EVALUATION OF LATEX SLUDGE AS A PHOSPHORUS SOURCE IN CROP PRODUCTION

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DECLARATION

I hereby declare that this thesis entitled "**Evaluation of latex sludge as a phosphorus source in crop production**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

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Dedicated to My

Beloved Parents and Brother

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LIST OF ABBREVIATIONS

C	-	Carbon
Ca	-	Calcium
cm	-	Centimetre
cm^2	-	Square centimetre
cv.	-	Cultivar
cmol	-	Centimole
CD	-	Critical Difference
DOI	-	Days of incubation
EC	-	Electrical conductivity
et al.	-	And others
FYM	-	Farmyard manure
Fig	-	Figure
g	-	Gram
hr	-	Hour
i.e.	-	That is
K	-	Potassium
K_2O	-	Potash
kg ha^{-1}	-	Kilogram per hectare
LS	-	Latex sludge
Mg	-	Magnesium
m	-	Metre
mm	-	Millimetre
mg	-	Milligram
ml	-	Millilitre
MSL	-	Mean Sea Level
N	-	Nitrogen
nm	-	Nanometer
P	-	Phosphorus
P_2O_5	-	Phosphate
ppm	-	Parts per million
q	-	Quintal

LIST OF ABBREVIATIONS Continued

RP	-	Rock phosphate
SSP	-	Single super phosphate
sp.	-	Species
t	-	Tonnes
t ha^{-1}	-	Tonnes per hectare
viz.	-	Namely
yr	-	Year
@	-	At the rate of
µS	-	Micro siemens
µg	-	Microgram
°C	-	Degree centigrade
%	-	Per cent
¼ LS + ¾ SSP	-	¼ P as LS and ¾ P as SSP
½ LS + ½ SSP	-	½ P as LS and ½ P as SSP
¾ LS + ¼ SSP	-	¾ P as LS and ¼ P as SSP
¼ LS + ¾ RP	-	¼ P as LS and ¾ P as RP
½ LS + ½ RP	-	½ P as LS and ½ P as RP
¾ LS + ¼ RP	-	¾ P as LS and ¼ P as RP

INTRODUCTION

1. INTRODUCTION

India, like any other developing country is on the threshold of rapid and phenomenal growth in the agriculture and industrial sectors. With 70 per cent of the population depending on agriculture, the prosperity of the nation to a great extent depends on its strength in this area. Indian agriculture is plagued by the problem of fragmented and scattered holdings, erratic monsoons, unscientific cultivation methods, stagnating yield levels and deteriorating quality of soil and environment. The pressure of population on land and the food demands of the ever increasing population has outlined the need for crop production strategies to maximize yield per unit area with least damage to the environment.

An inevitable consequence of these developmental activities is the problem of waste generation which has far exceeded the carrying and recycling capacity of the biosphere. Waste disposal strategies on scientific lines have to be taken up to prevent environmental and associated health problems. Agricultural and other biodegradable wastes can be recycled through effective composting methods. Industrial wastes on the other hand should either be put to alternative uses or tackled through safe and efficient disposal systems.

A critical appraisal of the data on garbage production at any level, state, national or global shows that industries are a major contributor to this malady. Of India's annual generation of 25 million tonnes of urban solid waste, rubber and rubber related industries account for 2.9 per cent (Sinha and Sinha, 2000), the foremost among such wastes being latex sludge, a byproduct of latex concentrate process in natural rubber industry.

Shifting from industrial to the agricultural scenario, the stumbling blocks in crop production are enumerous, the most serious among them being the ever hiking price of inputs, especially fertilizers. Different rock phosphates which have gained popularity as comparatively cheaper phosphorus source to crops have limitations like their occasional unavailability and unsuitability to certain soils and crops due to their chemical nature.

The exploitation and use of latex sludge, a byproduct of latex concentration process therefore assumes significance. Its agricultural utilization, if feasible, promises apparently to be the solution to the twin problems of waste disposal and fertilizer scarcity. About 800 tonnes of this material are produced annually in Kerala alone by 110 latex processing factories engaged in the process of concentrating field latex through centrifugation (The Rubber Board, 2001). As high content of Mg in field latex, adversely affects its stability on further processing a practice of precipitating it out as magnesium ammonium phosphate by adding diammonium hydrogen phosphate prior to centrifugation is usually resorted to. This precipitate gets collected on the sides and shaft of the centrifuge bowl which is later collected and dumped in the factory premises. Preliminary studies have shown this precipitate popularly known as 'bowl sludge' to be a very rich source of plant nutrients, especially phosphorus (Lowe, 1968; John *et al.*, 1977).

In this background, the present study was planned with detailed investigation on the following aspects of latex sludge.

- Basic physico-chemical properties
- Nutrient mineralisation pattern on incubation with soil
- Effect on the growth and yield parameters of a crop of chilli
- Residual effect on a subsequent crop of chilli

It is hoped that the findings of this study can elevate the status of this material now considered as just a troublesome waste to be disposed off to that of an indigenous cheap source of phosphorus to crops.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The present study is an attempt to explore the possibility of using latex sludge, a high phosphorus containing waste product of concentrate latex industry as a source of phosphorus in crop production. In this chapter are presented review on specific aspects of latex sludge relevant to the present investigation and also the role of phosphorus in the nutrition of test crop chilli.

The crop production scenario world over reveals that the increasing price of inputs, especially fertilizer is one of the gravest concerns of the farmer. Phosphorus is a major nutrient element required in large amounts for plant growth. Different rock phosphates which have now gained popularity as a comparative cheaper source of phosphorus to crops have limitations like occasional unavailability and unsuitability to certain soils and crops owing to their chemical nature. Heavy metals Cd and Pb are structural components of most rock phosphates. Prolonged use of rock phosphates can therefore lead to their accumulation and pollution of soil and ground water (Basak, 1999). In this context, the identification and popularization of alternate indigenous and cheap sources of plant phosphorus assumes importance.

2.1 ALTERNATE SOURCES OF PHOSPHORUS

Based on field experiments conducted in different crops, several industrial byproducts have been found to have potential as alternate source of phosphorus (P) like latex sludge (Lowe, 1968; Wahab *et al.*, 1979), basic slag (Mathur, 1995; Ghosh, 1999), press mud or filter cake (Raman *et al.*, 1999; Jeyabal *et al.*, 2000), fly ash (Maiti *et al.*, 1990; Mongia *et al.*, 2003), KCPL sludge (Thomas and Gopinathan, 2002), spent wash or distillery effluent (Joshi *et al.*, 1996; Jothimani and Bhaskaran, 2002), rubber effluent (Karim and Bachik, 1989; Augusthy and Mani, 2001), palm oil mill effluent (Kanapathy *et al.*, 1983; Teoh and Chew, 1984), paper mill effluent (Dutta and Boissya, 1999; Brien *et al.*, 2002), dye factory effluent (Swaminathan and Vaidheeswaram, 1991), oil refinery waste water (Ahmad *et al.*, 2003), dairy industry effluent (Gautam *et al.*, 1992), fertilizer factory effluent (Goswami and Naik, 1992), tannery effluent (Farooqui, 1994) and domestic effluents both solid (sludge) and liquid (sewage) (Dhaliwal and Malik, 1999; Reddy and Rao, 2000) .

The favourable effects of some indigenous phosphorus containing materials as alternate phosphorus sources in relation to crop growth are reviewed below. That pertaining to latex sludge and rubber effluent is presented in detail separately.

2.1.1 Specific Effect on Crop

Basic slag

Varadan *et al.* (1977) revealed that basic slag was as good as SP and RP in increasing the yield of finger millet at 60 kg P_2O_5 ha^{-1} in a red sandy loam soil. Mathur (1980) observed significant increase in yield of soyabean due to basic slag alone or with RP in 1:1 ratio. Similar work in rice was done by Mohandas and Appavu (2001) and they observed that application of 1000 kg basic slag with 18.75 t ha^{-1} of green leaf manure recorded the highest grain and straw yields.

Press mud Cake (Filter Cake)

Patil and Kale (1983) compared different sources of P and obtained the highest P uptake, cane and sugar yield and good juice quality by sugar cane receiving press mud cake @ 25 t ha^{-1}. Similar effect of press mud cake in increasing the cane yield and quality of sugar cane was reported by Kanwar and Kapur (1987) and Singh *et al.* (2001).

Fly ash

Reports by Kumar *et al.* (1999) indicated that application of fly ash increased the grain yield of both soyabean and wheat grown in a red loam soil. Srivastava and Chhonkar (2000) noted that phosphorus content of sudan grass and oats increased with graded levels of fly ash incorporation up to 100 g kg^{-1} soil. Increased phosphorus uptake in rice and lettuce was shown by Ramesh and Chhonkar (2001).

KCPL Sludge

Thomas and Gopinathan (2002) showed that a value added organic manure containing 9.05 per cent P prepared from KCPL sludge, an industrial waste produced by Kerala Chemicals and Proteins Limited, Thrissur, can be used as a potential P source in rice with no deleterious effect either on crop or soil even at higher doses of 20 t ha^{-1}.

Spent wash or Distillery effluent

Zalawadia *et al.* (1997) observed that application of 50 times diluted spent wash increased yield and P uptake in sugar cane. Patil and Chaudhari (2002) reported that application of spent wash @ 50 $m^3 ha^{-1}$ was the optimum dose for fodder maize as significantly higher fodder yield, leaf protein, chlorophyll content and P uptake were recorded at this level. Increased P uptake in maize with application of diluted spent wash was indicated by Sukanya *et al.* (2002).

Palm Oil Mill Effluent (POME)

Yeow (1983) found that application of POME increased the weight of fresh fruit bunch of oil palm by 10 to 35 per cent while Haron and Zakaria (1994) observed an increase by 2.4 per cent when POME was applied for four years.

Paper Mill Effluent

Kannan and Oblisami (1992) indicated that application of 25 per cent concentrated paper mill effluent favoured germination, growth and increase in dry matter production in groundnut. Singh *et al.* (2002) studied the effect of diluted pulp and paper mill effluent in wheat and found that its application increased chlorophyll content, plant height, shoot and root biomass, leaf protein content, grain yield, protein, carbohydrate and lipid contents.

Dye Factory Effluent

Swaminathan and Vaidheeswaram (1991) reported that 50 per cent diluted dye factory effluent was ideal for seed germination, hypocotyl development, seed vigour and seedling growth of groundnut.

Oil Refinery Effluent

Ahmad *et al.* (2003) revealed that application of waste water of oil refinery increased cane length, weight of ten canes and cane yield by 1.4, 6.7 and 7 per cent respectively.

Dairy Effluent

Trials by Gautam *et al.* (1992) showed that application of 25 per cent diluted dairy effluent resulted in maximum germination of kharif and rabi crops.

Fertilizer Factory Effluent

Goswami and Naik (1992) reported that application of 10 per cent diluted effluent of a phosphatic fertilizer factory improved the chlorophyll content of *Cyamopsis tetragonaloba.*

Tannery Effluent

Reports by Farooqui (1994) indicated that application of four times diluted tannery effluent promoted the vegetative and reproductive growth and yield of *Lens culinaris* Medic.

Domestic Effluent

Rajan and Sriramulu (1987) indicated apparently good growth of maize and ragi under sewage treatment. Rao and Shantaram (1996) reported the favourable effect of sewage sludge on dry matter production and yield of maize when applied at a rate of 33 t ha^{-1}. Favourable effect of sewage application in vegetables was reported by Mitra and Gupta (1999).

2.1.2 Specific Effect on Soil Available Phosphorus

Basic slag

Igbokwe and Tiwari (1985) showed that application of basic slag @ 3.79 t ha^{-1} in a silt loam soil of pH 6.4 brought about a significant increase in soil available P. Debnath and Basak (1986) noted that application of basic slag increased the available P status of laterite soils in the foot hills of Himalayas. Results on similar lines were reported by Naeidhe (2001).

Press mud Cake (PMC)

Raja and Raj (1979) showed a progressive increase in available P content of red, black, alluvial, non saline alkali and acid soils when press mud cake was applied. Agreeing reports had also been put forward by Patra *et al.* (1989) and Kumar and Mishra (1991).

Fly ash

Lal *et al.* (1996) indicated a significant increase in soil available P with fly ash application in soil of the farm of Birsa Agricultural University. Similar favourable effects of fly ash in increasing soil available P were also reported by Raman *et al.* (1996) and Srivastava and Chhonkar (2000).

Spent wash or Distillery effluent

Devarajan and Oblisami (1995) revealed an increase in available P content of sandy loam soil with the application of distillery effluent.

Similar increase in available P was reported by Singh and Bahadur (1998), Kayalvizhi *et al.* (2001) and Chatterjee *et al.* (2003).

Palm Oil Mill Effluent (POME)

Haron and Zakaria (1994) revealed that application of POME over four years increased soil available P eight times over the control plot. Agreeing result was reported by Oviasogie and Aghimien (2003).

Paper Mill Effluent

Based on their work, Palaniswami and Sriramulu (1994) concluded that paper mill waste application over 15 years increased available P in the surface 15 cm layer of a sandy loam soil in Tamilnadu. Similar positive effects of application of paper mill effluent were indicated by several workers (Achari *et al.*, 1998; Thawale *et al.*, 1999; Achari *et al.*, 1999; Gagnon *et al.*, 2003).

Tannery Effluent

Reports by Thangavel (2002) indicated that continuous irrigation of 25 times diluted tannery effluent significantly increased the P content in a sandy clay soil.

Domestic Effluent

Datta *et al.* (2000) noted 180 per cent increase in soil available P (Olsen P) when sewage effluent was applied. Bhatia *et al.* (2001) found that application of sewage at 7.5 cm ha^{-1} could provide 5 kg P ha^{-1} thereby increasing total P content of soil. Agreeing results were reported by Tiwari *et al.* (2003).

2.2 LATEX SLUDGE AS A SOURCE OF PHOSPHORUS

Since latex sludge as a research material has gained the focus of scientists only very recently and hence literature on the topic is meagre. So literature on similar lines bearing close association to the present study has also been included.

2.2.1 Nutrient Content of Latex Sludge

Lowe (1968) was the first to report that bowl sludge containing Mg, NH_4 and PO_4 was an excellent fertilizer. This sludge was shown to contain about 35 per cent rubber, 6 per cent Mg, 25 per cent P_2O_5 and 4 per cent NH_4 on wet basis.

John *et al.* (1977) gave the composition of bowl sludge as moisture (54.70 per cent), N (2.60 per cent), P (13.30 per cent), K (5.90 per cent), Ca (0.03 per cent) and Mg (7.00 per cent).

Wahab *et al.* (1979) showed that bowl sludge was relatively rich in P and Mg. Total P_2O_5 content ranged from 33.86 per cent to 39.46 per cent, the average being 37.43 per cent. The citrate soluble fraction of total P ranged from 7.22 per cent to 12.66 per cent whereas water soluble P fraction ranged from 13.16 per cent to 25.04 per cent. Besides P, it also contained 7.54 per cent N, 2.49 per cent K_2O and 0.08 per cent CaO. The moisture content of the sludge ranged from 36.21 per cent to 40.04 per cent.

Sivanadyan and Asokumar (1989) reported that Natural Rubber Serum Powder (NRSP) produced by concentrating the effluent serum from latex concentrate factory contained 7.5 per cent N, 1.2 per cent P_2O_5 and 1.4 per cent K.

Sivanadyan (1992) gave the nutrient content of NRSP blended with inorganic fertilizer as N (8 per cent), P_2O_5 (8 per cent) and K_2O (8.5 per cent).

Based on a preliminary chemical analysis of latex sludge, George *et al.* (1994) gave its nutrient content as N (5.1 per cent), P_2O_5 (32.7 per cent), K_2O (0.8 per cent) and MgO (14.8 per cent). In subsequent studies, George (2003) showed that another sample of latex sludge contained 5.0 per cent N, 30.0 per cent P_2O_5, 0.8 per cent K_2O, 1.0 per cent CaO and 14.0 per cent MgO.

2.2.2 Nutrient Composition of Rubber Effluent

Wood (1977) was the first to report the nutrient composition of rubber effluent and recommended it as a source of fertilizer for crops. He gave the nutrient content of the effluent from sheet rubber factory as total N (190 ppm), P (111 ppm), K (335 ppm), Mg (56 ppm) and Ca (21 ppm) and that from block rubber factory as total N (320 ppm), P (147 ppm), K (450 ppm), Mg (87 ppm) and Ca (5 ppm).

Dolmat (1978) analysed effluent from latex concentrate industries and found that the skim contained total N (952 ppm), P (99 ppm), K (724 ppm), Mg (80 ppm) and Ca (39 ppm).

According to Yeow and Yeop (1983), the nutrient content of mixed concentrate rubber effluent was N (718 ppm), P (43 ppm), K (461 ppm), Mg (28 ppm) and Ca (133 ppm), while that from block rubber factory effluent was N (182 ppm), P (81 ppm), K (246 ppm), Mg (51 ppm) and Ca (10 ppm).

Several workers had also suggested the potential of rubber effluent as a source of nutrients for crops (Nazeeb *et al.*, 1983; Lim and P'ng, 1984; Isa and Ibrahim, 1988; Lim, 1988; Augusthy and Mani, 2001).

The characterization of different samples of latex sludge obtained from factories producing different rubber products was done in detail by Karim *et al.* (1997). The values reported by them for organic C and N (per cent) and P, K, Ca and Mg (ppm) for sludge from a surgical glove factory was 12, 0.9, 9090, 4.1, 207.1, and 20, that from a household glove manufacturing factory was 11.5, 0.7, 1850, 12.2, 288.6 and 92.3 and that from a latex thread manufacturing factory was 14.7, 0.9, 2840, 15.7, 257.1 and 11.1 respectively.

2.2.3 Variation in Nutrient Content of Latex Sludge

Wahab *et al.* (1979) studied the daily variation in the nutrient composition of the bowl sludge from a latex concentrate factory. They reported that, over a period of almost two months, total P_2O_5 did not vary much but the citrate soluble P was quite variable ranging from as low as 5.38 per cent to as high as 10.47 per cent. Variation in N and K appeared minimal. However, in the case of Mg, values as low as 13.16 per cent and as high as 25.04 per cent MgO were recorded. So, they concluded that there was need to assess the nutrient content of the sludge before every use.

2.2.4 Phosphate Dissolution Pattern from Latex Sludge

George *et al.* (1991) conducted an incubation study for 90 days to understand the pattern of P release from bowl sludge and compared it with super phosphate and rock phosphate. A gradual increase in available P content was noticed up to 30^{th} day with a sharp decline on the 45^{th} day in all treatments which they attributed to the temporary immobilization of P by microorganisms. Afterwards a gradual increase was noticed up to 75^{th} day when the highest content was recorded by all the treatments.

