.952	0.772	12.08	21.00	29.14	34.16	40.50	47.30
12	MRP90K	0.357	0.659	0.911	1.120	1.070	0.880	14.03	23.50	31.95	38.39	43.80	50.40
13	SP45K	0.386	0.684	0.862	1.090	1.090	0.881	14.90	24.00	30.25	37.61	44.40	50.40
14	SP90K	0.397	0.684	0.926	1.140	1.180	0.991	14.90	24.00	31.38	39.40	49.10	53.60
15	SP(45+45)L	0.542	1.062	1.441	1.624	1.412	1.222	21.60	36.90	44.80	49.59	59.80	62.65
16	SP(45+45)K	0.456	0.738	0.979	1.286	0.947	1.204	16.88	25.00	33.40	43.65	52.60	60.20

Table 56. Mean values of potassium uptake by straw and straw yield as influenced by sources of P soils and levels of P application (second crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				K uptake by straw (g/pot)				
1	0.417	0.408	0.463	0.500	0.358	0.401	0.458	0.429
2	0.701	0.719	0.813	0.855	0.633	0.700	0.788	0.744
3	1.080	1.090	1.290	1.430	0.884	1.090	1.220	1.157
4	1.230	1.270	1.390	1.540	1.060	1.230	1.364	1.297
5	1.270	1.250	1.390	1.550	1.062	1.253	1.359	1.306
6	0.990	0.950	1.050	1.120	1.880	0.948	1.050	0.999
Mean	0.951	0.948	1.070	1.160	0.813	0.937	1.040	0.989
				Straw yield (g/pot)				
1	15.62	15.36	17.01	18.08	13.91	14.98	17.02	15.99
2	24.82	24.94	28.00	29.42	22.42	24.00	27.33	25.92
3	33.82	33.86	36.28	38.81	30.49	32.93	36.37	34.65
4	40.81	41.29	44.05	46.96	37.14	40.17	43.93	42.05
5	47.73	47.79	52.78	54.81	43.92	47.33	51.41	49.37
6	54.03	53.34	57.97	60.63	49.62	53.38	56.86	55.12
Mean	36.06	36.14	39.35	41.45	32.92	35.55	38.82	37.18

K uptake

CD(0.05) for periods = 0.0860
" " soils = 0.0336
" " levels = 0.0336
" " sources = 0.0411
" " soil x period = 0.1210

Straw yield

CD (0.05) for periods = 3.550
" " soils = 1.394
" " sources = 1.707
" " levels = 1.394

quantity of P as rockphosphate (Table 55). In laterite soil, initial application of SP at the rate of 90 kg P_2O_5/ha recorded higher uptake values compared to the treatments receiving the same quantity of P twice as SP. However, in kari soil, the uptake of K was high in treatments receiving SP twice compared to the treatments receiving the same quantity of P as SP initially due to the higher utilisation of P from SP by the first crop.

The per cent of K in straw and root and the uptake of K by straw varied significantly at different growth stages. In both the soils, the maximum level of K in the straw was observed during the third period, while the maximum level of K in the root was noticed during the second period (Table 53). However, the K uptake was maximum during the fourth and fifth periods in both the soils (Table 55). After attaining the maximum value, both the per cent and uptake decreased due to the dilution of nutrient brought about by the increase in the dry matter production and translocation of nutrient to the grain.

Application of P at higher level did not increase significantly the level of K in the straw, but increased the level of K in the root (Table 54).

However, increasing the level of P application from 45 to 90 kg P_2O_5/ ha increased the mean uptake of K to the extent of 0.103 g K/pot when soils, sources and periods were pooled (Table 56). When the soils and sources of P were considered independently, again the uptake of K increased with increasing levels of application (Table 47). Uptake of K during the first fortnight showed maximum correlation with the yield of straw ($r = 0.893^{**}$), grain ($r = 0.880^{**}$) and K uptake by the grain ($r = 0.921^{**}$).

1.3.2 Uptake of potassium by the grain

Effects of various treatments on the uptake of K by the grain in laterite and kari soils are presented in Table 57 and the analysis of variance in Appendix V.

When no P was added, uptake of K by the grain was 0.078 and 0.046 g K/pot in laterite and kari soils respectively which on addition of P fertilizers increased significantly to 0.106 and 0.072 g K/pot in these soils. The higher contribution of native P as well as the added P in the laterite soil due to the less utilization by the first crop was responsible for the higher uptake values observed in laterite soil.

Application of SP twice during the first and second crop seasons was superior to all the other treatments receiving P initially because of the higher immediate availability of P from the second dose. Among the initially applied P treatments, SP at both levels of application registered higher uptake of K compared to the rockphosphates. The uptake of K from treatments receiving the two rockphosphates did not vary significantly which indicated that transformation pattern of these two forms was similar in these soils.

Available P content during the first period of sampling showed maximum correlation with the K uptake by grain ($r = 0.827^{**}$). Uptake of K and grain yield were highly correlated ($r = 0.964^{**}$).

1.3.3 Total uptake of potassium

Total uptake of K as influenced by various sources and levels of applied P in laterite and kari soils is presented in Table 57 and the analysis of variance in Appendix V.

By the application of P fertilizers, the total uptake of K by rice increased significantly to the extent of 0.715 and 0.578 g K/pot in laterite and kari soils respectively. The increased vegetative and reproductive growth of the plants induced in the presence of added P resulted in a higher absorption of nutrients. Also, the increased root growth in the presence of added P would have helped in the absorption of nutrients from a larger soil volume. In addition, the Ca contained in the P fertilizers would have contributed to the increased growth of plants in P treated pots thus resulting in a higher absorption of nutrients.

In general, in both the soils, forms, levels and frequency of P application failed to show significant difference in increasing the total uptake of K by rice plant though higher uptake was observed in treatments receiving P twice as SP because of the higher dry matter production and higher absorption of K due to the higher supply of P and Ca.

2. Yield of straw and grain

Results on the influence of sources and levels of applied P on the yield of straw and grain in laterite and kari soils are given in Tables 47, 48 and 55 to 57 and the analysis of variance in Appendix III and V. Grain yield as influenced by various treatments is represented in Fig.14.

The increase observed in the yield of straw and grain over control due to the addition of P fertilizers was obviously due to the increased dry matter production induced by the presence of added P.

Table 57. Grain yield, nutrient per cent and uptake by grain and total uptake of nutrients as influenced by various treatments (second crop)

Treatment		Yield of grain, g/pot	Per cent of nutrients			Uptake of nutrients g/pot			Total uptake of nutrients		
No.	Notation		N	P	K	N	P	K	N g/pot	P mg/pot	K g/pot
1	OL	46.81	1.140	0.303	0.165	0.534	0.142	0.078	1.009	187.3	0.506
2	RRP45L	53.62	1.160	0.311	0.180	0.623	0.166	0.094	1.200	219.3	1.157
3	RRP90L	56.51	1.170	0.326	0.195	0.661	0.184	0.110	1.298	241.8	1.266
4	MRP45L	52.66	1.160	0.322	0.185	0.611	0.169	0.095	1.162	221.2	1.106
5	MRP90L	57.51	1.170	0.318	0.190	0.674	0.183	0.109	1.113	244.2	1.235
6	SP45L	57.55	1.170	0.326	0.185	0.674	0.188	0.107	1.306	250.5	1.223
7	SP90L	61.96	1.180	0.326	0.195	0.733	0.202	0.118	1.394	268.7	1.337
8	OK	32.39	1.110	0.280	0.140	0.360	0.090	0.046	0.637	114.9	0.376
9	RRP45K	43.92	1.130	0.303	0.155	0.497	0.133	0.066	0.905	166.8	0.912
10	RRP90K	45.63	1.140	0.311	0.160	0.521	0.139	0.071	0.975	175.9	0.991
11	MRP45K	42.51	1.140	0.295	0.145	0.468	0.126	0.060	0.879	158.7	0.833
12	MRP90K	46.52	1.140	0.311	0.160	0.530	0.145	0.074	1.018	183.6	0.957
13	SP45K	46.42	1.150	0.319	0.165	0.534	0.147	0.075	1.020	186.1	0.957
14	SP90K	49.48	1.140	0.318	0.170	0.565	0.157	0.084	1.309	198.3	1.076
15	SP(45+45)L	65.65	1.200	0.338	0.200	0.787	0.222	0.131	1.529	302.9	1.472
16	SP(45+45)K	56.55	1.350	0.342	0.190	0.764	0.194	0.108	1.593	244.8	1.314
CD(0.05)		5.986	N.S	N.S	0.0226	0.0997	0.0148	0.0149	0.2791	17.44	0.3942

In general, when no P was added, the grain and straw yield was more during the first crop season compared to the second crop season, the reason being the higher release of native available P formed during the initial periods of flooding which enhances the absorption of P. In the presence of added P, the yield of straw and grain was more during the first crop season in kari soil and more during the second crop season in laterite soil. In laterite soil, the contribution of native available P, formed consequent to flooding was high during the intial periods of flooding which masked the effect of added P as revealed by the nonconspicuous increase in the yield of straw and grain observed during the first crop season in this soil. But in kari soil, due to the lower content of native available P, the utilization of added P was more by the first crop, leaving only comparatively small amount of available P for the second crop.

