INFLUENCE OF SOURCE OF PHOSPHATIC FERTILIZERS AND COVER CROPS ON THE MANAGEMENT OF PHOSPHATE NUTRITION IN SOILS OF RUBBER PLANTATIONS

A Thesis

by

P. R. SURESH

Submitted to the Faculty of the Post-Graduate School,
Indian Agricultural Research Institute, New Delhi
in partial fulfilment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY
IN
SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

NEW DELHI

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CERTIFICATE

This is to certify that the thesis entitled "Influence of source of phosphatic fertilizers and cover crops on the management of phosphate nutrition in soils of rubber plantations" submitted to the Faculty of Post-Graduate School, Indian Agricultural Research Institute, New Delhi by Mr P.R. Suresh in partial fulfilment of the requirements for the award of the degree of DOCTOR OF PHILOSOPHY in Soil Science and Agricultural Chemistry, embodies the results of a piece of bonafide research carried out by him under my guidance and supervision and that no part of this thesis has been submitted for any other degree or diploma. The assistance and help received by him during the course of the investigation have been duly acknowledged.

(G. Narayanasamy)
Chairman
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P.R. Suresh

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INTRODUCTION

Phosphorus is a major plant nutrient, the extent of its deficienc in soils of India is next only to that of nitrogen. In plants it is constituent of proteins, nucleic acids and its esters and the energy-ric pyro phosphates representing the metabolic machinery of the cells make it the life line of plants. Unlike nitrate and sulphate, phosphate i not reduced in plants and remain in its highest oxidised forn (Marshner, 1986). The amount of supply of phosphorus to a plan directly affects the various phosphorus fractions of the plant in a typica manner and above optimal levels it is stored in inorganic form itsel (Ogawa *et al.* 1979). The effect of phosphorus supply on plant growth an development is related to its effect on phytochrome balance and thi relation holds true for decrease in the number of flowers/ delay in flowe initiation as a result of P deficiency (Rossiter, 1978).

In the soils, phosphate can readily be rendered unavailable t plant roots and it is the most immobile of the major plant nutrients. I soil solution its concentration can be below 10^{-8} M as in very poo tropical soils and in soils of moderate phosphate status it is 10^{-5} M (0. ppm in soil solution), which is much smaller as compared to nitroge and potassium. Since the early days of applying mineral fertilizers t soil, phosphate fertilization has always been an important practice, an a major breakthrough in modifying its availability to crops is no obtained so far. Indeed vast areas of potentially good lands are stil agriculturally poor because of P deficiency.

Phosphate rocks in its natural state is of only limited value to plants in general, though finely ground phosphate rocks are effective on acid soils of pH 5.5 or less. Phosphate rocks from deposits of different geological origin have been tried under varied soil-crop-climate situations with varying level of success. Most of these rocks on acidulation perform better, especially for short duration crops. But their use for long duration crops grown in acid soils is not justifiable when one considers the economics. For a country like India the use of acidulated rockphosphates is a costly proposition, since the sulphur needed for the acidulation is also imported. Much attention is being given to the direct application of phosphate rocks. In India, the annual consumption of P_2O_5 is nearly 3.01 million tonnes (Fertilizer Statistics 1989-90) and the annual crop removal has been estimated to be much higher than this. Recovery of the applied phosphorus in acid soils is usually less than 20 percent primarily because of so called P fixation. Currently the practice of direct application of phosphate rock to soil is being advocated for enriching P status of acid soils used for growing plantation crops.

India is the fourth major rubber producer in the world with 3.98 lakh ha under the crop, and produces 2.35 lakh tonnes of natural rubber annually, which falls short of the domestic demand. Scientific cultivation of rubber plants with judicious application of fertilizers is viewed as one of the strategies in increasing the latex production. Nearly 90% of the area under rubber plantation is in Kerala and most of the cultivators are small farmers, and for them fertilizer is a costly input. Rubber is a tree crop and the latex collected by the selective wounding of the bark is the economical yield of the crop. The crop is generally cultivated on the laterite soils which are well drained, very poor in N, P, K and Ca with low base saturation. But these soils respond well to good management practices (Aiyer and Nair, 1985). These soils being lateritic with high percentage of sesquioxides, pose special problems with respect to management of phosphatic fertilizers. Powdered phosphate rock is generally used in this crop, as source of P.

In the cultivation of rubber, cover crops of leguminous group are established and mainatined during the initial years with a view to conserving and also to improve or maintain the soil fertility. These cover crops being leguminous, as a general practice, application of phosphate, usually through rock phosphate, is done initially and the cover crop is recycled to the soil. Thus these crops have a great role in maintaining the general fertility status of the soil. Particularly their ability in utilising P from sparingly soluble fertilizer sources and then returning the same in the form of organic P to soil might be an important aspect of P nutrition of rubber plants. Legumes have a higher demand for calcium (Lonergan and Snowball, 1969) and this may further facilitate availability of P from calcium phosphate present in the phosphate rock, which contain appreciable amounts of calcium. Also the information on extent and nature of the turnover of phosphate applied to cover crops is inadequate and not well understood. Therefore an investigation on the various aspects pertaining to the phosphate nutrition of the two of the major cover crops *viz. Pueraria phaseoloids* and *Mucuna bracteata* in relation to phosphatic fertilizers of varied nature applied at different levels was carried out in two experiments with the following objectives.

1. To evaluate the effects of different types of phosphatic fertilizers on the biomass production through cover crops in rubber plantations.

2. To elucidate the role of cover crops in the turn-over of phosphate from several sources of phosphatic fertilizers.

3. To characterise the phosphate present in soils under rubber plantations of variable age receiving differential levels of management.

REVIEW OF LITERATURE

Effectiveness of rockphosphate as a direct application fertilizer is dependent not only on its intrinsic properties, but also on the characteristics of both soil and plant involved in any such evaluation. However, among these three interacting components, a consideration of the properties of the phosphate rocks received a great attention, probably because of the highly heterogeneous nature obtaining amongst the several deposits of this material. The efficacy of phosphate rocks is usually related to their chemical reactivity, which in turn depends on the degree of carbonate substitution for phosphate in the apatite structure. Phosphate rocks with a high potential for direct application have more than 17% of their total phosphorus soluble in neutral ammonium citrate, those with 12-17% citrate soluble part are rated as medium and sources with less than 12% citrate solubility are expected to have low potential. Ground rock phosphate with low potential may have efficiency of 30-60% depending on soil properties, crop type and management (Tisdale *et al.* 1985).

There has been considerable interest in studying the efficiency of rockphosphate for direct application in Indian soils. Out of the total reserve of 122-136 million tonnes of rockphosphate reserve in India, about 60% is considered to be unsuitable for manufacture of fertilizer (Jaggi, 1981, 1986). The reactivity of Indian rockphosphate is reported to below (Narayanasamy *et al.* 1981). Mussoorie rock is the most reactive among them and is about 25% as reactive compared to North Carolina rock (Tandon, 1987).

Plantation crops play an important role in our economy. Most of them yield exportable commodities, earn a considerable foreign exchange for the country and provide employment to a few lakhs of people. Rubber is one of the major plantation crops and India occupies fourth position among the rubber producing countries of the world. In India, nearly 91 percent of the area is located in Kerala, of which 75 percent of the area is in small holdings.

Phosphorus is an important fertilizer input in these plantations and owing to the special nature of the soil, it often is a major constraint for successful crop production. Phosphate applied through fertilizers gets fixed up into unavailable forms. Ground rockphosphates are widely used in these soils considering the acidic nature of the soils, with varying level of success. There is a need to increase the effectiveness of these materials. Such fertilizers are of an ideal choice considering the perennial nature of rubber plantations. A lot of literature is available suggesting the use of rockphosphates as an effective P fertilizer in acid soils.

A brief review of the recent literature relevant to the present investigation has been done under the following headings.

1. Inherent reactivity of rockphosphates.

2. Relative efficiency of rockphosphates.

3. Importance of cover plants and phosphate nutrition in rubber plantations.

4. Role of different fractions of phosphorus to plant availability.

5. Effect of liming on the release of phosphates.

Inherent Reactivity of Rockphosphates

Essentially the reactivity (susceptibility to disintegrate in soil medium and release P into soil solution for plant uptake) of a phosphate rock is largely influenced by its crystallo-chemical composition, particularly the degree of isomorphous substitution of phosphate by carbonate and fluoride in the crystal structure of the apatite mineral. Extensive research done through X-ray diffraction techniques on various phosphate rock samples have shown that the isomorphous substitution of carbonate for phosphate in the apatite structure, results in non-linear decrease in the `a' axis of the unit-cell lattice parameter. This decrease was found to be closely related to the degree of carbonate substitution, which in turn controls the rock activity.

Narayanasamy *et al.* (1981) after carrying out X-ray analysis of almost all the indigenous rockphosphates demonstrated the uniqueness of Mussoorie phosphate, in asmuch as the apatite present in it is extensively different from those present in other deposits. They identified the apatite forms as carbonate apatite. Rockphosphates from Jhamarkotra and Maton in Rajasthan and Jhabua (Madhya Pradesh) are fairly rich in phosphate content compared to the deposits in Mussoorie (Uttar Pradesh), Singhbhum (Bihar) and some parts of Jhabua. The Palaumu phosphorite is observed to be of very poor quality. Mineralogical studies conducted by them revealed that deposits in Rajasthan and Singhbhum contain fluorapatite and Mussoorie rockphosphate is a carbonate apatite. Similarly Bhujbal and Mistry (1981) indicated that in Mussoorie rockphosphate samples, the type of apatite present is a francolite with relatively larger degree of carbonate substitution, when compared with other Indian phosphate rock samples. Marwaha *et al.*(1981) following a chemical evaluation of some of the Indian rockphosphates opined that rockphosphate from Madhya Pradesh (Jhabua) is most suitable for superphosphate manufacture, and the Mussoorie rock is best suited for direct application.

Reactivity of Indian phosphate rock in relation to crystal chemical structure of apatite was also elaborated by Patnaik (1988). The crystal chemical structure of Indian rockphosphates examined from a chemical statistical model and X-ray diffraction data indicated very low substitution of CO_3 + F for PO_4, which made them less effective. The dissolution of P from rockphosphate was hastened under acid soil conditions and the ability of crops to absorb P from a soil system involving rocks may be different.

Fertilizer efficiency of three carbonate apatites varying in phosphate ratios to that of triple superphosphate (TSP) and the liming effects induced by liberation of carbonate from each source to that of calcium carbonate for a test crop of maize was studied Easterwood et al.. (1989). They observed lower yield for the carbonate apatite sources than for TSP during the first year of cropping period, but equal yield during the second cropping period with the rocks possessing a carbonate/ phosphate ratio greater than 0.14.

Laskar *et al.* (1990) studied the phosphate solubility and transformation of Mussoorie rockphosphate in acid soils. When applied alone, rockphosphate increased the available P, Al-P, Fe-P, Ca-P and total inorganic P in soil but did not increase saloid bound P. However rockphosphate combined with green manures (cowpea and hibiscus) had inconsistent effects on available P, but increased Al, Fe and Ca fractions of P with few exceptions. Green manuring increased total organic P content in the soils.

Hellums *et al.*. (1989) evaluated the potential agronomic value of calcium in some phosphate rocks (PR) with respect to $CaCO_3$ from South America and West Africa, by conducting a green house experiment. The results showed that PR's with medium or high reactivity have potential Ca values in addition to their use as P sources when applied directly to soil.

Of the total P_2O_5 applied worldwide, only 4.5% is in the form of unacidulated phosphate rock, and new potential exist in regions of acid soils, due to findings from recent research, cost advantage and moves to reduce chemical inputs (Hammond 1990). He also reported that highly reactive rocks are more versatile than generally presumed, and much of the traditional wisdom regarding rock effectiveness was derived from experience with low reactive rocks.

Relative Efficiency of Rockphosphates

Rockphosphates obtained from various places are found to differ in their chemical and mineralogical properties and thus in turn influence the effectiveness of rockphosphates for direct application.

Various igneous and sedimentary phosphate rocks were tested by Mathur *et al.*. (1979) in an acid red loam soil (pH 5.5) and noted that application of 150 kg P_2O_5 per hectare as phosphate rock was comparable to 50 kg of P_2O_5 as single superphosphate (SSP). They reported the relative agronomic effectiveness of rock phosphate on various crops to be in the order: groundnut > gram > soybean > peas > maize > wheat.

In a study on phosphate transformation from different rockphosphates, Shinde *et al.*. (1978) revealed that transformation from North Carolina, Gafsa and Jordan rockphosphates was more than that from Florida rockphosphates.

The effectiveness of five Indian rockphosphates along with one imported material (Jordan) was evaluated by Mishra *et al.*. (1985) for wheat and rice plants in three acid soils using ^{32}P as tracer. The overall ranking of the sources based on L value basis was Jordan > Jhabua > Mussoorie > Udaipur > Purulia > Singhbhum.

Debnath and Basak (1986) reported the effect of rockphosphate and basic slag on available P in acid soils in different moisture regimes and in different seasons. They noticed that all the fertilizers were more effective in winter than in summer and 50% water holding capacity as soil moisture regime was more favourable for the P release. The direct and residual effects of superphosphate and Mussoorie rockphosphate in conjunction with farmyard manure and mycorrhiza on sweet potatoes in acid laterite soil were examined by Kabeerathumma (1986). She noticed Mussoorie rock phosphate to be as efficient as superphosphate in direct effect, but superior to it in residual value, and the rockphosphate along with farmyard manure and mycorrhiza had significantly influenced tuber yield and P uptake by the crop.

The relative efficiency of Mussoorie rockphosphate and SSP applied singly and in combination with lime in acid soils, for different cropping sequences was tested by Dwivedi *et al.*. (1989). Mussoorie rockphosphate along with liming recorded maximum yield. Without liming, performance of Mussoorie phos was superior to SSP, in terms of crop yield and phosphate availability through direct as well as residual effect.

Marwaha (1989) reported that Mussoorie rockphosphate appeared to be the most reactive and agronomically effective of all indigenous rocks as measured by crop responses, P uptake and liming action. The effectiveness of finely ground rockphosphate relative to superphosphate is often less than 50%.

After comparing the effectiveness of different types of rockphosphates with superphosphate in several long-term field experiments on different non-leaching soils in south-western Australia, Bolland and Gilkes (1990) have included that all types of rockphosphate fertilizers are between one - twentieth to one - third as effective as freshly applied superphosphate, both in the year of application and in the subsequent years. Laboratory studies of soils from these experiments have shown the poor effectiveness of rock phosphates is primarily due to the small extent of dissolution of these fertilizers in west Australian soils.

Again SSP as a source of P was shown by Sharma (1990) as significantly superior to rockphosphate in terms of increased yield and uptake of P in potato tubers and haulms in acid sandy loam. Mean recovery of P was only 15.5% of the total P applied and tubers removed 72.9% of the total P accumulation. Application of P through rockphosphate did not show any significant variation in the tuber yield, P concentration in the tuber yield, P concentration and uptake of phosphorus over control.

Granular reactive apatite rockphosphate was not an effective fertilizer for short term crops in. laterite soils in south-western Australia, fertilizer efficiency of all the rockphosphates relative to superphosphate was very low at all the sites and fertilizer effectiveness of rock phosphate was about one-fifth to one-tenth, depending on crops and the maximum yield obtained for rockphosphate was generally 88 to 100% that obtained for superphosphate (Bolland *et al.* 1984). Quantitative indices of effectiveness of freshly applied rockphosphate relative to freshly applied superphosphate for 164 Australian pot and field experiments was reviewed by Bolland *et al.*. (1988). Statistical analysis of data indicated that variations in relative effectiveness values were due to systematic differences in experimental design and fertilizer solubility but not due to environmental factors. It was concluded that rockphosphate fertilizers were not economic substitutes for fertilizers containing water soluble P for most agricultural applications in Austrlia.

Panda (1990) estimated that India's rockphosphate reserve is about 260 million, of which only 30 million are rated has high grade, and the beneficiations of low grade material is expensive. He suggested direct use of the ground rock in acid soils and use of the farmyard manure along with the rocks for rice-based cropping system.

Kanabo and Gilkes (1987) compared the plant response and chemical measurement of dissolution of reactive phosphate rock (PR) in different soils of Australia. The chemical measurement of the dissolution was done as the increase in soil exchangeable Ca. Both dry weight and P content of clover tops showed no response to grater PR dissolution at low soil pH, but twice as much P was bicarbonate soluble, which was attributed partly due to PR dissolution. At 200 mg p/ kg soil level of fertilizer application, 19% of the rock phosphate was dissolved and at higher rates only 5% dissolved, but the absolute amount of dissolution however increased with level of PR application.

Poor effectiveness of different rockphosphates as compared with single superphosphate, for sub-terranean clover was reported by Yeats and Allen (1988). The P uptake was not correlated to soil bicarbonate P at harvest. Briones and Vicente (1986) reported yield response of soybean due to application of SSP at a rate of 80 kg P/ ha was equivalent to the yield increase to a supply of 120 kg P/ ha as rockphosphate.

Importance of Cover Plants and Phosphate Nutrition in Rubber Plantations

Establishment and maintenance of a ground cover in rubber plantations is an accepted agro-management practice for rubber. Cover crops help in the improvement of soil structure and other physical properties (Soong & Yap 1976). Studies conducted elsewhere have shown that leguminous ground cover help in better growth of Hevea during the immature phase and in attaining higher yield. (Watson, 1961; Watson *et al.*., 1964; Pushparajah and Chellappah, 1969; Wychereley and Chanda Pillai 1969). Leguminous cover also helps in the formation of large size aggregates and causes higher rate of infiltration. It facilitates good soil aeration and better root growth of rubber plants (Krishna Kumar, 1989).

The most widely used leguminous cover crop in India is *Pueraria phaseoloides*, though others like *Calapagonium mucunoides*, *Centrosema pubescens* and *Mimosa invisa* var. *intermis* are also grown on a limited scale (Potty *et al.*., 1980). An ideal cover crop should have such characters as fast growth, non-competition with rubber plants, shade tolerance, high nitrogen fixing capacity, *etc*. Pueraria crop is highly palatable to cattle and this nature of the crop results in the indiscriminate removal of the crop from the fields. *Mucuna bracteata* is a recently introduced cover crop. It is a wild fast growing legume, native to north-eastern India and possesses most of the desirable characters expected of a cover plant . It is not preferred by cattle and tolerant to drought situations also.

From their study Kothandaraman *et al.*. (1990) reported a higher biomass production for Mucuna, as compared to Pueraria. They also observed higher shoot/ root ratio for Mucuna and higher population of phosphate solubilising microorganisms in soils under that crop.