2.2.5 Latex Sludge as an Efficient and a Slow Release Fertilizer

Wahab (1976) noted that the small percentage of rubber residue in latex sludge resulted in 'encapsulation' of the plant nutrients present in it enabling it to act as a slow release fertilizer. Further investigations carried out by Wahab *et al.* (1979) confirmed this finding and on the basis of this they recommended latex sludge for sandy soils where losses of applied nutrients are high.

George *et al.* (1991) suggested that the presence of P in the sludge as ammonium phosphate could be the reason for the superiority observed in bowl sludge applied plants in growth as well as in the uptake of nutrients.

Controlled availability of nutrients from the NRSP was indicated by Sivanadyan and Asokumar (1989).

George (2003) observed that when latex sludge was applied along with rock phosphate for immature rubber, one third of the total P_2O_5 became water soluble.

2.2.6 Effect of Latex sludge on Crop Performance in Comparison with other P Fertilizers

Rubber Research Institute of Malaysia reported that the agronomic effectiveness of bowl sludge was comparable to that of generally used soluble super phosphate (RRIM, 1976).

The pioneer work on agricultural utilization of latex sludge was undertaken in cover crops in rubber plantations.

2.2.6.1 Cover Crops

Lowe (1968) found that a pre-planting preparation of a poor undulating lateritic soil under rubber incorporating latex sludge as a cheap fertilizer enabled early and better establishment of the cover crops and thus prevented erosion.

Pushparajah *et al.* (1975) also reported that bowl sludge could be used as a source of P for legume covers.

Wahab (1976) noted that increasing P application as bowl sludge from 45 to 135 kg P_2O_5 ha^{-1} resulted in improved yields of *Peuraria* and that further increase in P application was not beneficial.

John *et al.* (1977) studied the comparative effectiveness of seven commercially available rock phosphates with bowl sludge and found that bowl sludge application resulted in the highest dry matter yield of *Peuraria*.

Wahab *et al.* (1979) compared bowl sludge with some commercially available phosphate fertilizers, *viz.*, CIRP (36 per cent P_2O_5), Polyphos

(32 per cent P_2O_5) and Highlands RP (30 per cent P_2O_5) using *Peuraria javanica* as the indicator crop. Latex sludge application was found to result in better P uptake giving the highest cumulative yield over three years which was 45 per cent higher than that obtained with the commonly used source, CIRP. They also noted that the use of latex sludge as a starter dose of soluble P for legume cover establishment was as effective as two commonly used P sources.

George *et al.* (1991) compared three P sources – bowl sludge, super phosphate and mussorie rock phosphate with regard to their effects on dry matter production and uptake of nutrients by the cover crop *Peuraria phaseoloides* and found that 30 kg P_2O_5 ha^{-1} as bowl sludge was superior to others in dry matter production as well as uptake of nutrients.

George (2003) recommended that latex sludge could be used as a P fertilizer for cover crops in rubber plantations.

2.2.6.2 Cereals

Lowe (1968) postulated that bowl sludge could be used as a cheap alternative for fertilizers in cereal crops like rice and maize.

2.2.6.2.1 Rice

John *et al.* (1977) studied the effect of effluent from skim rubber factory on irrigated paddy and found that dilution of the effluent to 25 per cent gave the best results in terms of dry matter production.

Dolmat (1978) observed that the effluent from the latex concentrate factory increased yield of paddy in terms of dry weight of grain and total dry weight.

Similar favourable effects of rubber effluent on irrigated paddy were reported by Kanapathy (1968), Pushparajah *et al.* (1976) and Yapa (1984).

2.2.6.2.2 Maize

Pushparajah *et al.* (1975) reported that for maize, bowl sludge was the most efficient source of P.

Wahab (1976) reported an increase in dry matter production of maize due to application of bowl sludge when compared to the commonly used source of P, super phosphate. Similar effect was reported by John *et al.* (1977) also.

Wahab *et al.* (1979) observed that the difference in the effects of super phosphate and bowl sludge on maize was negligible.

Favourable effect of rubber effluent on maize was indicated by John *et al.* (1977) and Yeow (1983) also.

2.2.6.3 Fruits and Vegetables

According to Lowe (1968) bowl sludge could be used as a cheap alternative for fertilizers in watermelon.

Yeow (1983) reported that the experiments conducted by University Pertanian, an organization in Malaysia, on use of rubber effluent as a source of nutrients for vegetables had yielded a positive response.

Yapa (1984) reported that rubber serum was a good fertilizer for leafy vegetables.

Sivanadyan and Asokumar (1989) compared the NRSP against a common NPK compound fertilizer in spinach, sawi, tomato and lady's finger and found that NRSP out performed the compound fertilizer by giving extra yields. NRSP maintained its superior effect on yield of these vegetables even when it was blended with some inorganic fertilizer materials.

Sivanadyan (1992) noted that in a pot culture experiment, use of NRSP either alone or in combination with other inorganic fertilizers recorded better growth and yield for spinach, sawi and tomato than when inorganic NPK compound fertilizer was used alone.

2.2.6.4 ***Pulses and Legumes***

Wahab (1976) reported that for soyabean, bowl sludge was the most efficient source of phosphate. This was reflected by the total dry matter production and yield of seeds. Pushparajah *et al.* (1975) and John *et al.* (1977) also reported that bowl sludge could be used as a source of P for soyabean.

Wahab *et al.* (1979) compared bowl sludge with super phosphate and rock phosphate for manuring mung bean and obtained significant increase in both yield of pods and total plant dry weight with bowl sludge than that with other two P sources.

Augusthy and Mani (2001) studied the effect of rubber effluent on seed germination and seedling growth of cowpea and found that the length of root and shoot system and the number of lateral roots were increased when 50 per cent diluted effluent was applied.

Tewari *et al.* (2003) studied the effect of rubber effluent on growth of *Pisum sativum* (var. Auricle) and found that the growth parameters such as shoot and root length, number of leaves and branches, leaf area, shoot and root dry weight, plant dry weight, seed yield per plant and shoot: root ratio were the highest when treated with 25 per cent diluted effluent.

2.2.6.5 Oilseeds

Pushparajah *et al.* (1975) reported that bowl sludge could be used as a source of P for groundnut.

Wahab (1976) also found that, in the case of groundnut the yield obtained by the application of bowl sludge was higher than that obtained by applying rock phosphate and was comparable to that obtained by the use of super phosphate.

But John *et al.* (1977) observed that total dry matter production and yields with latex sludge were slightly less than that with super phosphate in groundnut.

Wahab *et al.* (1979) noted that in groundnut the difference in the effect between bowl sludge and super phosphate was negligible in terms of plant dry weight but in terms of pod yield super phosphate was slightly better.

2.2.6.6 Fodder

Lowe (1968) recommended that bowl sludge could be used as a source of N and P for pasture for both sheep and dairy cattle. By applying this on pasture such as *Brachiaria mutica* and *Axonopus compressus*, an increase in protein content was observed.

Tan *et al.* (1973) reported that napier grass responded favourably to rubber effluent application and yield increase up to 200 per cent over control could be obtained.

Pushparajah *et al.* (1975) were of the opinion that use of bowl sludge at the rate of 2.5 t ha^{-1} led to a two fold increase in the yield of Pusa giant grass and this increase was attributed to P, Mg, N and K in the bowl sludge.

Tan *et al.* (1975) showed that napier grass and star grass production increased significantly with rubber effluent application. The green forage yield of napier grass was more than 400 t ha^{-1} yr^{-1}. The crude protein content was also the highest with effluent application.

Yeow (1983) reported the experiments conducted in Malaysia, on the effect of rubber effluent as a source of nutrients for grass had yielded a positive response. Similar positive effect was also shown by Tan and Pillai (1976).

Jadi (1983) obtained fodder grass yield of 33 t ha^{-1} yr^{-1} when effluent from skim rubber factory was applied.

2.2.6.7 Plantation Crops

2.2.6.7 .1 Rubber

Wahab (1976) noted that bowl sludge could be a satisfactory source of P and Mg for rubber.

Tan and Pillai (1976) reported good response in rubber with the effluent application and higher yields were obtained, especially in conjunction with ethephon stimulation. Similar finding was reported by Pillai (1977).

Reports by John *et al.* (1976) indicated that effluent application particularly at weekly intervals resulted in significant increase in the girth of rubber seedlings. This was further corroborated by John *et al.* (1977).

Wahab *et al.* (1979) reported that bowl sludge was equally effective as rock phosphate for basal application in the planting hole of rubber. Similar effect was reported by John *et al.* (1977).

Dolmat *et al.* (1979) found that rubber responded positively to the nutrients in the rubber effluent. Good overall growth and yield performance were observed with increase in the rate of effluent applied. Based on another work, Dolmat *et al.* (1981) reported three cm growth advantage when rubber effluent was applied on young rubber seedlings.

Bachik *et al.* (1987) showed that the yield of rubber increased with the increased rate of rubber effluent application and the properties of the latex were also not affected.

Karim and Bachik (1989) made a comparative study of rubber effluent and an inorganic fertilizer as sources of plant nutrients for *Hevea* and found no significant differences in the latex yields between fertilizer treated and effluent treated seedlings.

Lim (1988) reported ten percent increase in rubber yields when latex concentrate effluent was applied.

George *et al.* (1991) found that application of bowl sludge was significantly superior in increasing the dry matter production in budded rubber stumps and also in improving their girth and height.

Sivanadyan (1992) reported that the concentrated serum from the effluent of a latex concentrate factory enhanced dry weight and budding success of rubber seedlings in a polybag nursery.

George *et al.* (1994) studied the comparative performance of latex sludge, super phosphate and rock phosphate on immature rubber and found that the girth increment brought about by the three sources in the third year of study was on par.

Soyza *et al.* (1994) studied the effect of crepe rubber factory effluent on the growth of young *Hevea* plants and observed that serum treatments had a mean height advantage of 14 cm over normal fertilizer application. Similar favourable effect was reported by Yapa (1987).

George (2003) observed that when latex sludge was used as P fertilizer for immature rubber, 70 per cent of the trees became ready for tapping in a period of 6.5 years and the yield and quality of latex from sludge fertilized plants were on par with that obtained when other conventional P fertilizers were applied. On the basis of this finding, latex sludge was recommended as a P fertilizer for both mature and immature rubber.

2.2.6.7.2 ***Oil Palm***

The results of trial conducted by Tan *et al.* (1975) on the use of rubber effluent in oil palm, showed that its application resulted in increased number of bunches and weight per bunch, and hence total weight of bunches palm^{-1} yr^{-1}.

Dolmat (1978) noted that in an estate in 'Negri Sembilan', use of mixed rubber effluent in oil palm gave an additional yield of two tonnes fresh fruit bunch. Similar results were also reported by several workers (Dolmat *et al.*, 1979; Yeow, 1983; Bachik *et al.*, 1987 and Wood and Lim, 1989).

Nazeeb *et al.* (1984) showed that rubber effluent could be beneficially used in oil palm nurseries.

2.2.6.8 Other Crops

Yapa (1984) reported that rubber serum was a good fertilizer for plantain trees.

Sivanadyan and Asokumar (1989) recommended that NRSP blended with inorganic fertilizer could be used as a source of nutrients in cocoa nursery.

Karim *et al.* (1997) observed that the dry weight of *Vetiver* spp. grown on latex sludge applied soil was significantly higher than that on untreated soil and this could be due to the higher concentrations of available macro and micronutrients in the sludge.

2.2.7 Effect on Plant Nutrient Content and Uptake

Lowe (1968) analysed the leaf nutrient content of fodder grasses fertilized with bowl sludge and observed that in the case of *Brachiaria mutica* application of 140 lb acre^{-1} of sludge increased the N per cent from 2.04 to 2.52, one month after application.

Tan *et al.* (1975) showed that rubber effluent application on grasses increased leaf ash, N, P and K and decreased Mg, whereas in oil palm, it increased N, K and Mg.

Wahab *et al.* (1979) noted that with the application of bowl sludge, there was a good uptake of P in *Peuraria* and high Mg uptake in maize, mung bean and groundnut.

Dolmat *et al.* (1979) observed that the oil palm trees in the rubber effluent treated field had higher leaf N, K, Mg and to a small extent Mn and Mo contents than those receiving routine manuring schedule. But, the values for ash content, P, Ca and Cu were comparable between the two treatments. For rubber, application of rubber effluent did not affect the leaf nutrient contents and the latex produced was of equally good quality compared to that from trees which received chemical fertilizer according to routine manuring schedule.

Bachik *et al.* (1987) compared the dynamics of leaf nutrient composition as a result of rubber effluent application in oil palm and rubber and observed the highest contents of N, P and K in treated leaves of both the crops.

George *et al.* (1991) noted that application of bowl sludge significantly increased the uptake of N, P, K and Mg in budded rubber stumps.

Habib (1995) obtained significantly lower concentrations of Ca, K, P. total N and crude protein in seeds of wheat cv. RR-21, when 50 per cent diluted rubber effluent was applied.

Karim *et al.* (1997) observed that the uptake of total N and Mg by *Vetiver* spp. grown on latex sludge treated soil was significantly greater than that in an untreated soil. But there was no significant difference in the uptake of K and P.

From her studies in mature rubber, George (2003) noted significantly higher uptake of N, P, K and Mg when latex sludge was applied.

2.2.8 Effect on Soil Properties

2.2.8.1 Physical Properties

The beneficial effect of skim latex formulated with oil in stabilizing soils and thus preventing soil erosion was shown by Soong and Yeoh (1974).

Dolmat (1978) reported that the concentrated serum from the effluent of a latex concentrate factory improved the physical conditions like soil structure, soil aggregation and moisture retention ability of a Rengam soil series (Typic Paleudult).

Dolmat *et al.* (1979) observed that application of rubber effluent increased bulk density and available water capacity and reduced the total porosity, total aggregation and aggregate stability in a Seremban soil series (Plinthic Paleudult).

Bachik *et al.* (1987) observed that application of rubber effluent increased the bulk density and available water capacity and reduced the total porosity of a soil belonging to Serdang series (Typic Paleudult).

2.2.8.2 Chemical Properties

2.2.8.2.1 Soil pH

According to Lowe (1968), magnesium phosphate present in latex sludge had a pH buffering effect in the soil and thus eliminated the need for further liming.

Tan *et al.* (1975) showed that application of rubber effluent did not bring any appreciable change in pH of an alluvial soil.

Dolmat *et al.* (1979) observed an increase in pH from 3.9 to 4.7 for a Seremban soil series (Plinthic Paleudult) and no marked change in pH for a Rengam soil series (Typic Paleudult) after rubber effluent application for about three years. In another study with acidic raw effluent, Dolmat *et al.* (1981) found an increase in soil acidity.

Yapa (1984) reported an increase in soil pH from 5.1 to 6.0 in a rubber plantation and from 4.61 to 5.24 in a paddy soil when rubber effluent was applied.

Karim and Bachik (1989) observed that pH was not affected by the application of rubber effluent in a Rengam soil series (Typic Paleudult) of pH 4.01.

George *et al.* (1991) from an incubation study using bowl sludge, super phosphate and rock phosphate noticed no significant difference in soil pH by the application of these different sources at different periods of incubation.

George *et al.* (1994) observed no significant difference in pH by the application of latex sludge continuously for three years in a soil of pH 5.01.

2.2.8.2.2 Available Nutrients

Tan *et al.* (1975) showed that application of rubber effluent increased soil K, but no appreciable change was observed in organic C, Mg, Ca and Mn in an alluvial soil.

Dolmat *et al.* (1979) observed that application of rubber effluent increased available and total P, total and exchangeable K and Ca in Seremban soil series (Plinthic Paleudult). In Rengam soil series (Typic Paleudult), there was an increase in organic C and N, but Mg and Mn contents were unaffected.

Dolmat *et al.* (1981) reported that application of rubber effluent considerably improved fertility by increasing the concentrations of N, P, K, Ca and Mg contents in Sogomana soil series (Oxic Tropaquult). The increase in soil P was very significant.

Yapa (1984) indicated that the levels of all nutrients tested *i.e.*, P, K, Ca and Mg were higher in soil treated with rubber effluent compared to the control. The increase in P was as high as 358 per cent.

Bachik *et al.* (1987) studied the impact of rubber effluent on soil properties and found that its application increased the organic C, N, total and available P and total and exchangeable K and Ca contents of the soil. However, soil Mn was not affected.

Karim and Bachik (1989) made a comparative study of rubber effluent and an inorganic fertilizer for their effects on soil properties and found that effluent treated soils contained higher concentrations of total P, K. Ca and Mg than fertilizer treated soils. But, no difference was observed in the N content.

George (2003) observed that application of latex sludge increased the fertility status of the soil in the experiment carried out in rubber at the Rubber Research Institute of India, Kottayam.

2.2.9 Residual Effects

Wahab (1976) reported the highest residual effect of bowl sludge as indicated by the dry matter yield of *Peuraria* in second and third croppings. Similar result in *Peuraria* was reported by Wahab *et al.* (1979).

Sivanadyan and Asokumar (1989) studied the residual effect of NRSP blended with inorganic fertilizer on a second crop of spinach by leaving its shoot stumps intact in the soil after the main harvest and found a large number of plants re-sprouting with higher shoot weights. Similar finding was also reported by Sivanadyan (1992).

2.2.10 Environmental Considerations

Bachik *et al.* (1987) found from their studies in oil palm plantations that application of latex sludge and its effluent had negligible effect on ground water quality but suggested that their indiscriminate application should be avoided.

Karim *et al.* (1997) based on their studies in *Vetiver* spp. observed that heavy metals in the sludge caused neither inhibition of growth nor toxicity to the plant.

2.3 EFFECT OF PHOSPHORUS ON CHILLI

The role of phosphorus in nutrition of chilli is highly recognized as it plays an important role in energy storage and transfer, development of reproductive parts, root formation, seed formation etc. (Bergmann, 1992).

2.3.1 Effect on Growth Characters

2.3.1.1 Plant Height

Joseph (1982) noted increase in height in chilli var. Pant C1 by the application of graded doses of P. Singh and Srivastava (1988) indicated significant effect of P on the height of chilli cv. Pant C1 with P_2O_5 @ 60 kg ha^{-1}. Results on similar lines also reported by several workers (Ram *et al.*, 1996; Srinivasan *et al.*, 1999; Hossain *et al.*, 2001).

However, Prabhakar *et al.* (1987) and Shukla *et al.* (1987) found that plant height was not influenced by P fertilization.

2.3.1.2 Branches per Plant

Chougule and Mahajan (1979) found that the number of main branches per plant was significantly increased due to different levels of P in chilli var.Jwala. John (1989) observed that application of P up to 60 kg P_2O_5 ha^{-1} significantly increased the number of branches per plant in chilli var. Jwalasakhi. Similar results were reported by Damke *et al.* (1988), Sharma and Singh (1994) and Gare *et al.* (2001).

However, Prabhakar *et al.* (1987) showed that P fertilization did not affect the number of branches in chilli cv. G3. Similar result was reported by Shukla *et al.* (1987).