In the absence of added P the yield of straw was 33.12 g/pot in laterite soil and 24.09 g/pot in kari soil which on addition of P fertilizers increased to 41.45 and 32.92 g/pot respectively in these soils (Table 48 and 56). By the addition of P fertilizers, the yield of grain increased from 46.81 to 56.65 g/pot in laterite soil and from 32.39 to 45.75 g/pot in kari soil (Table 57).

The three sources of P differed significantly in increasing the yield of straw (Table 56). The mean straw yield was significantly higher in treatments which received SP as the source of P (39.35 g/pot) compared to other treatments receiving RRP (36.06 g/pot) and MRP (36.14 g/pot). The two rockphosphates were on par.

Application of P at higher level significantly increased the yield of straw to the extent of 3.27 g/pot over the lower level (45 kg P_2O_5/ha) when the soils, sources and periods were pooled (Table 56). In general, increasing the level of application of RRP, MRP and SP resulted in an increase in the straw yield from 34.61 to 37.51 g/pot, 33.89 to 38.38 g/pot and 38.15 to 40.56 g/pot respectively when the effect of soils and periods were pooled (Table 47).

In laterite soil, among the initially applied P treatments, SP at both levels and the two rockphosphates at higher level did not differ significantly in increasing the yield of grain. Also, the two rockphosphates at lower level of application were on par. In the case of kari soil, SP at higher level of application registered significantly higher yield among the P treatments receiving P only once during the first crop season. All other forms and levels did not differ significantly in increasing the yield of grain.

In general, in treatments receiving rockphosphates as a source of P, the yield of grain was 92.67 per cent of that obtained in treatments receiving SP. Thus in the second crop also SP was found to be a better source of P with respect to the yield of straw and grain, probable reason being the higher supply of P, Ca and S from SP. This is in agreement with the findings of Marwaha et al. (1981). The two rockphosphates did not vary significantly with regard to the yield of straw and grain which indicated that the dissolution of the two rockphosphates was similar in these soils.

Application of P twice as SP produced 36.28 per cent more straw yield and 18.96 per cent more grain yield compared to the application of the same quantity of P as rockphosphates (Table 55 and 57). In kari soil application of P for the first and second crop seasons separately, produced 22.16 and 14.29 per cent more yield of straw and grain compared to the application of P as SP initially for the first crop only. In laterite soil, the increase in grain and straw yield in treatments receiving SP twice was

1.16 and 5.96 per cent respectively compared to the treatments receiving the same quantity of P as SP during the first crop only. The higher immediate availability of plant nutrients from SP applied during the second crop season is responsible for the higher yield of straw and grain. The relationships of grain and straw yield with nutrient uptake and available P in soil at the time of harvest are given in Table 60.

3. Available phosphorus

Results on the effect of various sources and levels of applied P on the content of available P (Bray 1 and 2) in laterite and kari soils are given in Tables 48, 58 and 59 and the analysis of variance in Appendix IV.

In the absence of added P, the mean available P content was 3.47 ppm (Bray 1) and 5.53 ppm (Bray 2) in laterite soil and 1.97 ppm (Bray 1) and 4.34 ppm (Bray 2) in kari soil (Table 48). These values were comparatively lesser than the mean available P content formed during the first crop season. The lesser amount of native available P (Bray 1 and 2) during the second crop season was due to the higher absorption of P by the first crop. This was further confirmed by the higher uptake of P during the first

Table 58. Available P (ppm) of air dried soil as influenced by the treatments at different periods of crop growth (second crop)

Treatment		Available P (Bray 1) at different periods, fortnights							Available P (Bray 2) at different periods, fortnights						
No.	Notation	0	1	2	3	4	5	6	0	1	2	3	4	5	6
1	OL	2.86	5.33	4.10	3.29	2.90	2.33	2.14	5.75	9.68	7.84	4.80	3.89	3.49	3.11
2	RRP45L	3.41	7.38	5.55	4.20	3.60	2.97	2.87	8.31	20.47	18.84	14.12	9.99	8.16	6.05
3	RRP90L	4.72	9.18	7.00	5.68	4.60	3.49	3.01	10.75	21.49	20.40	13.73	8.97	6.92	5.89
4	MRP45L	3.29	7.68	4.92	3.25	2.51	2.13	1.97	8.22	19.71	19.21	15.81	9.53	6.97	6.13
5	MRP90L	4.41	9.14	6.56	4.31	3.97	3.00	2.19	11.37	22.62	20.14	15.83	10.77	9.31	6.82
6	SP45L	4.71	10.20	5.42	4.55	3.43	2.75	2.33	9.54	20.77	19.21	15.95	11.59	8.02	6.79
7	SP90L	5.59	11.75	8.52	6.63	4.31	3.09	2.53	10.97	20.49	19.56	14.40	9.58	9.15	7.29
8	OK	2.27	3.15	2.27	1.97	1.33	1.27	1.52	3.82	7.37	6.86	4.60	3.47	2.57	1.73
9	RRP45K	3.50	4.28	3.63	2.99	2.58	2.44	2.12	6.37	15.05	11.58	11.05	7.95	7.16	5.57
10	RRP90K	4.08	4.92	3.86	3.14	2.63	2.45	2.15	6.41	14.92	12.01	10.99	7.03	6.27	5.46
11	MRP45K	3.55	4.16	3.95	3.07	2.45	2.10	2.10	6.51	14.41	10.28	9.56	8.21	7.21	5.59
12	MRP90K	3.68	4.63	4.06	3.17	2.76	2.45	2.14	7.12	16.79	12.96	9.45	7.66	7.44	5.79
13	SP45K	3.81	4.98	4.29	3.59	3.05	2.70	2.30	7.73	17.12	14.41	10.81	7.82	6.42	4.79
14	SP90K	4.25	4.89	3.81	3.35	2.99	2.70	2.73	7.60	16.75	13.63	10.98	7.82	6.52	5.51
15	SP(45+45)L	4.79	10.54	6.02	5.25	3.98	3.01	2.78	10.01	21.08	19.99	16.45	12.56	9.99	7.38
16	SP(45+45)K	3.99	4.99	4.64	4.01	3.95	3.01	2.95	8.21	18.19	16.46	11.56	8.27	7.01	6.95

crop season compared to the second crop season in the absence of added P.

On addition of P fertilizers, the available P was increased to 4.83 ppm (Bray 1) and 12.82 ppm (Bray 2) in laterite soil and 3.29 ppm (Bray 1) and 9.39 ppm (Bray 2) in kari soil (Table 59).

Table 59 revealed that the mean available P (Bray 1) content from SP (4.46 ppm) was significantly higher than that from RRP (4.01 ppm) and MRP (3.69 ppm). When the contribution from native P is deducted the increase in the available P (Bray 1) content due to the addition SP was 0.61 ppm more than that produced by the rockphosphates. Thus in the second crop also SP was found to be better than the rockphosphates for rice. Available P (Bray 1) as influenced by forms of P fertilizers are represented in Fig.15.

Maximum available P (Bray 1 and 2) irrespective of treatments was observed during the first fortnight of sampling and after this period, it decreased gradually and significantly and attained the minimum value at the time of harvest (Table 58). The absorption of P by plant was responsible for the decrease observed after the first fortnight. Increasing the level of application of P from 45 to 90 kg P_2O_5/ha increased

Table 59. Mean values of available P (Bray 1 and 2) as influenced by sources of P, soils and levels of P application (second crop)

Periods of crop growth, fortnights	Sources of P			Soils		Levels of P_2O_5, kg/ha		Mean
	RRP	MRP	SP	Laterite	Kari	45	90	
				Available P (Bray 1), ppm				
0	3.930	3.730	4.590	4.360	3.810	3.710	4.450	4.080
1	6.440	6.400	7.960	9.220	4.640	6.450	7.420	6.930
2	5.010	4.870	5.510	6.330	3.930	4.620	5.630	5.130
3	4.000	3.450	4.530	4.770	3.220	3.610	4.380	3.990
4	3.350	2.920	3.450	3.740	2.740	2.300	3.540	3.240
5	2.840	2.420	2.790	2.910	2.470	2.510	2.860	2.690
6	2.540	2.090	2.390	2.480	2.210	2.280	2.410	2.340
Mean	4.010	3.690	4.460	4.830	3.290	3.730	4.380	4.060
				Available P (Bray 2), ppm				
0	7.96	8.30	8.96	9.86	6.96	7.78	9.03	8.41
1	17.98	18.38	18.82	20.92	15.86	17.94	18.84	18.39
2	15.71	15.65	16.62	19.50	12.48	15.56	16.42	15.99
3	12.47	12.56	13.03	14.91	10.47	12.88	12.16	12.69
4	8.48	9.04	9.20	10.07	7.74	9.18	8.64	8.91
5	7.12	7.73	7.52	8.09	6.83	7.32	7.59	7.46
6	5.75	5.88	6.09	6.36	5.45	5.82	5.99	5.91
Mean	10.78	11.08	11.46	12.82	9.39	10.92	11.79	11.11

Bray 1 P

CD(0.05) for soils = 0.1841
" " sources = 0.2255
" " periods = 0.4693
" " levels = 0.1841
" " soil x period = 0.6637

Bray 2 P

CD(0.05) for soils = 0.5346
" " periods = 1.363
" " soil x period = 1.927

Table 60. Interrelationships of nutrient uptake by straw and grain, yield of straw and grain and available P at the time of harvest (second crop)

(coefficient of linear correlation)

	Uptake by straw			Uptake by grain			Available P		Yield of straw	Yield of grain
	N	P	K	N	P	K	Bray 1	Bray 2		
N uptake by straw	--	0.674**	0.644**	0.763**	0.198	0.729**	0.487*	0.342	0.767**	0.759**
P uptake by straw		--	0.669**	0.921**	0.354	0.925**	0.507**	0.451*	0.937**	0.922**
K uptake by straw			--	0.716**	-0.136	0.652**	0.518**	0.529**	0.716**	0.733**
N uptake by grain				--	0.287	0.960**	0.578**	0.464*	0.983**	0.994**
P uptake by grain					--	0.298	0.141	-0.089	0.313	0.296
K uptake by grain						--	0.595**	0.406*	0.974**	0.964**
Bray 1 P							--	0.290	0.607**	0.625**
Bray 2 P								--	0.456*	0.465*
Yield of straw									--	0.986**
Yield of grain										--

** Significant at 1 per cent level

* Significant at 5 per cent level

significantly the available P (Bray 1) from 3.73 ppm to 4.38 ppm.