While studying the nature, extent and distribution of the root systems of different cover plants Chanda Pillai (1968) observed a more shallow rooting pattern for Pueraria in the form of network of fibrous roots of easily decomposable nature. The dry weight of the roots of a 3-month-old individual plant was reported to be 3.22 g, and the mean dry weight of shoot was 1.11 g. They also observed a reduction in the horizontal spread and vertical penetration of roots of the creeping covers at the twelve-month-sampling compared to the six-month-sampling.

Deep penetration of the roots of the cover plants reportedly increased the fertility of the surface soil by extracting nutrients from the deeper layers and depositing them on the surface in the organic matter of their litter. (Wycherley, 1963). This effect is increased by the recommended plantation practice of periodical slashing of the vigorously growing cover crops.

Yoon (1967) indicated that the net assimilation rate of the Pueraria was drastically reduced under shade. As a consequence of this, the cover plant was eventually eliminated from its stand by the growing canopy of the rubber plants.

Performance of *Hevea brasiliensis* (rubber trees) when grown with covers of legumes, grasses and without covers was compared by Watson (1961) and Watson *et al.*. (1964). They reported better growth of Hevea trees in association with the creeping legumes. They also studied the root systems of the various cover plants to understand the influence of these crops on the growth of Hevea, and the results were not conclusive.

Pueraria had a better growth with single superphosphate folowed by Mussoorie rockphosphate(Anonymous 1990). P content of stem and leaves and number of root nodules also followed the similar pattern. After subsequent incubation of the soil samples of the pots, those received Mussoorie rockphosphate registered highest available P (extracted by Bray I).

Role of Different P Fractions to Plant Available P in Soils of Rubber Plantations

Total P in soil is rather poorly correlated with availabe P, and is rarely used to describe P fertility status of soils. Although P in soils occur both in organic and inorganic forms most of the research effort has been directed at inorganic P, for under tropical climate where organic matter status is rather low, much of the P needs of a growing crop is probably met by the inorganic sources of P. Phosphorus bound to aluminium (Al-P), iron (Fe-P) and calcium (Ca-P) constitute the major active forms of inorganic P. Relatively less active are the occluded and reductant - soluble forms of P. All these forms exist in soils to varying extent, but Al-P and Fe-P are more abundant in acid soils, while Ca-: dominates the neutral-alkaline soils (Tandon 1987).

In four soils under rubber cultivation studied by Bachik and Bare (1981) more than 60% of the P was found in the Fe-P fraction. Th amounts of P extracted by four soil available P testing methods wer found to be low. Freshly adsorbed P in the soil was readily extracted b Bray No. II and ammonium lactate reagents. Drying had little influenc on the amount of adsorbed P extractable by the two reagents Overcoating the phosphated samples with a prepared Fe(III) greatl reduced the amount of extractable P and they suggested such an overcoating process by iron oxide in soils.

Residual effect of applied phosphates on the performance of *Hevea brasiliensis* and *Pueraria phaseoloides* was examined by Pushparajah *et al.*. (1977). They fractionated the inorganic P in soils receiving superphosphate or rock phosphate into Al, Fe, and Ca fractions. Mobility of the applied phosphate in the soil and distribution of the various soil P fractions were found to be significantly different, when superphosphate and rock phosphate were applied. They concluded that rockphosphates had a higher residual effect on Hevea and Pueraria compared to superphosphate.

Inorganic phosphates in soil samples collected from various agro-climatic rubber growing regions in India were fractionated by Karthikutty Amma (1989) and she observed Fe-P as the major fraction of total P followed by Al-P or Ca-P and saloid bound P was a minor fraction

Effect of Liming on Phosphate Availability in Acid Soils

Low crop yields in much of the humid tropics are associated with high soil acidity and/ or acute P deficiency. Between these two, since the latter to a great extent is the result of the former property of soil, one of the primary reasons commonly proposed for liming acid soils, is to increase the availability of P to plants (Sanchez and Uehara 1980). The mechanism by which an increase in P availability occurs is still a matter of conjecture, though both the soil and plant components of the system are believed to be involved in this.

Acid soils frequently contain phytotoxic levels of soluble and exchangeable Al (Foy and Fleming, 1978; McLean, 1976; Webber *et al.*., 1982). A major characteristic feature of Al toxicity is an inhibition of the uptake and translocation of P by plant (Foy and Fleming, 1978; Jones and Fox, 1978). Thus, liming acid soils often increases P uptake by plants by decreasing Al toxicity rather than a direct effect on soil P availability *per se* (Haynes and Ludecke, 1981; Vickers and Zak, 1978).

A perusal of published results on the effect of liming on phosphate adsorption and availability highlights quite a bit of contradictions. Some experiments have shown that P adsorption decreased with increasing pH (Lopez-Hernandez and Burnham, 1974; Murrmann and Peech, 1969; Parfitt, 1977; Smith and Sanchez, 1980) Lopez-Hernandez and Burnham (1974) made a comparison between recently limed soil in the laboratory and a field-limed soil adjusted to different pH values many years before. A decrease in phosphours adsorption with lime application was found for the field-limed soil, but liming samples of similar soil group in the laboratory did not reduce phosphate adsorption to the same extent.

However, other studies have shown that phosphate adsorption either increased with increasing pH up to a given value (Amarasiri and Olsen,1973; Mokwunye, 1975; Ryan and Smillie, 1975) or did not get affected by changes in pH (Jones and Fox, 1978; Janghorbani *et al..*, 1975; Martini *et al..*, 1974; Reeve and Sumner, 1970).

An increase in solution P up to pH 7.0 was found by Volksweiss (1973) in soil samples of an Oxisol that were limed and incubated for five months. But samples incubated for 2 weeks showed a minimum of solution P at pH 4.5. It was suggested that this could be due to the precipitation of exchangeable Al as amorphous polynuclear complex with high surface area and high affinity for P. The same minimum was not observed with samples of five- month- old, possibly because of crystallization of Al complexes.

While studying the effect of liming on phosphate availability in acid soils, Haynes (1982) observed that liming can increase phosphate availability by stimulating mineralization of soil organic phosphorus. However at high soil pH values, the precipitation of insoluble calcium phosphate can decrease the phosphate availability. Liming is also beneficial in ameliorating the Al toxicity and thereby increasing utilization of soil phosphates. In soils initially high in exchangeable Al3+ ions, liming result in the precipitation of Al3+ ions into insoluble polymeric hydroxy-Al cation species. Thus if an acid soil is reacted with lime and then phosphate is applied without intervening air-drying, liming may increase phosphate adsorption. Air-drying alters the surface characteristics of recently limed soils, probably by promoting crystallization of hydroxy-Al cation polymers as gibbsite. He cautioned that while making lime recommendations or interpreting the data collected from lime-phosphate experiments it is important to consider all the complex interacting soil and plant factors involved.

In a study on the effect of lime on phosphate adsorption and barley growth in three acid soils, Anjos and Rowel (1987) observed a markedly increased root and shoot dry matter and P uptake due to liming. They attributed the higher uptake of P due to the reduction in Al toxicity as a consequence of liming and thereby better root growth. The roots accumulated Al without apparently being damaged.

Naidu *et al.*. (1990) studied the effect of lime and P additions on the amount of soil extractable P and Al and on the growth of tropical legume *Leucaena leucocephala* on a highly weathered acid soil. They observed an increase in resin extractable P with lime addition, but at higher pH there was a decrease. The KCl-extractable Al decreased to undetectable levels at or above pH 5.2. Plant growth was adversely affected at low and high pH, even in the presence of added P. They observed a positive lime x P interaction for three out of the four soils studied, but pH above 5.2 was not desirable.

MATERIALS AND METHODS

The present investigation entitled "Influence of sources of phosphatic fertilizers and cover crops on the management of phosphate nutrition in soils of rubber plantations", was carried out with a view to evaluate the effects of different types of phosphatic fertilizers on the biomass production through cover crops and the phosphate turn-over thus brought about in rubber plantations. The investigation comprised:

a) A field experiment

b) A Green-house experiment

c) An incubation experiment

d) Another experiment to characterise the phosphate present in soils under rubber plantations and the adjacent non rubber areas with comparable features.

MATERIALS

A brief description of the materials used in different experiments conducted in this investigation is presented hereunder.

FIELD EXPERIMENT

Field experiment site was located in a rubber estate at Erumeli, Kerala. Four different sources of phosphatic fertilizers, of which three were rockphosphates, and the fourth one being single superphosphate, were included in this study. The details of the rockphosphates are as follows:

Mussoorie rockphosphate (MRP)

This deposit occur in the Mussoorie syncline in Uttar Pradesh and the ore reserve is estimated to be around 12.8 million tonnes. This is a sedimentary deposit with better reactivity amongst the Indian phosphate rocks and the material is widely used in rubber plantations as a phosphatic fertilizer.

Udaipur rockphsophate (URP)

This is a sample of the low grade Udaipur rockphosphate material obtained from Rajastan State Mines and Minerals Ltd. This material was collected from Jhamar Kotra.

North Carolina rockphosphate (NRP)

This is a sample obtained from Texas Gulf (USA) with a specification of 67% BPL. It is a brownish black material with angle of repose 30 degree and reportedly analysing 13.3% total P, with 3.7% of total P as soluble in neutral ammonium citrate.

Superphosphate (SSP)

A commercial grade sample of single superphosphate was used as a standard phosphatic fertilizer for comparison. This contained 7% P in water - soluble form.

The two cover crops used in the study were:

a) *Pueraria phaseoloides* (C-1):- It is a widely used leguminou cover crop in India. It is a good cover plant ideally suited for rubbe plantations, except the fact that it is highly palatable to cattle and thu liable to indiscriminate removal from the fields.

b)*Mucuna bracteata* (C-2):- This is a wild fast growing legume introduced from the north-eastern states of India possessing idea characters. Apart from being a legume not relished by cattle, it thrives well in drought situations.

The experiment was laid out in a randomised block design with a nett plot size of 1.5 m x 1.5 m, which being the space available in between four plants of one-year-old rubber seedlings in a plantation laid on terraces. The different treatment combinations were as follows:

Cover Crops

C0 - No cover plants.

C1 - *Pueraria phaseoloides*

C2 - *Mucuna bracteata*

Fertilizer treatments

1. Control

2. Mussoorie rockphosphate 25 kg P/ha (MRP L1)

3. Mussoorie rockphosphate 50 kg P/ha (MRP L2)

4. Udaipur rockphosphate 25 kg P/ha (URP L1)

5. Udaipur rockphosphate 50 kg P/ha (URP L2)

6. North Carolina rockphosphate 25 kg P/ha (NRP L1)

7. North Carolina rockphosphate 50 kg P/ha (NRP L2)

8. Single superphosphate 25 kg P/ha (SSP L1)

9. Single superphosphate 50 kg P/ha (SSP L2)

These nine treatments were combined with C0, C1 and C2 so as to get 27 treatment combinations, and the treatments were replicated twice.

The plots were prepared by working the surface soil with fork and then levelling. A basal dose of 10 kg N/ha as urea and 20 kg K_2O/ ha as muriate of potash was added to each plot. The required quantity of various phosphatic fertilizers were also added and thoroughly mixed with the soil to a depth of 6 inches with the help of a soil rake. For Pueraria crop, seeds were used. The seeds were prepared after scarification by slightly grinding it with sand in a wooden mortar. Five seeds each were sown at a spacing of 50 cm x 50 cm so that each plot contained nine seeding spots. For Mucuna crop one month old rooted cuttings were used, and this was also planted at the above spacing so as to accommodate nine plants per plot. The planting was done on 10th July, 1990, along with the the start of monsoons. Thinning of the Pueraria crop to one plant per spot and gap filling of the Mucuna crop was done after a period of one month. Observations were again made periodically . The crops were harvested on 30th December, 1990 and fresh weight of the crops were noted at the field. A representative sample from each plot was then brought to the laboratory dried in the oven and used for further analyses. The dry matter yield of each plot was also calculated using moisture percentage of the samples brought to the laboratory.

Along with the plant samples, approximately 0.5 Kg of soil was collected from each of the plots separately, dried under shade, sieved with a 2 mm sieve and brought to the laboratory for further analysis.

a) GREENHOUSE EXPERIMENT

A representative bulk sample of soil was collected from the field experiment site before laying out the field experiment and brought to IARI, New Delhi to carry out this experiment. Here also the 27 treatment combinations as followed in field experiment were made and it was replicated thrice, making a total of 81 pots. Each pot contained 4.5 kg of sieved (-5 mm) dry soil. The levels of phosphate fertilizers, however were 25 and 50mg P per Kg soil (112.5 and 225 mg P/pot, respectively).

The soil was moistened to approximately half the field capacity before filling into the pots. The phosphate fertilizers were added and mixed with the top 6 inch of the soil. A basal dressing of nitrogen at the rate of 10 ppm and potassium at the rate of 20 ppm (as K_2O) was done through a combined solution of urea and muriate of potash. Seeds of Pueraria and Mucuna were prepared after scarification inoculated with a Rhizobium culture and were sown in the pots at a rate of five seeds per pot. The twenty seven pots corresponding to no crop treatments were left as such. Sowing was done on 12th July 1991. Resowing/ thinning out was done 20 days after planting so as to ensure a stand of four plants per pot. Mite attack was observed on the plants and a spray of 0.02% Roger was given in order to control the pest . The plants were irrigated as and when required using tap water. The crop was harvested on 28th October, 1991, and the plant material was dried in the oven and their dry weights recorded. Roots of the plants were collected from each pot, and observed for dry weight. Nodulation was very poor in both the crops. Soil samples from the pots were also collected, air-dried and sieved through a 2 mm sieve for further analyses.

The plant and soil samples from these experiments were subjected to various chemical analyses.

INCUBATION EXPERIMENT

An incubation experiment was carried out to study the effect of liming on the release of P from the samples collected from the plots of the field experiment laid at Kottayam, and of the green house experiment done at IARI, which received various fertilizer treatments. A portion of the field experiment samples were limed to a soil pH of 6.8 on the basis of Shoemaker's method, and from this a sub sample of 5 g soil was maintained at half the moisture content of field capacity in an incubator at 35± $1^{o}C$, for 28 days. After this period, phosphate was determined using 0.5 M $NaHCO_3$ (Olsen *et al.* 1954) extractant. For the green-house experiment samples the incubation was done in two sets using 200 g of soil (< 2 mm) samples. One set was limed to raise the pH to 6.8 while in the other set half the quantity of lime required to increase the pH to 6.8 was added. All the samples were maintained at 50%

moisture of the field capacity (which was 15% of the soil by weight) and at a temperature of 35 ± 1°C in an incubator. Samples were drawn at weekly interval for 28 days and 0.5 M $NaHCO_3$ (Olsen *et. al* 1954) extractable phosphate was determined. The moisture content of the samples were determined periodically and loss of water was made good by addition of the required amount of it in all the samples in order to ensure 50% moisture of the field capacity during the entire period of the experiment. The experiment was continued for 28 days.

NEUBAUER STUDY

A Neubauer experiment was conducted using soil samples collected after the field experiment as well as greehouse experiment. Each experiment was done in two sets, one with the addition of crop residues proportionate to the dry matter yield of the crops and the other without that. The experiment was done in Neubauer dish using 100 g of soil and 100 wheat seeds. The crop residue was added after powdering, mixed with the soil and incubated for 14 days at 35± 1°C after wetting the soil to field capacity. Seedlings were grown for 24 days after sowing. Then they were uprooted and washed free of soil, first with tap water and then with distilled water. The whole of plant material thus collected from each Neubauer dish was dried in a oven and their dry weights recorded. The dried materials were then digested in triacid mixture and concentration of P in the clear aliquots was estimated colorimetrically by vanado-molybdo-phosphoric yellow complex method as described by Jackson (1973). The uptake values of P by seedlings were then calculated and the same has been reported as P supplying power of the soils (Neubauer value) in mg P/kg soil.

SOIL P CHARACTERIZATION

For the characterization of phosphate present in soils of rubber plantation and the comparable adjacent areas, five locations representing the major rubber growing tracts, were selected, viz. Kottayam, Pathanamthitta, Idukki and Calicut districts in Kerala and Kanyakumari district in Tamil Nadu. From each district, four rubber plantations with corresponding nearby non-plantation areas were selected. Thus a total number of 40 samples were collected, of which 20 represent rubber plantations and the rest 20 being from the complementary non-plantation sites.

METHODS

The different methods used for the analysis of rockphosphates, soil and plant samples and the statistical analyses done for the interpretation of results are described in this section.

Analysis of Rockphosphate

Water soluble, citrate soluble and citrate insoluble fractions of the rock phosphate materials were done following the procedures as described in the Fertilizer (Control) Order, 1957, excepting the method of determination of P in aqueous medium, for which the vanado-molybdo-phosphate yellow colour method as outlined by Jackson (1973) was adopted.

Soil Analysis

The soil samples were air dried, ground with wooden pestle and mortar and sieved through 2 mm sieve. For certain analysis soil materials passing through a 0.2 mm sieve were used. The various physicochemical analyses done for the samples are as under.

Particle-size distribution:- Particle-size distribution of the soil passing through 2 mm sieve was worked out following a hydrometer (Bouyoucos) method for estimation of silt and clay contents and the percentage composition of sand was arrived at indirectly (by resorting to difference method).

Soil reaction (pH):- For the measurement of soil reaction, a soil-water suspension was prepared in 1:2.5 ratio by weight, and the pH of the suspension was recorded with the help of a glass electrode - calomel (reference) electrode assembly connected to a pH meter.

Cation exchange capacity:- The cation exchange capacity of the soil samples was determined as per the method described by Hesse (1971), and result is reported as c mol (p^+)/kg of air-dry soil.

Organic carbon:- For the estimation of organic carbon, soil passing through a 0.2 mm sieve was used. Organic carbon in the samples was estimated by the wet digestion technique of Walkley and Black (1934), as described by Jackson (1973).

Available phosphate:- Available phosphate in the soil samples was extracted using 0.5 M $NaHCO_3$ (Olsen *et al.* 1954), and phosphate in the extract determined colorimetrically using ascorbic acid, as the reductant (Murphy and Riley 1962). Available phosphate was also extracted by the method of Bray and Kurtz (1945, Bray No.I) and P in the extract again was estimated colorimetrically by developing blue colour, though stannuous chloride was used as the reductant. The results are expressed as mg P/ kg of soil.

Anion exchange resin phosphate:- Phosphate in the soil samples were estimated using anion exchange resin as proposed by Amer *et al.* (1955). Here also the results are expressed as mg P/Kg soil .