2.3.1.3 Leaf Area

Significant effect of P on leaf area was observed by Joseph (1982) in chilli var. Pant C1 and John (1989) in var. Jwalasakhi. Maya *et al.* (1999) reported that 100 kg P ha^{-1} resulted in the highest leaf area at all stages of chilli.

2.3.1.4 Time of Flowering

Khan and Suryanarayana (1977) observed that in chilli var. NP 46A, the effect of P was significant on the time of flowering. The higher the level of P, the lesser was the time required for flowering. Chougule and Mahajan (1979) found that in chilli var. Jwala, the number of days required for 50 per cent flowering were significantly influenced due to different levels of P. Similar observations were reported by several workers (Joseph and Pillai, 1985; Ahmed and Tanki, 1991; Medhi *et al.*, 1993; Pundir and Porwal, 1999).

2.3.2 Effect on Yield and Yield Attributes

2.3.2.1 Fruits per Plant

Ahmed and Tanki (1991) observed increased number of fruits per plant with P application in chilli and the optimum rate was found to be 82.8 kg P_2O_5 ha^{-1}. Singh and Srivastava (1988) reported that in chilli cv. Pant C-1, P application showed a significant effect on the number of fruits per plant. Similar effect of P on number of fruits per plant also indicated by Srinivasan *et al.* (1999), Jayaraj *et al.* (1999) and Mohanty *et al.* (2001).

2.3.2.2 *Fruit Length and Girth*

Khan and Suryanarayana (1977) observed that in chilli var. NP 46A, P was essential for good pod length and girth. Chougule and Mahajan (1979) found that in chilli var. Jwala, the length of pods were significantly increased due to higher dose of P used, *i.e.*, 120 kg ha^{-1}. Gare *et al.* (2001) obtained the highest fruit length of 8.1 cm with 50 kg P ha^{-1}.

However, John (1989) observed that the difference in length and mean girth of pods due to graded dose of P was not statistically significant in chilli var. Jwalasakhi.

2.3.2.3 *Fruit Weight*

Chougule and Mahajan (1979) found that in chilli var. NP 46A, the mean weight of fruits per plant and weight of 100 fruits were significantly increased due to higher dose of P used *i.e.*, 120 kg ha^{-1}. In var. Jwalasakhi, John (1989) observed that 100 fruit weight increased significantly up to 60 kg P_2O_5 ha^{-1}. Report on similar lines was indicated by Thiagarajan (1990).

2.3.2.4 *Total Chilli Yield*

Dharmatti and Kulkarni (1988) obtained the highest yield in capsicum cv. California Wonder with the application of 112.5 kg P_2O_5 ha^{-1}. Nasreen and Islam (1989) noted that in chilli the highest fruit yield can be obtained with P application @ 90 kg ha^{-1}. Singh and Naik (1990) observed that P fertilization significantly influenced fruit yield in Bell Pepper and the highest yield of 116.4q ha^{-1} was recorded at 150 kg P_2O_5 ha^{-1} which was about 16 per cent higher than the yield obtained at 50 kg P_2O_5 ha^{-1}. Increase in total yield of chilli with P application was noted by several other workers (Niranjana and Devi, 1990; Das and Rath, 1992; Sharma *et al.*, 1996; Aliyu, 2002; Mukhopadhyay, 2004).

However, Subbiah *et al.* (1982) showed that yield of green chilli was not influenced by P application. Results on similar lines were put forward by Srinivas (1983), Gonzalez and Beale (1987) and Shukla *et al.* (1987).

2.3.3 Effect on Quality Characters

2.3.3.1 Ascorbic Acid Content

Joseph (1982) reported that P application significantly increased ascorbic acid content in chilli var. Pant C1.Agreeing results were reported by Niranjana and Devi (1990), Uddin and Begum (1990) and Murugan (2001).

However, John (1989) noted that the differences due to graded levels of P in the mean fruit ascorbic acid content were not statistically significant in chilli var. Jwalasakhi.

2.3.3.2 Capsaicin Content

Saga (1973) noted that, the capsaicin content of chilli was very low in plots without P. The best rate for its higher content was found to be 30 ppm. Favourable effect of P on capsaicin content was shown by several workers (Subbiah *et al.*, 1980; Niranjana and Devi, 1990; Yodpetch, 2000; Murugan, 2001).

2.3.3.3 Oleoresin Content

Yodpetch (2000) reported that P fertilizer influenced the quantity and quality of oleoresin in cayenne peppers (*Capsicum annuum* L.). The optimum level to produce the highest content (32.63 per cent) was found to be 187.5 kg ha^{-1}. Recent reports by Muthumanickam (2003) showed that application of P resulted in the highest oleoresin content in black pepper.

2.3.3.4 Protein Content

In sweet pepper, Bajaj *et al.* (1979) obtained the highest fruit protein content when P was applied @ 48 kg ha^{-1}. Significant effect of P in increasing protein content in chilli was noted by Niranjana and Devi (1990) and Murugan *et al.* (2002).

2.3.4 Total Dry Matter Production

John (1989) observed significant increase in total dry matter production in chilli up to 60 kg P_2O_5 ha^{-1} and he attributed this to the cumulative effect of P on increasing the plant height, number of branches per plant and number of pods per plant. Kaminwar and Rajagopal (1993) studied the fertilizer response of rainfed chilli and found that dry matter production increased continuously from 45 to 150 days and the main effect was due to P.

However, Aliyu (2002) observed that the effect of P on dry weight of chilli was less marked.

2.3.5 Effect on Nutrient Uptake

Tapia and Dabed (1984) studied nutrient uptake by sweet pepper grown in quartz and noted that 53 per cent of total P uptake occurred in the last third of ontogenesis *i.e.*, after full fruit set. Santiago and Goyal (1985) observed that the greatest amount of nutrient uptake in chilli occurred during the last third of the growing season and was in the order K>N>P. Kaminwar and Rajagopal (1993) studied the fertilizer response of rainfed chilli and found that P uptake increased continuously from 45 to 150 days and to produce one quintal of dry pods, the P nutrient requirement was 0.25 kg. Agreeing results were reported by Patil and Biradar (2002).

2.3.6 Phosphorus Deficiency in Chilli

Mehrotra *et al.* (1968) indicated that P deficient chilli plants were stunted in growth but dark green in colour. The leaves were small and bluish green in the beginning later turning to dirty greyish green. Older ones prematurely dried to a brownish colour and shed prematurely.

Moreover, there was a reduction in root mass, branching, number of leaves, number of flowers and fruit set.

Roychoudhury *et al.* (1990) noted the visual symptoms of P deficiency in chilli as stunted growth and smaller leaves which were narrow and inwardly curved. The older leaves were yellowish with pink margin. Fruits were small and distorted in shape and there was drastic reduction in flower number.

Balakrishnan (1999) observed that P deficient chilli plants produced smaller leaves with bluish green appearance. The plant height, total dry matter production and yield were also reduced. Reports on similar lines were indicated by Mukhopadhyay (2004).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A detailed investigation was carried out at College of Agriculture, Vellayani, to evaluate the efficiency of latex sludge (LS), a waste product of latex concentrate industry as a source of phosphorus (P) in crop production. Chilli (*Capsicum annuum* L.), a vegetable crop with a relative high P requirement was used as the test crop.

The experiment was carried out in four steps.

3.1 Study of the basic properties of latex sludge.

3.2 Incubation study on its nutrient mineralization.

3.3 Study of the effect on a main crop of chilli.

3.4 Study of the residual effect on a subsequent crop of chilli.

The details regarding the laboratory and pot culture studies conducted, observations recorded, analytical methods used and statistical procedures followed are discussed in this chapter.

3.1 STUDY OF THE BASIC PROPERTIES OF LATEX SLUDGE

Being a relatively new compound, little is known of the various physico-chemical characters of LS. The material was procured from the centrifuge latex factory attached to 'The Vaikundam Rubber Co., Ltd'. at Marthandam in Kanyakumari district. The material air dried, ground and sieved was used for characterization studies and later for incubation and pot culture studies.

For characterizing the material, the important physico-chemical properties, *viz*., pH, moisture content, loss on ignition and contents of organic C, N, P, K, Ca and Mg were estimated. In addition to total P content, its water and citrate soluble fractions were also determined. Standard procedures adopted for the various analyses are given in Table 1.

Table 1. Analytical methods adopted for latex sludge analysis

Sl. No	Estimated character	Method	Reference
1	pH	Direct reading using Perkin-Elmer Metrion V pH meter (Model 80)	Jackson (1973)
2	Moisture content	Gravimetric method using Labline laboratory hot air oven (Model MHOS)	Piper (1967)
3	Loss on ignition	Muffle furnace method (Pyromaster 3.5 kW)	Jackson (1973)
4	Organic C	Chromic acid wet digestion	Walkley and Black (1934)
5	Total N	Microkjeldahl digestion in sulphuric acid and distillation	Jackson (1973)
6	Total P_2O_5	Volumetric ammonium phosphomolybdate method	AOAC (1960)
7	Water soluble P_2O_5	Volumetric ammonium phosphomolybdate method	AOAC (1960)
8	Citrate insoluble P_2O_5	Colorimetric method after removing citrate and water soluble P_2O_5	AOAC (1960)
9	Citrate soluble P_2O_5	Subtracting water soluble and citrate insoluble P_2O_5 from total P_2O_5	AOAC (1960)
10	Total K	Nitric- perchloric acid (9:3) digestion and flame photometry	Jackson (1973)
11	Total Ca and Mg	Nitric – perchloric acid (9:3) digestion and versenate titration with standard EDTA	Jackson (1973)

3.2 INCUBATION STUDY ON NUTRIENT MINERALIZATION.

An incubation study was conducted during October 2002 to January 2003 to find out the periodical release of plant nutrients from LS to the soil. This was compared against two other phosphatic fertilizers – Single Super Phosphate (SSP) and Rock Phosphate (RP). The technical details of the incubation study are given below.

Design – CRD

Number of replications – 5

Number of treatments – 4

T_1 – LS (35.98 per cent P_2O_5) to provide P @ 40 kg ha^{-1}

T_2 – SSP (13.52 per cent P_2O_5) to provide P @ 40 kg ha^{-1}

T_3 – RP (25.65 per cent P_2O_5) to provide P @ 40 kg ha^{-1}

T_4 – Control (Soil alone)

The study was carried out in plastic containers identical in all aspects for a period of 120 days. The soil for the study belonging to Vellayani series (Typic Kandiustult) was collected from the Instructional Farm, attached to the College of Agriculture, Vellayani. The collected samples were thoroughly mixed, air dried under shade and sieved through a 2 mm sieve and analysed for the important basic physico-chemical characters according to the standard procedures given in Table 2.

The containers were filled with one kg each of this soil and the treatments were applied at room temperature. The field capacity of the soil worked out initially was maintained throughout the study period by replenishing the moisture lost by evaporation, found out by noting the weight difference.

Soil samples were taken at two weeks intervals and estimated for pH, EC, organic C, available N, P, K, Ca and Mg as per the standard procedures given in Table 2.

Table 2. Analytical methods adopted for soil analysis

Sl. No	Estimated character	Method	Reference
1	Mechanical composition	International Pipette method	Piper (1967)
2	Particle density	Pycnometer method	Black *et al.* (1965)
3	Bulk density	Undisturbed core sample	Black *et al.* (1965)
4	Water holding capacity	Undisturbed core sample	Black *et al.* (1965)
5	Hydraulic conductivity	Undisturbed core sample	Black *et al.* (1965)
6	Soil reaction	Direct reading using Perkin Elmer Metrion V pH meter (Model 80) in 1:2.5 soil water suspension	Jackson (1973)
7	Electrical conductivity	Direct reading using Elico Soil Bridge Type CM.84 in 1:2.5 soil water suspension	Jackson (1973)
8	Cation exchange capacity	Ammonium saturation using neutral normal ammonium acetate	Jackson (1973)
9	Organic C	Chromic acid wet digestion method	Walkley and Black (1934)
10	Available N	Alkaline potassium permanganate method	Subbiah and Asija (1956)
11	Available P	Bray extraction and photo electric colorimetry	Jackson (1973)
12	Available K	Neutral normal ammonium acetate extraction and Flame photometry	Pratt (1965)
13	Exchangeable Ca and Mg	Neutral normal ammonium acetate extraction and titration with EDTA (Versenate titration)	Hesse (1971)

3.3 STUDY OF THE EFFECT ON A MAIN CROP OF CHILLI

In order to study the possibility of using LS as a P source in crop production, a pot culture experiment was conducted using chilli as the test crop.

3.3.1 Experimental Site

The pot culture experiment was conducted in the Instructional Farm, Vellayani. Geographically the area is $8^{0}5'$ North latitude, 77^{0} 1' East longitude and at an altitude of 29 m above MSL.

3.3.2 Design and Layout of Experiment

The lay out of the experiment is presented in Fig.1

Design	– CRD
Number of replications	– 3
Number of treatments	– 11

Treatments

T_1 – Full P as LS

T_2 – Full P as SSP

T_3 – Full P as RP

T_4 – ¼ P as LS + ¾ P as SSP

T_5 – ½ P as LS + ½ P as SSP

T_6 – ¾ P as LS + ¼ P as SSP

T_7 – ¼ P as LS + ¾ P as RP

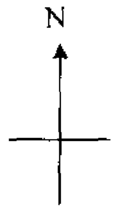
T_8 – ½ P as LS + ½ P as RP

T_9 – ¾ P as LS + ¼ P as RP

T_{10} – No P

T_{11} – Absolute control

An overview of the experimental site is presented in Plate 1.



Replication I	Replication II	Replication III
T_{11}	T_{10}	T_7
T_6	T_1	T_4
T_2	T_4	T_5
T_{10}	T_{11}	T_3
T_9	T_5	T_{11}
T_8	T_9	T_{10}
T_1	T_8	T_6
T_3	T_2	T_1
T_4	T_7	T_8
T_7	T_3	T_9
T_5	T_6	T_2

Fig 1. Layout of the experiment - CRD

An overview of the experimental site

Plate 1. Main crop

Plate 2. Residue crop

3.3.3 Pots and Potting Mixture

Earthen pots of 25 cm diameter and 30 cm height were filled with soil @ 8 kg pot $^{-1}$ collected from the same site from where soil samples for incubation study were earlier collected.

3.3.4 Crop and Variety

Jwalamukhi, a high yielding culinary variety of chilli suitable for pot culture with a maximum yielding period of 90 to 120 days was selected. This variety was evolved by Kerala Agricultural University, by crossing Pusa Jwala and local variety Vellanotchi. The fertilizer recommendation as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 2002) for the crop is 75:40:25 kg N: P_2O_5: K_2O ha^{-1}.

3.3.5 Season

The crop was grown from September to December 2003. Weather parameters during the entire cropping season were recorded from the Meteorological observatory attached to the Department of Agronomy, College of Agriculture, Vellayani, and presented as fortnightly averages in Appendix I and graphically in Fig.2.

3.3.6 Planting Material

Seeds of Jwalamukhi were purchased from Instructional farm, Vellayani.

3.3.7 Manures and Fertilizers

Urea (46 per cent N) and Muriate of potash (56 per cent K_2O) were used as source of N and K respectively. The sources of P were LS (35.98 per cent P_2O_5), SSP (13.52 per cent P_2O_5) and RP (25.65 per cent P_2O_5). Urea, muriate of potash and FYM were applied uniformly to all treatments except absolute control, as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 2002). The P fertilizers were applied as per treatment schedule.

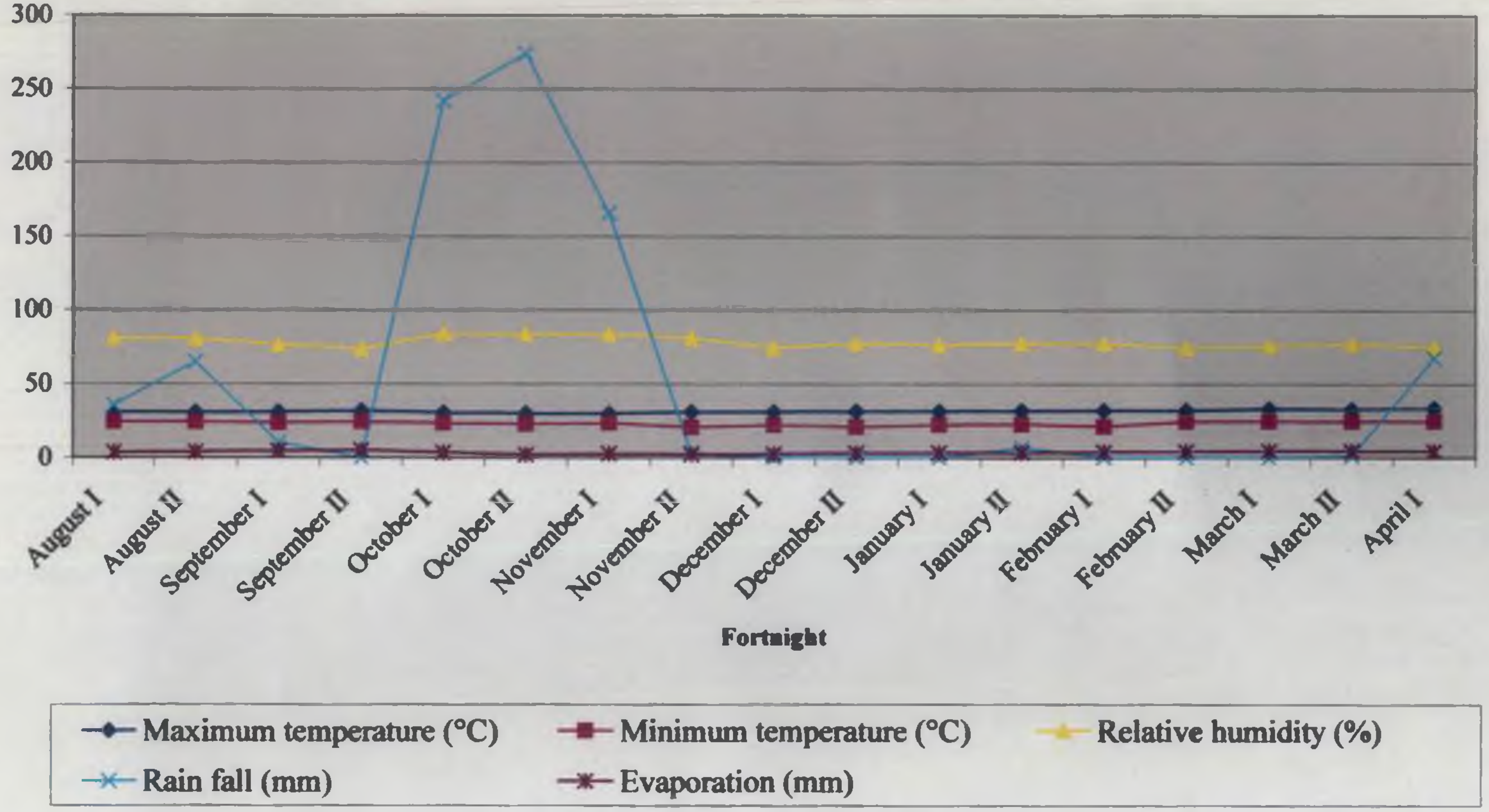


Fig. 2 Weather parameters during the cropping period
(Main crop - August to December 2003
Residue crop - January to April 2004)

3.3.8 Details of Cultivation

3.3.8.1 Nursery

Chilli seedlings were raised in well prepared elevated nursery beds of 1.2 m width and 15 cm height with channels around to facilitate drainage of excess water. A basal dressing of powdered cattle manure @ 1 kg m^{-2} was applied in nursery beds. The seeds were sown on 1-8-2003. The seedlings were irrigated daily. Hand weeding was done at weekly intervals. Plant protection operations were undertaken as and when required as per the Package of Practices Recommendations.