Available P content of the soil in the treatments receiving SP twice during the first and second crop seasons was 75.31 and 73.58 per cent more than that in the treatments receiving the same quantity of P initially for the first crop only as rockphosphates in laterite and kari soils respectively. However, treatment receiving SP twice was only 9.65 per cent more efficient than the application of the same quantity of P as SP initially for the first crop in laterite soil and 47.44 more efficient than the application of the same quantity of P as SP initially in kari soil. The higher available P content (Bray 1 and 2) in treatments receiving SP twice during the first and second crop season was attributed to its higher content of water soluble P.

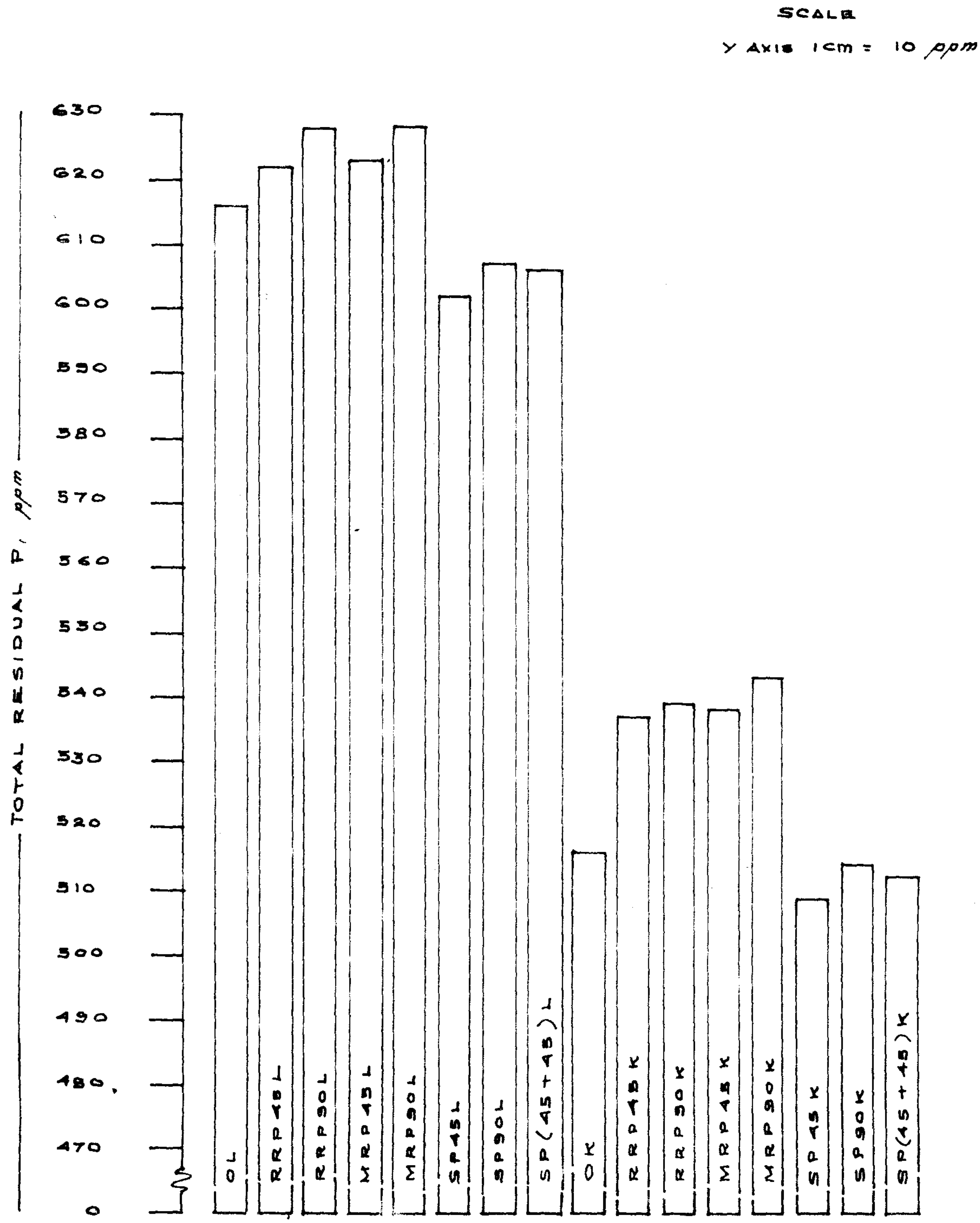
Linear coefficient of correlation (r) revealed that the available P content during the third and fourth periods was maximum correlated with the yield of straw (0.861^{**}) and grain (0.824^{**}) respectively.

Analysis of the soil for total P after the harvest of the second crop showed that on an average, treatments receiving rockphosphates contained more P in soil than those receiving SP. When the soils and

Table 61. Total residual P after the harvest of second crop

Treatment		Residual P, ppm
No.	Notation	
1	OL	616.4
2	RRP45L	621.8
3	RRP90L	628.3
4	MRP45L	623.0
5	MRP90L	627.9
6	SP45L	602.1
7	SP90L	606.6
8	OK	516.4
9	RRP45K	536.8
10	RRP90K	538.7
11	MRP45K	537.9
12	MRP90K	543.1
13	SP45K	508.9
14	SP90K	514.4
15	SP(45+45)L	605.7
16	SP(45+45)K	512.2

FIG: 16. RESIDUAL P IN SOIL AFTER SECOND CROP AS INFLUENCED BY FORMS OF P FERTILIZERS



levels were pooled, the difference in the content of P left in the soil was 20 ppm more in the treatments receiving rockphosphates compared to SP. This indicates that considerable amount of P applied as rockphosphate remains in the soil even after growing rice for two seasons and therefore it is possible that the availability of P to the third or subsequent crops may be better in pots receiving rockphosphates as compared to SP. In other words, evaluation of the performance of rockphosphates in the soil is possible only on a long term basis. The amounts of residual P as influenced by various treatments are given in Table 61 and Fig.16.

SUMMARY

SUMMARY

An incubation study and a potculture experiment were conducted in order to assess the suitability of Rajastan rockphosphate (RRP) in comparison with that of Mussoorie rockphosphate (MRP) and superphosphate (SP) in laterite (Kodakara, Trichur district) and kari (Karumadi, Alleppey district) soils of Kerala. In the incubation study, these three P sources were added to the two soils at the rate of 45 and 90 kg P_2O_5/ha and their transformations under submergence were studied for 180 days drawing samples at regular intervals of 15 days. The samples were analysed for various inorganic P fractions and available P. In the potculture experiment using rice as the test crop, the direct and residual effects of the two rockphosphates in comparison with the water soluble SP were studied. The soils and levels of P application were the same as in the incubation study. Application of N and K was done uniformly in all the treatments. Soil and plant samples were taken at 15 days intervals for the determination of available P and the uptake of major nutrients. The residual effect of phosphatic fertilizers was

assessed by continuing the experiment for the second season without the addition of P fertilizers.

A treatment receiving SP at the rate of 45 kg P_2O_5/ha in both the seasons was also maintained for comparison in both the soils (T_{15} and T_{16}). The results of the study are:

1) The initial concentration of available P in both the soils was rated as 'low' as per the soil fertility classification norms of Kerala.
2) Application of phosphatic fertilizers, irrespective of their water solubility increased the various inorganic fractions and available P content of the soil.
3) Before incubation, the total inorganic P accounted to 73.15 and 76.14 per cent of the total P in laterite and kari soils respectively which on incubation increased to 88.29 per cent in laterite soil and 96.02 per cent in kari soil. Addition of P fertilizers, increased the content of native inorganic P by increasing the mineralization of native organic P.
4) Among the various inorganic fractions, Fe-P was the dominant fraction in both the soils accounting to 41 to 44 per cent of the total inorganic P. Al-P was the second most abundant fraction

representing 29 to 30 per cent of the total inorganic P. The contents of reductant soluble-P, occluded-P and Ca-P were less and that of saloid-P was negligible in the soil.

5) With increasing periods of incubation, saloid-P, Al-P, Fe-P and available P (Bray 1 and 2) increased, while the reductant soluble-P, occluded-P and Ca-P decreased. The rate of change in the various inorganic fractions was more during the initial periods of flooding.