Total phosphate:- Total phosphate content of the soil samples were determined by digesting two grams of soil (< 0.2 mm) with 30 mL of perchloric acid as suggested by Page *et al.* (1982). Phosphorus in an aliquot of the extract was determined colorimetrically as vanado-molybdo-phosphate yellow complex in nitric acid system (Jackson 1973).

Organic and inorganic phosphate fractions:- The organic phosphorus fraction of the soil was estimated by the sequential extraction procedure with concentrated sulphuric acid and dilute base, as suggested by Bowman (1989). The inorganic fraction was obtained by subtracting the organic fraction from the total soil phosphorus.

Fractionation of inorganic phosphate:- Different fractions of the phosphate present in soil were determined by schematic extraction of soil as suggested by Chang and Jackson (1957) and modified by Peterson and Corey (1966). The different fractions are expressed as mg P/ kg of soil.

P fixing capacity:- P fixing capacity of the soils was estimated by the method described by Waugh and Fitts (1966).

Lime requirement of soil:- Lime requirement of soil samples was estimated using Shoemaker's buffer and the results are expressed as tonnes $CaCO_3$/ ha.

Analysis of Plant Samples

Digestion of samples:- A suitable amount of oven-dried and ground plant material was digested in a triacid mixture of nitric, perchloric and sulphuric acids prepared in the ratio of 10:4:1 on an electric hot plate. The digested material was made up to 100 mL volume and concentrations of P and Ca in the aliquots were estimated.

Total phosphorus:- Phosphorus determination in the acid digested extract was accomplished colorimetrically by vanado-molybdo-phosphoric yellow complex method as described by Jackson (1973).

Calcium content:- Calcium concentration in the aliquots were determined using a flamephotometer.

The concentration of these elements in the plant materials thus calculated, and the dry matter yield recorded at the time of harvest of the crop were used to calculate the uptake of these nutrients.

STATISTICAL ANALYSIS OF DATA

The data from the field experiment was analysed using the statistical procedures suggested for randomised block design with different factorial combinations. For the green-house experiment and laboratory studies statistical techniques appropriate for completely randomised design were followed. These analyses were done with the help of a micro-computer.

RESULTS

The results of the physicochemical analyses of the soils and statistical analysis of the data on dry matter yield, phosphorus concentration in plant samples and uptake of phosphorus by the crops and various other related aspects of the present investigation are presented in this chapter.

General Characteristics of the Soils

Some of the general characters of the soil pertinent to the present investigation are given in Table 1. The soil was a lateritic sandy clay loam with a pH of 5.3. The CEC of the soil was low and the active Fe_2O_3 and $Al_2 O_3$ were relatively higher. The P fixing capacity was very high (65%). Total P content and available P were low. Organic matter content of the soil was medium.

Phosphate Fractions in the Rockphosphates

The total P content of the rockphosphate was fractionated as water soluble, citrate soluble and citrate insoluble parts. The contents of P in the different fractions are given in Table 2. Water soluble P was below detectable limits in all the three rockphosphates. Citrate soluble part was more in North Carolina rockphosphate and it was at comparable levels in Udaipur and Mussoorie rocks. Total P content was maximum in North Carolina followed by Mussoorie and Udaipur.

Table 1

General Characteristics of the soil

Particle Size distribution	
Sand (%)	59.2
Silt (%)	7.4
Clay (%)	33.4
Texture	Sandy clay loam
pH	5.3
Organic carbon (%)	1.3
C.E.C.[C mol $(P^+)kg^{-1}$] of soil	12.3
Total P (ppm)	640
Available P (ppm)	
Olsen's P	0.6
Bray's-I P	1.6
Anion exchange resin P	2.2
P fixing capacity (%)	65
Active Fe oxides (%)	2.94
Active Al oxides (%)	0.38

Table 2

Chemical composition of phosphate rock

Phosphate rock Sample	Total P (%)	W.S.P. (%)	C.S.P. (%)
Mussoorie	9.5	Traces	1.02
Udaipur	8.00	Traces	1.23
North Carolina	13.2	Traces	2.40
(As reported by Texasgulf)	13.3	Traces	3.73

FIELD EXPERIMENT

The field experiment was laid out in a randomised block design with 27 treatment combinations, each being replicated twice, at Erumeli estate, Kottayam,Kerala. The experiment was started in July 1990 and the crop was harvested in December 1990. The different observations made, were subjected to statistical analysis and the data are presented along with a discussion in the following section.

Dry Matter Yield

Results of the effect of various phosphate sources at two levels on the dry matter yield of the two cover crops are presented in Table 3. Owing to addition of phosphatic fertilizers there was an over-all significant increase in dry matter yield of the crops. But the two crops between themselves also differed significantly, with Pueraria being better than the other crop. Among the fertilizer sources, SSP was the best, followed by NRP and MRP while URP gave the lowest dry matter yield (384 g/ plot). All the four sources were significantly different from each other at 5% level of significance. Irrespective of the sources of fertilizers and crops, higher level of application was superior to the lower level. SSP at L-2 level recorded the heighst yield of 1081 g/ plot and URP at L-1 level the lowest. Among the rockphosphates, sample from North Carolina performed the best, but its performance at both the levels was at par with the L-1 level of superphosphate. Similarly the higher level of URP was in no way different from the lower level of MRP. Both these two (MRP and URP) sources recorded lower yield when compared to North Carolina. When the different sources at individual levels were

Table 3

Effect of different phosphatic fertilizers on the dry matt yield (g/ plot) of the cover crops grown at Erumeli estat Kottayam

Ferti-lizers	Cover crops	
	C-1	C-2
MRP L-1	415	553
MRP L-2	625	765
URP L-1	260	388
URP L-2	412	478
NRP L-1	1062	713
NRP L-2	1012	738
SSP L-1	1075	738
SSP L-2	1238	925
Control	350	478
Mean	717	641

P Sources	P levels		
	L-1	L-2	Mean
MRP	484	695	589
URP	324	445	384
NRP	888	875	881
SSP	906	1081	994
Mean	650	774	712
Control	--	--	414

CD (P = 0.05)

Control vs Rest	--	42
Bet. Crops	--	27
Bet. Sources	--	40
Bet. Levels	--	28
S x L	--	58
Crop x Fert.	--	82

compared within the two crops, Pueraria receiving 50 kg P/ ha (L-2) of superphosphate gave maximum yield. With North Carolina and SSP as the sources of P, Pureria treated at L-1 level of fertilizer gave yields comparable to Mucuna receiving L-2 level of fertilizer. But with MRP and URP Mucuna performed better, with significantly higher values for both the levels of MRP, and lower level of URP.

P Concentration and P Uptake by the Crops

Phosphorus concentration in dry matter of the two crops receiving different sources of phosphatic fertilizers at two levels were compared and the results are shown in Table 4. Phosphatic fertilizer addition had significantly increased the P content of the crops as compared to the no-P control. Between the two crops Mucuna tended to have a higher P content as compared to Pueraria, when phosphate was supplied through either water soluble source or a reactive phosphate rock like North Carolina sample. Among the sources of P, irrespective of crops and levels, SSP gave the highest P content of 1419 ppm and the lowest by URP (1089 ppm), which was significantly lower than all the others. NRP and MRP were at par with each other but both of them were significantly inferior to SSP. Phosphate application at higher level also recorded a higher P content irrespective of the sources. Within sources and levels, SSP at 50 kg P/ ha was superior. NRP at 50 kg P/ ha, level was at par with SSP at 25 kg P/ ha, whereas URP even at higher level recorded significantly lower P content than the SSP applied at the lower dose. Among the different source, level and crop combinations, Mucuna crop receiving SSP and NRP at the lower dose of P had P contents which are

Table 4

Effect of different phosphatic fertilizers on P content (mg P/ kg dry matter) of cover crops grown at Erumeli estate, Kottayam

Fertilizers	Cover crops	
	C-1	C-2
MRP L-1	1212	1100
MRP L-2	1390	1447
URP L-1	1100	965
URP L-2	1225	1065
NRP L-1	1175	1275
NRP L-2	1262	1337
SSP L-1	1125	1487
SSP L-2	1388	1675
Control	1050	1037
Mean	1214	1266

P Sources	P levels		
	L-1	L-2	Mean
MRP	1156	1419	1288
URP	1033	1145	1089
NRP	1225	1300	1263
SSP	1306	1531	1419
Mean	1180	1449	1314
Control	--	--	1044

		CD (P =
Control vs Rest	--	80
Bet. Crops	--	52
Bet. Sources	--	76
Bet. Levels	--	54
S x L	--	107
Crop x Fert.	--	156

comparable to those in Pueraria treated with the same two sources of P but at the higher level.

The results of P uptake are presented in Table 5. Here again crops receiving P fertilizers recorded a significantly higher uptake, than the crops in control. But between the two crops, there was no significant difference in the uptake. SSP was the most effective source while URP the least and all four sources were significantly different each other. Between NRP and MRP, the former was better than the latter. Between the levels of application of P, the higher level caused a significantly larger P uptake than the lower dose. Between sources and levels, SSP even at the lower level was superior to higher levels of application of URP and MRP, though not of NRP. Among the crop and fertilizer treatment level combinations, in lower levels of SSP, MRP and URP, both the crops were having almost similar uptake, but with North Carolina rock Pueraria derived relatively more benefit from lower dose as compared with Mucuna. At higher level of P application, with URP both the crops recorded similar uptake, with MRP Mucuna benefited more while with NRP and SSP it was so with Pueraria. In the case of Pueraria crop, level 2 of MRP was similar to level 1 of SSP and NRP.

Olsen's P, Bray's P and AER P

After the harvest of the crop, soil samples from each plot including the bare plots, were analysed for Olsen's extractable P, Bray's extractable P and AER-P (anion exchange resin P). Trends were similar for the three methods, AER - P being the highest in absolute terms, followed by Bray's P and Olsen's P. These results are presented in Tables 6, 7 and 8.

Table 5

Effect of different phosphatic fertilizers on P uptake (mgP/plot by cover crops grown at Erumeli estate, Kottayam

Ferti-lizers	Cover crops	
	C-1	C-2
MRP L-1	503	608
MRP L-2	867	1107
URP L-1	287	374
URP L-2	505	508
NRP L-1	1250	911
NRP L-2	1278	987
SSP L-1	1207	1098
SSP L-2	1717	1550
Control	370	494
Mean	887	848

P Sources	P levels		
	L-1	L-2	Mean
MRP	556	987	77
URP	330	507	41
NRP	1080	1133	110
SSP	1153	1634	139
Mean	780	1065	92
Control	--	--	43

CD (P = .(

Control vs Rest	--	72
Bet. Crops	--	NS
Bet. Sources	--	68
Bet. Levels	--	48
S x L	--	96
Crop x Fert.	--	139

Olsen's extractable P (Tabel 6), in no fertilizer control was lower than fertilized plots in general. Irrespective of source and level of fertilizers, cropped plots had significantly higher content of Olsen's P and the mean P content in plots of Pueraria and Mucuna were similar. Among the sources, SSP recorded the highest Olsen's P, closely followed by URP, MRP and NRP, with the last two being at par with each other. Higher level (L-2) left larger residual P (Olsen's) in soil. Between sources and levels, MRP at level 2 had highest value, followed by URP, SSP and NRP at L-2 level. At lower level (25 kg P/ ha) SSP recorded the maximum value, follwed by URP, NRP and MRP all being significantly different from one another. The interaction between crops, sources and levels of P did not follow any particular trend. But the only consistency observed relates to the by and large lower quantities of 0.5 M extractable P in uncropped but fertilized plots compared to the cropped plots.

In the case of Bray-I P (Table 7) fertilizer applied plots recorded significantly higher P content than the unfertilized control. Evaluating the effect of crops, plots supporting either of the two crops contained significantly higher amounts of extractable P when compared with no crop (bare) plots and between the two crops plots under Pueraria recorded larger P than those under Mucuna. Among the different sources, SSP recorded the lowest amount, which nevertheless at par with NRP. The highest amount was in URP treated plot, the quantity being comparable with that due to MRP. Both of them are significantly by higher than those due to NRP and SSP. P application at higher level resulted in significantly larger Bray-I P than the lower rate of application. The interaction between crops and fertilizer treatments was

Table 6

Effect of different phosphatic fertilizers on available P (Olsen's P - mg P/ kg soil) in soil after the experiment at Erumeli estate, Kottayam

Fertilizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	1.2	0.7	1.4
MRP L-2	1.8	5.4	4.9
URP L-1	2.5	2.9	1.9
URP L-2	2.0	4.6	4.0
NRP L-1	1.4	0.9	4.0
NRP L-2	1.9	2.1	4.6
SSP L-1	1.1	4.9	2.7
SSP L-2	2.0	5.1	3.0
Control	0.6	1.2	1.2
Mean	1.6	3.1	3.1

P Source	P levels		Mean
	L-1	L-2	
MRP	1.1	4.0	2.5
URP	2.4	3.6	3.0
NRP	2.1	2.9	2.5
SSP	2.9	3.4	3.2
Mean	2.1	3.5	2.8
Control	--	--	1.0

	CD (P = .05)
Control vs Res	-- 0.15
Bet. Crops	-- 0.21
Bet. Sources	-- 0.15
Bet. Levels	-- 0.10
S x L	-- 0.21
Crop x Fert.	-- 0.36

Table 7

Effect of phosphatic fertilizers on the available P (Bray-I P) in soil after the experiment (mg P/ kg soil) at Erumeli estate, Kottayam

Fertilizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	3.0	2.2	4.1
MRP L-2	16.4	6.5	13.9
URP L-1	7.1	2.8	1.7
URP L-2	6.3	17.4	12.2
NRP L-1	5.4	2.4	12.6
NRP L-2	5.4	6.8	6.0
SSP L-1	3.6	15.8	3.9
SSP L-2	5.7	5.2	2.8
Control	1.6	2.8	3.1
Mean	6.1	6.9	6.7

P Source	P levels		Mean
	L-1	L-2	
MRP	3.1	12.3	7.7
URP	3.9	12.0	7.9
NRP	6.8	6.1	6.5
SSP	7.8	4.6	6.2
Mean	5.4	8.7	7.1
Control	--	--	2.5

CD (P = .05)

Control vs Rest -- 0.77
Bet. Crops -- 0.12
Bet. Sources -- 0.72
Bet. Levels -- 0.51
S x L -- 1.02

u

Crop x Fert. -- 0.36

also significant. In all the plots, the P content estimated by Bray-I extraction was higher than Olsen's P.

Table 8 presents the content of AER - P. These values are higher than Olsen's P as well as Bray-I P. In this case also fertilized plots contained significantly higher amounts of P than the no-P control. Both Pueraria and Mucuna cropped plots contained a significantly higher amount than no cropped plots and both the cropped plots, were at par in this respect. Among the sources, MRP applied plots left significatnly largest mean AER-P compared to all other sources, followed by URP plots. Both NRP and SSP plots were least effective. Plots receiving the higher rate of application, contained significantly higher AER-P than those supplied P at the lower rate. Between the sources and levels URP at level 2 was superior to all others. Between the fertilizer treatment and the crops, cropped plots in general recorded higher level of AER-P as compared with uncropped bare plots, except in case of MRP source were trend was reversed. With SSP and URP as sources Pueraria cropped plots contained more AER-P than Mucuna cropped plots, but with NRP and MRP as sources the situation got reversed.

A comparison of the extractability of residual P by the three methods for the different sources averaged over levels and crops are presented in Figure 1. It is apparent that AER-P was consistently the largest for each source, with Olsen's P being the least and Bray-I P occupying an intermediate position. The inter-relations of the three extractants were examined by calculating the values of correlation coefficients (r). Olsen's P showed highly significant and positive relations with Bray-I P and AER-P (r values of 0.60 and 0.55 respectively,

Table 8

Effect of different phosphatic fertilizers on the anion exchange resin extractable P (AER-P mg P/ kg soil) in soil after the field experiment at Erumeli estate, Kottayam

Fertilizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	20.0	10.8	17.6
MRP L-2	21.6	8.2	16.0
URP L-1	9.2	9.8	9.4
URP L-2	9.6	25.2	17.0
NRP L-1	7.6	4.0	16.8
NRP L-2	9.6	9.4	18.4
SSP L-1	6.4	21.6	5.2
SSP L-2	8.8	17.6	9.0
Control	2.2	4.2	4.0
Mean	10.4	12.3	12.6

P Source	P levels		
	L-1	L-2	Mean
MRP	16.0	15.3	15.6
URP	9.5	17.3	13.2
NRP	9.5	12.5	11.0
SSP	11.1	11.8	11.4
Mean	11.6	14.2	12.8
Control	--	--	3.5

CD (P = .05)

Control vs Rest	-- 0.72
Bet. Crops	-- 0.56
Bet. Sources	-- 0.68
Bet levels	-- 0.48
S x L	-- 0.96
Crop x Fert.	-- 1.6

***Fig.1* Comparison of extractants for available P in soils treated with different fertilizers** (after field experiment)