3.3.8.2 Transplanting

Thirty days old robust seedlings were transplanted in earthen pots filled with soil and FYM. Shade was provided to the seedlings for four days.

3.3.8.3 Application of Fertilizers

Fertilizers were applied as per the treatment schedule. Half of N, full P and half of K were applied as basal dose before transplanting. One fourth of N and half of K were applied 30 days later and the remaining one fourth N one month later.

3.3.8.4 After Cultivation

Gap filling was done with healthy seedlings wherever necessary so as to maintain one plant per pot. Regular irrigation and weeding were carried out.

3.3.8.5 Plant Protection

Dimethoate 0.05 per cent was sprayed four times to control mites.

3.3.8.6 Harvesting

The first harvest was done about two and a half months after transplanting and subsequent harvests were made at eight days interval.

3.3.9 Growth Characters Observed

The following important growth characters were recorded from each plant on the last day of harvest.

3.3.9.1 Plant Height

The height of the plant was measured from the base to the growing tip and expressed in centimetre.

3.3.9.2 Number of Branches

The total number of branches arising from main stem were counted and recorded.

3.3.9.3 Number of Leaves

The total number of leaves per plant were counted and recorded.

3.3.9.4 Leaf Area

The leaf area was found out using graph paper method.

3.3.9.5 Days to Flowering

The number of days took by plants from transplanting to reach first flowering were noted and recorded.

3.3.10 Yield and Yield Attributes

The following important yield attributes were recorded.

3.3.10.1 Fruits per Plant

The total number of fruits collected from each plant from different harvests were counted and recorded.

3.3.10.2 Fruit Length

Ten fruits were randomly selected, their lengths measured from the point of pedicel attachment to fruit apex, averages worked out and expressed in centimetre.

3.3.10.3 Fruit Girth

Fruits used for measuring length were used for recording the girth also. Girth was measured at the broadest part of fruits and expressed in centimetre.

3.3.10.4 Fruit Weight

Fruits used for measuring length were used for recording the weight also. Averages were worked out and expressed in gram.

3.3.10.5 Yield per Plant

Fruit yield from each plant was computed by adding the weights of fruits of each harvest and expressed as g plant^{-1}.

3.3.11 Chemical Analysis

3.3.11.1 Soil Analysis

Soil samples collected immediately after final harvest were air dried and passed through 2 mm sieve. These were used for the analysis of pH, EC, organic C, available N, P, K, Ca and Mg using standard procedures given in Table 2.

3.3.11.2 Plant Analysis

The plants after final harvest were uprooted, soil particles adhering to roots removed and total fresh weights recorded. Then, the entire plants were chopped and pooled and homogenous samples were drawn for analysis.

The preweighed samples were oven dried at 70°C and their final weights recorded to calculate the moisture content. Then, they were ground in Wiley mill and used for the estimation of dry matter content and constituents *viz.*, N, P, K, Ca and Mg following the standard procedures given in Table 3.

Table 3. Analytical methods adopted for plant analysis

Sl. No.	Element	Method	Reference
1	Moisture content	Gravimetric method	Piper (1967)
2	Nitrogen	Microkjeldahl digestion in sulphuric acid and distillation	Jackson (1973)
3	Phosphorus	Nitric - perchloric acid digestion (9:3) and colorimetry (Vanado molybdo phosphoric yellow colour method)	Jackson (1973)
4	Potassium	Nitric-Perchloric acid (9:3) digestion and flame photometry	Jackson (1973)
5	Calcium and Magnesium	Nitric –Perchloric acid (9:3) digestion and versenate titration with standard EDTA	Jackson (1973)
6	Ascorbic acid	Titrimetric method	Sadasivam and Manickam (1992)
7	Capsaicin	Folin-Dennis method	Mathew *et al.* (1971)
8	Oleoresin	Gravimetric method after extraction in Soxhlet apparatus using solvent acetone	Sadasivam and Manickam (1992)
9	Protein	Computation from nitrogen content	Simpson *et al.* (1965)

3.3.11.3 Fruit Analysis

The moisture and chemical contents, *viz.*, N, P, K, Ca and Mg of harvested fruits were determined using the same procedures as those adopted for plant analysis. Quality characters of fruit *viz.*, capsaicin, oleoresin and protein were analysed on dried ground samples while ascorbic acid was analysed on fresh fruits. The standard procedures adopted for quality parameters are also given in Table 3.

3.3.12 Total Dry Matter Production

The total dry weight of bhusa and fruits were added to get the total dry matter production.

3.3.13 Nutrient Uptake

Uptake of nutrients by fruit and bhusa which were calculated separately by multiplying the nutrient concentration with corresponding dry weights were summed up to get the total nutrient uptake by the plant.

3.4 STUDY OF THE RESIDUAL EFFECT ON A SUBSEQUENT CROP OF CHILLI

To understand the residual effects of treatments, another crop of chilli with the same variety Jwalamukhi was raised after the harvest of the main crop, in the same soil without any P addition during January to April 2004. Urea (N), Muriate of Potash (K_2O) and FYM were applied in all pots except absolute control, as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 2002). All other cultivation operations practiced for the main crop were repeated.

An overview of the experimental site is presented in Plate 2.

3.4.1 Observations Recorded

Observations on yield and yield attributes of the residue crop were recorded. These included fruit yield per plant and total dry matter production.

3.4.2 Chemical Analysis

The oven dried and ground bhusa and fruit samples were analysed for N, P, K, Ca and Mg using the same procedures as adopted for the main crop.

3.4.3 Nutrient Uptake

Uptake of nutrients by bhusa and fruits were calculated separately by multiplying the nutrient concentrations with corresponding dry weight. Then the total uptake was calculated by adding these two.

3.5 STATISTICAL ANALYSIS

The data generated out of incubation, pot culture studies and the subsequent chemical analyses were scrutinized statistically using the technique of Analysis of variance applicable to Complete Randomized Design (CRD) described by Cochran and Cox (1965) and significance tested by F test (Snedecor and Cochran, 1967).

3.6 ECONOMIC ANALYSIS

The benefit - cost ratios of the main and residue crops were calculated separately by working out the respective total costs of output and the total costs of inputs and taking the ratios between them.

RESULTS

4. RESULTS

A study was undertaken at College of Agriculture, Vellayani during the period August 2003 to April 2004 to explore the agricultural utilization potential of latex sludge, a waste product of concentrate latex industry, as a source of P in crop production. The salient results generated out of the studies are presented in this chapter under the following subheadings.

4.1 Study of the basic properties of latex sludge

4.2 Incubation study on its nutrient mineralization

4.3 Study of the effect on a main crop of chilli

4.4 Study of the residual effect on a subsequent crop of chilli

4.1 BASIC PROPERTIES OF LATEX SLUDGE

The basic physico-chemical properties of the latex sludge are presented in Table 4a and 4b.

The LS used for analysis was near neutral in reaction (pH 6.49) and had a moisture content of about 44 per cent. The loss on ignition was 65 per cent. It had 5.09 per cent organic C, six per cent N and less than one per cent K and Ca. The Mg content was 6.86 per cent. In addition to total P, water and citrate soluble fractions were analysed. The total P content was 35.98 per cent. Of the total P, the water and citrate soluble fractions were 13.18 per cent and 35.66 per cent respectively. So, the available P content *i.e.*, sum of water and citrate soluble P was 48.84 per cent.

4.2 INCUBATION STUDY ON NUTRIENT MINERALISATION

The important physico-chemical properties of the soil used for incubation study and later for pot culture studies are presented in Table 5.

The soil used for incubation and pot culture experiments was sandy loam in texture and had a bulk density of 1.02 Mg m^{-3} and particle density of 2.86 Mg m^{-3}. The water holding capacity was 33.93 per cent and hydraulic conductivity 0.50 cm hr^{-1}. The soil was acidic in reaction (pH 5.63) and had an EC of 91.41 μS m^{-1}. It was high in organic C rating (0.63 per cent) and available P (91.28 kg ha^{-1}) but low in the case of available N (215.13 kg ha^{-1}) and available K (91.84 kg ha^{-1}). The exchangeable Ca and Mg contents were 1.80 and 0.70 cmol kg^{-1} respectively.

The dynamics of important soil chemical properties on incubation with latex sludge (T_1), single super phosphate (T_2) and rock phosphate (T_3) studied against control (T_4, soil alone) over a period of 120 days are presented below.

Table 4a. Analytical profile of latex sludge used for the experiment

Sl. No.	Parameters	Content
1	pH	6.49
2	Moisture content (%)	44.26
3	Loss on ignition (%)	65.00
4	Organic C (%)	5.09
5	Total N (%)	6.05
6	Total P_2O_5 (%)	35.98
7	Total K (%)	0.86
8	Total Ca (%)	0.87
9	Total Mg (%)	6.86

Table 4b. Fractionation of total phosphorus in latex sludge

Sl. No.	P fraction	Content
1	Water soluble P_2O_5 (%)	13.18
2	Citrate insoluble P_2O_5 (%)	51.16
3	Citrate soluble P_2O_5 (%)	35.66

Table 5. Important physico-chemical characteristics of the soil used for incubation and for pot culture experiments.

Sl.No	Parameter	Content
A. Mechanical composition		
1	Coarse sand	42.50%
2	Fine sand	23.50%
3	Silt	14.29%
4	Clay	17.60%
5	Texture	Sandy loam
B. Physical properties		
1	Bulk density	1.02 Mg m^{-3}
2	Particle density	2.86 Mg m^{-3}
3	Water holding capacity	33.93%
4	Hydraulic conductivity	0.50 cm hr^{-1}
C. Chemical properties		
1	pH	5.63
2	Electrical conductivity	91.41 μS m^{-1}
3	Organic C	0.63%
4	Available N	215.13 kg ha^{-1}
5	Available P	91.28 kg ha^{-1}
6	Available K	91.84 kg ha^{-1}
7	Exchangeable Ca	1.80 cmol kg^{-1}
8	Exchangeable Mg	0.70 cmol kg^{-1}

4.2.1 Soil pH

Soil pH was not significantly influenced by treatment application at any stage of incubation (Table 6). However, the values ranged from 5.33 to 5.59, 5.26 to 5.62, 5.38 to 5.79, 5.40 to 5.61,5.44 to 5.79, 5.13 to 5.89, 5.31 to 5.42, 5.60 to 5.68 on 15^{th}, 30^{th}, 45^{th}, 60^{th}, 75^{th}, 90^{th}, 105^{th} and 120^{th} DOI respectively.

Table 6. pH of soil at different periods of incubation

Treatments	15th DOI	30th DOI	45th DOI	60th DOI	75th DOI	90th DOI	105th DOI	120th DOI
T_1	5.54	5.41	5.38	5.40	5.79	5.67	5.33	5.60
T_2	5.59	5.47	5.79	5.56	5.76	5.89	5.31	5.63
T_3	5.33	5.62	5.70	5.61	5.44	5.13	5.42	5.68
T_4	5.51	5.26	5.67	5.42	5.77	5.41	5.41	5.60
F (3,16)	0.72^{NS}	1.08^{NS}	1.78^{NS}	0.35^{NS}	0.38^{NS}	1.19^{NS}	0.88^{NS}	0.21^{NS}
CD (0.05)	-	-	-	-	-	-	-	-

NS- Non significant, DOI- Days of Incubation

T_1 – Latex sludge
T_2 – Single super phosphate
T_3 – Rock phosphate
T_4 – Control (Soil alone)

4.2.2 Electrical Conductivity

A perusal of data (Table 7) revealed that the EC of soil during the period of incubation did not show any consistent pattern. T_4 recorded the lowest value throughout the incubation period.

On the 15th DOI, the highest EC (191.84 μS m^{-1}) was recorded by T_2 and it was on par with T_1 and T_3. These three treatments recorded significantly higher values than T_4.

T_1 registered the highest EC (179.96 μS m^{-1}) on 30th DOI and it was on par with T_3 and T_2. T_4 was significantly lower than all other treatments and recorded the lowest EC of 140.16 μS m^{-1}.

The EC values ranged from 243.60 μS m^{-1} to 272.32 μS m^{-1} on 45th DOI. The maximum value was registered by T_2 followed on par with T_3 and T_1 and the lowest value was shown by T_4.

The same pattern was seen to repeat on the 60th DOI with T_2 showed the highest EC of 244.02 μS m^{-1} and T_4 recorded the lowest value of 199.78 μS m^{-1}.

On the 75th DOI, T_1 recorded the highest EC of 249.36 μS m^{-1} followed by T_3 and T_2. All the three treatments were on par and significantly higher than T_4, which recorded the lowest value of 198.74 μS m^{-1}.

On 90th DOI, the highest EC was recorded by T_2 (178.70 μS m^{-1}) followed by T_1 (145.90 μS m^{-1}). Both T_1 and T_2 were significantly different from each other and also from the rest of the treatments. The lowest EC of 100.02 μS m^{-1} was observed in T_4 and it was on par with T_3.

On 105th DOI, the EC values ranged from 91.09 μS m^{-1} (T_4) to 110.25 μS m^{-1} (T_3). T_3 was significantly higher than all other treatments and T_2 and T_1 were on par.

Table 7. Electrical conductivity ($\mu S\ m^{-1}$) of soil at different periods of incubation

Treatments	15th DOI	30th DOI	45th DOI	60th DOI	75th DOI	90th DOI	105th DOI	120th DOI
T_1	167.30	179.96	255.44	230.72	249.36	145.90	102.32	99.62
T_2	191.84	166.12	272.32	244.02	222.74	178.70	105.58	106.68
T_3	182.86	178.72	272.26	243.52	247.82	119.96	110.25	106.27
T_4	127.14	140.16	243.60	199.78	198.74	100.02	91.09	84.44
F (3,16)	11.41**	14.34**	4.34**	8.65**	4.23**	21.28**	3.81**	9.93**
CD (0.05)	25.40	14.62	20.14	21.47	34.92	22.11	12.54	9.89

** Significant at 1 per cent level, DOI- Days of Incubation

T_1 – Latex sludge
T_2 – Single super phosphate
T_3 – Rock phosphate
T_4 – Control (Soil alone)

T_2 registered the maximum EC of 106.68 µS m^{-1} on 120[th] DOI. It was on par with T_3 and T_1. T_4 recorded the lowest EC of 84.44 µS m^{-1} and was significantly lower than all other treatments.

4.2.3 Organic Carbon

Statistical analysis of the data (Table 8) on organic C content of soil showed that except on 15[th] DOI, the only stage when the treatment effects were not significant T_1 recorded values significantly superior to all other treatments.

On the 15[th] DOI, the treatments failed to produce any significant difference.

Organic C content ranged from 0.598 per cent to 0.660 per cent on 30[th] DOI. The highest value was recorded by T_1 and it was significantly superior to all other treatments. T_2, T_3 and T_4 were on par.

On 45[th] DOI, the values ranged from 0.600 per cent (T_4) to 0.682 per cent (T_1). T_1 was significantly higher than all other treatments. T_2 and T_3 were on par.

There was no change in the trend of T_1 on 60[th] DOI also. It recorded the highest value of 0.700 per cent and all other treatments were on par. The lowest value of 0.604 per cent was registered by T_4.

The maximum value of 0.756 per cent on 75[th] DOI was recorded by T_1 and the lowest value by T_4 (0.624 per cent). All the treatments were significantly higher than absolute control.

On the 90[th] DOI, T_1 maintained the same pattern. It recorded the maximum value of 0.700 per cent followed by T_2. Both T_1 and T_2 were significantly different from each other and from rest of the treatments. T_4 recorded the lowest value of 0.628 per cent and was on par with T_3.

Table 8. Organic carbon (%) of soil at different periods of incubation

Treatments	15th DOI	30th DOI	45th DOI	60th DOI	75th DOI	90th DOI	105th DOI	120th DOI
T_1	0.616	0.660	0.682	0.700	0.756	0.700	0.690	0.680
T_2	0.616	0.608	0.630	0.624	0.637	0.666	0.647	0.642
T_3	0.616	0.598	0.619	0.628	0.639	0.636	0.644	0.646
T_4	0.614	0.600	0.600	0.604	0.624	0.628	0.626	0.626
F (3,16)	0.16^{NS}	7.36**	8.51**	9.27**	3.77**	5.63**	4.18*	3.93**
CD (0.05)	-	0.021	0.015	0.013	0.009	0.008	0.009	0.009

** Significant at 1 per cent level, * Significant at 5 per cent level, NS- Non significant, DOI- Days of Incubation

T_1 – Latex sludge
T_2 – Single super phosphate
T_3 – Rock phosphate
T_4 – Control (Soil alone)

The highest value on 105^{th} DOI was shown by T_1 (0.690 per cent), which was significantly different from all other treatments. T_2 and T_3 were on par and T_4 showed the lowest value of 0.626 per cent.

On 120^{th} DOI, the previous pattern was found to repeat. The highest value of 0.680 per cent was recorded by T_1 which was superior to T_3 and T_2, which were on par. The lowest value of 0.626 per cent was recorded by T_4.

4.2.4 Available Nitrogen

At all stages of incubation except the last, there was significant influence for the treatments on available N content of the soil (Table 9). A perusal of data revealed that all the treatments recorded a gradual increase in available N up to 60^{th} DOI, followed by a decrease. On all days of incubation, except on 105^{th} day, T_1 recorded the highest N content.

On 15^{th} DOI, the values ranged from 216.95 kg ha^{-1} to 227.28 kg ha^{-1}. The maximum content was recorded by T_1 and it was on par with T_3. The lowest value was recorded by T_2 and it was on par with T_4.

The maximum value of 245.98 kg ha^{-1} on 30^{th} DOI was recorded by T_1 and it was significantly superior to all other treatments. The lowest value was shown by T_4 (222.93 kg ha^{-1}), which was on par with T_2 and T_3.

On 45^{th} DOI, the previous pattern repeated. The highest value of 254.34 kg ha^{-1} was for T_1 and the lowest value of 228.39 kg ha^{-1} was for T_4.

T_1 was significantly superior to all other treatments on 60^{th} DOI also. The N content was 258.42 kg ha^{-1}. The lowest content was registered by T_4 (228.45 kg ha^{-1}), which was on par with T_3.