6) Prediction equations were worked out to establish various inorganic fractions of P and available P at different periods of incubation.

7) The three sources of P did not differ significantly in increasing the various inorganic fractions of the soil except that of saloid-P.

8) The contents of Al-P, Fe-P, reductant soluble-P and occluded-P were more in laterite soil compared to kari soil while saloid-P and Ca-P were high in kari soil.

9) Saloid-P during the first period of incubation was observed only in treatments receiving SP. But on incubation, saloid-P was recovered from all the treatments. The mean content of saloid-P was significantly higher in treatments receiving

assessed by continuing the experiment for the second season without the addition of P fertilizers.

A treatment receiving SP at the rate of 45 kg P_2O_5/ha in both the seasons was also maintained for comparison in both the soils (T_{15} and T_{16}). The results of the study are:

1) The initial concentration of available P in both the soils was rated as 'low' as per the soil fertility classification norms of Kerala.

2) Application of phosphatic fertilizers, irrespective of their water solubility increased the various inorganic fractions and available P content of the soil.

3) Before incubation, the total inorganic P accounted to 73.15 and 76.14 per cent of the total P in laterite and kari soils respectively which on incubation increased to 88.29 per cent in laterite soil and 96.02 per cent in kari soil. Addition of P fertilizers, increased the content of native inorganic P by increasing the mineralization of native organic P.

4) Among the various inorganic fractions, Fe-P was the dominant fraction in both the soils accounting to 41 to 44 per cent of the total inorganic P. Al-P was the second most abundant fraction

representing 29 to 30 per cent of the total inorganic P. The contents of reductant soluble-P, occluded-P and Ca-P were less and that of saloid-P was negligible in the soil.

5) With increasing periods of incubation, saloid-P, Al-P, Fe-P and available P (Bray 1 and 2) increased, while the reductant soluble-P, occluded-P and Ca-P decreased. The rate of change in the various inorganic fractions was more during the initial periods of flooding.

6) Prediction equations were worked out to establish various inorganic fractions of P and available P at different periods of incubation.

7) The three sources of P did not differ significantly in increasing the various inorganic fractions of the soil except that of saloid-P.

8) The contents of Al-P, Fe-P, reductant soluble-P and occluded-P were more in laterite soil compared to kari soil while saloid-P and Ca-P were high in kari soil.

9) Saloid-P during the first period of incubation was observed only in treatments receiving SP. But on incubation, saloid-P was recovered from all the treatments. The mean content of saloid-P was significantly higher in treatments receiving

superphosphate compared to other treatments.

10) Irrespective of the sources and levels of applied P, saloid-P content was maximum during the seventh period of incubation. The linear coefficient of correlation (r) between saloid-P and period of incubation was 0.550**, 0.577**, 0.408** for RRP, MRP and SP respectively.

11) Saloid-P was positively correlated with Fe-P (r = 0.772**), Al-P (r = 0.731**) and Ca-P (r = 0.278**) and negatively correlated with reductant soluble-P (r = -0.249*) and occluded-P (r = -0.319**).

12) Concentration of Al-P was maximum during the twelfth period. A positive and significant correlation was obtained between Al-P and period of incubation (r = 0.789**).

13) Al-P was highly correlated with the saloid-P (r = 0.731**), and Fe-P (r = 0.789**) and negatively correlated with the reductant soluble-P (r = -0.407**) and occluded-P (r = -0.452**).

14) The peak content of Fe-P was observed during the twelfth period. Period of incubation and Fe-P content were positively and significantly correlated (r = 0.669**).

15) Content of Fe-P showed negative correlation with reductant soluble-P (r = -0.366**) and occluded-P

($r = -0.455^{**}$).

16) Concentrations of reductant soluble and occluded-P were maximum during the initial period of incubation. Negative correlation was observed for period of incubation with reductant soluble-P ($r = -0.661^{**}$) and occluded-P ($r = -0.707^{**}$).

17) The minimum values of Ca-P were observed during the twelfth fortnight of sampling. Period of incubation and Ca-P were negatively correlated ($r = -0.233^{*}$).

18) Concentration of available P (Bray 1 and 2) did not vary with the forms and levels of applied P.

19) The peak values of available P were observed during the seventh fortnight. The linear coefficients of correlation between period of incubation and available P content were 0.474^{**} and 0.609^{**} for Bray 1 and Bray 2 respectively.

20) The contribution of various inorganic fractions to available P was different. Maximum correlation values for available P (Bray 1 and 2) were obtained with saloid-P ($r = 0.887^{**}$ and 0.881^{**} for Bray 1 and 2 respectively) followed by Fe-P ($r = 0.761^{**}$ and 0.859^{**} for Bray 1 and 2 respectively) and Al-P ($r = 0.683^{**}$ and 0.820^{**} for Bray 1 and 2 respectively).

Contribution of Ca-P to available P was less ($r = 0.243^{*}$, 0.291^{**} for Bray 1 and 2 respectively) while reductant soluble-P ($r = -0.273^{**}$, -0.310^{**} for Bray 1 and 2 respectively) and occluded-P ($r = -0.269^{**}$, -0.386^{**} for Bray 1 and 2 respectively) had negative correlations with available P.

21) Path analysis revealed that the saloid-P had the maximum positive direct effect on available P, followed by Fe-P. The indirect effect of Fe-P through saloid-P in increasing the available P was highly significant. Higher correlation of Al-P with available P was due to its positive indirect effect on saloid-P. The negative correlation of reductant soluble and occluded-P on available P was due to their indirect negative effect on other inorganic fractions. The positive correlation obtained between Ca-P and available P was mainly due to its indirect positive effect on saloid-P and Fe-P.

22) The extent of contribution of various inorganic fractions to available P was the same in all the three sources of P added to the soil.

23) Application of SP at the rate of 90 kg P_2O_5/ha in two equal split doses on the first and ninety-first day of incubation did not increase conspicuously

the inorganic fractions and available P content of the soil compared to the initial single application of the same quantity of P as SP and rockphosphates.

24) In the potculture experiment in general, application of P fertilizers had resulted in a better utilization of major plant nutrients by the rice plant and this effect was more pronounced in kari soil during the first crop season. However, in the second crop season, effect of P fertilizers on uptake of nutrients was pronounced in both soils.

25) During the first crop season, in the absence of added P, the uptake of nutrients and yield of straw and grain were more in laterite soil compared to kari soil, while in the presence of added P, uptake of nutrients and yield were higher in kari soil. However, in the second crop season, both in the presence and absence of added P, the uptake of nutrients and yield were more in laterite soil.

26) The uptake of N and K by the straw was maximum during the third and fourth fortnight of sampling, while that of P was maximum during the fourth and fifth periods. The rate of increase in the yield of straw was more during the second fortnight of sampling.

27) Uptake of N and K by the straw during the first crop season was significantly higher in treatments receiving SP compared to other treatments receiving rockphosphates though the uptake of P by the straw did not vary significantly with the variations in the source of P. However, in the second crop season, uptake of N, P and K by the straw was significantly higher in treatments receiving SP.

28) The efficiency of two rockphosphates (RRP and MRP) in terms of uptake of P by the straw was 73.68 and 70.55 per cent as that of SP during the first and second crop seasons respectively.

29) Increasing the level of application of P from 45 to 90 kg P_2O_5/ha increased the uptake of N and K significantly while uptake of P by the straw and straw yield did not increase significantly with increasing the level of application. But in the second crop season, the uptake of N, P and K by the straw and straw yield increased conspicuously with increasing the level of application.

30) Content of available P and the uptake of N, P and K by the straw at different stages of plant growth were positively correlated.

31) By the application of P fertilizers uptake of N and P by the grain of the first crop did not

increase significantly over control in laterite soil, while that of K showed significant increase over control in both the soils. However, in the second crop, uptake of N, P and K by grain increased conspicuously in both these soils in the presence of added P.

32) In the first crop season, total uptake of K was significantly higher over control in both the soils, while that of N and P was higher only in kari soil. But the total uptake of N, P and K increased over control in both the soils in the second crop season.

33) In general, application of SP was found to be superior to the application of rockphosphates with respect of the uptake of the N, P and K by grain and their total uptake by rice plant in both the seasons of crop growth.

34) On an average, the two rockphosphates (RRP and MRP) were 92.43 and 89.38 per cent as efficient as SP with regard to the total uptake of P by rice plant during the first and second crop seasons respectively.

35) In the absence of added P, uptake of nutrients, yield of straw and grain were more during the first crop season compared to the second crop.

Also, in the presence of added P, uptake and yield were found to be more during the first crop season in kari soil. But in laterite soil, uptake and yield were more in the second crop season.

36) The yield of grain by the application of phosphatic fertilizers showed significant increase over control only in kari soil during the first crop season. In the second crop season both the soils were found to be responsive to the application of P fertilizers with respect to the increase in the yield of grain.

37) In the treatments receiving rockphosphate as a source of P, the yield of grain was 93.18 and 92.67 per cent of that obtained in treatments receiving SP during the first crop and second crop seasons respectively.

38) In both the seasons of crop growth, available P in soil was significantly higher in treatments receiving SP than that in treatments receiving rockphosphates. Increasing the rate of application of P from 45 to 90 kg P_2O_5/ha increased the available P content of the soil to the extent of 11.97 and 17.43 per cent over the lower level during the first and second crop seasons respectively.