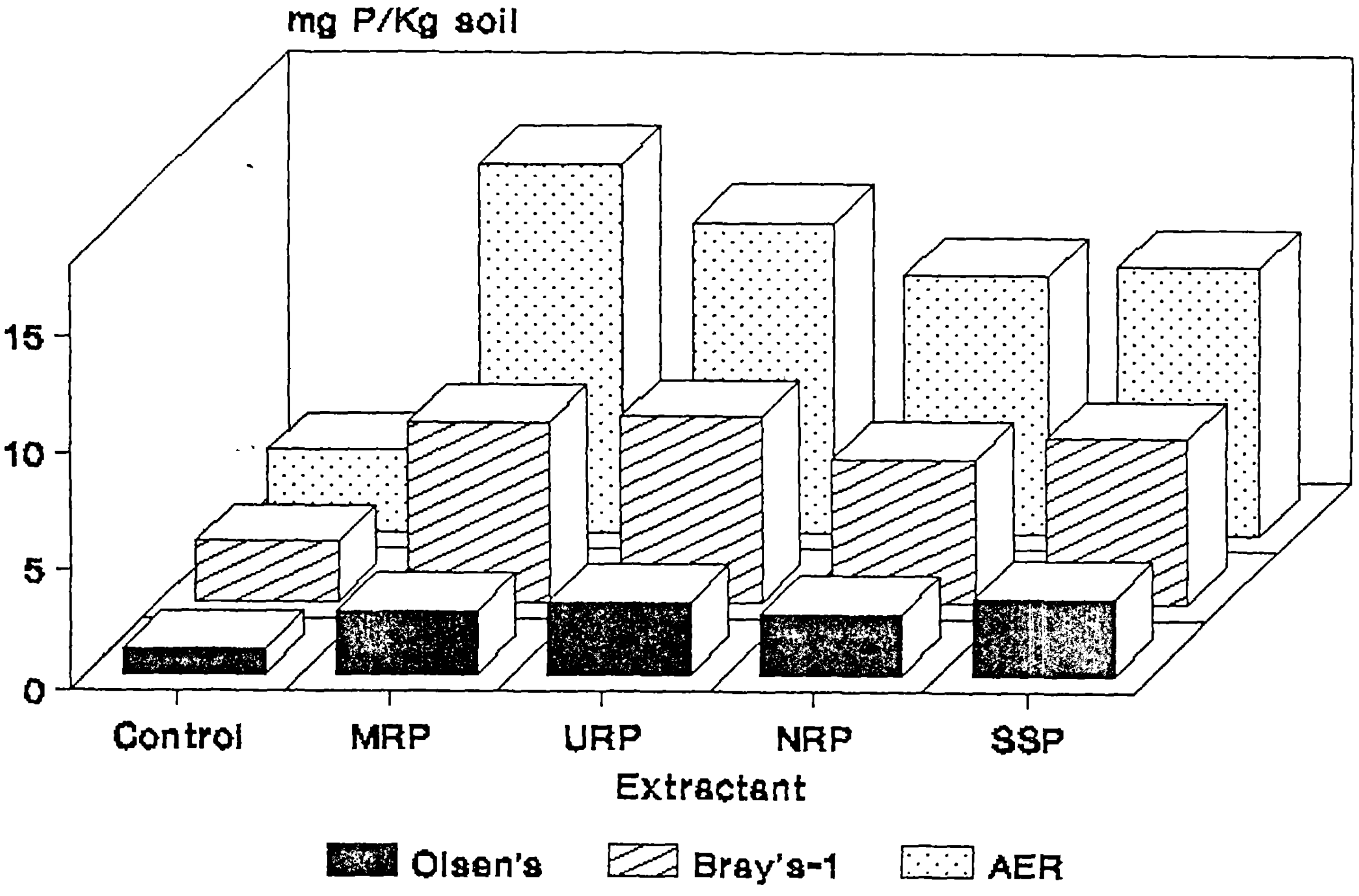


Table 9

Effect of different phosphatic fertilizers on the P supplyin power (Neubauer P , mg P/ kg soil) of the soils after fiel experiment without recycling crop residues

Fertilizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	18	17	19
MRP L-2	25	24	27
URP L-1	19	21	22
URP L-2	24	24	26
NRP L-1	15	21	28
NRP L-2	18	22	28
SSP L-1	33	36	40
SSP L-2	36	39	47
Control	12	15	12
Mean	22	24	28

P Source	P levels		
	L-1	L-2	Mean
MRP	18	25	22
URP	21	24	23
NRP	21	23	22
SSP	36	40	38
Mean	24	28	26
Control	--	--	13

CD (P = .05)

Control vs Rest	--	0.67
Bet. Croprs	--	0.53
Bet Sources	--	0.63
Bet. Levels	--	0.45
S x L	--	0.87
Crop x Fert.	--	1.57

both being significant at 1% level). So also the relation between Bray-I P and AER-P (r = 0.73).

Nuebauer P after Recyling the Green Matter

Proportionate amount of dried and powdered crop residue was added to soil depending on the dry matter yield and the soil was incubated at field capacity for 14 days at a temperature of 35 $\pm$ 1oC. Then the P supplying capacity of the soil samples were estimated using Neubauer seedling method. The amount of P taken up from different treatments are presented in Table 10 and the corresponding data for the treatments without organic residue addition are presented in Table 9. A significant difference between the no cropped on one hand plots and the cropped plots, which received the organic residues on the other, in their P supplying power was observed. The effect of recycling P through the two crops on the P supplying power of soil however was similar between the two crops. Among the combinations of different fertilizers, levels and the crops, in the non-fertilized plots, both Pueraria and Mucuna were effective in recycling P through crop in available form. Further among the fertilized plots Mucuna crop that received SSP at L-2 level recycled maximum amount of P, and with this level treatment both the crops were better than the no cropped control plots. Among the different rockphosphates, both the crops were effectively recycling P from the fertilizer and thus the P supplying power of the soils receiving crop residues were significantly better than the no cropped plots SSP among the sources was far better than the rockphosphates, amongst which URP was significantly superior to MRP, besides being at par with NRP.

Table 10

Effect of different phosphatic fertilizers on the P supplying power (Neubauer P mg P/ kg soil) after the field experiment with crop residue recycling

Fertilizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	18	19	20
MRP L-2	25	29	30
URP L-1	19	25	24
URP L-2	24	29	29
NRP L-1	15	27	33
NRP L-2	18	26	29
SSP L-1	33	39	44
SSP L-2	36	44	49
Control	12	18	15
Mean	22	28	30

	P levels		
P Source	L-1	L-2	Mean
MRP	19	28	23
URP	23	27	25
NRP	25	24	24
SSP	38	43	41
Mean	26	31	28
Control	--	--	15

CD (P = .05)

Control vs Rest	--	1.2
Bet. Crops	--	3.0
Bet. Sources	--	1.0
Bet. Levels	--	0.80
S x L	--	2.0
Crop x Fert.	--	4.0

Effect of Recycling the Crop Residue on P Supplying Power

A comparison of the Neubauer P supplying capacity of the soil samples incorporated with crop residue with those not treated with such residues is depicted in Figure 2. SSP applied plots had the highest values in all the cases. Recycling had effected a marginal increase in the Nuebauer P values. Recycling of Mucuna residue was found slightly better than Pueraria recycling in case of SSP and NRP applied plots, though for MRP and URP, they were comparable. In control, Pueraria was better.

Effect of Liming on P Release

The available P content of the soil samples were estimated after liming the soil to pH 6.8 and incubating for 28 days at a temperature of $35 \pm 1^{o}C$. Here also the no fertilizer control plots contained significantly lower amount of P than fertilizer treated samples taken together (Table 11). Cropping was beneficial to increase the P content and both the crops were having similar effects. Among the sources, SSP treated plots recorded significantly lowest content of P, while the highest was for URP treated plots and those of MRP and NRP were at par. Level 2 was superior to level 1 irrespective of the sources. While considering the effect of crops and the various fertilizer level combinations, Pueraria cropped plots receiving 50 kg P/ ha through MRP had highest amount of P after liming and the plots of Mucuna receiving MRP at L-1 level recorded the lowest. In the no fertilizer control plots, crops tended to push up availability of P as compared to bare plots.

Fig.2 Effect of recycling crop residues on P supplying power of soils treated with different fertilizers
(after field experiment)

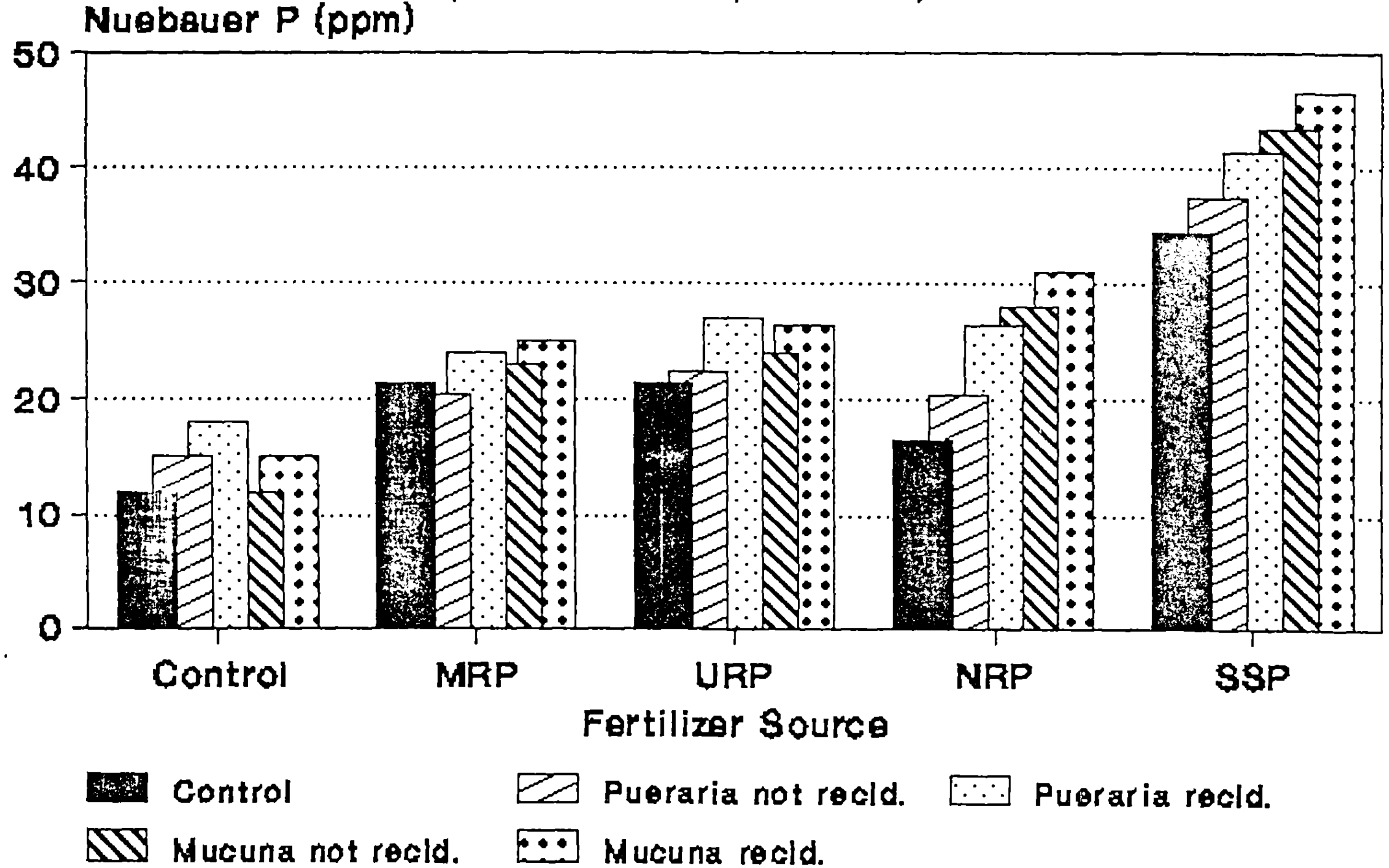


Table 11

Effect of liming to pH 6.8 on the Olsen's reagent extractable P (mg P/ kg soil) of the soils treated with different phosphatic fertilizers under different cover crops after the field experiment (28 days incubation)

Ferti-lizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	3.1	2.5	1.8
MRP L-2	6.6	6.0	5.6
URP L-1	2.7	4.2	2.6
URP L-2	4.8	7.1	6.6
NRP L-1	4.3	2.0	4.4
NRP L-2	3.1	5.2	6.6
SSP L-1	2.3	2.7	3.0
SSP L-2	4.6	6.2	5.6
Control	1.1	1.3	1.2
Mean	3.6	4.2	4.2

	P levels		
P Source	L-1	L-2	Mean
MRP	2.5	6.1	4.3
URP	3.2	6.2	4.7
NRP	3.6	5.0	4.3
SSP	2.7	5.5	4.1
Mean	3.0	5.7	4.3
Control	--	--	1.2

CD (P = .05)

Control vs Rest	--	0.13
Bet. Crops	--	0.10
Bet. Sources	--	0.12
Bet. Levels	--	0.08
S x L	--	0.17
Crop x Fert.	--	0.29

The effect of liming on the P release as compared with the initial non-limed samples is presented in Figure 3. After liming increase in Olsen's P was nearly three-fold in the fertilizer applied plots, maximum increase was in URP applied plots where the increase was nearly nine times the initial value.

POT EXPERIMENT

The results of the pot experiment, which was conducted with the same set of treatments as in field experiment, with one exception being the levels of phosphate fertilizers tried were 25 (L-1) and 50 (L-2) mg P/ kg soil instead of 25 and 50 kg P/ ha, are presented here. The various observations made and their interpretations after suitable statistical analysis are as follows.

Dry Matter Yield

The effect of the various sources of P fertilizers *viz*, MRP, URP, NRP and SSP on the dry matter yeild of the two crops are shown in Table 12. A significant difference between the no - P control treatment and phosphate treatments as a group was evident. Between the two crops, Pueraria was better yielder than Mucuna. Among the sources all four of them were different to one another significantly with SSP resulting in the highest yield of 16.45 g/pot followed by NRP, MRP and URP, which yielded the lowest (5.29). Level 2 of P application was superior to level 1. Between the crops and source-level combinations, URP at lower level of application recorded the lowest yield of Pueraria though it was at par with its own higher dose and of MRP applied at L-1 to Pueraria. With NRP and SSP as sources Pueraria yields were significantly higher than

Fig.3 Effect of liming on Olsen's P in soils treated with different fertilizers

(incubation experiment)

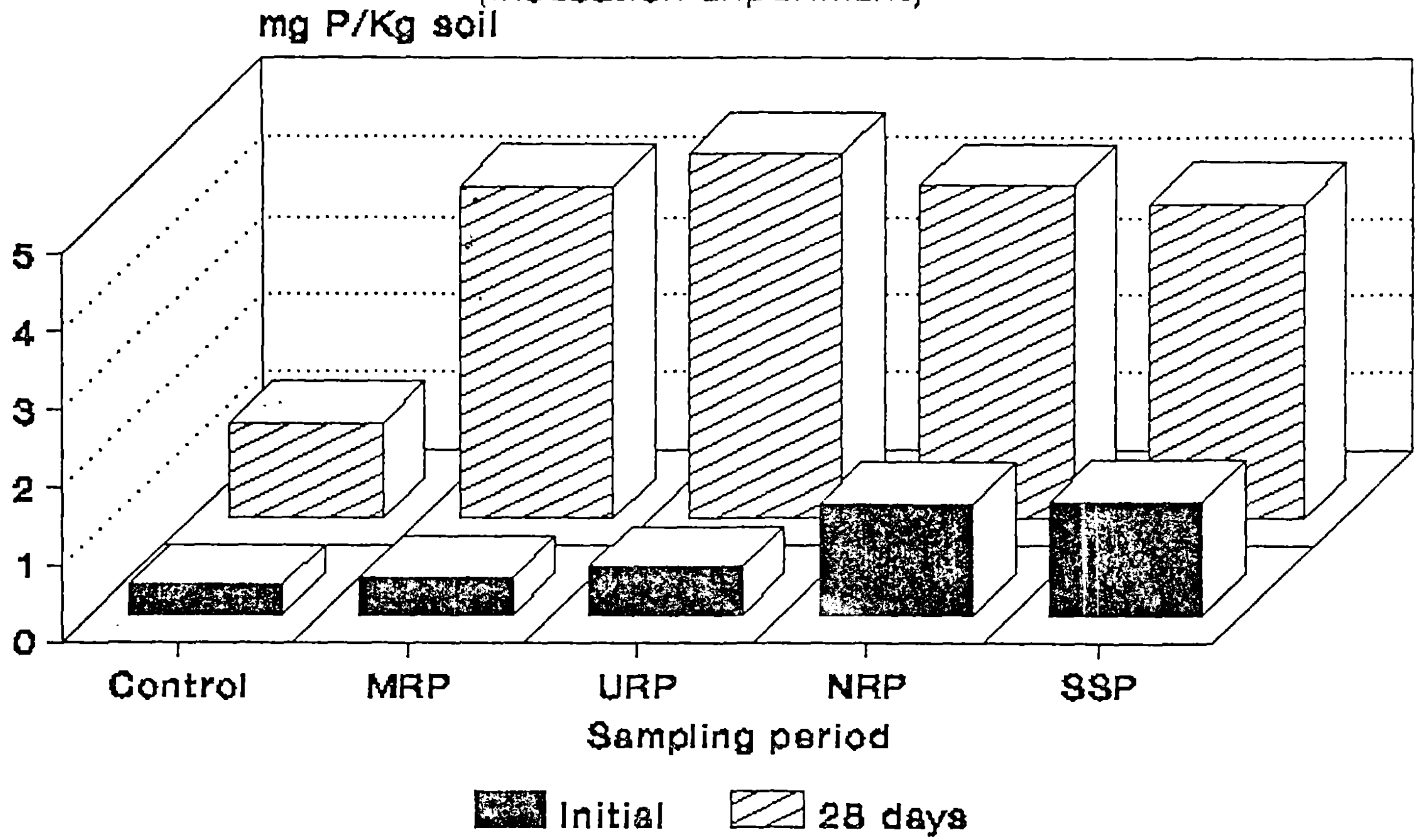


Table 12

Effect of different phosphatic fertilizers on the dry matter yield (g/ pot) of the cover crops grown in greenhouse on soils of Erumeli estate, Kottayam

Fertilizers	Cover crops	
	C-1	C-2
MRP L-1	6.87	8.08
MRP L-2	10.25	10.22
URP L-1	3.35	5.83
URP L-2	6.85	5.13
NRP L-1	16.17	9.35
NRP L-2	16.45	12.57
SSP L-1	18.39	13.17
SSP L-2	21.47	12.78
Control	5.59	7.50
Mean	11.71	9.40

P Sources	P levels		
	L-1	L-2	Mean
MRP	7.47	10.23	8.85
URP	4.59	5.99	5.29
NRP	12.76	14.49	13.62
SSP	15.78	17.12	16.45
Mean	10.15	11.96	11.05
Control	--	--	6.54

CD (P = 0.05)

Control Vs Rest	--	1.78
Bet. Crops	--	1.27
Bet. Sources	--	1.68
Bet. Levels	--	1.19
S x L	--	NS
Crop x Fert.	--	3.81

of Mucuna yield at both the levels. Further these two sources were, in general, better than URP and MRP in influencing dry matter yield.

Root Weight

The data on root weight are presented in Table 13. In the fertilized pots root weight obtained was significantly more than that in the non-fertilized pots. Between the two crops, Pueraria had a significantly larger root mass than Mucuna crop. Among the various sources, SSP and NRP were at par, but both were superior to MRP and URP, both of which were again at par. Level-2 was superior to level-1. Interaction between the levels and sources of P was not significant. Among the crops and source-level combinations, Mucuna had more or less similar root mass in all the treatments. Pueraria receiving URP at both the levels and MRP at L-1 resulted in root mass of lower weight, which was comparable with no-P control and all others were superior with SSP at L-2 resulting in the highest root weight.

Total Dry Matter

Total biomass yield, which is the sum of root and shoot dry matter, also followed the pattern of shoot dry matter yield. The results are presented in Table 14. Here the over-all difference between the two crops got further widened, because of the proportionately lower root mass, which is associated with Mucuna pushed it further away from Pueraria. But for this divergence, the main effect of sources, levels and their interaction followed trends which are more or less similar to shoot yield described already.