Table 9. Available nitrogen (kg ha^{-1}) of soil at different periods of incubation

Treatments	15th DOI	30th DOI	45th DOI	60th DOI	75th DOI	90th DOI	105th DOI	120th DOI
T_1	227.28	245.98	254.34	258.42	242.62	235.32	215.30	208.51
T_2	216.95	225.54	232.69	237.45	235.45	219.52	210.38	205.50
T_3	224.57	227.53	230.44	235.30	228.53	225.67	216.66	203.56
T_4	218.24	222.93	228.39	228.45	230.49	225.63	203.62	208.37
F (3,16)	4.59*	15.9**	19.25**	22.45**	5.27*	5.85**	4.68*	0.796^{NS}
CD (0.05)	6.94	7.89	8.23	8.18	8.19	8.09	8.16	-

** Significant at 1 per cent level, * Significant at 5 per cent level, NS- Non significant, DOI- Days of Incubation

T_1 – Latex sludge
T_2 – Single super phosphate
T_3 – Rock phosphate
T_4 – Control (Soil alone)

The maximum value on 75th DOI was registered by T_1 (242.62 kg ha^{-1}) followed by T_2 and they were on par. The lowest value of 228.53 kg ha^{-1} was shown by T_3.

On 90th DOI, the values ranged from 219.52 kg ha^{-1} to 235.32 kg ha^{-1}. T_1 was significantly superior to all other treatments and recorded the highest content. T_3 and T_4 were on par. T_2 which recorded the lowest value was significantly inferior to all other treatments.

The highest value on 105th DOI was recorded by T_3 (216.66 kg ha^{-1}) followed by T_1 and T_2. These three treatments were on par. The lowest value of 203.62 kg ha^{-1} was recorded by T_4.

4.2.5 Available Phosphorus

Statistical analysis of the data (Table 10) which showed significance at all stages revealed a gradual increase in P content followed by a decrease. Throughout the period of incubation, the lowest value was recorded by absolute control.

On the 15th DOI, all the treatments were significantly different from each other in their P content. The highest content of 97.56 kg ha^{-1} was recorded by T_2 followed by T_1 (95.11 kg ha^{-1}) and T_3 (92.80 kg ha^{-1}). The lowest value of 90.68 kg ha^{-1} was recorded by absolute control.

The values for P content on 30th DOI, ranged from 91.33 kg ha^{-1} (T_4) to 96.46 kg ha^{-1} (T_2). T_2 and T_1 were on par and they were significantly different from T_3 and T_4, which were on par.

The highest P content on 45th DOI was recorded by T_1 (99.28 kg ha^{-1}) followed by T_2 and they were on par and significantly different from T_3 and T_4, which were on par. T_4 recorded the lowest value of 91.79 kg ha^{-1}.

On the 60th DOI, the maximum P content of 102.02 kg ha^{-1} was recorded by T_2 and it was significantly higher than all other treatments.

Table 10. Available phosphorus (kg ha^{-1}) of soil at different periods of incubation

Treatments	15th DOI	30th DOI	45th DOI	60th DOI	75th DOI	90th DOI	105th DOI	120th DOI
T_1	95.11	96.41	99.28	98.39	109.31	106.54	103.86	103.78
T_2	97.56	96.46	97.28	102.02	104.34	106.82	103.33	103.50
T_3	92.80	92.71	95.07	98.33	100.71	99.60	100.18	100.18
T_4	90.68	91.33	91.79	91.58	92.03	90.90	90.46	90.61
F (3,16)	19.91**	8.19**	5.75**	22.95**	10.27**	11.98**	14.25**	14.44**
CD (0.05)	1.99	2.73	4.01	2.73	6.59	6.49	4.93	4.86

** Significant at 1 per cent level, DOI- Days of Incubation

T_1 – Latex sludge
T_2 – Single super phosphate
T_3 – Rock phosphate
T_4 – Control (Soil alone)

T_1 was on par with T_3 and they were significantly inferior to T_2 and significantly superior to T_4, which recorded the lowest value of 91.58 kg ha^{-1}.

The P content on 75th DOI ranged from 92.03 kg ha^{-1} to 109.31 kg ha^{-1}. T_1 showed the maximum content and was on par with T_2. The lowest content was recorded by T_4 and it was significantly inferior to all other treatments.

The same pattern was seen to repeat on the 90th DOI, with T_2 registering maximum value of 106.82 kg ha^{-1} followed by T_1. T_4 registered the minimum value of 90.90 kg ha^{-1}.

On 105th DOI, the values ranged from 90.46 kg ha^{-1} to 103.86 kg ha^{-1}. The highest content was recorded by T_1 followed on par by T_2 and T_3. The lowest value was recorded by T_4 and it was significantly inferior to all other treatments.

The same pattern repeated on 120th DOI also. The highest value of 103.78 kg ha^{-1} was recorded by T_1 and the lowest by T_4 (90.61 kg ha^{-1}).

4.2.6 Available Potassium

There was no significant effect for various treatments on the available K content of soil at any stage of incubation (Table 11). However, the values ranged from 82.02 to 88.38, 91.93 to 98.56, 87.15 to 91.91, 84.77 to 92.07, 84.50 to 90.26, 86.16 to 90.74, 73.23 to 81.27, 77.83 to 80.98 kg ha^{-1} on 15th, 30th, 45th, 60th, 75th, 90th, 105th and 120th DOI respectively.

4.2.7 Exchangeable Calcium

Statistical analysis of the data (Table 12) showed significant effect for various treatments on the exchangeable Ca content of soil from 45th to 105th DOI but the effects were not significant up to 30th DOI and on 120th day.

Table 11. Available potassium (kg ha^{-1}) of soil at different periods of incubation

Treatments	15^{th} DOI	30^{th} DOI	45^{th} DOI	60^{th} DOI	75^{th} DOI	90^{th} DOI	105^{th} DOI	120^{th} DOI
T_1	86.80	98.56	90.38	90.39	90.26	86.16	73.23	80.10
T_2	82.02	94.36	91.91	92.07	86.80	90.74	74.79	80.04
T_3	87.21	91.93	91.24	84.77	84.50	87.90	81.27	77.83
T_4	88.38	92.50	87.15	89.00	90.27	89.36	78.83	80.98
F (3.16)	0.483^{NS}	0.86^{NS}	0.51^{NS}	1.17^{NS}	0.88^{NS}	0.605^{NS}	2.13^{NS}	0.115^{NS}
CD (0.05)	-	-	-	-	-	-	-	-

NS- Non significant, DOI- Days of Incubation

T_1 – Latex sludge
T_2 – Single super phosphate
T_3 – Rock phosphate
T_4 – Control (Soil alone)

Table 12. Exchangeable calcium (cmol kg^{-1}) of soil at different periods of incubation

Treatments	15th DOI	30th DOI	45th DOI	60th DOI	75th DOI	90th DOI	105th DOI	120th DOI
T_1	1.600	1.578	1.668	1.586	1.580	1.484	1.582	1.480
T_2	1.616	1.572	1.570	1.460	1.474	1.620	1.744	1.574
T_3	1.588	1.580	1.600	1.540	1.360	1.494	1.580	1.506
T_4	1.562	1.596	1.400	1.592	1.470	1.502	1.458	1.484
F (3.16)	0.417^{NS}	0.92^{NS}	14.1**	8.02**	15.04**	4.8*	10.19**	3.13^{NS}
CD (0.05)	-	-	0.091	0.064	0.069	0.087	0.110	-

** Significant at 1 per cent level, * Significant at 5 per cent level, NS- Non significant, DOI- Days of Incubation

T_1 – Latex sludge
T_2 – Single super phosphate
T_3 – Rock phosphate
T_4 – Control (Soil alone)

On 45th DOI, the highest value of 1.668 cmol kg^{-1} was recorded by T_1 and it was on par with T_3. The lowest value was recorded by T_4 (1.400 cmol kg^{-1}) and it was significantly inferior to all other treatments.

The highest value on 60th DOI was registered by T_4 (1.592 cmol kg^{-1}) which was on par with T_1 and T_3. The lowest value of 1.460 cmol kg^{-1} was recorded by T_2 and it was significantly inferior to all other treatments.

T_1 recorded the highest value of 1.580 cmol kg^{-1} on 75th DOI and was significantly superior to all other treatments. T_2 and T_4 were on par. T_3 recorded the lowest value of 1.360 cmol kg^{-1}.

On the 90th DOI, the variation was from 1.484 cmol kg^{-1} for T_1 to 1.620 cmol kg^{-1} for T_2. T_2 was significantly superior to all other treatments. T_4 and T_3 were on par.

The maximum value on 105th DOI was registered by T_2 (1.744 cmol kg^{-1}) followed by T_1 and T_3, both of which were on par. T_4 recorded the lowest value of 1.458 cmol kg^{-1}.

4.2.8 Exchangeable Magnesium

Critical appraisal of the data (Table 13) pointed out that only during the mid period of incubation the treatments were able to produce significant effects on Mg content of soil. Up to the 30th and after the 90th DOI, there was no significant effect for the treatments.

On the 45th DOI, the maximum value of 0.728 cmol kg^{-1} was for T_4, which stood on par with T_1. The minimum value of this was for T_3 (0.624 cmol kg^{-1}) which was significantly inferior to all other treatments.

The values ranged from 0.646 cmol kg^{-1} to 0.744 cmol kg^{-1} on the 60th DOI, registered by T_3 and T_2 respectively. T_2 was on par with T_4 and T_1.

Table 13. Exchangeable magnesium (cmol kg^{-1}) of soil at different periods of incubation

Treatments	15^{th} DOI	30^{th} DOI	45^{th} DOI	60^{th} DOI	75^{th} DOI	90^{th} DOI	105^{th} DOI	120^{th} DOI
T_1	0.704	0.700	0.726	0.718	0.684	0.622	0.590	0.568
T_2	0.730	0.732	0.670	0.744	0.688	0.568	0.632	0.600
T_3	0.682	0.730	0.624	0.646	0.606	0.600	0.622	0.608
T_4	0.668	0.684	0.728	0.726	0.616	0.610	0.584	0.588
F (3,16)	1.72^{NS}	1.05^{NS}	22.29**	4.30*	4.97*	0.69^{NS}	0.71^{NS}	1.02^{NS}
CD (0.05)	-	-	0.032	0.062	0.058	-	-	-

** Significant at 1 per cent level, * Significant at 5 per cent level, NS- Non significant, DOI- Days of Incubation

T_1 – Latex sludge
T_2 – Single super phosphate
T_3 – Rock phosphate
T_4 – Control (Soil alone)

T_2 registered the maximum value of 0.688 cmol kg^{-1} on the 75^{th} DOI and was on par with T_1. T_3 registered minimum content of 0.606 cmol kg^{-1} and was on par with T_4.

4.3 STUDY OF THE EFFECT ON A MAIN CROP OF CHILLI

The results of the pot culture experiment are presented below.

4.3.1 Climate

The atmospheric temperature during the cropping period was conducive for the growth of irrigated chilli. The maximum and minimum temperature did not show much fluctuation between the extreme values. The relative humidity was also more or less steady throughout the cropping period but the monthly distribution of rainfall was highly erratic.

4.3.2 Effect of Treatments on Growth Characteristics

4.3.2.1 Plant Height

Statistical analysis of the data (Table 14) revealed that treatment application significantly influenced plant height. Irrespective of the source or combinations, all the treatments, which received P recorded significantly higher values than the treatments receiving no P (both T_{10} and T_{11}). The maximum height of 35.13 cm was recorded by T_2 (full P as SSP) and it was on par with T_8 (½ LS + ½ RP) and T_3 (full P as RP). The lowest height of 19.10 cm was recorded by absolute control (T_{11}) and it was on par with T_{10} (No P).

4.3.2.2 Branches per Plant

Critical appraisal of the data (Table 14) revealed that T_2 (full P as SSP) recorded maximum number of branches (44.67) and it was on par with T_8 (½ LS + ½ RP. These two treatments were significantly superior

Table 14. Effect of treatments on growth characters

Treatments	Plant height (cm)	Number of leaves	Leaf area (cm^2)	Branches $plant^{-1}$	Days to flowering
T_1	32.00	191.33	1510.33	33.00	31.67
T_2	35.13	215.33	1725.00	44.67	33.00
T_3	34.17	181.00	1656.33	33.67	34.00
T_4	32.70	202.67	1707.33	29.33	33.67
T_5	34.30	190.67	1683.67	34.67	32.00
T_6	32.10	159.00	1250.00	26.67	31.67
T_7	29.77	169.67	1608.00	34.67	32.33
T_8	33.80	192.33	1705.33	43.67	32.67
T_9	31.60	135.33	1389.67	29.67	32.00
T_{10}	22.67	124.67	1165.67	27.00	37.67
T_{11}	19.10	99.33	932.00	21.00	38.33
F (10, 22)	13.64**	4.57**	3.55**	22.02**	5.09**
CD (0.05)	4.07	49.45	414.65	4.41	3.03

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

to all other treatments. Absolute control (T_{11}) recorded the lowest value (21.00) and was significantly inferior to all other treatments.

4.3.2.3 Number of Leaves and Leaf Area

The number of leaves and leaf area (Table 14) showed the same trend as that of plant height. Irrespective of the P source, its application significantly influenced these characters.

The maximum number of leaves (215.33) was recorded by T_2 (full P as SSP) and it was on par with T_8 (½ LS + ½ RP) and T_3 (full P as RP). The maximum leaf area of 1725.00 cm^2 was also recorded by T_2 and it was on par with T_8 (1705.33 cm^2) and T_3 (1656.33 cm^2). Absolute control recorded the lowest number of leaves (99.33) and the minimum leaf area of 932.00 cm^2.

4.3.2.4 Days to Flowering

Treatment application significantly influenced the number of days to first flowering (Table 14). T_1 (full P as LS) and T_6 (¾ LS + ¼ SSP) were the earliest to flower (31.67). They were on par with T_8 (½ LS + ½ RP), T_2 (full P as SSP) and T_3 (full P as RP). The maximum number of days for first flowering (38.33) was taken by absolute control (T_{11}) followed by T_{10} (no P) and they were on par.

4.3.3 Effect of Treatments on Yield and Yield Attributes

4.3.3.1 Fruits per Plant

From the statistical analysis of data (Table 15), which showed significant effects for the treatments, it was seen that the maximum number of fruits per plant (53.33) was produced by T_7 (¼ LS + ¾ RP) followed on par by T_8 (½ LS + ½ RP), T_2 (full P as SSP) and T_3 (full P as RP). The lowest value of 20.33 was recorded by absolute control.

Table 15. Effect of treatments on yield and yield attributes

Treatments	Fruits plant^{-1}	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Yield per plant (g plant^{-1})
T_1	44.00	9.62	4.63	6.13	244.63
T_2	50.33	10.29	4.98	6.90	278.75
T_3	48.33	9.99	5.12	6.73	269.05
T_4	41.33	8.57	4.81	5.23	223.90
T_5	32.00	9.68	5.09	6.67	163.57
T_6	44.00	9.64	5.04	5.83	234.33
T_7	53.33	8.89	5.75	6.67	295.28
T_8	49.67	9.58	5.10	6.90	274.37
T_9	29.67	9.58	4.68	5.50	141.67
T_{10}	26.33	9.13	5.12	5.20	117.73
T_{11}	20.33	9.30	4.23	4.73	91.50
F (10, 22)	7.48**	0.68^{NS}	2.07^{NS}	5.04**	11.06**
CD (0.05)	11.87	-	-	1.02	62.94

** Significant at 1 per cent level, NS-Non significant

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

4.3.3.2 Fruit Length

No significant difference was observed in the length of fruits due to the application of various treatments (Table 15). However, the maximum fruit length (10.29 cm) was recorded by T_2 (full P as SSP) and minimum of 8.57 cm by T_4 (¼ LS + ¾ SSP).

4.3.3.3 Fruit Girth

As in the case of length of fruits, the treatments failed to produce any significant effect on girth of pods (Table 15). The variation was from 4.23 cm for T_{11} (absolute control) to 5.75 cm for T_7 (¼ LS + ¾ RP).

4.3.3.4 Fruit Weight

Individual fruit weight (Table 15) was significantly influenced by the treatments. The maximum fruit weight of 6.90 g was recorded by both T_8 (½ LS + ½ RP) and T_2 (full P as SSP) followed on par by T_3 (full P as RP). The lowest fruit weight (4.73 g) was recorded by absolute control (T_{11}).

4.3.3.5 Yield per Plant

There was significant effect for the treatments on the fruit yield per plant (Table 15). The highest yield of 295.28 g was recorded by T_7 (¼ LS + ¾ RP) followed on par by T_8 (½ LS + ½ RP), T_2 (full P as SSP) and T_3 (full P as RP). The lowest yield (91.50 g) was from absolute control.

4.3.4 Effect of Treatments on Quality Characters of Fruit

4.3.4.1 Capsaicin Content

Significance was observed for treatment effects on the capsaicin content of chilli (Table 16). The maximum content (0.457 per cent) was recorded by T_1 (full P as LS) followed on par by T_8 (½ LS + ½ RP). The lowest content of 0.246 per cent was recorded by absolute control (T_{11}).

Table 16. Effect of treatments on quality characters of fruit

Treatments	Capsaicin (%)	Oleoresin (%)	Ascorbic acid (mg 100 g^{-1})	Protein content (%)
T_1	0.457	9.83	103.17	10.97
T_2	0.289	13.16	138.88	10.42
T_3	0.288	11.33	186.50	9.93
T_4	0.307	13.00	175.92	9.70
T_5	0.441	12.33	203.70	10.72
T_6	0.414	11.67	163.75	12.40
T_7	0.351	12.50	166.66	10.90
T_8	0.430	12.17	194.44	12.28
T_9	0.365	12.33	148.14	9.77
T_{10}	0.249	9.83	159.99	9.40
T_{11}	0.246	9.00	94.61	6.13
F (10, 22)	3.6**	2.93*	6.27**	19.96**
CD (0.05)	0.121	2.40	40.82	0.518

* Significant at 5 per cent level, ** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

4.3.4.2 Oleoresin Content

The statistical analysis of data (Table 16) on oleoresin content, which turned out to be significant revealed that, the maximum content of 13.16 per cent was recorded by T_2 (full P as SSP) followed on par with T_8 (½ LS + ½ RP) and T_3 (full P as RP). The lowest value of 9.00 per cent was recorded by absolute control (T_{11}) and was on par with T_{10} (No P).

4.3.4.3 Ascorbic Acid Content

The treatments were effective in producing significant variation in the ascorbic acid content of fruits (Table 16). The maximum content of 203.70 mg 100 g^{-1} fruit was recorded by T_5 (½ LS + ½ SSP) followed on par by T_8 (½ LS + ½ RP) and T_3 (full P as RP). They were significantly superior to T_2 (full P as SSP) and T_1 (full P as LS), which were statistically on par. The lowest content of 94.61 mg 100 g^{-1} fruit was recorded by absolute control (T_{11}).