39) Application of SP at the rate of 45 kg P_2O_5/ha separately for the first crop and second crop seasons increased the uptake of nutrients, yield of grain, straw and available P content of the soil compared to application of the same total quantity of P initially for the first crop only as SP and rockphosphate.

40) The residual P in soil left after the harvest of the second crop was much higher in treatments receiving rockphosphates as compared to superphosphate.

REFERENCES

REFERENCES

Ahmad, N. and Jha, K.K. 1977. Effect of inoculation with phosphate solubilizing organisms on the yield and P uptake of gram. J. Indian Soc. Soil Sci. 25, 391-393

Aiyer, R.S. and Nair, C.S. 1979. Phosphate fractions of Kerala rice soils in relation to their occurrence and pedogenesis. Agric. Res. J. Kerala 17, 39-42

Annonymous, 1982. Package of Practices Recommendations. Kerala Agricultural University, Vellanikkara, pp 199

Atanisu, N. 1971. A comparative study on the effect of water and citrate soluble phosphatic fertilizers on yield and P uptake on tropical and subtropical soils. J. Indian Soc. Soil Sci. 19, 119-127

Balasubramanian, V. and Raj, D. 1969. Study of the forms of soil phosphorus in Tamil Nadu. Madras agric. J. 56, 790-793

Banerjee, B.K. 1979. Characterisation of rockphosphate. Phosphorus in Soils, Crops and Fertilizers. Bull. Indian Soc. Soil Sci. 12, 149-160

Bapat, M.V., Padole, G.C., Totey, N.G. and Bedekar, V.G. 1965. Forms of P in Vidharbha soils. J. Indian Soc. Soil Sci. 13, 31-36

Basak, M.N. and Bhattacharya, R. 1962. Phosphate transformations in rice soils. Soil Sci. 94, 258-262

Chang, S.C. and Chu, W.K. 1961. The fate of soluble phosphate applied to soils. J. Soil Sci. 12, 286-293

Chang, S.C. and Jackson, M.L. 1958. Soil phosphorus fractions in some representative soils. J. Soil Sci. 9, 109-119

Chaudhary,M.L. and Mishra,B. 1978. Factors affecting transformation of rockphosphate in soils. J. Indian Soc. Soil Sci. 28, 295-301

Chaudhary,M.L. and Mishra,B. 1980. Factors affecting transformation of rockphosphate in soils. J. Indian Soc. Soil Sci. 28, 295-301

Chauhan,S.S., Bhatnagar,R.K. and Seth,S.P. 1972. Effect of phosphatic fertilizers in soils of Chambal command area, Rajastan. J. Indian Soc. Soil Sci. 20, 111-116

Cho,C.M. and Cladwell,A.C. 1959. Forms of phosphorus and fixation in soils. Proc. Soil Sci. Soc. Am. 23, 458-459

Choudhari,J.S., Saxena,S.N. and Somani,L.L. 1974. Studies on chemical availability of inorganic phosphorus fractions and their utilization by crops in some soils of Rajastan. J. Indian Soc. Soil Sci. 22, 258-261

Chu,C.R., Moschler,W.W. and Thomas,G.W. 1962. Rockphosphate transformations in acid soils. Proc. Soil Sci. Soc. Am. 26, 476-478

Dash,R.N., Mohanty,S.K. and Patnaik,S. 1980. Efficiency of indigenous rockphosphates for rice. Annual Report, CRRI, Cuttack, 100-102

Datta,N.P. and Khera,M.S. 1969. Phosphorus soil tests based upon correlations with inorganic phosphorus fractions and green house tests. J. Indian Soc. Soil Sci. 17, 191-196

Datta,N.P., Motsara,M.R. and Ghosh,A.B. 1972. Studies on the utilization of basic slag, blast-furnace slag and some indigenous phosphatic deposits in acid soils of Jorhat and Ranchi. J. Indian Soc. Soil Sci. 20, 263-269

Debnath,N.C. and Hajra,J.N. 1972. Inorganic transformation of added phosphorus in soil in relation to soil characteristics and moisture regimes. J. Indian Soc. Soil Sci. 20, 327-335

Doharey, A.K., Nayak, P., Katyal, V., Sagar, R.L. and Mandal, A.K. 1980. Relation of inorganic P fractions with soil available P, fibre yield and P uptake by jute (Corchorus capsularis L). J. Indian Soc. Soil Sci. 28, 110-112

Ellis, R., Quader, M.A. and Truog, E. 1955. Rockphosphate availability as influenced by soil pH. Proc. Soil Sci. Soc. Am. 19, 484-487

Gupta, A.P., Khanna, S.S. and Tomar, N.K. 1983. Residual efficiency of different phosphatic fertilizers by paddy (Oryza sativa) as influenced by levels of $CaCO_3$. Trop. Pl. Sci. Res. 1, 43-47

Gupta, M.L. and Nayan, K. 1972. Inorganic phosphorus transformation in Dhankar soil. J. Indian Soc. Soil Sci. 20, 337-342

Gupta, M.L. and Nayan, K. 1975. Transformation of soil inorganic phosphorus in red soils. J. Indian Soc. Soil Sci. 23, 61-65

Gupta, M.L. and Singh, A.P. 1969. Studies on inorganic soil phosphorus fractions in Varanasi soils. J. Indian Soc. Soil Sci. 17, 63-66

Hesse, P.R. 1971. A Textbook of Soil Chemical Analysis. John Murray (Publishers) Ltd. London, pp 520

Hsu, P.H. and Jackson, M.L. 1960. Inorganic phosphate transformations by chemical weathering in soils as influenced by pH. Soil Sci. 90, 16-24

Islam, A. 1970. Transformation of inorganic phosphorus in flooded soils under rice cropping. Pl. Soil 33, 533-544

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice - Hall Inc, U.S.A., pp 498

Jackson, M.L. 1975. Soil Chemical Analysis-Advanced Course. LB Publishers and Distributors Ltd. Bangalore, pp 894

Jaggi,T.N. and Luthra,K.L. 1983. Mussoorie phosphate rock as an economic but effective source of fertilizer phosphorus. Indian J. agric. Chem. **15**, 41-51

Jenkins,W.L. 1966. The relationship between labile soil phosphorus and the Al and Fe-bound phosphorus in tropical soils. Pl. Soil **24**, 407-421

Jose,A.I. 1973. Studies on Soil Phosphorus in the South Indian Soils of Neutral-to-Alkaline Reaction. Ph.D. thesis, Tamil Nadu Agrl. Univ., Coimbatore, pp 444

Kadeba,O. and Boyle,J.R. 1978. Evaluation of P in forest soils - Comparison of P uptake, extraction method and soil properties. Pl. Soil **49**, 285-297

Kadrekar,S.B., Chavan,A.S., Talashilkar,S.C., Dhane,S.S. and Powar,S.L. 1983. Utility of rockphosphate to rice under submerged condition in laterite soils of Maharastra. Indian J. agric. Chem. **15**, 95-101

Kadrekar,S.B. and Talashilkar,S.C. 1977. Efficiency of applied phosphorus in relation to its saturation in laterite soils of Konkan. J. Indian Soc. Soil Sci. **25**, 197-200

Khanna,S.S. and Chaudhary,M.L. 1979. Residual and cumulative effect of phosphatic fertilizers. Phosphorus in Soil, Crops and Fertilizers, Bull. Indian Soc. Soil Sci. **12**, 142-149

Khanna,P.K. and Datta,N.P. 1968. Distribution of inorganic soil phosphorus in some Indian soils as affected by added phosphates. Indian J. agric. Sci. **38**, 668-676

Kothandaraman,G.V. and Krishnamoorthy,K.K. 1977. Distribution of inorganic phosphorus fractions in Tamil Nadu soils. Madras agric. J. **64**, 516-521

Krishnappa, A.M., Krishnappa, M., Rao, B.V.V. and Perur, N.G. 1979. Residual effect of phosphates, Phosphorus in Soils, Crops and Fertilizers. Bull. Indian Soc. Soil Sci. 12, 485-489

*Lehr, J.R. and Mc Clellan, G.M. 1972. A revised laboratory reactivity scale of evaluating phosphate rocks for direct application. National Fertilizer Centre TVA Bull. Y-43

Luthra, K.L., Saha, S.K. and Awasthi, P.K. 1983. Role of rockphosphate in present day agriculture. Indian J. agric. Chem. 15, 13-27

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

Maloth, S. and Prasad, R. 1976. Relative efficiency of rockphosphate and superphosphate for cowpea (Vigna sinensis) fodder. Pl. Soil 45, 295-300

Mandal, L.N. 1964. Effect of time, starch and lime on the transformation of inorganic phosphorus in a waterlogged rice soil. Soil Sci. 97, 127-132

Mandal, L.N. and Chatterjee, G.N. 1972. Transformation of applied water soluble phosphate in latosolic low land rice soils. J. Indian Soc. Soil Sci. 20, 343-353

Mandal, L.N. and Khan, S.K. 1972. Release of phosphorus from insoluble phosphatic materials in acidic lowland rice soils. J. Indian Soc. Soil Sci. 20, 19-25

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

Mandal, L.N. and Khan, S.K. 1977. Transformation of fixed phosphorus in soils under waterlogged conditions. J. Indian Soc. Soil Sci. 25, 122-128