Table 13

Effect of different phosphatic fertilizers on the root weight (g/pot) of the cover crops grown in greenhouse

Fertilizers	Cover crops	
	C-1	C-2
MRP L-1	3.46	1.85
MRP L-2	7.26	2.31
URP L-1	1.25	1.76
URP L-2	3.90	1.21
NRP L-1	9.78	2.76
NRP L-2	9.80	2.80
SSP L-1	8.73	2.96
SSP L-2	15.50	3.78
Control	3.58	1.90
Mean	7.03	2.37

P Sources	P levels		Mean
	L-1	L-2	
MRP	2.65	4.78	3.71
URP	1.50	2.56	2.03
NRP	6.27	6.30	6.29
SSP	5.84	9.65	7.74
Mean	4.06	5.86	4.94
Control	--	--	2.74

CD (P = 0.05)

Control Vs Rest	--	1.78
Bet. Crops	--	1.12
Bet. Sources	--	1.68
Bet. Levels	--	1.18
S x L	--	NS
Crop x Fert.	--	3.36

Table 14

Effect of different phosphatic fertilizers on the total biomass (root + shoot - g/pot) of the cover crops grown in greenhouse

Fertilizers	Cover crops C-1	Cover crops C-2
MRP L-1	10.33	9.93
MRP L-2	16.84	12.54
URP L-1	4.59	7.60
URP L-2	10.76	6.34
NRP L-1	25.96	12.12
NRP L-2	26.26	15.34
SSP L-1	27.17	16.13
SSP L-2	36.98	16.56
Control	9.17	9.40
Mean	18.67	11.77

P Sources	P levels L-1	P levels L-2	Mean
MRP	10.13	14.69	12.40
URP	6.10	8.55	7.32
NRP	19.04	20.80	19.91
SSP	21.65	26.77	24.21
Mean	14.22	17.69	15.95
Control	--	--	9.29

CD (P = 0.05)

Control Vs Rest	--	2.89
Bet. Crops	--	1.82
Bet. Sources	--	2.73
Bet. Levels	--	1.92
S x L	--	NS
Crop x Fert.	--	5.45

Phosphorus Concentration in Shoot

Phosphorus contents of the shoot portion of plants are presented in Table 15. P content of the plants receiving P fertilizers was higher than those of no-P control plants. Between the crops, there was no significant difference in the P contents. Among the sources SSP and NRP were similar, but superior to MRP and URP. Again MRP was a better source than URP. Level-2 was superior to level-1. The source x level interaction was not significant. So also the interactions involving the crop x source-level combinations.

P Uptake by Shoot

The results on uptake of P by shoot are presented in Table 16. The uptake was significantly higher in P treated pots vis-a-vis no-P control. Between the two crops, Pueraria recorded higher uptake, though the same was not significantly different from that by the other crop. SSP among the sources was far superior, followed by NRP. MRP also resulted in fairly large uptake, but URP was the least effective source in this regard. The source x level interaction was not significant. Level 2 of P application led to higher uptake, than level 1. Among the crops and source-level combinations, with Pueraria crop both levels of URP and L1 level of MRP were observed to be not different from the no-P control. But Mucuna benefited from MRP applicatin, though not from URP. For, both the crops, SSP which gave maximum uptakes of P, was closely followed by NRP.

Tabel 15

Effect of different phosphatic fertilizers on the P concentration in shoot (mg P/kg dry matter) of the cover plants grown in green house

Ferti- lizers	Cover crops	
	C-1	C-2
MRP L-1	814	948
MRP L-2	813	1093
URP L-1	801	627
URP L-2	880	691
NRP L-1	880	1133
NRP L-2	1053	1280
SSP L-1	1040	1093
SSP L-2	1067	1387
Control	760	627
Mean	900	987

P Sour- ces	P levels		
	L-1	L-2	Mean
MRP	881	953	916
URP	714	785	749
NRP	1007	1167	1086
SSP	1067	1227	1146
Mean	916	1032	974
Control	--	--	694

CD (P = 0.05)

Control Vs Rest	--	167
Bet. Crops	--	NS
Bet. Sources	--	157
Bet. Levels	--	111
S x L	--	NS
Crop x Fert.	--	NS

Table 16

Effect of different phosphatic fertilizers on the P uptake (mg/pot) by the cover crops grown in greenhouse

Fertilizers	Cover crops	
	C-1	C-2
MRP L-1	5.57	7.60
MRP L-2	8.49	11.10
URP L-1	2.66	3.66
URP L-2	6.00	3.62
NRP L-1	13.94	10.59
NRP L-2	18.10	15.49
SSP L-1	19.93	14.38
SSP L-2	22.81	17.28
Control	4.23	4.74
Mean	11.30	9.83

P Sources	P levels		
	L-1	L-2	Mean
MRP	6.58	9.79	8.18
URP	3.16	4.81	3.98
NRP	12.27	16.80	14.52
SSP	17.16	20.05	18.60
Mean	9.78	12.85	11.32
Control	--	--	4.49

CD (P = 0.05)

Control Vs Rest	--	2.19
Bet. Crops	--	1.38
Bet. Sources	--	2.07
Bet. Levels	--	1.46
S x L	--	NS
Crop x Fert.	--	4.15

Ca Concentration and Uptake by Shoot

The results on concentration of Ca in shoot material of the two crops are presented in Table 17. Application of phosphatic fertilizers in general did not affect the Ca content. However, some marginal differences due to other treatments, of which some were significant. But as far as the uptake of Ca is concerned, in P treated pots there was higher uptake of Ca than the control (Table 18). Between the two crops, Pueraria had higher uptake than Mucuna. Among the different sources, SSP treated pots facilitated the highest uptake, as compared with the others. All were significantly different from one another. Among the rockphosphates NRP was the best source followed by MRP and URP. The source x level interaction was not significant. Between the crops and source-level combinations, for Mucuna crop SSP at both levels and NRP at 50 mg P/kg soil were significantly higher and others were not significantly different. For Pueraria crop, URP at both the levels and MRP at level 1 were not significantly different from control and others were better. For both the crops, SSP at higher level gave highest uptake of calcium.

A correlation of the P uptake and Ca uptake from the rock phosphate sources gave a positive and highly significant value ($r = 0.94$).

P Uptake per Gram of Roots

The total P uptake by one gram of root from the different pots were compared and the results are presented in Table 19. In the phosphatic fertilizer applied pots, P uptake per gram of root was higher than of the control. Between crops also, there was a significant difference with

Table 17

Effect of different phosphatic fertilizers on the plant Ca content (Ca%) of the cover crops grown in green house

Ferti-lizers	Cover crops	
	C-1	C-2
MRP L-1	0.63	0.62
MRP L-2	0.71	0.63
URP L-1	0.51	0.62
URP L-2	0.63	0.62
NRP L-1	0.69	0.72
NRP L-2	0.70	0.64
SSP L-1	0.75	0.69
SSP L-2	0.72	0.75
Control	0.57	0.62
Mean	0.65	0.66

P Sour-ces	P levels		
	L-1	L-2	Mean
MRP	0.62	0.67	0.65
URP	0.57	0.62	0.60
NRP	0.71	0.67	0.69
SSP	0.72	0.74	0.73
Mean	0.65	0.68	0.68
Control	--	--	0.60

CD (P = 0.05)

Control Vs Rest	--	NS
Bet. Crops	--	0.05
Bet. Sources	--	0.03
Bet. Levels	--	NS
S x L	--	0.02
Crop x Fert.	--	0.07

Table 18

Effect of different phosphatic fertilizers on the Ca uptak (mg/pot) by the cover crops grown in green house

Fertilizers	Cover crops C-1	Cover crops C-2
MRP L-1	43.21	50.34
MRP L-2	72.06	65.03
URP L-1	17.29	36.22
URP L-2	43.06	31.56
NRP L-1	111.23	67.61
NRP L-2	114.70	81.36
SSP L-1	137.91	91.12
SSP L-2	155.77	94.98
Control	31.84	47.05
Mean	80.78	62.81

P Sources	P levels L-1	P levels L-2	Mean
MRP	46.77	68.55	57.66
URP	26.75	37.31	32.03
NRP	89.43	98.03	93.73
SSP	114.52	125.38	119.94
Mean	69.37	82.31	75.84
Control	--	--	39.45

CD (P = 0.05)

Control Vs Rest	--	12.59
Bet. Crops	--	7.92
Bet. Sources	--	11.87
Bet. Levels	--	8.39
S x L	--	NS
Crop x Fert.	--	23.75

Table 19

Effect of different phosphatic fertilizers on the P uptaken by the cover crops per unit weight of roots (mg P/g root)

Ferti-lizers	Cover crops	
	C-1	C-2
MRP L-1	2.31	4.74
MRP L-2	1.22	5.06
URP L-1	2.16	2.31
URP L-2	1.66	2.99
NRP L-1	1.71	3.81
NRP L-2	1.87	5.57
SSP L-1	2.39	4.97
SSP L-2	1.64	4.63
Control	1.48	2.60
Mean	1.83	4.08

P Sources	P levels		Mean
	L-1	L-2	
MRP	3.53	3.14	3.34
URP	2.24	2.33	2.28
NRP	2.76	3.72	3.24
SSP	3.68	3.14	3.41
Mean	3.05	3.08	3.06
Control	--	--	2.04

CD (P = 0.05)

Control Vs Rest	--	0.93
Bet. Crops	--	0.59
Bet. Sources	--	0.88
Bet. Levels	--	NS
S x L	--	NS
Crop x Fert.	--	NS

Mucuna recording higher value than Pueraria. Among the sources, URP was associated with lower value and all others were significantly higher and similar. Between levels there was no significant difference. The source x level interaction and the crop x fertilizer treatment interaction were also not significant.

Available P Status after the Experiment

The available P status of the soil in each pot was extracted with Olsen's extractant, Bray-I extractant and anion exchange resin. The results are presented in Tables 20, 21 and 22. There was a significant difference in Olsen's P between the control pots and the P treated pots. Among the two crops and the non-cropped pots, the mean P content of the pots cropped with the two crops were comparable, but the ones under Mucuna recorded a significantly lower P content than the uncropped pots. Among the sources, SSP and NRP were similar and recorded significantly higher values than MRP and URP. Among the two levels, pots receiving L2 level contained significantly higher amounts than L1 level. Between the sources and levels, SSP at level-2 gave the highest, followed by NRP at level-2. Their respective lower levels were superior to the higher level of MRP and URP. Among the crops and source-level combinations, in no crop pots, both levels of MRP and URP were similar to control and others were significantly different. In all cases SSP at L-2 level were superior.

With Bray P-1 extractant and AER, trends similar to the the one from Olsen's P were observed. But here the SSP as the source was even superior to NRP (Tables 21 and 22). A comparision of the three methods are presented in Figure 4. AER method yielded nearly double the

Table 20

Effect of different phosphatic fertilizers on the Olsen's extractable P (mg P/kg soil) of the soils after greenhouse experiment

Ferti-lizers	Cover crops C-0	C-1	C-2
MRP L-1	0.7	0.5	0.3
MRP L-2	0.5	0.4	0.6
URP L-1	0.6	0.2	0.7
URP L-2	0.6	0.9	0.6
NRP L-1	1.2	1.2	1.0
NRP L-2	2.0	1.9	1.4
SSP L-1	1.2	1.1	1.1
SSP L-2	1.9	1.8	1.6
Control	0.6	0.2	0.3
Mean	1.0	0.9	0.8

P Sources	P levels L-1	L-2	Mean
MRP	0.5	0.5	0.5
URP	0.5	0.7	0.6
NRP	1.2	1.7	1.4
SSP	1.2	1.8	1.5
Mean	0.8	1.2	1.0
Control	--	--	0.4

CD (P = .05)

Control Vs Rest	--	0.13
Bet. Crops	--	0.10
Bet. Sources	--	0.12
Bet. levels	--	0.08
S x L	--	0.17
Crop x Fert.	--	0.30

Table 21

Effect of different phosphatic fertilizers on Bray-I P (mg P/ } soil) of the soils after greenhouse experiment

Ferti-lizers	Cover crops C-0	C-1	C-2
MRP L-1	2.0	2.6	1.7
MRP L-2	2.1	2.4	1.6
URP L-1	2.4	2.1	1.6
URP L-2	2.8	1.6	1.0
NRP L-1	4.5	2.8	2.2
NRP L-2	5.6	4.0	3.1
SSP L-1	5.1	2.7	2.7
SSP L-2	6.9	4.0	4.7
Control	1.6	1.3	1.0
Mean	3.7	2.6	2.2

P Sources	P levels L-1	L-2	Mean
MRP	2.1	2.1	2.1
URP	2.0	1.8	1.9
NRP	3.2	4.3	3.7
SSP	3.5	5.2	4.3
Mean	2.7	3.3	3.0
Control	--	--	1.3

CD (P = .05)

Control Vs Rest	--	0.25
Bet. Crops	--	0.19
Bet. Sources	--	0.24
Bet. levels	--	0.17
S x L	--	0.34
Crop x Fert.	--	0.58

Table 22

Effect of different phosphatic fertilizers on the anion exchange resin extractable P (AER-P mg P/kg soil) of the soils after greenhouse experiment

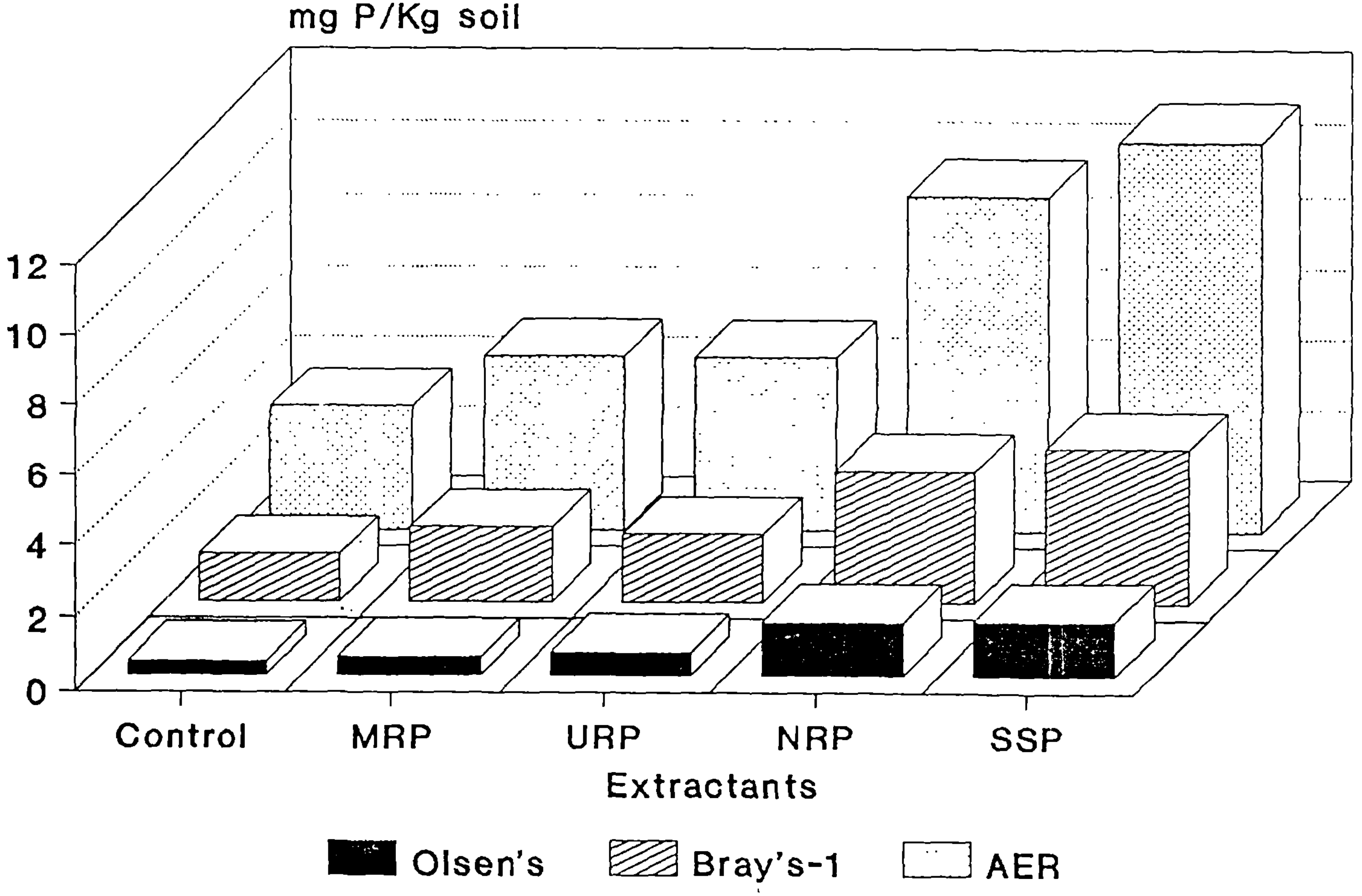
Fertilizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	5.0	4.7	4.7
MRP L-2	5.5	5.8	4.1
URP L-1	5.8	5.8	3.9
URP L-2	6.9	4.0	3.3
NRP L-1	11.4	7.1	5.6
NRP L-2	14.7	10.1	8.0
SSP L-1	12.9	6.9	6.8
SSP L-2	17.5	10.2	11.8
Control	4.5	3.3	2.7
Mean	9.4	6.4	5.7

P Sources	P levels		
	L-1	L-2	Mean
MRP	4.8	5.1	5.0
URP	5.2	4.7	5.0
NRP	8.0	1.1	9.5
SSP	8.9	13.2	11.0
Mean	6.7	8.5	7.6
Control	--	--	3.5

CD (P = .05)

Control Vs Rest	--	0.68
Bet. Crops	--	0.52
Bet. Sources	--	0.64
Bet. levels	--	0.45
S x L	--	0.91
Crop x Fert.	--	1.58

Fig. 4 Comparison of extractants for available P in soils treated with different fertilizers (after green house experiment)



amount of P extracted by Bray's solution. Olsen's P was the lowest in all the cases. The inter-relations of the three extractants were examined here also by calculating values of correlation coefficients (r). Olsen's P showed highly significant and positive relations with Bray-I P ($r = 0.83$) and with AER-P ($r = 0.84$). The association between Bray-I P and AER-P was also significant and positive($r = 0.90$).