4.3.4.4 Protein Content

The fruit protein content (Table 16) was significantly influenced by the various treatments and the variation was from 6.13 per cent to 12.40 per cent. The highest content was recorded by T_6 (¾ LS + ¼ SSP) very closely on par with T_8 (½ LS + ½ RP). These two treatments were significantly superior to all other treatments. The lowest content was recorded by absolute control (T_{11}) and it was significantly inferior to all other treatments.

4.3.5 Moisture Content of Plant

4.3.5.1 Bhusa Moisture Content

No significant effect due to the application of various treatments was observed on bhusa moisture content (Table 17). However, the content varied from 87.20 per cent for T_5 (½ LS + ½ SSP) to 84.93 per cent for T_4 (¼ LS + ¾ SSP).

Table 17. Effect of treatments on moisture and dry matter content of plant

Treatments	Moisture (%)		Dry matter content (g $plant^{-1}$)		
	Bhusa	Fruit	Bhusa	Fruit	Total
T_1	85.63	83.31	36.43	32.58	69.01
T_2	85.83	87.09	40.11	37.12	77.24
T_3	87.15	86.14	39.07	35.83	74.90
T_4	84.93	86.65	37.85	29.82	67.67
T_5	87.20	88.86	34.51	21.78	56.29
T_6	86.26	86.69	34.21	31.21	65.42
T_7	85.96	86.79	41.89	39.33	81.22
T_8	86.63	87.78	39.64	36.54	76.18
T_9	85.43	86.66	33.21	18.86	52.07
T_{10}	85.96	87.18	31.87	15.68	47.55
T_{11}	86.46	85.98	21.97	12.18	34.00
F (10, 22)	0.678^{NS}	24.76**	6.19**	11.06**	9.33**
CD (0.05)	-	0.80	6.49	8.38	14.08

** Significant at 1% level, NS – Non significant

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

4.3.5.2 Fruit Moisture Content

The maximum fruit moisture content (Table 17) of 88.86 per cent was recorded by T_5 (½ LS + ½ SSP) and it was significantly higher than all other treatments. T_1 (full P as LS) recorded the lowest moisture content of 83.31 per cent and was significantly lower than all other treatments.

4.3.6 Dry Matter Content of Plant

4.3.6.1 Bhusa Dry Matter Content

Statistical analysis revealed the significant influence of different treatments on bhusa dry matter production (Table 17). The treatment T_7, which received ¼ P as LS and ¾ P as RP recorded the highest dry matter content of 41.89 g plant^{-1} followed on par by T_8 (½ LS + ½ RP), T_2 (full P as SSP) and T_3 (full P as RP). The lowest value of 21.97 g plant^{-1} was for T_{11} (absolute control), which was significantly inferior to all other treatments.

4.3.6.2 Fruit Dry Matter Content

The treatments were statistically effective on the dry matter content of fruit (Table 17). The highest dry matter content of 39.33 g plant^{-1} was recorded by T_7 (¼ LS + ¾ RP) followed on par by T_8 (½ LS+ ½ RP), T_2 (full P as SSP) and T_3 (full P as RP). The lowest dry matter content of 12.18 g plant^{-1} was recorded by absolute control (T_{11}).

4.3.6.3 Total Dry Matter

The data on total dry matter production are presented in (Table 17). T_7 (¼ LS + ¾ RP) recorded the highest dry matter production of 81.22 g plant^{-1} followed on par by T_8 (½ LS + ½ RP), T_2 (full P as SSP) and T_3 (full P as RP). Absolute control (T_{11}) recorded the lowest value of 34.00 g plant^{-1}.

4.3.7 Nutrient Concentration in Plant

The tissue concentration of N, P, K and Ca varied significantly under the influence of different treatments. But the variation in Mg content was not significant.

4.3.7.1 Bhusa Nutrient Content

4.3.7.1.1 Nitrogen

The N content (Table 18) ranged from 0.987 to 2.262 per cent. The highest content was recorded by T_6 (¾ LS + ¼ SSP) followed by T_2 (full P as SSP), which was on par with T_8 (½ LS + ½ RP) and T_3 (full P as RP). The lowest value was recorded by absolute control (T_{11}). All the treatments showed significantly higher values compared to T_{11}.

4.3.7.1.2 Phosphorus

The highest P content (Table 18) of 0.288 per cent was recorded by T_2 (full P as SSP) and it was on par with T_3 (full P as RP), which in turn was on par with T_8 (½ LS + ½ RP ½ LS). Absolute control (T_{11}) recorded the lowest content of 0.113 per cent and it was on par with T_{10} (No P). All other treatments were significantly superior to T_{10} and T_{11}.

4.3.7.1.3 Potassium

The bhusa K content (Table 18) varied from 2.13 per cent to 3.76 per cent. The highest content was recorded by T_4 (¼ LS + ¾ SSP) followed on par by T_8 (½ LS + ½ RP) and T_7 (¼ LS + ¾ RP). Absolute control (T_{11}) was significantly inferior to all other treatments and recorded the lowest value.

4.3.7.1.4 Calcium

The data on bhusa calcium content are presented in (Table 18). T_9 (¾ LS + ¼ RP) recorded the highest Ca content of 1.673 per cent followed on par by T_8 (½ LS + ½ RP). The lowest content of 0.913 per cent was recorded by T_{11} (absolute control).

4.3.7.1.5 Magnesium

There was no significant effect for the treatments on bhusa Mg content (Table 18). However, the highest Mg content of 0.448 per cent

Table 18. Effect of treatments on the nutrient content of bhusa

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
T_1	1.731	0.282	3.320	1.417	0.381
T_2	1.993	0.288	3.300	1.440	0.441
T_3	1.561	0.282	3.300	1.333	0.400
T_4	1.943	0.259	3.760	1.387	0.401
T_5	1.699	0.247	3.463	1.443	0.416
T_6	2.262	0.282	3.440	1.413	0.390
T_7	1.754	0.202	3.710	1.260	0.304
T_8	1.709	0.207	3.650	1.503	0.448
T_9	1.895	0.214	3.660	1.673	0.448
T_{10}	1.539	0.126	3.413	1.073	0.299
T_{11}	0.987	0.113	2.133	0.913	0.224
F (10, 22)	4.48**	5.61**	8.36**	2.39*	2.18^{NS}
CD (0.05)	0.447	0.077	0.452	0.393	-

*Significant at 5% level, ** Significant at 1% level, NS – Non significant

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

was recorded by T_8 (½ LS + ½ RP) and T_9 (3/4 LS + ¼ RP). Absolute control (T_{11}) recorded the lowest value of 0.224 per cent.

4.3.7.2 Fruit Nutrient Content

There was significant effect for the treatments on N, P and K contents of fruit but not on Ca and Mg.

4.3.7.2.1 Nitrogen

The N content (Table 19) in fruits varied from 0.98 per cent to 1.98 per cent. The highest content was recorded by T_6 (¾ LS + ¼ SSP) followed by T_8 (½ LS + ½ RP) and they were on par with each other and significantly higher than all other treatments. The lowest N content was recorded by absolute control (T_{11}) and it was significantly inferior to all other treatments.

4.3.7.2.2 Phosphorus

With regard to P content in fruit (Table 19), all the treatments which received P from any source, recorded significantly higher values than the treatments which received no P (both T_{10} and T_{11}). The highest P content of 0.437 per cent was recorded by T_9 (¾ LS + ¼ RP) followed on par by T_8 (½ LS + ½ RP), T_4 (¼ LS + ¾ SSP) and T_3 (full P as RP). The lowest content of 0.202 per cent was recorded by T_{11} (absolute control), which was on par with T_{10} (No P).

4.3.7.2.3 Potassium

The fruit K content (Table 19) varied from 1.273 per cent to 3.290 per cent. The highest K content was recorded by T_9 (¾ LS + ¼ RP), which was on par with T_5 (½ LS + ½ SSP), which in turn was on par with T_8 (½ LS + ½ RP). The lowest content was recorded by absolute control (T_{11}), which was significantly inferior to all other treatments.

Table 19. Effect of treatments on nutrient content of fruit

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
T_1	1.755	0.384	2.273	0.213	0.112
T_2	1.667	0.381	2.400	0.240	0.096
T_3	1.589	0.391	2.247	0.267	0.112
T_4	1.553	0.432	2.427	0.267	0.128
T_5	1.715	0.384	2.927	0.293	0.112
T_6	1.983	0.375	2.453	0.240	0.128
T_7	1.744	0.379	2.427	0.213	0.112
T_8	1.964	0.407	2.553	0.240	0.128
T_9	1.563	0.437	3.290	0.240	0.128
T_{10}	1.503	0.203	2.667	0.187	0.092
T_{11}	0.980	0.202	1.273	0.133	0.088
F (10, 22)	8.84**	11.09**	8.54**	1.91 NS	1.91 NS
CD (0.05)	0.837	0.072	0.497	-	-

** Significant at 1 per cent level, NS-Non significant

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

4.3.7.2.4 Calcium

The variation in Ca content of fruit (Table 19), though not significant was from 0.133 per cent recorded by absolute control (T_{11}) to 0.293 per cent recorded by T_5 (½ LS + ½ SSP).

4.3.7.2.5 Magnesium

Similar to Ca, no significance could be noticed for the treatments on the Mg content of fruits (Table 19). However, the content varied from 0.088 per cent for T_{11} (absolute control) to 0.128 per cent for T_8 (½ LS + ½ RP).

4.3.8 Uptake of Nutrients

4.3.8.1 Nitrogen Uptake

Total as well as individual bhusa and fruit uptake were significantly influenced by the treatments.

Bhusa

The N uptake values of bhusa (Table 20) varied from 0.217 to 0.802 g plant^{-1}. The highest uptake was recorded by T_2 (full P as SSP) and it was on par with T_8 (½ LS + ½ RP) and T_3 (full P as RP). Absolute control (T_{11}) recorded the lowest uptake and was significantly inferior to all other treatments.

Fruit

The data on fruit N uptake are presented in (Table 20). T_8 (½ LS + ½ RP) recorded the highest uptake of 0.717 g plant^{-1} and it was on par with T_2 (full P as SSP) and T_3 (full P as RP). The lowest uptake of 0.118 g plant^{-1} was recorded by absolute control (T_{11}).

Total uptake

The highest total uptake (Table 20) of N (1.421 g plant^{-1}) was recorded by T_7 (¼ LS + ¾ RP) followed on par by T_8 (½ LS + ½ RP) and

Table 20. Effect of treatments on plant nitrogen uptake

Treatments	N uptake (g plant^{-1})		
	Bhusa	Fruit	Total
T_1	0.633	0.572	1. 205
T_2	0.802	0.618	1.420
T_3	0.728	0.580	1.308
T_4	0.734	0.462	1.196
T_5	0.589	0.374	0.962
T_6	0.768	0.169	1.387
T_7	0.736	0.685	1.421
T_8	0.674	0.717	1.391
T_9	0.630	0.294	0.924
T_{10}	0.491	0.235	0.726
T_{11}	0.217	0.118	0.335
F (10, 22)	6.928**	17.71**	13.85**
CD (0.05)	0.184	0.138	0.274

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

T_2 (full P as SSP). The absolute control (T_{11}) recorded the lowest uptake of 0.335 g plant^{-1} and was significantly inferior to all other treatments.

4.3.8.2 Phosphorus Uptake

The bhusa, fruit and total P uptake were significantly influenced by the treatments.

Bhusa

The data on P uptake by bhusa (Table 21) indicated a maximum value of 0.116 g plant^{-1} by T_2 (full P as SSP) followed by T_3 (full P as RP) and they were on par with T_8 (1/2 LS + ½ RP). The lowest uptake of 0.025 g plant^{-1} was by absolute control (T_{11}) and it was on par with T_{10} (no P). These two treatments were significantly inferior to all other treatments.

Fruit

The fruit P uptake (Table 21) values ranged from 0.024 g plant^{-1} to 0.148 g plant^{-1}. The highest value was recorded by T_8 (½ LS + ½ RP) and T_7 (¼ LS + ¾ RP) followed on par by T_2 (full P as SSP) and T_3 (full P as RP). Absolute control (T_{11}) recorded the lowest uptake and was on par with T_{10} (no P).

Total Uptake

The data on total P uptake are presented in (Table 21). T_2 (full P as SSP) recorded the highest uptake of 0.257 g plant^{-1} followed by T_3 (full P as RP) and they were on par with each other and also with T_8 (½ LS + ½ RP). The lowest uptake of 0.049 g plant^{-1} was registered by T_{11} (absolute control), which was on par with T_{10} (no P). T_{10} and T_{11} were significantly inferior to all other treatments.

4.3.8.3 Potassium Uptake

The K uptake by bhusa and fruit as well as its total uptake were significantly influenced by the treatments.

Table 21. Effect of treatments on plant phosphorus uptake

Treatments	P uptake (g $plant^{-1}$)		
	Bhusa	Fruit	Total
T_1	0.104	0.125	0.229
T_2	0.116	0.140	0.257
T_3	0.111	0.139	0.250
T_4	0.098	0.131	0.230
T_5	0.084	0.083	0.168
T_6	0.096	0.116	0.212
T_7	0.084	0.148	0.232
T_8	0.082	0.148	0.230
T_9	0.081	0.082	0.163
T_{10}	0.039	0.032	0.071
T_{11}	0.025	0.024	0.049
F (10, 22)	6.27**	11.16**	10.22**
CD (0.05)	0.033	0.039	0.065

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

Bhusa

Table 22 show that the maximum bhusa K uptake (1.550 g plant^{-1}) was recorded by T_7 (¼ LS + ¾ RP) followed on par by T_8 (½ LS + ½ RP), which in turn was on par with T_2 (full P as SSP) and T_3 (full P as RP). All the treatments were significantly superior to absolute control (T_{11}), which recorded the lowest value of 0.463 g plant^{-1}.

Fruit

The data on fruit K uptake are presented in Table 22. T_7 (¼ LS + ¾ RP) registered the highest K uptake of 0.955 g plant^{-1} followed on par by T_8 (½ LS + ½ RP), T_2 (full P as SSP) and T_3 (full P as RP). All the treatments registered values significantly higher than the absolute control (T_{11}), which recorded the lowest uptake of 0.155 g plant^{-1}.

Total Uptake

The total K uptake (Table 22) values ranged from 0.618 g plant^{-1} to 2.505 g plant^{-1}. The highest uptake was registered by T_7 (¼ LS + ¾ RP) and was on par with T_8 (½ LS + ½ RP) which in turn was on par with T_3 (full P as RP). The lowest uptake of 0.618 g plant^{-1} was recorded by T_{11} (absolute control), which was significantly inferior to all other treatments.

4.3.8.4 Calcium Uptake

The treatments significantly influenced the bhusa, fruit and total uptake of Ca.

Bhusa

The data given in table 23 indicate that T_8 (½ LS + ½ RP) recorded the highest Ca uptake of 0.601 g plant^{-1} followed on par by T_2 (full P as SSP) and T_3 (full P as RP). The absolute control (T_{11}) recorded the lowest uptake of 0.201 g plant^{-1}.

Table 22. Effect of treatments on plant potassium uptake

Treatments	K uptake (g $plant^{-1}$)		
	Bhusa	Fruit	Total
T_1	1.207	0.737	1.943
T_2	1.317	0.893	2.209
T_3	1.290	0.802	2.093
T_4	1.407	0.713	2.120
T_5	1.190	0.634	1.824
T_6	1.173	0.763	1.936
T_7	1.550	0.955	2.505
T_8	1.440	0.930	2.370
T_9	1.217	0.617	1.834
T_{10}	1.080	0.417	1.497
T_{11}	0.463	0.155	0.618
F (10, 22)	16.93**	11.75**	17.87**
CD (0.05)	0.202	0.202	0.353

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

Table 23. Effect of treatments on plant calcium uptake

Treatments	Ca uptake (g plant^{-1})		
	Bhusa	Fruit	Total
T_1	0.520	0.068	0.588
T_2	0.565	0.087	0.652
T_3	0.527	0.097	0.624
T_4	0.528	0.077	0.605
T_5	0.495	0.064	0.559
T_6	0.437	0.075	0.512
T_7	0.532	0.083	0.615
T_8	0.601	0.087	0.688
T_9	0.558	0.045	0.603
T_{10}	0.342	0.029	0.371
T_{11}	0.201	0.016	0.217
F (10, 22)	3.67**	5.38**	4.66**
CD (0.05)	0.178	0.033	0.188

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

Fruit

The fruit Ca uptake (Table 23) values ranged from 0.016 to 0.097 g $plant^{-1}$. The highest uptake was recorded by T_3 (full P as RP) followed on par by T_8 (½ LS + ½ RP) and T_2 (full P as SSP). Absolute control (T_{11}) recorded the lowest uptake.

Total Uptake

The highest total uptake (Table 23) of Ca of 0.688 g $plant^{-1}$ was recorded by T_8 (½ LS + ½ RP) followed on par by T_2 (full P as SSP) and T_7 (¼ LS + ¾ RP). The lowest uptake of 0.217 g $plant^{-1}$ was recorded by absolute control (T_{11}).

4.3.8.5 Magnesium Uptake

The treatments significantly influenced the Mg uptake by bhusa and also its total uptake in general in spite of the insignificant effect on fruit.

Bhusa

T_8 (½ LS + ½ RP) recorded the highest Mg uptake (Table 24) of 0.176 g $plant^{-1}$ followed on par by T_2 (full P as SSP) and T_3 (full P as RP). Absolute control (T_{11}) recorded the lowest uptake of 0.049 g $plant^{-1}$.

Fruit

No significant effect due to the application of various treatments was observed on fruit uptake of Mg (Table 24). However, the highest uptake of 0.047 g $plant^{-1}$ was recorded by T_8 (½ LS + ½ RP) and lowest of 0.014 g $plant^{-1}$ by T_{10} (no P).

Total Uptake

Table 24 depicts total Mg uptake values.T_8 (½ LS + ½ RP) recorded the highest uptake of 0.222 g $plant^{-1}$ followed on par by T_2 (full

Table 24. Effect of treatments on plant magnesium uptake

Treatments	Mg uptake (g plant^{-1})		
	Bhusa	Fruit	Total
T_1	0.137	0.036	0.172
T_2	0.174	0.035	0.209
T_3	0.160	0.038	0.198
T_4	0.150	0.036	0.187
T_5	0.142	0.024	0.166
T_6	0.135	0.040	0.174
T_7	0.129	0.043	0.172
T_8	0.176	0.047	0.222
T_9	0.150	0.024	0.174
T_{10}	0.095	0.014	0.109
T_{11}	0.049	0.039	0.088
F (10, 22)	3.71**	1.09 ^{NS}	3.63**
CD (0.05)	0.056	-	0.061

** Significant at 1 per cent level, NS – Non significant

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

P as SSP) and T_3 (full P as RP). The lowest Mg uptake of 0.088 g $plant^{-1}$ was recorded by absolute control (T_{11}), which was significantly inferior to all other treatments.