Marwaha, B.C., Kanwar, B.S. and Tripathi, B.R. 1981. Direct and residual effect of Mussoorie rockphosphate related to the crop species in an acid soil. J. Indian Soc. Soil Sci. 29, 249-355

Mathur, B.S., Jha, K.K., Lal, S. and Srivastva, B.P. 1979. Utilisation of phosphate rock deposits in acid soils of Chotanagpur, Bihar. Phosphorus in Soils, Crops and Fertilisers. Bull. Indian Soc. Soil Sci. 12, 505-515

Mehrotra, C.L. 1968. Relative efficiency of rockphosphate as compared to superphosphate. Fertil. News 13, 27-31

Minhas, R.S. and Kick, M. 1974. Comparative availability of superphosphate and rockphosphate and their distribution into different inorganic phosphate fractions after addition of heavy doses. Fertil. News 19, 12-16

Mishra, B. and Gupta, R.P. 1978. Evaluation of Mussoorie rockphosphate as a P source of maize on acid soils of Kumaon hills. Indian J. agric. Sci. 48, 239-244

Motsara, M.R. and Datta, N.P. 1971. Rockphosphate as a fertilizer for direct application in acid soils. J. Indian Soc. Soil Sci. 19, 107-113

Nair, C.S. 1978. Investigations on the Use of Mussoorie Rockphosphate in the Acid Soils of Kerala. M.Sc.(Ag) thesis, Kerala Agrl. Univ., pp 136

Nair, C.S. and Aiyer, R.S. 1979. Effect of liming and application of Mussoorie rockphosphate on the yield of green gram, var. Co 1 grown in the upland laterites of Kerala State. Agric. Res. J. Kerala 17, 189-193

Nair, K.M. and Padmaja, P. 1982. Efficiency of primed rockphosphate for grain production in rice. Agric. Res. J. Kerala 20, 31-36

Nair,R.R. and Pisharody,P.N. 1970. Response of rice to phosphate manuring in a waterlogged lateritic sandy loam of Kerala. Agric. Res. J. Kerala 8. 6-13

Natarajan,K., Rajagopal,C.K. and Manickam,T.S. 1983. A study on Mussoorie rockphosphates as a straight phosphatic fertiliser. Indian J. agric. Chem. 15. 117-125

Panse,V.G. and Sukhatme,P.V. 1967. Statistical Method for Agricultural Workers. ICAR, New Delhi, pp 347

Patnaik,S., Sarangamath,P.A. and Shinde,B.A. 1974. Methods to increase efficiency of rockphosphates for growing rice. Fertil. News 19. 46-50

Peech,M., Alexander,L.T., Dean,L.H. and Reed,J.E. 1947. Methods of Soil Analysis for Soil Fertility Investigations. USDA Circ. pp 757

Piper,C.S. 1942. Soil and Plant Analysis. Asian reprint 1966, Hans Publishers, Bombay, pp 368

*Ponnamperuma,F.N. 1955. Chemistry of Submerged Soil in Relation to the Growth and Yield of Rice. Ph.D. thesis, Cornell Univ.

Prasad,R. and Dixit,L.A. 1976. Fertilizers Containing Partially Water or No Water Soluble Phosphate. I.C.A.R., New Delhi, pp 34

Puranik,R.B. and Bapat,M.V. 1977. Phosphorus availability in textural fractions of Vidarbha soils. J. Maharastra agric. Univ. 2. 101-103

Rajakkannu,K. and Ravikumar,V. 1978. Transformation of P in rice soils under field capacity and flooded conditions. Madras agric. J. 65. 296-302

Ramanathan,K.M., Francis,H.J., Subbiah,S. and Krishnamoorthy,K.K. 1978. Progressive uptake of phosphorus at different stages of growth of Co 7 ragi (Eleusine coracana Gaertn). Madras agric. J. 65. 458-462

Ramanathan,K.M., Francis,H.J., Subbiah,S. and Krishnamoorthy,K.K. 1979a. A study on the influence of N, P and K applications on the N uptake at different stages of growth of Co 7 ragi (*Eleusine corogana* Gaertn). *Madras agric. J.* **66**, 437-441

Ramanathan,K.M., Subbiah,S., Francis.H.J. and Krishnamoorthy,K.K. 1979b. Effect of NPK fertilizers on the soil available P, yield and P uptake at successive growth stages of ragi Co 7. *Andhra agric. J.* **26**, 189-191

Ramaswamy,S., and Arunachalam,G. 1983. Influence of Mussooriephos in the main and residual crop of paddy in neutral soils. *Indian J. agric. Chem.* **15**, 125-139

Rana,D.S., Meelu,O.P., Sharma,K.N. and Randhawa,N.S. 1975. Effect of phosphobacteria on the availability of phosphorus from rockphosphate to wheat. *J. Res. (Punjab)* **12**, 232-235

Rao,T.S., Ahmed,N. and Rao,H.K.G. 1972. Fractionation of the residual phosphorus compounds in black and red soils treated with phosphatic fertilizers. *J. Indian Soc. Soil Sci.* **20**, 323-326

Raychaudhari,S.P. 1980. Phosphorus and potassic fertilizers and their management. *Soil Fertility - Theory and Practice* (ed. Kanwar,J.S.) I.C.A.R., New Delhi, 371-398

Reddy,S.N. and Rao,C.R. 1983. Effect of phosphorus on uptake of N, P, K, growth and yield of rice. *Andhra agric. J.* **30**, 58-61

Sacheti,A.K. and Saxena,S.N. 1974. Correlations between inorganic phosphorus fractions and soil tests. *J. Indian Soc. Soil Sci.* **22**, 57-59

Sahu,B.N., Maity,K. and Mishra,S.N. 1974. Comparative efficiencies of rockphosphate and superphosphate for rice in a laterite soil. *Fertil. News* **19**, 23-25

Sahu,S.K. and Pal,S.S. 1983. Efficient utilization of rockphosphate in acidic red soil (Inceptisol) under rice - wheat farming system. *Indian J. agric. Chem.* **15**, 87-95

Sample,E.C., Allen,S.E. and Bengtson,G.W. 1974. Response of slash pine seedlings to P sources of varying citrate solubility. Pl. Soil 40, 83-96

Sarangamath,P.A., Shinde,B.N., Patnaik,S. 1975. Efficiency of water soluble, citric acid soluble and insoluble phosphate fertilizers for rice in different soils. Indian J. agric. Sci. 45, 106-111

Sarangamath,P.A. and Shinde,B.N. 1977. ^{32}P tracer studies on the methods of increasing the efficiency of citrate soluble and insoluble phosphates for rice in acid soils. Soil Sci. 124, 40-44

Sharma,R.C., Grewal,J.S. and Sud,K.C. 1976. Relative suitability of different phosphatic fertilizers for potato on brown hill soils of Simla. J. Indian Soc. Soil Sci. 24, 95-97

Sharma,P.K., Verma,S.P. and Bhumbla,D.R. 1980. Transformation of added P into inorganic P fractions in some acid soils of Himachal Pradesh. J. Indian Soc. Soil Sci. 28, 450-454

Shinde,B.N., Sarangamath,P.A. and Patnaik,S. 1978. P transformations from rockphosphate in acid soils and measures for increasing their efficiency for growing rice. (Oryza sativa) Pl. Soil 49, 449-459

Shukla,G.C. 1973. Effectiveness of different source of phosphates on yield, available soil phosphorus and phosphorus content of bluebelle rice. Pl. Soil 38, 447-455

Singh,R. and Bahaman,P.C. 1976. Transformation of phosphorus in acid soils under waterlogged and upland conditions. J. Indian Soc. Soil Sci. 24, 171-174

Singh,D. and Datta,N.P. 1973. Effect of particle size of rockphosphate on their fertilizer value for direct application to the soil. J. Indian Soc. Soil Sci. 21, 315-318

Singh, D. and Datta, N.P. 1974. Saturation of soil with respect of P in relation to the efficiency of utilization of applied P from indigenous phosphate rocks. J. Indian Soc. Soil Sci. 22, 125-129

*Singh, D. and Datta, N.P. 1976. Availability of phosphorus in acid soils from indigenous phosphate rocks. Acid Soils of India: Their Genesis Characteristics and Management. Bull. Indian Soc. Soil Sci. 11, 206-213

Singh, D., Mannikkar, N.D. and Srivas, N.C. 1976a. Fertilizer value of indigenous rockphosphates compared with single superphosphate - Laboratory incubation studies with farm yard manure. J. Indian Soc. Soil Sci. 24, 78-80

Singh, D., Mannikkar, N.D. and Srivas, N.C. 1976b. Phosphate fertilizer value of indigenous rockphosphates and superphosphate for lucerne and their residual effect on guar. J. Indian Soc. Soil Sci. 24, 186-191

Singh, D., Mannikkar, N.D. and Srivas, N.C. 1979. Comparative performance of indigenous rockphosphates and superphosphate in a forage legume cropping pattern. J. Indian Soc. Soil Sci. 27, 170-173

Singh, R.S. and Ram, H. 1976. Inorganic transformation of added water soluble phosphorus in some soils of Uttar Pradesh. J. Indian Soc. Soil Sci. 24, 53-56