Neubauer P after the Experiment without Incorporation of Plant Residue

After the harvest of the crops, the P supplying capacity of the soil from each pot was assessed using Neubauer seedling technique and the data are presented in Table 23. P supply capacity of non-fertilized soils were significantly lower than the treated pots. The cropped pots have higher capacity to supply P when compared with non-cropped pots. Between the two crops Mucuna was better than Pueraria. All the sources were differing significantly, with NRP being the best, followed by SSP, URP and MRP. Between the two levels, higher level gave better P supply capacity. The source x level interaction was not significant. Among the crops and the various source-level treatments all the treatements were better than control, except the level 1 of MRP for Mucuna. The highest values were obtained for Mucuna receiving NRP with both levels being similar.

Neubauer P after Recycling the Plant Materials

Ground materials of the leguminous crops grown in the preceding season were incorporated to a portion of the soil, incubated for 14 days at $35 \pm 1^{o}C$ and then the P supplying capacity was assessed

Table 23

Effect of different phosphatic fertilizers on the P supplying power (Neubauer P - mg P/kg soil) after the green house experiment without crop residue recycling

Ferti- lizers	Cover crops C-0	C-1	C-2
MRP L-1	23	28	26
MRP L-2	26	28	28
URP L-1	25	27	28
URP L-2	26	28	31
NRP L-1	28	29	34
NRP L-2	31	33	34
SSP L-1	31	29	31
SSP L-2	33	30	30
Control	21	22	26
Mean	27	28	30

P Sources	P levels L-1	L-2	Mean
MRP	26	27	26
URP	27	28	28
NRP	30	33	32
SSP	30	31	31
Mean	28	30	29
Control	--	--	23

<u>CD (P = .05)</u>

Control Vs Rest	--	0.80
Bet. Crops	--	0.60
Bet. Sources	--	0.70
Bet. levels	--	0.58
S x L	--	NS
Crop x Fert.	--	1.70

using Neubauer seedling method (Table 24). Here also the no-P control had lower capacity than the fertilized soils. The cropped plots were significantly better than the uncropped soils. Among the sources, NRP was superior to all others, followed by SSP, URP and MRP. Level 2 was superior to level 1. The source x level interaction was not significant. Among the crops and various fertilizer treatment combinations. Mucuna cropped soils, in general, were better supplier of P than uncropped pots. As compared with the no phosphate fertilizer control, all the treatment combinations were significantly superior to the control.

The effect of incorporation of plant material on P supplying capacity of soil is presented in Figure 5. In the fertilizer treated pots, recycling did not bring about any significant increase and in all cases it slightly reduced the P taken up by the seedlings in the Neubauer seedling experiment.

Effect of Liming on Release of P

After the pot experiment, samples of soil from each pot were limed to pH 6.8 and incubated for 28 days. Weekly observations were made on the 0.5 M $NaHCO_3$ extractable P status, and the data are presented in tables from 25 to 28. Up to the 28 days of incubation, the available P content had increased only marginally. However, throughout the period, fertilized pots registered higher P content than the control pots. Between the cropped as well as uncropped pots the effect was non-significant. However among the different sources of P, SSP registered the highest value followed closely by NRP. MRP and URP on the other hand resulted in considerably lower amounts of P as compared

Table 24

Effect of different phosphatic fertilizers on the P supplying power (Neubauer P - mg P/kg soil) after greenhouse experiment with crop residue recycling

Fertilizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	23	26	25
MRP L-2	26	27	27
URP L-1	25	25	28
URP L-2	26	26	29
NRP L-1	28	29	32
NRP L-2	31	31	33
SSP L-1	31	26	28
SSP L-2	33	28	29
Control	21	22	26
Mean	27	27	29

P Sources	P levels		Mean
	L-1	L-2	
MRP	25	27	26
URP	26	27	27
NRP	30	32	31
SSP	28	30	29
Mean	27	29	28
Control	--	--	23

CD (P = .05)

Control Vs Rest	--	0.80
Bet. Crops	--	0.59
Bet. Sources	--	0.70
Bet. levels	--	0.56
S x L	--	NS
Crop x Fert.	--	2.00

Fig.5 Effect of recycling crop residues on P suppling power of soils treated with different fertilizers
(after greenhouse experiment)

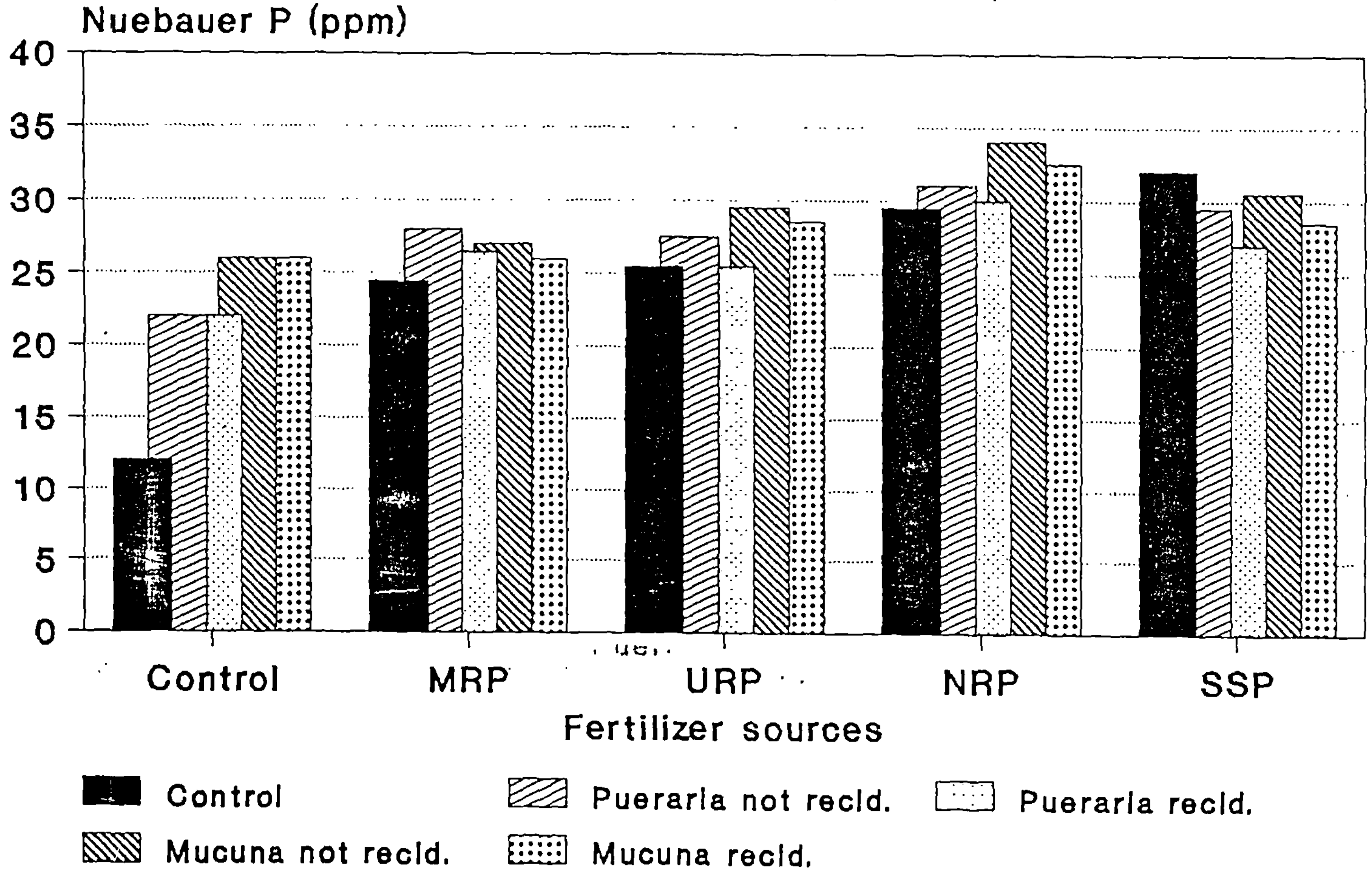


Table 25

Effect of liming (pH 6.8) on the Olsen's extractable P (mg P/kg soil) after seven days incubation of the soils of greenhouse experiment

Ferti-lizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	0.4	0.5	0.4
MRP L-2	0.8	0.5	0.7
URP L-1	0.6	0.3	0.8
URP L-2	0.7	0.9	0.8
NRP L-1	1.1	1.4	1.3
NRP L-2	2.1	2.1	1.7
SSP L-1	1.3	1.3	1.3
SSP L-2	2.3	1.5	1.9
Control	0.8	0.3	0.3
Mean	1.1	1.0	1.0

P Sources	P levels		
	L-1	L-2	Mean
MRP	0.4	0.7	0.5
URP	0.6	0.8	0.7
NRP	1.3	2.0	1.6
SSP	1.3	1.9	1.6
Mean	0.9	1.3	1.1
Control	--	--	0.5

<u>CD (P = .05)</u>

Control Vs Rest	--	0.20
Bet. Crops	--	NS
Bet. Sources	--	0.19
Bet. levels	--	0.14
S x L	--	0.27
Crop x Fert.	--	NS

Table 26

Effect of liming (pH 6.8) on the Olsen's extractable P (mg P/Kg soil) after 14 days incubation of the soils of greenhouse experiment

Fertilizers	Cover crops C-0	C-1	C-2
MRP L-1	0.7	0.5	0.5
MRP L-2	1.2	0.7	0.8
URP L-1	0.6	0.5	0.8
URP L-2	0.9	1.5	1.3
NRP L-1	1.3	1.6	1.9
NRP L-2	2.3	2.4	2.3
SSP L-1	1.9	1.8	1.8
SSP L-2	3.0	2.2	2.3
Control	0.9	0.5	0.4
Mean	1.4	1.3	1.4

P Sources	P levels L-1	L-2	Mean
MRP	0.6	0.9	0.7
URP	0.7	1.2	0.9
NRP	1.6	2.3	2.0
SSP	1.9	2.5	2.2
Mean	1.2	1.7	1.5
Control	--	--	0.6

CD (P = .05)

Control Vs Rest	--	0.21
Bet. Crops	--	NS
Bet. Sources	--	0.20
Bet.levels	--	0.14
S x L	--	0.28
Crop X Fert.	--	0.53

Table 27

Effect of liming (pH 6.8) on the Olsen's extractable P (mg P/kg soil) after 21 days of incubation of the soils of greenhouse experiment

Ferti-lizers	Cover crops C-0	C-1	C-2
MRP L-1	1.0	1.2	0.8
MRP L-2	1.3	0.8	0.9
URP L-1	0.8	0.9	1.3
URP L-2	0.9	1.7	1.6
NRP L-1	1.4	1.5	2.3
NRP L-2	2.6	2.5	2.4
SSP L-1	2.3	1.9	1.9
SSP L-2	3.4	2.6	2.7
Control	0.9	1.1	0.8
Mean	1.6	1.6	1.6

P Sources	P levels L-1	L-2	Mean
MRP	1.0	1.0	1.0
URP	1.0	1.4	1.2
NRP	1.8	2.5	2.1
SSP	2.0	2.9	2.4
Mean	1.4	1.9	1.7
Control	--	--	0.9

CD (P = .05)

Control Vs Rest	--	0.21
Bet. Crops	--	NS
Bet. Sources	--	0.20
Bet. levels	--	0.14
S x L	--	0.28
Crop x Fert.	--	0.50

Table 28

Effect of liming (pH 6.8) on the Olsen's extractable P (mg P/Kg soil) after 28 days incubation of soils after the greenhouse experiment

Ferti- lizers	Cover crops C-0	C-1	C-2
MRP L-1	1.2	1.3	0.8
MRP L-2	1.3	0.8	0.9
URP L-1	0.8	0.9	1.2
URP L-2	1.0	1.7	1.6
NRP L-1	1.4	1.5	2.4
NRP L-2	2.7	2.5	2.6
SSP L-1	2.5	2.0	2.0
SSP L-2	3.5	2.7	2.8
Control	1.7	1.7	1.7
Mean	0.9	1.4	1.1

P Sources	P levels L-1	L-2	Mean
MRP	1.1	1.0	1.1
URP	1.0	1.5	1.2
NRP	1.8	2.6	2.2
SSP	2.2	3.0	2.6
Mean	1.5	2.0	1.8
Control	--	--	1.1

CD (P = .05)

Control Vs Rest	--	0.21
Bet. Crops	--	NS
Bet. Sources	--	0.20
Bet. levels	--	0.14
S x L	--	0.28
Crop x Fert.	--	0.49

with the other two sources and both of them were generally at par with each other. Between the sources and levels, SSP at level 2 was superior to all others. In case of MRP there was no difference between the levels and in all other cases level-2 was superior to the respective level-1.

The increase in the available P status of the various fertilizer treated soils along with control are presented in Figure 6.

In a similar experiment, another set of samples were limed with half the quantities as required to raise the pH to 6.8. The data are presented in tables 29 to 32. The absolute values were slightly of lower magnitude compared to the other set. The trend of result in this set of incubation experiment was the same as noticed with the other set where liming was done up to pH 6.8.

The increase of the available P status of the various fertilizer treated soils along with the control are presented in Figure 7. Here also the trend was similar to that of full lime treatment series, inasmuch as slight increase after 14 days of incubation was discernible in all the cases including no-P control.

Comparison of Different Characters of the Rubber Plantation Soils with Non-rubber Area

Soil samples collected from the different rubber plantations and the comparable non-rubber area were analysed for pH, organic C, available P status as extracted by Bray's I extractant, Olsen's reagent and anion exchange resin, P fixing capacity, different fractions of P, organic P, inorganic P and total P. Appropriate leaf samples were also collected from the rubber plantations and were analysed for the P

Fig.6 effect of liming on Olsen's P in soils treated with different fertilizers
(after greenhouse experiment)

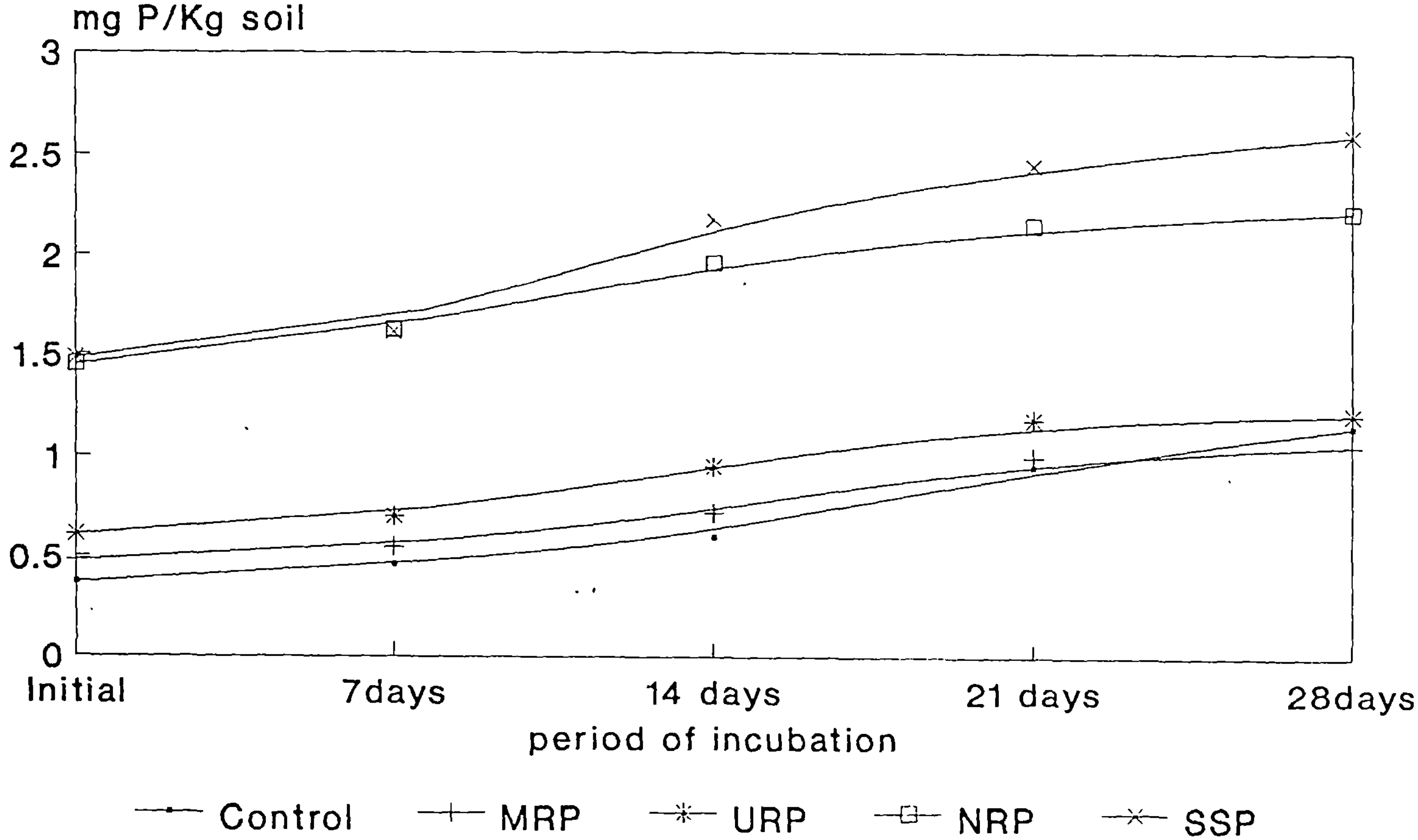


Table 29

Effect of partial liming on the Olsen's extractable P (mg p/Kg soil) after 7 days of incubation of the soils of greenhouse experiment

Ferti-lizers	Cover crops C-0	C-1	C-2
MRP L-1	0.8	0.5	0.7
MRP L-2	0.8	0.5	0.8
URP L-1	0.6	0.3	0.7
URP L-2	0.6	0.7	0.7
NRP L-1	1.2	1.2	1.2
NRP L-2	1.6	1.5	1.2
SSP L-1	1.4	1.0	1.3
SSP L-2	2.4	1.8	1.7
Control	0.2	0.4	0.3
Mean	1.1	0.9	1.0

P Sources	P levels L-1	L-2	Mean
MRP	0.7	0.7	0.7
URP	0.5	0.6	0.6
NRP	1.2	1.4	1.3
SSP	1.2	1.9	1.6
Mean	0.9	1.2	1.0
Control	--	--	0.3

CD (P = .05)

Control Vs Rest	--	0.19
Bet. Crops	--	0.14
Bet. Sources	--	0.18
Bet. levels	--	0.12
S x L	--	0.25
Crop x Fert.	--	NS

Table 30

Effect of partial liming on the Olsen's extractable P (mg P/kg soil) after 14 days incubation of the soils of greenhouse experiment

Fertilizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	1.0	0.8	0.7
MRP L-2	1.0	0.6	0.7
URP L-1	0.7	0.4	0.7
URP L-2	0.7	1.0	0.7
NRP L-1	1.8	1.8	1.6
NRP L-2	1.8	1.6	1.6
SSP L-1	1.5	1.4	1.5
SSP L-2	1.9	2.1	1.8
Control	0.7	0.6	0.4
Mean	1.2	1.2	1.2

P Sources	P levels		Mean
	L-1	L-2	
MRP	0.8	0.8	0.8
URP	0.6	0.8	0.7
NRP	1.7	1.7	1.7
SSP	1.5	2.0	1.7
Mean	1.2	1.3	1.2
Control	--	--	0.6

CD (P = .05)

Control Vs Rest	--	0.12
Bet. Crops	--	0.09
Bet. Sources	--	0.11
Bet. levels	--	0.08
S x L	--	0.16
Crop x Fert.	--	0.27

Table 31

Effect of partial liming on the Olsen's extractable P (mg P/ kg soil) after 21 days incubation of the soils of greenhouse experiment

Fertilizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	0.9	0.9	0.8
MRP L-2	1.1	0.6	0.8
URP L-1	0.8	0.5	0.8
URP L-2	0.8	1.4	0.8
NRP L-1	1.9	2.0	1.8
NRP L-2	2.0	1.8	1.8
SSP L-1	1.6	1.8	1.8
SSP L-2	2.2	2.2	2.0
Control	0.8	0.7	0.4
Mean	1.4	1.4	1.3

P Sources	P levels		Mean
	L-1	L-2	
MRP	0.9	0.8	0.9
URP	0.7	1.0	0.8
NRP	1.9	1.9	1.9
SSP	1.7	2.1	1.9
Mean	1.3	1.4	1.4
Control	--	--	0.6

<u>CD (P = .05)</u>

Control Vs Rest	--	0.09
Bet. Crops	--	0.07
Bet. Sources	--	0.09
Bet. levels	--	0.06
S x L	--	0.12
Crop x fert.	--	0.21

Table 32

Effect of partial liming on the Olsen's extractable P (mg P/ kg soil) after 28 days incubation of the soils of greenhouse experiment

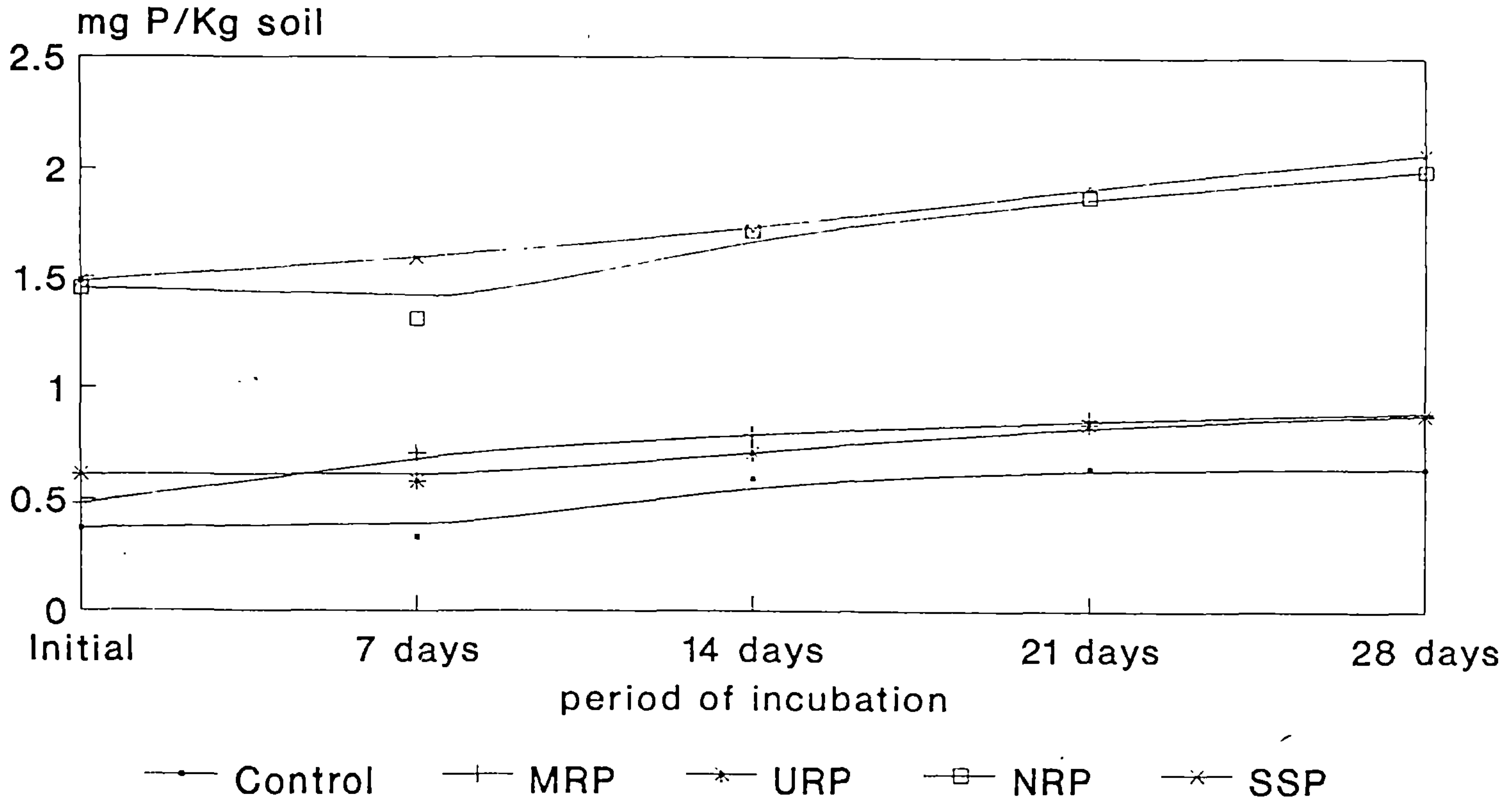
Ferti- lizers	Cover crops		
	C-0	C-1	C-2
MRP L-1	0.9	0.9	0.9
MRP L-2	1.2	0.6	0.8
URP L-1	0.8	0.5	0.8
URP L-2	0.8	1.5	0.8
NRP L-1	2.1	2.0	1.9
NRP L-2	2.2	1.9	1.9
SSP L-1	1.7	1.9	1.9
SSP L-2	2.3	2.4	2.2
Control	0.7	0.7	0.4
Mean	1.4	1.4	1.3

P Sources	P levels		
	L-1	L-2	Mean
MRP	0.9	0.9	0.9
URP	0.7	1.1	0.9
NRP	2.0	2.0	2.0
SSP	1.8	2.3	2.1
Mean	1.4	1.5	1.5
Control	--	--	0.6

CD (P = .05)

Control Vs Rest	--	0.06
Bet. Crops	--	0.04
Bet. Sources	--	0.05
Bet. levels	--	0.03
S x L	--	0.08
Crop x Fert.	--	0.13

Fig.7 Effect of partial liming on Olsen's P in soils treated with different fertilizers
(after greenhouse experiment)



content. Different characters of the soils collected from the two situations were compared using paired `t' test and the results are shown in Table 33.

The difference in the pH values of the two groups was not significant though rubber plantation soils generally showed higher pH values than the adjoining non-rubber area. Bray's P, Olsen's P and AER-P contents were significantly higher in the soils of rubber plantations, with the former two being significant at 1% level, while the latter being so at 5% level. A comparison of the P fixing capacity indicates that the non-rubber area having higher capacity to fix the added phosphates compared to the rubber plantations.

The different P fractions also showed significant differences between the two groups, except for the occluded P fractions, the trend being uniform in all the fractions with higher values for rubber plantations as compared with the other situation. The average Ca-P content of the rubber growing soils was nearly double that of the adjacent area, though for the other fractions the differences were not so wide. Organic P, inorganic P and total P contents also registered significantly higher values in the rubber plantation soils than the non-rubber area. The differences between inorganic P fractions and between total P contents were very much conspicuous when compared with the organic P fraction.

A comparison of the organic carbon content which is taken as a measure of the organic matter status, of the soils of the two groups showed significant difference between them and the soils of rubber plantations were having higher organic matter .

Table 33

Comparison of mean values and ranges in different soil characters of rubber plantation soils with soils of non-rubber area

Character	Soils from Rubber Plant-tions		Soils of non rubber area		t test
	Mean	Range	Mean	Range	
pH	---	4.9-6.0	---	4.7-5.9	NS
Bray's P (mg/kg Soil)	4.9	2.1-7.2	3.7	1.8-6.0	**
Olsen's P (mg/kg Soil)	2.3	1.1-3.6	1.8	1.2-2.6	**
AER P (mgP/kg Soil)	10.2	5.5-15.3	8.0	2.8-15.1	*
% P fixing Capacity	66.0	60-78	70.0	60-80	**
Saloid P (mgP/Kg Soil)	3.3	2-5	2.4	1-4	**
Al-P (mg P/ Kg Soil)	39.8	14-60	34.4	6-60	*
Fe-P (mg P/Kg Soil)	76.3	24-93	66.7	35-92	*
Red.Sol.P(mg P/kg Soil)	87.6	48-110	73.2	45-90	*
Occld. P (mg P/kg Soil)	77.8	50-110	68.3	20-106	NS
Ca-P (mg P/kg Soil)	62.1	30-78	39.1	26-56	**
Organic P(mg P/kg Soil)	140.6	65-200	111.0	50-180	*
Inorg. P(mg P/kg Soil)	240.6	170-360	192.3	130-296	**
Total P (mg P/ kg Soil)	381.0	298-660	303.0	221-500	**
Organic Carbon %	2.13	1.8-3.1	1.94	0.8-2.4	NS

NS . not significant
* significant at 5% level
** significant at 1% level

Relationship among various fractions of soil phosphate, different characters and leaf P content in rubber plantations: Various parameters of the soil phosphorus and other soil characters viz. pH, Bray's P, Olsen's P, AER-P, P fixing capacity, different fractions of soil phosphate, organic C and the leaf P content of the rubber plants were tested statistically for their inter-relationships, and the correlation coefficient (r) values of these characters are presented in Table 34. pH showed highly significant and positive correlations with Bray-I P and AER-P, but it did not influence Olsen's P significantly. The relationship of Bray-I P with Olsen's P, AER-P or organic C was positive and significant, whereas its relationship with P fixing capacity and saloid P were negative and significant. Olsen's P showed positive and significant associations with AER-P, Al-P and inorganic P, besides Bray-I P, but was negatively related with P fixing capacity and saloid P. The P fixing capacity showed, in addition to its negative and significant relations with Olsen's P and Bray's P, significantly positive relationship with occluded P.

Saloid P apart from its inverse and significant relationships with pH and Bray's P recorded positively significant r - values with all the inorganic P fractions except Ca-P, organic P, inorganic P, total P and leaf P. Among the several inorganic P fractions, Al-P was positively related to reductant soluble P, Fe-P was so with reductant soluble P, occluded P and Ca-P, while the last two fractions between themselves in turn had such a significant inter-relationship.Organic P not only recorded positive relationship with saloid P, but also with Al-P, Fe-P and reductant soluble P. Inorganic P influenced positively saloid P, Al-P, Fe-

Table 34

Correlation coefficeints among soil characters (soils of non-rubber area)

	Bray's P	Olsen's P	AER P	P fixing capacity	Saloid P	Al-P	Fe-P	Red Sol. P	Occl. P	Ca-P	Org. P	Inorg. P	Total P	Org. C
pH	0.77	0.64	-0.56	-0.25	-0.40	0.04	-0.26	-0.17	-0.24	-0.14	-0.20	-0.06	-0.13	-0.44
Bray's P		0.68	0.71	-0.49	0.51	0.17	-0.19	0.09	-0.05	0.48	-0.11	0.19	0.05	0.76
Olsen's P			0.70	-0.45	0.11	0.52	0.11	-0.28	0.09	-0.08	0.28	0.41	0.37	0.56
AER P				0.49	-0.26	0.10	0.01	-0.06	0.02	-0.30	-0.05	0.19	0.08	0.39
P fixing capacity					-0.06	-0.29	-0.42	-0.29	-0.27	0.27	-0.26	-0.30	-0.30	-0.57
Saloid P						0.45	0.53	0.50	0.38	0.43	0.56	0.33	0.46	-0.08
Al-P							0.46	0.61	0.13	0.17	0.72	0.76	0.78	0.38
Fe-P								0.45	0.25	0.37	0.44	0.45	0.46	-0.03
Red Sol.P									0.59	0.31	0.58	0.54	0.59	0.53
Occld. P										0.29	0.34	0.22	0.30	0.39
Ca-P											0.36	0.06	0.20	-0.24
Org. P												0.78	0.94	0.18
Inorg. P													0.95	0.35
Total P														0.29

Values above 0.55 are significant at 1% level, while values above 0.43 are significant at 5% level

P, reductant soluble P and organic P. Total P controlled all the P fractions excepting Ca-P, inorganic P and organic P. Organic C could influence Bray's P, occluded P, inorganic P and total P only. Leaf P was positively affected by saloid P, Al-P, organic P, inorganic P, total P and organic C.

Relationships of the Various Characters of the Soils of Non-rubber Areas.

A similar comparison of the various characters of the soils collected from the adjacent non-rubber area was also made and the correlation coefficients are presented in Table 35. Here pH is correlated with all the available P extractions using Bray's solution, Olsen's reagent and AER. All the three extractants were inter-correlated to one another positively, but all were negatively related with the P fixing capacity of the soils. Their relations with organic P, inorganic P and total soil P were by and large not significant, though the values were positive. Here also the Olsen's P was found to be positively related with Al-P, and Bray's P with Ca-P.

While examining the relationships of the different soil P fractions, it is seen that saloid P correlated with all other fractions positively, but significance was observed only with Al-P, Fe-P, reductant soluble P, inorganic P and total soil P. Al-P was related positively and significantly with Fe-P, reductant soluble P, inorganic P, organic P and total P in soil. The relation with occluded P and Ca-P with other fractions were not significant. Both Fe-P and reductant soluble P were positively and significantly related with each other, besides they being individually correlated positively with organic P, inorganic P and total P. The

Table-35

Correlation coefficients of soil characters
(soils of rubber plantations)

	Bray's P	Olsen's P	AER P	P fixing capacity	Saloid P	Al-P	Fe-P	Red Sol. P	Occl. P	Ca-P	Org. P	Inorg. P	Total P	Org. C	Leaf P
pH	0.75	0.36	0.68	-0.21	-0.52	0.17	-0.18	-0.31	-0.25	-0.20	-0.43	-0.01	-0.16	-0.30	-0.18
Bray's P		0.46	0.73	-0.55	-0.57	-0.05	-0.36	-0.21	-0.33	-0.29	0.36	0.12	-0.29	0.47	0.03
Olsen's P			0.76	-0.50	-0.02	0.45	0.01	-0.02	-0.12	-0.15	0.07	0.45	0.21	0.31	0.28
AER P				-0.32	-0.33	0.13	-0.06	-0.16	-0.26	-0.22	-0.15	0.22	0.02	0.38	0.16
P fixing capacity					0.25	-0.04	0.28	0.26	0.46	0.37	0.08	-0.05	0.38	-0.09	-0.14
Saloid P						0.64	0.50	0.47	0.53	0.10	0.72	0.49	0.72	-0.08	0.52
Al-P							0.39	0.46	-0.25	-0.16	0.73	0.57	0.60	0.28	0.49
Fe-P								0.56	0.50	0.47	0.45	0.25	0.53	0.06	0.21
Red Sol.P									0.42	0.11	0.65	0.50	0.56	0.37	0.42
Occld. P										0.66	0.29	0.42	0.74	0.48	0.42
Ca-P											0.04	0.13	0.24	0.16	-0.04
Org. P												0.65	0.71	0.21	0.60
Inorg. P													0.72	0.52	0.76
Total P														0.51	0.67
Org C %															0.54

Values above 0.55 are significant at 1% level, while values above 0.43 are significant at 5% level reductant soluble P fraction was also related positively with the occluded P fraction, which however was not related with any of the other characters examined in this study. Ca-P was also related with the organic, inorganic and total soil P contents, though the latter three were correlated amongst themselves in a very highly and positive way.

The general trend of inter-relationships amongst the soil parameters is more or less same for the two classes of soils namely plantation soils and non-rubber areas. However, major deviations were associated with influence of organic C status of the soils on other soil-P parameters on one hand and the behaviour of occuluded P among the soil-P fractions on other.

DISCUSSION

The salient results reported in the previous chapter are briefly discussed here.

Dry matter Yield of the Crops

In the field experiment as well as in the pot experiment Pueraria crop recorded a higher dry matter yield as compared to Mucuna, irrespective of the various fertilizer treatments. The better growth of Pueraria may be due to the better root mass of the crop as observed in the pot experiment. Pushparajah *et al.* (1977) have also reported a better growth of Pueraria crop when phosphate was applied through single superphosphate or rockphosphate (Christmas Island rockphosphate). This nutrient being immobile in soil, a main mechanism of its movement in soil is through diffusion and possibly root interception too plays some role in this regard. A higher amount of root growth, especially in the form of a fibrous mat for Pueraria as reported by Chanda Pillai (1968), probably resulted in a better foraging for of phosphate from the water-soluble form and from reactive phosphate rock forms.

This trend is evident from the results on dry matter yield of the Pureria crop in both the experiments, where Pueraria performed better with single superphosphate and NRP. The crystallographical examination of NRP indicated presence of carbonate apatite as a major constituent, which is well recognised as a form of reactive apatite. But the dry matter yield performance of Mucuna was better than that of Pueraria, when phosphatic fertilizer sources were MRP and URP, the differences between the two crops being more wide at the lower levels of the phosphate rocks applied. This clearly shows the capacity of the Mucuna crop to grow better with difficultly soluble rockphosphate forms and a preference fo readily available sources of P in case Pueraria. Kothandaraman *et al.* (1990) had reported a higher population of phosphate solubilising microorganisms in the rhizosphere of Mucuna crop, and this may be a reason responsible for the better utilization of the difficultly dissolving phosphate rocks by that crop.

Another salient observation is that the higher level of NRP was equivalent to the lower level of SSP for both the crops. In Mucuna, additionally the higher level of MRP was also comparable to SSP level-1. Generally the L-2 levels of the other phosphate rocks were inferior to the SSP level-1. This clearly shows that among the rocks, relative efficiency of NRP is the best, followed by MRP and URP. Mishra *et al.* (1985) have reported better performance of MRP compared to URP, in other crops. NRP was also reported to have better relative efficiency (Shinde 1978).