4.3.9 Economic Analysis

Significant variations in benefit-cost ratios (Table 25) resulted, consequent to treatment application. The values ranged from 0.914 to 2.880, the minimum being recorded by absolute control (T_{11}) and the maximum by T_7 (¼ LS + ¾ RP) which was on par with T_8 (½ LS + ½ RP).

4.3.10 Effect of Treatments on Soil Parameters

4.3.10.1 Soil pH

The treatments failed to produce any significant effect on soil pH (Table 26). However, the values ranged from 5.35 to 5.91. The most neutral value was recorded by T_1 (full P as LS).

4.3.10.2 Electrical Conductivity

Significant influence was exerted by the treatments on EC values of the soil. The maximum EC (Table 26) value (154.70 $\mu S\ m^{-1}$) was registered by T_8 (½ LS + ½ RP) followed by T_1 (full P as LS) and they were statistically on par. The significantly lowest value of 81.97 $\mu S\ m^{-1}$ was recorded by absolute control (T_{11}).

4.3.10.3 Organic Carbon

The treatment application significantly influenced soil organic C content (Table 26). T_1 (full P as LS) recorded significantly superior value of 1.023 per cent. T_{11} (absolute control) recorded the lowest value of 0.732 per cent and was significantly inferior to all other treatments.

4.3.10.4 Available Nitrogen

The available N content (Table 27) of soil varied significantly under the influence of treatments from 203.50 kg ha^{-1} to 273.24 kg ha^{-1}.

Table 25. Benefit - cost ratio of treatments

Treatments	B:C ratio
T_1	2.387
T_2	2.717
T_3	2.620
T_4	2.182
T_5	1.595
T_6	2.203
T_7	2.880
T_8	2.673
T_9	1.383
T_{10}	1.143
T_{11}	0.914
F (10, 22)	10.94**
CD (0.05)	0.614

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

Table 26. Effect of treatments soil pH, electrical conductivity and organic carbon contents

Treatments	Soil pH	Electrical conductivity ($\mu S\ m^{-1}$)	Organic carbon (%)
T_1	5.91	144.73	1.023
T_2	5.59	126.57	0.877
T_3	5.48	113.23	0.920
T_4	5.59	115.77	0.850
T_5	5.59	126.87	0.857
T_6	5.35	118.30	0.947
T_7	5.59	116.97	0.837
T_8	5.38	154.70	0.903
T_9	5.63	134.50	0.923
T_{10}	5.53	103.63	0.787
T_{11}	5.59	81.97	0.732
F (10, 22)	0.64^{NS}	15.72**	25.86**
CD (0.05)	-	14.57	0.046

** Significant at 1 per cent level, NS : Non significant

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

Table 27. Effect of treatments on soil available nitrogen, phosphorus and potassium contents

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1	233.70	105.05	70.33
T_2	222.02	97.32	55.81
T_3	269.92	100.36	72.58
T_4	270.31	104.23	72.89
T_5	251.62	98.01	46.96
T_6	258.35	107.60	58.70
T_7	264.00	106.42	67.95
T_8	273.24	111.18	62.57
T_9	267.63	101.42	47.68
T_{10}	245.78	79.33	63.39
T_{11}	203.50	77.33	38.69
F (10, 22)	2.86*	4.3**	3.63**
CD (0.05)	39.33	22.71	17.58

*Significant at 5 per cent level, ** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

The highest content was recorded by T_8 (½ LS + ½ RP) followed on par by T_4 (¼ LS + ¾ SSP) and T_3 (full P as RP). The absolute control (T_{11}) recorded the lowest value.

4.3.10.5 Available Phosphorus

The treatments significantly influenced the available P content (Table 27) of the soil. T_8 (½ LS + ½ RP) recorded the highest content of 111.18 kg ha^{-1} and it was followed on par by T_6 (¾ LS + ¼ SSP), T_7 (¼ LS + ¾ RP), T_2 (full P as SSP) and T_3 (full P as RP). The lowest content of 77.33 kg ha^{-1} was recorded by T_{11} (absolute control), which was on par with T_{10} (no P).

4.3.10.6 Available Potassium

The available K content (Table 27) of soil varied significantly due to the application of treatments. T_4 (¼ LS + ¾ SSP) recorded the highest value (72.89 kg ha^{-1}) followed on par by T_8 (½ LS + ½ RP), T_7 (¼ LS + ¾ RP) and T_2 (full P as SSP). Absolute control (T_{11}) recorded the lowest value of 38.69 kg ha^{-1}.

4.3.10.7 Exchangeable Calcium

Significance was noticed as a result of treatment application on exchangeable Ca content (Table 28) of soil. The values ranged from 0.630 cmol kg^{-1} to 0.755 cmol kg^{-1}. The highest content was recorded by T_4 (¼ LS + ¾ SSP) followed on par by T_8 (½ LS + ½ RP), T_7 (¼ LS + ¾ RP) and T_2 (full P as SSP). The lowest value was registered by absolute control.

4.3.10.8 Exchangeable Magnesium

Exchangeable Mg of soil (Table 28) was significantly influenced by treatments. T_1 (full P as LS) recorded the highest content of 1.3 cmol kg^{-1} followed on par by T_8 (½ LS + ½ RP) and T_7 (¼ LS + ¾ RP). The lowest value of 0.5 cmol kg^{-1} was recorded by absolute control (T_{11}),

Table 28. Effect of treatments on soil exchangeable calcium and magnesium contents

Treatments	Exchangeable Ca ($cmol\ kg^{-1}$)	Exchangeable Mg ($cmol\ kg^{-1}$)
T_1	0.704	1.300
T_2	0.743	0.900
T_3	0.680	1.033
T_4	0.755	1.200
T_5	0.705	1.133
T_6	0.724	1.100
T_7	0.744	1.067
T_8	0.701	1.233
T_9	0.667	0.867
T_{10}	0.648	0.600
T_{11}	0.630	0.500
F (10, 22)	3.93**	11.58**
CD (0.05)	0.060	0.221

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

which was on par with T_{10} (no P) and they were significantly inferior to all other treatments.

4.4 STUDY OF THE RESIDUAL EFFECT ON A SUBSEQUENT CROP OF CHILLI

Results of the investigation on the residual effect of applied fertilizers on a subsequent crop of chilli grown on the same soil are presented below.

4.4.1 Yield per Plant

There was significant difference in the fruit yield (Table 29) of residue crop due to treatment application. The variation was from 25.86 g plant^{-1} to 104.37 g plant^{-1}. T_8 (½ LS + ½ RP) recorded the maximum value followed on par by T_5 (1/2 LS + ½ SSP), T_4 (¼ LS + ¾ SSP), T_3 (full P as RP) and T_7 (¼ LS + ¾ RP). The lowest yield was recorded by T_{11} (absolute control), which was significantly lower than all other treatments even T_{10} (no P).

4.4.2 Plant Dry Matter Content

The treatments were effective in creating variation in total dry matter content as well as bhusa and fruit dry matter of the residue crop.

4.4.2.1 Bhusa

The data on bhusa dry matter are presented in table 29.T_8 (½ LS + ½ RP) recorded the highest dry matter content of 24.17 g plant^{-1} followed on par by T_1 (full P as LS) and T_3 (full P as RP). The lowest dry matter content of 10.50 g plant^{-1} was recorded by absolute control (T_{11}) to which all treatments were superior.

4.4.2.2 Fruit

Statistical analysis of the fruit dry matter content (Table 29), which showed significance revealed that the maximum of 13.89 g plant^{-1}

Table 29. Fruit yield and dry matter production - residue crop

Treatments	Fruit yield (g plant^{-1})	Dry matter content (g plant^{-1})		
		Bhusa	Fruit	Total
T_1	95.47	24.00	12.71	36.71
T_2	93.93	20.83	12.51	33.34
T_3	102.13	22.03	13.60	35.63
T_4	102.50	20.73	13.65	34.38
T_5	103.17	23.90	13.74	37.64
T_6	95.13	22.30	12.67	34.97
T_7	102.90	19.43	13.70	33.13
T_8	104.37	24.17	13.89	38.06
T_9	95.27	22.60	12.69	35.29
T_{10}	61.67	16.20	8.21	24.41
T_{11}	25.86	10.50	3.44	13.94
F (10, 22)	12.42**	7.77**	12.43**	18.38**
CD (0.05)	20.14	4.29	2.68	4.90

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

was recorded by T_8 (½ LS + ½ RP) followed on par by T_5 (½ LS + ½ SSP) and T_3 (full P as RP). T_{11} (absolute control) recorded the minimum content of 3.44 g $plant^{-1}$ and it was significantly inferior to all other treatments.

4.4.2.3 Total Dry Matter

Total dry matter content (Table 29) was also significant under treatment application. The variation was from 13.94 g $plant^{-1}$ recorded by T_{11} (absolute control), which was significantly the lowest to 38.06 g $plant^{-1}$ registered by T_8 (½ LS + ½ RP), which was on par with T_5 (½ LS + ½ SSP) and T_3 (full P as RP).

4.4.3 Nutrient Concentration in Plant Parts

4.4.3.1 Bhusa

The bhusa nutrient composition *viz.*, N, P, K, Ca and Mg varied significantly as a result of treatment application.

4.4.3.1.1 Nitrogen

The data on bhusa N content (Table 30) showed that there existed a range from 0.617 per cent for T_{11} (absolute control) to 2.503 per cent for T_4 (¼ LS + ¾ SSP). T_4 was on par with T_8 (½ LS + ½ RP), T_3 (full P as RP) and T_6 (¾ LS + ¼ SSP). T_{11} was significantly inferior to all other treatments.

4.4.3.1.2 Phosphorus

Table 30 depicts the data on bhusa P content. T_8 (½ LS + ½ RP) recorded the highest P content of 0.293 per cent followed on par by T_3 (full P as RP), T_9 (¾ LS + ¼ RP) and T_6 (¾ LS + ¼ SSP). Absolute control (T_{11}) recorded the lowest (0.103 per cent), which was on par with T_{10} (no P). T_{10} and T_{11} were significantly inferior to all other treatments.

Table 30. Concentration of nutrients in bhusa - residue crop

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
T_1	1.853	0.202	3.587	1.133	0.624
T_2	1.937	0.199	3.920	1.040	0.592
T_3	1.973	0.221	3.693	1.133	0.576
T_4	2.503	0.197	3.933	1.013	0.480
T_5	1.789	0.180	3.373	1.027	0.528
T_6	2.112	0.239	4.127	1.040	0.448
T_7	1.710	0.214	3.800	1.007	0.544
T_8	1.949	0.293	3.793	1.040	0.608
T_9	1.637	0.242	3.753	0.973	0.576
T_{10}	1.699	0.105	3.690	0.703	0.243
T_{11}	0.617	0.103	1.687	0.480	0.203
F (10, 22)	5.71**	3.45**	3.94**	7.88**	9.1**
CD (0.05)	0.564	0.088	0.969	0.205	0.139

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

4.4.3.1.3 Potassium

The K content of bhusa (Table 30) varied from 1.687 per cent to 4.127 per cent. The maximum content was registered by T_6 (¾ LS + ¼ SSP) to which all other treatments except T_{11} (absolute control) were on par.

4.4.3.1.4 Calcium

With regard to bhusa Ca content (Table 30), all the treatments except T_{10} (no P) and T_{11} (absolute control) were on par to one another. The highest content of 1.13 per cent was recorded by T_3 (full P as RP) followed on par by T_1 (full P as LS) and T_8 (½ LS + ½ RP). The lowest content of 0.48 per cent was registered by T_{11} and it was significantly inferior to T_{10}.

4.4.3.1.5 Magnesium

The highest Mg content (Table 30) of 0.624 per cent was registered by T_1 (full P as LS) followed on par by T_8 (½ LS + ½ RP). The lowest content of 0.203 per cent was recorded by absolute control (T_{11}) and it was on par with T_{10} (no P). These two treatments were significantly inferior to all other treatments.

4.4.3.2 Fruit

Statistical scrutiny of the data on fruit nutrient composition of residue crop showed significant response for N, P and K, but Ca and Mg contents were unaffected.

4.4.3.2.1 Nitrogen

The range of fruit N content (Table 31) was from 0.674 per cent recorded by absolute control (T11), which was significantly the lowest to 2.133 per cent recorded by T_2 (full P as SSP) followed on par by T_8 (½ LS + ½ RP), T_5 (½ LS + ½ SSP) and T_6 (¾ LS + ¼ SSP).

Table 31. Concentration of nutrients in fruit - residue crop

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
T_1	1.799	0.354	3.703	0.320	0.080
T_2	2.133	0.388	3.800	0.373	0.096
T_3	1.800	0.365	3.787	0.400	0.064
T_4	1.695	0.329	3.717	0.347	0.072
T_5	1.935	0.402	3.793	0.293	0.088
T_6	1.913	0.369	3.947	0.373	0.096
T_7	1.833	0.377	3.847	0.373	0.056
T_8	2.113	0.317	3.690	0.320	0.112
T_9	1.731	0.334	3.750	0.347	0.064
T_{10}	1.710	0.165	3.560	0.160	0.029
T_{11}	0.674	0.126	1.420	0.140	0.018
F (10, 22)	4.0**	5.98**	6.58**	1.91^{NS}	2.21^{NS}
CD (0.05)	0.570	0.108	0.814	-	-

** Significant at 1 per cent level, NS – Non significant

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

4.4.3.2.2 Phosphorus

The P content of fruit (Table 31) ranged from 0.126 per cent to 0.402 per cent. T_5 (½ LS + ½ SSP) registered the highest content followed on par by T_8 (½ LS + ½ RP), T_2 (full P as SSP) and T_3 (full P as RP). The lowest content was registered by T_{11} (absolute control), which was on par with T_{10} (no P). They two were significantly inferior to all other treatments.

4.4.3.2.3 Potassium

Table 31 depicts fruit K content. The treatment, ¾ P as LS and ¼ P as SSP (T_6) recorded the highest K content of 3.947 per cent followed on par by T_8 (½ LS + ½ RP) and T_7 (¼ LS + ¾ RP). Absolute control (T_{11}) recorded the lowest content of 1.420 per cent.

4.4.3.2.4 Calcium

No significant effect due to the application of various treatments was observed on fruit Ca content (Table 31). However, the highest Ca content of 0.40 per cent was recorded by T_3 (full P as RP) and lowest value of 0.14 per cent by T_{11} (absolute control).

4.4.3.2.5 Magnesium

Similar to fruit Ca content, the various treatments had no significant effect on Mg content (Table 31) also. However, T_8 (½ LS + ½ RP) recorded the highest content of 0.112 per cent while the lowest value of 0.018 per cent was for T_{11} (absolute control).

4.4.4 Uptake of Nutrients

4.4.4.1 Nitrogen Uptake

The total N uptake by the residue crop as well as the individual bhusa and fruit uptake was significantly influenced by the treatments.

Bhusa

The data on bhusa N uptake (Table 32) showed a range of 0.064 to 0.505 g plant^{-1}. The maximum uptake was recorded by T_4 (¼ LS + ¾ SSP) followed on par by T_8 (½ LS + ½ RP), T_6 (¾ LS + ¼ SSP) and T_3 (full P as RP). Absolute control (T_{11}) registered the lowest uptake and it was significantly inferior to all other treatments.

Fruit

The fruit uptake of N (Table 32) varied from 0.023 to 0.297 g plant^{-1}. T_8 (½ LS + ½ RP) registered the highest uptake followed on par by T_5 (½ LS + ½ SSP) and T_3 (full P as RP). The lowest uptake was recorded by absolute control (T_{11}), which was significantly the lowest.

Total Uptake

Table 32 depicts total N uptake of the residue crop. T_8 (½ LS + ½ RP) recorded the highest uptake of 0.765 g plant^{-1} followed on par by T_4 (¼ LS + ¾ SSP), T_6 (¾ LS + ¼ SSP) and T_3 (full P as RP).Absolute control (T_{11}) registered the lowest uptake of 0.087 g plant^{-1}. All the treatments were significantly superior to it.

4.4.4.2 Phosphorus Uptake

The treatment application significantly influenced bhusa, fruit and total P uptake of the residue crop.

Bhusa

With regard to bhusa P uptake (Table 33), T_8 (½ LS + ½ RP) recorded the maximum P uptake of 0.070 g plant^{-1} followed on par by T_6 (¾ LS + ¼ SSP), T_3 (full P as RP) and T_9 (¾ LS + ¼ RP). Absolute control (T_{11}) registered the lowest P uptake of 0.010 g plant^{-1} and was on par with T_{10} (no P). They were significantly inferior to all other treatments.

Table 32. Effect of treatments on plant nitrogen uptake - residue crop

Treatments	N uptake (g plant^{-1})		
	Bhusa	Fruit	Total
T_1	0.446	0.231	0. 677
T_2	0.401	0.262	0.662
T_3	0.437	0.248	0.685
T_4	0.505	0.235	0.740
T_5	0.432	0.268	0.700
T_6	0.464	0.240	0.704
T_7	0.333	0.252	0.585
T_8	0.468	0.297	0.765
T_9	0.368	0.219	0.587
T_{10}	0.278	0.143	0.421
T_{11}	0.064	0.023	0.087
F (10, 22)	8.08**	4.89**	12.17**
CD (0.05)	0.128	0.100	0.164

**Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

Table 33. Effect of treatments on plant phosphorus uptake - residue crop

Treatments	P uptake (g $plant^{-1}$)		
	Bhusa	Fruit	Total
T_1	0.042	0.044	0.093
T_2	0.040	0.048	0.088
T_3	0.049	0.049	0.097
T_4	0.040	0.044	0.084
T_5	0.042	0.055	0.098
T_6	0.054	0.045	0.099
T_7	0.041	0.051	0.092
T_8	0.070	0.044	0.114
T_9	0.053	0.042	0.095
T_{10}	0.023	0.014	0.037
T_{11}	0.010	0.004	0.014
F (10, 22)	4.57**	13.3**	10.72**
CD (0.05)	0.022	0.013	0.027

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

Fruit

In the case of P, the highest fruit uptake (Table 33) of 0.055 g plant^{-1} was registered by T_5 (½ LS + ½ SSP) followed on par by T_8 (½ LS + ½ RP), T_7 (¼ LS + ¾ RP) and T_3 (full P as RP). Absolute control (T_{11}) registered the lowest uptake of 0.004 g plant^{-1}. T_{10} (no P) and T_{11} were significantly different from each other and significantly inferior to all other treatments.

Total Uptake

The total P uptake (Table 33) ranged from 0.014 to 0.114 g plant^{-1}. The treatment receiving P as ½ LS and ½ RP (T_8) registered the highest uptake followed on par by T_6 (¾ LS + ¼ SSP), T_3 (full P as RP) and T_5 (½ LS + ½ SSP). The lowest uptake was recorded by T_{11} (absolute control) and it was on par with T_{10} (no P). T_{10} and T_{11} were significantly inferior to all other treatments.