Singh, R.S. and Ram, H. 1977. Effect of organic matter on the transformation of inorganic phosphorus in soils. J. Indian Soc. Soil Sci. 25, 118-121

Singh, S. and Singh, S.B. 1975. Effect of waterlogging and organic matter on inorganic P fractions of soils. J. Indian Soc. Soil Sci. 24, 88-90

Singlachar, M.A. and Samaniego, R.S. 1973. Effect of flooding and cropping on the changes in the inorganic phosphate fractions in some rice soils. Pl. Soil 39, 351-359

Smith, A.N. 1965. The supply of soluble P to the wheat plant from inorganic soil P. Pl. Soil 22, 314-317

Srivastava, O.P. and Pathak, A.N. 1972. Fate of applied phosphorus in some soils of U.P. J. Indian Soc. Soil Sci. 20, 103-109

Subramanian, C.K. and Manjunath, K.T. 1983. Response to Mussooriephos in Karnataka soils. Indian J. agric. Chem. 15, 81-87

Syers, J.K., Shah, R. and Walker, T.W. 1969. Fractionation of phosphorus in two alluvial soils and particle size separates. Soil Sci. 108, 283-289

Talati, N.R., Mathur, G.S., and Attri, S.C. 1975. Distribution of various forms of phosphorus in north west Rajastan soils. J. Indian Soc. Soil Sci. 23, 202-206

Talashilkar, S.C. and Patil, M.D. 1979. Effect of organic matter on the availability of P from superphosphate and rockphosphate in a submerged soil. J. Indian Soc. Soil Sci. 27, 201-202

Thakur, R.S., Bisen, D.C. and Dubey, S.M. 1975. Transformation of applied phosphorus under waterlogged conditions in rice culture. J. Indian Soc. Soil Sci. 23, 423-427

Tiwari, K.N., Pathak, A.N., Ram, N., Shukla, B.R., Upadhyay, R.L., Prasad, L. and Gangwar, B.R. 1979. Effect of rockphosphate, superphosphate and their mixtures on yield and phosphorus uptake by crops in soils of Uttar Pradesh. Phosphorus in Soils, Crops and Fertilizers. Bull. Indian Soc. Soil Sci. 12, 527-539

Varadan, K.M., Satyanarayan, T. and Havanagi, G.V. 1977. Some phosphate studies on ragi. J. Indian Soc. Soil Sci. 25, 388-390

Venkataramaiah, N. 1979. Uptake of P and K as influenced by phosphatic and potash fertilization in Jaya paddy. Andhra agric. J. **26**, 248-250

Wright, B.C. and Peech, M. 1960. Characterization of phosphate reaction products in acid soils by the application of solubility criteria. Soil Sci. **90**, 32-43

Zende, G.K. 1983. Behaviour of rockphosphate in different soils of Maharashtra. Indian J. agric. Chem. **15**, 29-39

* Original not seen

APPENDICES

Appendix I. An abstract of the analysis of variance of inorganic P fractions and available P (Incubation study)

(Mean sum of squares)

Sources	Degrees of freedom	Saloid-P	Al-P	Fe-P	Reductant soluble-P	Occluded-P	Ca-P	Bray 1 P	Bray 2 P
Soil	1	9.536**	9608**	2089**	3974**	1434**	9577**	1002**	379.1**
Sources of P	2	1.540**	352.9	453.2	94.30	16.24	40.69	0.262	0.426
Soil x Sources	2	0.019	11.42	13.11	32.79	10.02	11.22	0.262	1.051
Level	1	1.037**	2134**	1094	275.3**	130.9*	826.5**	2.170	5.150
Soil x Level	1	8.610	5.547	5.980	3.180	0.090	91.76	0.005	0.004
Source x Level	2	0.013	2.619	16.33	24.10	2.740	7.130	0.068	0.061
Period	12	7.190**	16430**	38310**	1185**	267.4**	604.9**	237.1**	952.3**
Soil x Period	12	0.135**	81.41	286.5	38.24	248.7**	331.2**	8.990**	3.510
Source x Period	24	0.081*	29.62	65.08	13.34	4.260	3.760	0.209	0.910
Level x Period	12	0.014	23.27	8.930	15.37	1.080	8.090	0.089	0.440
Between Control	1	0.063	44.68	7701**	31.08	302.4**	334.1**	0.889	3.820
Higher order interactions	86	0.018	15.12	11.29	11.20	1.910	3.390	0.069	0.172
Control Vs treated	1	21.71**	20601**	46789**	2077**	2171**	12877**	1092**	2389**
Error	206	0.046	157.4	306.2	41.58	32.59	26.32	2.102	11.00

* Significant at 5 per cent level

** Significant at 1 per cent level

Appendix II. An abstract of the analysis of variance of nutrient uptake, nutrient per cent and straw yield during first crop season

(Mean sum of squares)

Sources	Degrees of freedom	% of nutrient in straw			% of nutrient in root			Nutrient uptake by straw			Straw yield
		N	P	K	N	P	K	N	P	K	
Soil	1	1.191*	0.002	16.61**	2.475	1.2×10^{-3}**	0.975**	0.078	143.9	2.830**	0.045
Sources of P	2	0.285	0.006	0.557*	0.039	1.9×10^{-4}*	0.005	0.196**	324.4	0.313**	124.6
Soil x Sources	2	0.075	0.003	0.021	0.011	4.6×10^{-6}	0.010	0.022	104.5	0.015	1.030
Level	1	0.339	0.005	0.111	0.250	2.7×10^{-4}*	0.083*	0.227**	359.6	0.303**	268.6*
Soil x Level	1	0.001	0.003	0.006	0.013	9.3×10^{-5}	0.0001	0.032	194.2	0.063	41.66
Source x Level	2	0.042	0.008	0.008	0.022	5.2×10^{-5}	0.003	0.003	46.30	0.005	7.810
Period	5	31.09**	0.036**	11.60**	14.96**	4.0×10^{-3}**	3.640**	3.650**	14791**	2.340**	5824**
Soil x Period	5	0.233	0.006	0.762**	0.285	2.8×10^{-4}**	0.164**	0.147**	255.9	0.601**	113.6*
Source x Period	10	0.023	0.005	0.044	0.005	1.6×10^{-5}	0.005	0.012	22.03	0.020	9.790
Level x Period	5	0.012	0.005	0.051	0.011	6.3×10^{-6}	0.002	0.012	33.66	0.001	5.030
Between Control	1	0.542	0.003	0.042	0.464	2.5×10^{-4}**	0.586**	0.576**	1912**	0.483**	1130**
Higher order interactions	37	0.014	0.005	0.023	0.004	8.7×10^{-6}	0.005	0.004	26.17	0.006	4.590
Control Vs treated	1	2.461**	0.014	15.45**	0.677**	2.2×10^{-3}**	7.640**	1.250**	3319**	3.230**	1332**
Error	94	0.220	0.004	0.133	1.320	4.9×10^{-5}	0.015	0.024	119.8	0.018	41.59

* Significant at 5 per cent level

** Significant at 1 per cent level

Appendix III. An abstract of the analysis of variance of nutrient uptake, nutrient per cent and straw yield during second crop season

(Mean sum of squares)

Sources	Degrees of freedom	% of nutrient in straw			% of nutrient in root			Nutrient uptake by straw			Straw yield
		N	P								
Soil	1	14.58**	2.2×10^{-2}**	3.750**	0.752**	3.0×10^{-4}**	0.235**	4.880**	11751**	4.430**	2622**
Sources	2	0.038	2.9×10^{-4}	0.120	0.039	5.7×10^{-5}	0.052	0.123**	321.7**	0.224**	169.6*
Soil x Source	2	0.046	3.6×10^{-5}	0.030	0.001	1.3×10^{-6}	0.002	0.001	64.00	0.041	13.78
Level	1	0.125	8.6×10^{-5}	0.029	0.053	3.0×10^{-4}**	0.216**	0.296**	536.5**	0.384**	385.1**
Soil x Level	1	0.005	1.6×10^{-4}	0.009	0.004	5.1×10^{-5}	0.004	0.028	165.5	0.039	27.43
Source x Level	2	0.016	6.0×10^{-7}	0.008	0.019	6.3×10^{-6}	0.027	0.010	13.43	0.011	14.19
Period	5	10.93**	1.6×10^{-2}**	6.240**	5.750**	3.0×10^{-3}**	2.530**	1.420**	8488**	2.870**	5166**
Soil x Period	5	2.030**	9.2×10^{-4}**	0.430*	0.022	3.9×10^{-5}	0.017	0.351**	650.2**	0.175**	41.85
Source x Period	10	0.007	2.4×10^{-5}	0.030	0.003	2.8×10^{-5}	0.003	0.003	22.85	0.008	5.160
Level x Period	5	0.033	1.4×10^{-5}	0.006	0.002	2.0×10^{-5}	0.003	0.003	24.06	0.005	3.190
Between Control	1	2.560**	2.2×10^{-3}**	0.024	0.087	3.5×10^{-5}	0.202**	0.632**	1024**	0.337**	488.9**
Higher order interaction	37	0.014	1.5×10^{-5}	0.013	0.004	1.1×10^{-5}	0.003	0.004	4.340	0.005	1.350
Control Vs treated	1	0.510	4.1×10^{-2}**	2.990*	0.393**	5.7×10^{-3}**	0.414**	0.955**	3073**	2.530**	1514**
Error	94	0.147	1.9×10^{-4}	0.160	0.073	2.6×10^{-5}	0.019	0.015	55.37	0.022	38.64