The biomass yield of the two crops observed by Kothandaraman *et al.* (1990) was contradictory to the present observation. They made observations after three-year-growth period of the crops and in the present investigation biomass yield were recorded after six month period and this may be a possible reason for the disparity. They had also reported that Mucuna depleted phosphates more from the lower layers, which may be coupled with their luxuriant growth after the initial lag.

P Content of the Crops

Phosphate application is shown to have significant influence on the P content of the plant parts, suggesting thereby that the two cover crops tried in this experiment have enough capacity to take up the phosphate from the applied fertilizers and subsequently can return it to soil along with their organic residues. In both the experiments, cover plants contained higher levels of P in their plant parts, when supplied with higher doses than the respective lower doses. This indicate the capacity of the crops to extract P from the soil, and store in their plant parts or utilise for their own metabolic processes at relatively higher amounts when P is present in the soil in good amounts either as a soluble source or as a difficultly dissolving source. This enables a better conservation of the nutrient, which is otherwise fixed up in unavailable forms in the soil when present freely. Thus the growing of the cover crops brings about such a beneficial role as mentioned by Pushparajah and Chellapah (1969). The difference in the P content between the two crops was not consistent in the field and pot experiments. In the pot experiment the difference was not significant, while in the field experiment Mucuna crop contained more P. This may be due to ability of Mucuna to draw nutrients from deeper soil layers (Kothandaraman *et. al.* 1990). This, however, is not feasible in the pot experiment.

Root Weight

The root weight of the crops assessed from the pot experiment showed significant differences, with Pueraria crop having better root mass in all the situations. The work of Kothandaraman *et al.* (1990) had showed a higher build up of soil organic matter as a consequence of growing Pueraria crop when compared to the Mucuna crop after a three year period. This may be due to the better root mass of the former. Among the different sources, SSP was the best source and URP gave poor root growth. This indicates the necessity of at least some amount of readily available phosphate sources during the initial growth stages of the crop for a better root development and the subsequent good growth.

Phosphate Uptake by Crops

The phosphate uptake pattern of both the crops were similar in the field experiment and in the pot experiment Pueraria recorded a better uptake. From the difficultly soluble phosphate rocks like MRP and URP (compared to NRP), the field experiment and pot experiment data show better uptake by Mucuna crop, except for the higher level URP in the pot experiment. Among the different sources, URP was inferior to all others, and in both the experiments SSP gave highest uptake. This shows that both the crops prefer water soluble form of phosphate, if available in soil. With the rockphosphate forms, NRP and MRP resulted in comparable uptakes. So both the rockphosphates can be applied as a source of phosphate to the cover crops in general, whereas in certain situations, where the difficultly soluble forms are to be used, the suitability of the two crops have to be further assessed since the pot culture experiment and the field experiment did not show concordant results with respect to the uptake pattern from MRP and URP.

Plant Ca Content and Uptake

The calcium content of the two crops in the pot experiment showed not much differences between the no-fertilizer control pots and the fertilizer applied pots. This may be because the biomass yield of the no-fertilizer control pots were significantly lower than that of the fertilizer applied pots and consequently the Ca requirements in terms of absolute quantity were lower. This could possibly be met from the native soil Ca sources or that obtained through the irrigation water.

The uptake pattern of the crops receiving different rockphosphate sources were further examined (Table 18) and it is observed that fertilized pots had a significantly higher uptake than the no-fertilizer applied control except for the URP applied pots. These differences mainly stem from the variations in plant yield, rather than Ca concentration in plants. Here also the SSP applied pots had better Ca uptake due to a positive impact on Ca content of plants as well as on dry matter yield. Ca supplied through the phosphatic fertilizers were many times more the uptake values. Yet the sparingly soluble phosphate rocks might not met readily the crop need. However, Ca in SSP being in water soluble (largely gypsum) form, can be expected to be absorbed rather readily and consequently resulted in a better uptake.

Among the rock phosphates, NRP and MRP were associated with significantly higher Ca uptake than the control. The Ca uptake of the crops receiving rock phosphate has shown a highly significant positive correlation with the phosphate uptake. This also suggests dissolution of the phosphate rocks, and the subsequent uptake of Ca and phosphates by the crops. Looking from this angle, Pueraria derived more benefit form NRP, whereas Mucuna seems to have benefited more from URP and MRP (Table 16 and 18). But conclusive inferences regarding the phosphate rock dissolution based on the measure of calcium uptake by the crops from the present investigations cannot be made since the input of Ca through irrigation water was not monitored, which often is not in inconsequential amounts. Khasawneh and Doll (1978) have mentioned about such an indirect measure of phosphate rock dissolution by monitoring the changes in the exchangeable Ca level of the soil after the application of the rocks to soils.

P Uptake Capacity of Roots.

The phosphate uptake capacity of the two crops was assessed using the amount of P taken up per unit weight of the dry roots. Mucuna crop was observed to take up lesser amounts of total P as compared to Pueraria crop. Yet the quantitity of phosphate taken up by the whole crop per every gram of the root was significantly higher. The difference between the two crops in the amount of P taken up per gram of root was observed to be more wide in the case of rockphosphates like NRP, MRP, and the higher level of URP application (Table 19). This suggests a better P foraging capacity of Mucuna crop as reported by Kothandaraman *et. al.* (1990). Although The root mass observed after a period of 6 months were less for Mucuna, its capacity to take up phosphate from the sparingly soluble rockphosphates is better compared to Pueraria crop. This may be due to variations in physiological characteristics of roots of these plants, which need further investigation. Thus, Mucuna as a cover crop in the initial few years in rubber plantations appears to be an appropriate one, especially in view of its ability to extract P from sparingly soluble materials of P like phosphate rocks, which often are the sources applied in these plantations.

Availability P Status after the Experiment

The phosphate availability status of each of the treatments after the field experiment and the pot experiment was assessed by Olsen's reagent, Bray-I extractant and anion exchange resin. The relationships among these extractants were highly positive and AER always extracted more amount of P, followed by Bray-I and Olsen's reagent (Figure 1). The higher extraction of P by the AER, especially from the soils receiving rockphosphates or SSP may be due the fact that AER is capable of extracting substantial amounts of P, even when phosphate rock alone is added to an AER system as reported by Khasawneh and Doll (1978). The above authors had also reported that Bray's solution extracts Ca-P fraction also, while Olsen's P was mainly from Al-P and Fe-P fractions, since it reacts little with the unreacted apatites present in phosphate rocks. Thus the higher values observed for AER and Bray's-I extraction may be due to the fact that, these two would be extracting a part of Ca-P also from the unreacted phosphate rocks remaining in the soil.

Effect of Addition of Crop Residues on the Phosphate Availability Status of Soil

The effect of recycling of crop residues from the two cover crops on the P availability status of the soils treated with different forms of phosphate ferilizers was assessed by conducting a Neubauer seedling tests with and without adding the residues. In the field experiment soil samples, SSP applied soils showed significantly higher values for the no cropped plots and the cropped but not recycled and as well as for the crop residue recycled plots. Recycling of the crop residue always showed a marginal increase in the available P status, the SSP applied and Mucuna recycled plots showing the highest values (Figure 2). For MRP and URP applied plots Mucuna and Pueraria did not show any difference with respect to available P, as a consequence of recycling, while in no fertilizer control plots Pueraria recycling was superior (Figure 5).

In the case of Neubauer experiment after the pot experiment, the practice of crop residue recycling lowered the content of Neubauer P, as compared to the non-recycled samples. But the no fertilizer control plots did not show any visible effect on the recycling in available P status, though the crop raising had significantly increased the P availability. Here the crop raising and the subsequent recycling did not show much difference in the Neubauer P content in the fertilizer applied pots, as observed in the soil samples after the field experiment. Consistency of results on the Neubauer P values between the two sets of experiments is lacking.

Effect of Liming on the P Release

Changes in P availability (Olsen's P) as a result of liming (to pH 6.8) the field experiment soil, which received different phosphatic fertilizers was assessed after an incubation of the samples for 28 days in an incubator at 35 $\pm 1^{o}$C. In the field experiment samples, liming had significantly increased the available P content, the highest increase was observed in MRP and URP treated soils. For URP the increase was eight times. Haynes (1982) had also reported a similar increase in availability of P as a consequence of liming. He had mentioned that liming could increase phosphate availability by stimulating mineralization of soil organic phosphorus, which is often overlooked. He had also mentioned the reduction in Al toxicity for the greater P availability, based on the results of crop uptake of phosphates in limed and unlimed soils. The contribution of such a phenomenon to the increase in P availability in the present investigation could however not be assessed as no crop uptake studies were done after the liming experiment.

For the soils after the pot experiments also such an incubation was done. But here liming was done at two levels, either to raise the pH to 6.8 or one-half lime requirement of that. Here the increase in P availability observed was not as high as that observed on the field experiment soil samples. The 28-day incubation after liming resulted in only a slight increase in the available P status. The increase was observed to be gradual throughout the incubation period as observed from the data on P availability assessed at weekly intervals (Figure 6). The increase in P availability mainly occurred in the 7-21 days period of the incubation. After 21 days the change in available P status is observed to be very little.

In the case of soils receiving one-half of the lime required to raise the pH to 6.8, in the soils treated previously with SSP the increase was uniform till the 28th day of incubation, while NRP and no-fertilizer control soils showed maximum changes in the 7-14 day period. Here also the changes after 21 days of incubation was not so conspicuous.

The overall changes in the P availability after liming were similar at both the liming rates and the increase in P availability was only marginal. Anjos and Rowell (1987) had observed only very little changes in P availability as a consequence of liming, in soils containing higher amounts of exchangeable Al. In some cases they even observed a decrease in P availability and gave the explanation that P might be getting adsorbed on the freshly formed precipitates of aluminium hydroxides as a result of liming. Here, again the results of the two experiments being somewhat inconsistent, drawing conclusive inferences regarding the mechanism of P availability changes brought forth by liming the soils is not fully justified.

Comparison of Different Characters of the Rubber Plantation Soils with Non-rubber Area

Soil samples collected from the rubber plantation and the samples from nearby area were analysed for various soil characters and the two sets of data were compared using 't' test. There was no significant difference in the pH values of the two groups of soils, though the rubber plantions were receiving fertilizers for over 30 years. In rubber plantations, least soil disturbance is done during the cultivation of the plant and nutrients present in the litter of the trees is naturally recycled between soil and phytomass. Thus there is very little amount of nutrient removal from the system, especially with respect to bases. That may be the reason for the stable pH in these soils. The slight increase in pH observed may be due to the continuous application of rockphosphates, which are rich in Ca.

Available P extracted by all the extractants showed a significantly higher P content in plantation samples and the P fixing capacity of such soils was also comparatively less. This may also be due to the build-up of P resulting from the continuous application of phosphatic fertilizers of the type mentioned above. Except the occluded P fraction, all the other fractions of P were higher in the rubber growing soils. This clearly points to a possible dissolution of rockphosphate applied over a long period and the formation of less soluble fractions like Al-P. Similar build-up in Al-P and Fe-P fractions was reported on the basis of the studies conducted on the rubber growing regions of Tripura (Anonymous 1990). The content of Ca-P fraction in the rubber growing soil was nearly double that observed in the nearby areas. This may be due to the fact that, a considerable part of the applied rockphosphate in the soil might not have undergone dissolution and this part can be expected to contribute to the Ca-P fraction of the soil. Mussoorie rockphosphate is the generally applied fertilizer source for P in these soils and its reactivity is considered to be low (Narayanasamy *et al.* 1981). There is, thus, a large chance for the build up of Ca-P in the soil.

Organic P fraction of the soils were also higher, for which possibly two reasons can be adduced. Rubber leaves contain good amount of P (about 0.2%) and when these leaves are recycled is soil in the form of litter, they may add to the organic P pool. Another reason may be the involvement of the soil microflora in converting the inorganic form of P from the applied fertilizers to the organic forms. With respect to the organic carbon content of the soils, the two groups did not show any significant difference.

On the basis of comparison of all these factors, it can be concluded that rubber cultivation with the recommended package of practices does not degrade the soil with respect to the availability of phosphate. However, inferences regarding the overall land degradation, if any, can be drawn only after studying several other physicochemical characters of the soil.

Interrelations of Various Characters of the Soils under Rubber Plantations and their Influence to Leaf P Content

The different characters of the soils under rubber plantations collected for the present investigation were compared statistically for their interrelations and also for their bearing on leaf P content. pH showed to be positively related with the available P measured by Bray's-I and AER, suggesting whereby an increased availability of P under higher pH soils. The interrelations among all the three extractants for P were also significant and positive. Amer *et al.* (1955) had mentioned about a close relationship of P extracted by AER with that of Bray's extractant, and the values for AER were higher. But the P extracted by these methods showed a poor relation with the leaf P content of the rubber plants, while the organic P content of the soil showed a positive relation, so also saloid-P and Al-P. So a major contribution of these fractions to the plant P is a distinct possibility. Among these, role of organic P with respect to the P nutrition of rubber plants appears to be an important one, since the organic carbon content of the soil was also found to influence the P content of the rubber leaves in a positive way.

Similar comparisons were made for the soils collected from the non-rubber area. The relationships among the different extractants were highly significant here also. The relationship of organic P with the total P was also significant. These results suggest the importance of soil organic matter with respect to the P nutrition in acid soils which inherently have high capacity for fixation of the applied inorganic phosphatic fertilizers into unavailable forms.

SUMMARY AND CONCLUSION

Phosphate rock in its natural form is only of limited value as a source of P fertilizer but finely ground forms can effectively be used in acid soils. In the cultivation of rubber, which is a cash crop, phosphatic fertilizers are mainly applied through rockphosphates. These plantations in India are mainly confined to the laterite soils of Kerala, and such soils are low in phosphorus and have inherent problems with respect to P nutrition. In the initial years of establishing rubber plantions, cover crops of leguminous group are raised with a view to conserve the soil and maintain the soil fertility. Application of phosphate is done to these cover plants in the form of rockphosphates, and these cover plants are later recycled to the soil as the canopy of the rubber plants develop. Thus these crops are likely to have an important role in maintaining the soil fertility in general, and particularly their influence in dissolving P from the sparingly soluble fertilizer sources and then returning that nutrient to soil in the organic form might be a worthwhile aspect with respect to the P nutrition of the rubber plants.

The present investigation was carried out to evaluate the effects of different types of phosphatic fertilizers on the biomass production of the two cover crops *viz. Pueraria phaseoloides* and *Mucuna bracteata,* and to elucidate the role of cover crops in the turn-over of phosphate from the rockphosphates. Another objective of the experiment was to characterise the phosphate present in soils under rubber plantations and to compare them with soils of similar non-rubber areas.

The investigation consisted of two experiments, a field experiment laid out at Erumeli estate, Kottayam, Kerala and a green-house experiment on the soils brought from the field experiment site. In both the cases three rockphosphates *viz.* Mussoorie rockphosphate (MRP), Udaipur rockphosphate (URP) and North Carolina rockphosphate (NRP) were tried and single superphosphate (SSP) was included as a standard source. The rate of phosphate application was at two levels *i.e.* 25 kg P/ ha as a lower rate and 50 kg P/ ha as the higher dose for the field experiment (25 and 50 mg P/ kg soil respectively were the lower and higher levels in the pot experiment). A no-fertilizer control was included to study the effect of P addition to the crops. Similarly a no-crop set was also included in the factorial combination of the treatments, so as to assess the effect of the crops on the P dissolution from the rockphosphate. After the completion of the experiment the soils from the individual pots/ plots were limed to pH 6.8 and incubated to study the effect of liming on the release of P from the soils. Additionally the role of recycling the crop residues of the cover plants in enhancing the P supplying power of the soil was done by conducting Neubauer tests in two sets, one set receiving proportionate amounts of powdered dry matter and the other without that. The experiment was done separately after the field experiment and pot experiment.

Characterisation of phosphate present in soils of rubber plantation were attempted and these were compared with those soils of adjacent non-rubber area. Five locations representing the major rubber growing tracts in south India were selected and from each of the places four plantations and four adjacent non-rubber areas were selected and soil samples collected. Thus samples representing 20 rubber plantations and 20 non-rubber areas were included. Different forms of phosphate fractions present in these soils were determined and compared, using suitable statistical tests. Based on the results obtained from these experiments the following conclusions were drawn.

1. Phosphate fertilizer addition resulted in higher biomass yield of the two cover plants studied in both the experiments. SSP was found to be the best source of P and amoung the rockphosphates, NRP was superior followed by MRP and URP.

2. The two crops also differed significantly in their capacity to produce biomass, with Pueraria being superior. The performance of the crops at higher level of fertilizer application was also better.

3. With respect to the uptake of phosphate, the two crops were differing significantly, with Pueraria taking up more P than Mucuna. SSP was the most effective source and URP the least. Though Mucuna crop recorded lower dry matter yield, P content in the foliage was higher than that in Pueraria. Due to application of higher level of the less-reactive MRP, Mucuna derived more benefit than Pueraria, which however preferred SSP and NRP as P sources.

4. Raising of the cover crops coupled with fertilizer application resulted in higher content of soil available P after the six- month-period of field experiment. Such increase was similar due to both the crops. Again SSP applied soils were showing higher P available content.

5. The different extractants for measuring the available P status *viz.* Olsen's, Bray's-I and AER (anion exchange resin) showed significant and positive correlation among themselves. In all cases AER extracted maximum amount of P followed by Bray's-I and Olsen's.

6. Recycling of the organic residues of the cover plants resulted only in a marginal increase in the P supplying capacity of the soil as assessed by the Neubauer seedling test carried out after the field experiment. Similar observations were not forthcoming in the experiment conducted with the soils after the pot experiment.

7. Liming of the soils after the field experiment showed significant increase in the available P content as assessed by Olsen's extractant. In the fertilizer applied plots the increase in P availability due to liming was nearly three fold, the maximum increase was in the URP applied plots. The soil samples after the pot experiment did not show a similar trend, where the increases were only marginal.

8. The Pueraria crop was observed to have a higher root mass in the form of a fibrous network of roots, while with Mucuna crop it was less. The P uptake by the crop per gram of root was higher for Mucuna crop, suggesting thereby a higher capacity for P absorption by the roots of that plant. The studies done on the characterisation of the phosphate present in the soils of rubber plantation lead to the following conclusions.

9. The rubber growing soils were having a significantly higher content of all the inorganic as well as organic P fractions as compared to non-rubber areas. Aavailable phosphates as extracted by the different extractants also showed higher values for plantation samples.

10. The leaf P content of rubber plants was poorly correlated with the available P estimated by the different extractants. Saloid-P, Al-P, organic-P and the organic carbon content of the soils, however, showed significant and positive correlations with the leaf P content.

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