* Significant at 5 per cent level

** Significant at 1 per cent level

Appendix IV. An abstract of the analysis of variance of available P (Potculture experiment)

(Mean sum of squares)

Sources	Degrees of freedom	First crop		Second crop	
		Bray 1	Bray 2	Bray 1	Bray 2
Soil	1	39.61**	440.4**	99.56**	490.9**
Sources	2	13.91**	41.90**	8.22**	6.560
Soil x Source	2	4.780*	0.837	2.530*	1.099
Level	1	20.60**	62.85**	17.92**	5.560
Soil x Level	1	0.001	7.570	11.25**	1.780
Source x Level	2	0.180	0.316	0.012	5.860
Period	6	55.59**	637.2**	59.63**	527.5**
Soil x Period	6	1.020	4.930	4.060**	29.21**
Source x Period	12	1.430	4.110	0.733	0.357
Level x Period	6	1.340	0.562	0.625	2.760
Between Control	1	13.48*	11.92	15.71**	9.780
Higher order interaction	44	0.876	0.774	0.363	1.390
Control Vs treated	1	90.58**	464.7**	43.19**	914.2**
Error	110	1.370	5.960	0.674	5.690

* Significant at 5 per cent level

** Significant at 1 per cent level

Appendix V. An abstract of analysis of variance of nutrient uptake, nutrient per cent and grain yield

(Mean sum of squares)

Sources	Degrees of freedom	Nutrient % in grain			Nutrient uptake by grain			Total nutrient uptake			Yield of grain
		N	P	K	N	P	K	N	P	K	
First crop											
Treatment	13	3.9×10^{-4}	3.9×10^{-4}	4.9×10^{-4}*	9.6×10^{-3}**	8.8×10^{-4}**	5.2×10^{-4}**	3.6×10^{-2}**	1724**	4.5×10^{-3}**	61.15**
Error	14	1.6×10^{-2}	1.9×10^{-4}	1.5×10^{-4}	8.7×10^{-4}	1.5×10^{-4}	6.6×10^{-5}	8.6×10^{-3}	230.4	1.2×10^{-4}	6.120
Second crop											
Treatment	15	5.7×10^{-3}	4.9×10^{-4}	7.0×10^{-4}**	2.6×10^{-2}**	2.2×10^{-3}**	1.1×10^{-3}**	1.3×10^{-1}**	4526**	1.7×10^{-1}**	140.0**
Error	16	3.6×10^{-3}	3.4×10^{-4}	1.1×10^{-4}	2.2×10^{-3}	4.9×10^{-5}	4.9×10^{-5}	1.7×10^{-2}	67.65	3.5×10^{-2}	7.970

* Significant at 5 per cent level

** Significant at 1 per cent level

SUITABILITY OF ROCKPHOSPHATE FOR DIRECT APPLICATION IN ACID RICE SOILS OF KERALA

By

REGI. P. MATHEWS

ABSTRACT OF A THESIS

submitted in partial fulfilment of

the requirement for the degree

Master of Science in Agriculture

Faculty of Agriculture

Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry

COLLEGE OF HORTICULTURE

Vellanikkara - Trichur

1985

ABSTRACT

An incubation study and a potculture experiment were conducted to assess the suitability of Rajastan rockphosphate (RRP) supplied from Rajastan State Mineral Development Corporation, in comparison with that of Mussoorie rockphosphate (MRP) supplied from Pyrites Phosphates and Chemicals Ltd. (U.P) and superphosphate (SP) in two acid rice soils of Kerala namely laterite (Kodakara, Trichur district) and kari (Karumadi, Allappey district) soils. Transformations of P fertilizers applied at the rate of 45 and 90 kg P_2O_5/ha in these soils under continuous submergence were studied in the incubation experiment. Soil samples were drawn at 15 days interval for the determination of various inorganic P fractions and available P. The direct and residual effects of the two rockphosphates in comparison with the water soluble SP were studied in the potculture experiment using rice (Jaya) as the test crop. The soils and levels of P applications were the same as in the incubation study. Application of N and K was done uniformly in all the treatments. Soil and plant samples were drawn at 15 days interval for the determination of available P

and the uptake of major nutrients. The residual effect of phosphatic fertilizers was assed by continuing the experiment for the second season with out the addition of P fertilizers. However, for the second season a treatment receiving P at the rate of 45 kg P_2O_5/ha as SP in both the season was incorporated for comparison in both the soils.

Application of phosphatic fertilizers irrespective of their water solubility increased the various inorganic fractions and available P content of the soil. The total native inorganic P increased in the presence of added P due to the enhanced mineralization of organic P. Among the various inorganic fractions, Fe-P was the dominant form accounting for 41 to 44 per cent of the total inorganic P. Second most abundant fraction was Al-P. The contents of reductant soluble-P, occluded-P and Ca-P were relatively less and that of saloid-P was negligible.

The three sources of P did not differ significantly in increasing the various inorganic fractions of the soil except that of saloid-P. The contents of Al-P, Fe-P, reductant soluble-P and occluded-P were more in laterite soil compared to kari soil, while saloid-P and Ca-P were high in kari soil. Prediction equations were worked out to establish various inorganic P fractions and available-P at different periods of incubation.

The peak values of saloid-P were observed during the seventh fortnight. Saloid-P was found to be positively correlated with Fe-P ($r = 0.772^{**}$), Al-P ($r = 0.731^{**}$) and Ca-P ($r = 0.278^{**}$) and negatively correlated with reductant soluble-P ($r = -0.249^{*}$) and occluded-P ($r = -0.319^{**}$). Concentrations of Al-P and Fe-P were maximum during the twelfth period of sampling and they were negatively correlated with reductant soluble-P and occluded-P. Highest values of reductant soluble-P and occluded-P were observed during the first period of incubation and the concentration of Ca-P was minimum in the twelfth fortnight.

Forms and levels of applied P had little effect on increasing the available P content of the soil. The contribution of various inorganic fractions to available P was different. Direct and indirect effects of various inorganic P fractions on available P from RRP, MRP and SP were brought out by the path analysis. Saloid-P, Fe-P, Al-P and Ca-P were positively correlated with available P (Bray 1 and 2) and reductant soluble-P and occluded-P were negatively correlated. The extent of contribution of various inorganic fractions to available P was the same in all the three sources of P added to the soil.

Application of SP at the rate of 90 kg P_2O_5/ha twice in two equal doses during the first and ninety-first day of incubation did not increase conspicuously the inorganic fractions and available P content of the soil compared to the initial application of the same quantity of P as SP and rockphosphate.

In the potculture experiment in general, application of P fertilizers had resulted in a better utilization of major nutrients by the rice plant and this effect was more pronounced in kari soil during the first crop season. However, in the second crop season, the effect of P fertilizers on uptake of nutrients was pronounced in both the soils. During the first crop season, in the absence of added P, the uptake of nutrients and yield of straw and grain were more in laterite soil compared to kari soil while in the presence of added P, uptake of nutrients and yield were higher in kari soil. However, in the second crop season, both in the presence and absence of added P, the uptake of nutrients and yield were more in laterite soil.

Uptake of N and K by the straw during the first crop season was significantly higher in treatments receiving SP compared to other treatments receiving rockphosphates though the uptake of P by the straw did not vary significantly with the variations in the source of P. However, in the second crop season, uptake of N, P and K by the straw was significantly higher in treatments receiving SP. Increasing the level of application of P from 45 to 90 kg P_2O_5/ha increased the uptake of N and K significantly while uptake of P by the straw and straw yield did not increase significantly with increasing the level of application. But in the second crop season, the uptake of N, P and K by the straw and straw yield increased markedly with increasing the level of application.

Uptake of N and P by the grain of the first crop did not increase significantly over control in laterite soil, while that of K showed significant increase over control in both the soils. However, in the second crop, uptake of N, P and K by the grain increased conspicuously in both these soils. In the first crop season, total uptake of K was significantly higher over control in both the soils, while that of N and P was higher only in kari soil. But the total uptake of N, P and K increased over control in both the soils in the second crop season. In general, application of SP was found to be superior to the application of rockphosphates with respect of the uptake of N, P and K by grain and their total uptake by rice plant in both the seasons of crop growth. The yield of grain by the application of phosphatic fertilizers showed significant increase over control only in kari soil during the first crop season. In the second crop season, both the soils were found to be responsive to the application of P fertilizers with respect to the increase in the yield of grain. In the treatments receiving rockphosphates as a source of P, the yield of grain was 93.18 and 92.67 per cent of that obtained in treatments receiving SP during the first crop and second crop seasons respectively.

In both the seasons of crop growth, available P in the soil was significantly higher in treatments receiving SP than that in treatments receiving rockphosphates. Increasing the level of application of P from 45 to 90 kg P_2O_5/ha increased the available P content of the soil to the extent of 11.97 and

17.43 per cent over the lower level during the first and second crop seasons respectively.

Application of SP at the rate of 90 kg P_2O_5/ha applied twice in two equal doses separataly for the first crop and second crop seasons increased the uptake of nutrients, yield of grain and straw and available P content of the soil compared to the application of the same total quantity of P initially for the first crop only as SP and rockphosphate.