4.4.4.3 Potassium Uptake

The K uptake (bhusa, fruit and total) by the residue crop was significantly influenced by the treatments.

Bhusa

The highest bhusa K uptake (Table 34) of 0.929 g plant^{-1} was registered by T_6 (¾ LS + ¼ SSP) followed on par by T_8 (½ LS + ½ RP) and T_1 (full P as LS). Absolute control (T_{11}) recorded the lowest uptake of 0.176 g plant^{-1} and was significantly inferior to all other treatments.

Fruit

The fruit K uptake (Table 34) values ranged from 0.049 to 0.526 g plant^{-1}. The maximum uptake was recorded by T_7 (¼ LS + ¾ RP) followed on par by T_8 (½ LS + ½ RP), T_5 (½ LS + ½ SSP) and T_3 (full P as RP). Absolute control (T_{11}) recorded the minimum value.

Table 34. Effect of treatments on plant potassium uptake – residue crop

Treatments	K uptake (g $plant^{-1}$)		
	Bhusa	Fruit	Total
T_1	0.868	0.473	1.341
T_2	0.816	0.472	1.288
T_3	0.815	0.504	1.319
T_4	0.801	0.502	1.303
T_5	0.809	0.522	1.331
T_6	0.929	0.497	1.426
T_7	0.731	0.526	1.258
T_8	0.911	0.514	1.425
T_9	0.851	0.477	1.328
T_{10}	0.602	0.294	0.896
T_{11}	0.176	0.049	0.225
F (10, 22)	5.27**	11.68**	13.47**
CD (0.05)	0.271	0.124	0.281

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

Total Uptake

The treatment receiving P as ¾ LS and ¼ SSP (T_6) recorded the highest total K uptake (Table 34) of 1.426 g $plant^{-1}$ followed on par by T_8 (½ LS + ½ RP) and T_1 (full P as LS). The lowest uptake of 0.225 g $plant^{-1}$ was registered by T_{11} (absolute control) and was significantly inferior to all other treatments.

4.4.4.4 Calcium Uptake

The bhusa, fruit and total Ca uptake were significantly influenced by the treatments.

Bhusa

The bhusa Ca uptake (Table 35) ranged from 0.050 g $plant^{-1}$ to 0.275 g $plant^{-1}$. The maximum uptake was recorded by T_1 (full P as LS) followed on par by T_8 (½ LS + ½ RP) and T_3 (full P as RP). The lowest uptake was recorded by absolute control (T_{11}) and it was on par with T_{10} (no P) and they were significantly inferior to all other treatments.

Fruit

T_3 (full P as RP) recorded the highest fruit Ca uptake (Table 35) of 0.052 g $plant^{-1}$ followed on par by T_8 (½ LS + ½ RP), T_7 (¼ LS + ¾ RP) and T_6 (¾ LS + ¼ SSP). The lowest uptake of 0.005 g $plant^{-1}$ was registered by T_{11} (absolute control) and was on par with T_{10} (no P). All the treatments were significantly superior to T_{10} and T_{11}.

Total Uptake

With regard to Ca (Table 35), the maximum uptake of 0.316 g $plant^{-1}$ was registered by T_1 (full P as LS) followed on par by T_3 (full P as RP) and T_8 (½ LS + ½ RP). Absolute control (T_{11}) recorded the minimum value of 0.055 g $plant^{-1}$ and all the treatments were significantly superior to it.

Table 35. Effect of treatments on plant calcium uptake – residue crop

Treatments	Ca uptake (g $plant^{-1}$)		
	Bhusa	Fruit	Total
T_1	0.275	0.041	0.316
T_2	0.215	0.047	0.262
T_3	0.250	0.052	0.302
T_4	0.212	0.044	0.256
T_5	0.246	0.040	0.286
T_6	0.230	0.047	0.278
T_7	0.196	0.050	0.247
T_8	0.250	0.044	0.294
T_9	0.221	0.043	0.264
T_{10}	0.113	0.013	0.126
T_{11}	0.050	0.005	0.055
F (10, 22)	7.51**	4.2**	11.65**
CD (0.05)	0.071	0.022	0.069

*Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

4.4.4.5 Magnesium Uptake

The total Mg uptake as well as that by individual bhusa and fruit was significantly influenced by the treatments.

Bhusa

The bhusa uptake of Mg (Table 36) ranged from 0.021 to 0.152 g plant^{-1}. The maximum uptake was registered by T_1 (full P as LS) followed on par by T_8 (½ LS + ½ RP), T_9 (¾ LS + ¼ RP) and T_3 (full P as RP). Absolute control (T_{11}) registered the minimum value and was on par with T_{10} (no P). All the treatments were significantly superior to these.

Fruit

The data on fruit uptake of Mg (Table 36) revealed that it varied from 0.001 to 0.014 g plant^{-1}. T_8 (½ LS + ½ RP) recorded the highest uptake followed on par by T_5 (½ LS + ½ SSP) and T_3 (full P as RP). The lowest value was recorded by T_{11} (absolute control) and it was significantly inferior to all other treatments.

Total Uptake

The total uptake of Mg (Table 36) varied from 0.022 to 0.162 g plant^{-1}. The maximum value was recorded by T_1 (full P as LS) followed on par by T_8 (½ LS + ½ RP) and T_3 (full P as RP). Absolute control (T_{11}) recorded the lowest value and it was on par with T_{10} (no P). These two treatments were significantly inferior to all other treatments.

4.4.5 Economic Analysis

The economic analysis (Table 37) of input and out put costs of residue crop showed that the highest benefit-cost ratio of 1.993 for T_8 (½ LS + ½ RP) and the lowest of 0.493 for T_{11} (absolute control), which was significantly inferior to all other treatments.

Table 36. Effect of treatments on plant magnesium uptake - residue crop

Treatments	Mg uptake (g $plant^{-1}$)		
	Bhusa	Fruit	Total
T_1	0.152	0.010	0.162
T_2	0.123	0.012	0.135
T_3	0.127	0.009	0.135
T_4	0.100	0.010	0.109
T_5	0.125	0.012	0.137
T_6	0.099	0.011	0.107
T_7	0.104	0.008	0.111
T_8	0.144	0.014	0.158
T_9	0.130	0.008	0.138
T_{10}	0.039	0.002	0.041
T_{11}	0.021	0.001	0.022
F (10, 22)	11.91**	2.55*	13.64**
CD (0.05)	0.035	0.007	0.036

*Significant at 5 per cent level, **Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

Table 37. Benefit - cost ratio of treatments - residue crop

Treatments	B:C ratio
T_1	1.827
T_2	1.793
T_3	1.950
T_4	1.957
T_5	1.967
T_6	1.817
T_7	1.963
T_8	1.993
T_9	1.817
T_{10}	1.176
T_{11}	0.493
F (10, 22)	12.41**
CD (0.05)	0.385

** Significant at 1 per cent level

T_1 – Full P as LS
T_2 – Full P as SSP
T_3 – Full P as RP
T_4 – ¼ P as LS + ¾ P as SSP
T_5 – ½ P as LS + ½ P as SSP
T_6 – ¾ P as LS + ¼ P as SSP
T_7 – ¼ P as LS + ¾ P as RP
T_8 – ½ P as LS + ½ P as RP
T_9 – ¾ P as LS + ¼ P as RP
T_{10} – No P
T_{11} – Absolute control

DISCUSSION

5. DISCUSSION

The salient results of the investigations carried out at College of Agriculture, Vellayani, to evaluate latex sludge as a source of P in crop production are discussed here. This investigation was carried out in four steps.

5.1 Study of the basic properties of latex sludge.

5.2 Incubation study on its nutrient mineralization.

5.3 Study of the effect on a main crop of chilli

5.4 Study of the residual effect on a subsequent crop of chilli

5.1. BASIC PROPERTIES OF LATEX SLUDGE

Preliminary studies have shown, latex sludge, a waste product of concentrate latex industry, to be a very rich source of plant nutrients especially P (Lowe, 1968 and Wahab *et al.*, 1979). Its suitability under Indian conditions was shown by George *et al.*, through their trials in cover crops in 1991 and in immature rubber in 1994 (George *et al.*, 1991 and George *et al.*, 1994).

The material was near neutral (pH 6.49) in reaction (Table 4a and 4b). Lowe (1968) observed that the pH buffering effect of LS imparted by its magnesium phosphate content eliminated the need for further liming a soil. George *et al.* (1994) observed no significant difference in soil pH by the application of LS continuously for three years. These results substantiate the neutrality of the material. A fertilizer material that does not change soil pH is highly beneficial, especially under Kerala conditions where majority of soils are acidic.

The material being magnesium ammonium phosphate, it contains Mg, N and P. In addition, it contains organic C, Ca and K. The total P content was 35.98 per cent. Closely agreeing values of 37.43 per cent and 32.70 per cent P_2O_5 in LS was reported by Wahab *et al.* (1979) and George *et al.* (1994) respectively. The nutrient value is higher than that of commonly used rock phosphates like Mussooriephos and Rajphos. Of the total P, the water soluble fraction was 13.18 per cent. A similar value of 13.16 per cent was reported by Wahab *et al.* (1979). The citrate soluble P fraction in the present study was 35.66 per cent which was much higher than that of commonly used rock phosphate - Mussooriephos, which is 7.5 per cent according to Awasthi (1990). The available P content, which is the sum of water and citrate soluble fractions, is 48.84 per cent. The presence of both fractions is an added advantage for LS in comparison to RP and SSP, as this provides both readily available and slowly available forms of P, making it suitable for a wide range of crops and soils. In RP, the P fraction is only slowly available while in SSP the entire fraction is water soluble posing problems of fixation in acidic soil (Tisdale *et al.*, 1997).

But in slight contrast to the above findings, Lowe (1968) reported 25 per cent P_2O_5 in the sample of LS. This variation in P_2O_5 content may be due to the heterogeneity of the chemical composition of latex arising due to differences in genetic and environmental factors. A wide variation in the nutrient content of LS especially that of citrate soluble P and Mg even on a daily basis, was observed by Wahab *et al.* (1979).

Wahab (1976) and George *et al.* (1991) opined that, the presence of small amounts of rubber residues enabled the sludge to behave as an 'encapsulated' fertilizer slowly releasing the nutrients in accordance with crop growth and need. Further, the leaching loss of nutrients under heavy rainfall conditions of Kerala can be minimized.

The presence of about five per cent organic C is another factor contributing to the suitability of LS as an organic P source. In general, organic C can improve the porosity of the material and enlarge its internal surface area for better dissolution in soils. Moreover, the CO_2 evolved during its disintegration produces weak carbonic acid, which dissolves the phosphate.

The N content of the material was 6.05 per cent and Mg content 6.86 per cent, while K and Ca contents were less than one per cent. George (2003) recorded 5.00 percent N, 0.80 per cent K, 1.00 per cent CaO and 14.00 per cent MgO in LS. George *et al.* (1991) suggested that N in sludge being present as ammonium phosphate was readily plant available. The presence of Mg in LS is highly beneficial as it is needed by many plants in about the same quantities as P (Tisdale *et al.*, 1997), being a primary constituent of chlorophyll molecule, structural component of ribosomes and involved in the phosphate transfer from ATP (Devlin and Witham, 1983). The Mg content obtained in the present study is comparable to that reported by Lowe (1968) and John *et al.* (1977).

5.2 INCUBATION STUDY

5.2.1 Soil pH

The various phosphatic sources could not bring about a significant change in soil pH (Table 6) at any stage of incubation. The neutral nature of LS (pH 6.49) may be the possible reason for it not bringing about any change in soil pH. Moreover, the magnesium phosphate in the sludge has a pH buffering effect as indicated by Lowe (1968). George *et al.* (1991) in an incubation study for a period of 90 days to understand the P release pattern from LS in comparison with SSP and RP noticed no significant difference in soil pH by the application of these different sources at different incubation periods. The insignificant effect of SSP and RP to change soil pH was noticed by Sharma and Sinha (1989) and Datta and Sharma (2001). So in this respect, LS is comparable to the conventional P sources – SSP and RP.

5.2.2 Electrical Conductivity

A perusal of the data (Table 7) revealed that soil EC was significantly influenced by the treatments. Except on 90^{th} and 105^{th} day, the effects of various P sources on soil EC were statistically comparable. Absolute control recorded the lowest value throughout the incubation period. Irrespective of the source of P, the highest EC values were registered on the 45th day of incubation. The enrichment of the soil solution by exchangeable ions like $Ca^{2+}$and Mg^{2+} which recorded higher values during this period, together with the phosphates might have contributed to this phenomenon. A similar significant effect of applied P on the EC of the medium was earlier reported by Baevre and Gislerod (1990).

5.2.3 Organic Carbon

The superiority of LS over other P sources in increasing the soil organic C content was evident from the incubation study since it contains5.09 per cent organic carbon (Table 8 and Fig.3).

The treatment effects became significant from the 30th day and continued the same trend till the end of incubation. Latex sludge was significantly superior to RP and SSP in increasing organic C content. Absolute control recorded the lowest content throughout the incubation period and it was significantly inferior to all other treatments.

In the case of LS, the values gradually increased to a maximum on 75th day followed by a slow decline. But for SSP and RP such a definite pattern was not observed. Subehia (1998) indicated the superiority of SSP over RP in increasing organic C content, while a reverse result was given by De *et al.* (1984).

The requirement of 30 days for LS to produce a significantly superior effect on organic C content, compared to other P sources, might be due to the slow activity of microorganisms in disintegrating the isoprene units of rubber residues, which are present in low concentration in the sludge.

Much research has not been undertaken on the effect of LS on the organic C content of the soil. But Dolmat *et al.* (1979) and Bachik *et al.* (1987) showed that application of rubber effluent to rubber trees increased soil organic C content.

5.2.4 Available Nitrogen

The treatment application significantly influenced soil available N at all stages except the 120th DOI (Table 9 and Fig.4).

All the P sources showed a gradual increase in available N content up to 60th day followed by a decline. Latex sludge recorded the highest value throughout the incubation period except on 105th day. Except on 15th and last two sampling days, LS was significantly superior to both RP and SSP as far as available N content was concerned.

The additional presence of N in considerable quantity (about 6.00 per cent) makes LS superior to the conventional P sources. George *et al.* (1991) suggested that N is present in the sludge as ammonium phosphate. The enhancement of soil available N on its application, clearly indicates that this ammoniacal N is in the readily available form. The overall effect of P application according to Singaram and Kothandaraman (1992) was to encourage the build up of available N, attributable to enhanced microbial activity.

Wahab (1976) and George *et al.* (1991) indicated that the substantial amount of rubber residues remaining in the sludge enabled it to act as an encapsulated fertilizer. This might be the reason for the slow but steady increase in soil available N up to 60th day with LS application.

5.2.5 Available Phosphorus

The soil available P was significantly influenced by the various sources – LS, SSP and RP (Table 10 and Fig.5). There was a gradual increase in P content to a maximum value followed by a decline in the

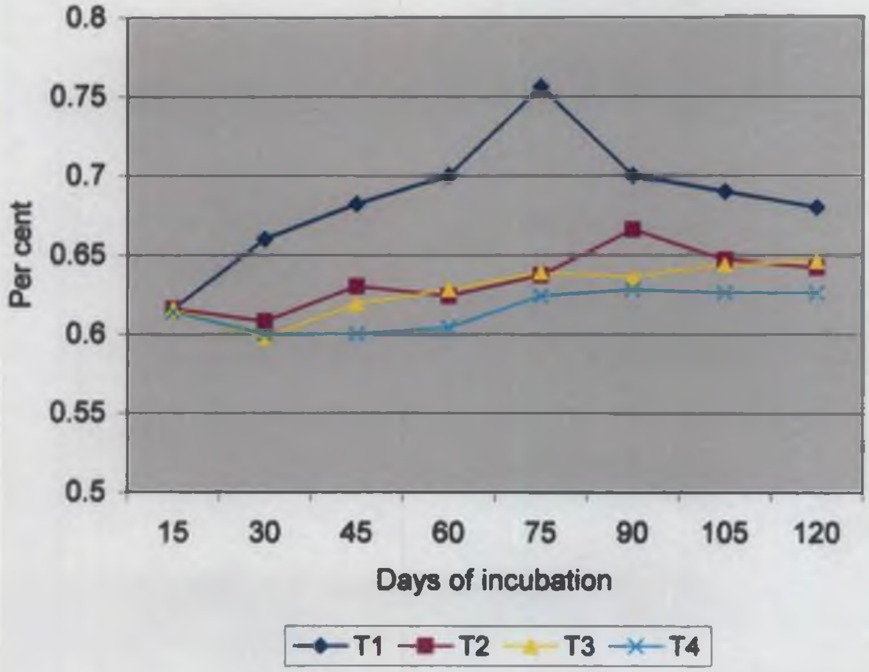


Fig. 3 Organic carbon-incubation study

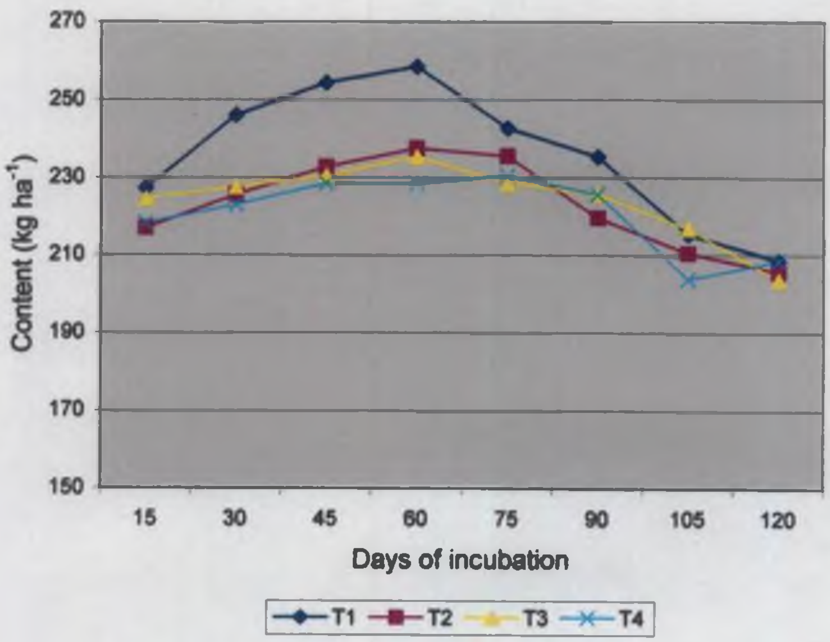


Fig. 4 Available nitrogen-incubation study

case of all treatments. The absolute control recorded the lowest value throughout the incubation period.

On the 15th day, all the treatments were significantly different from each other in their P contents and the highest value was recorded by SSP. This might be expected as the entire fraction of P in SSP is water soluble. Latex sludge recorded the next highest value and was significantly superior to RP. This might be due to the water soluble phosphates present in LS as evidenced by the earlier analytical procedures.

SSP maintained higher value on 30th day also but was on par with LS. So it can be inferred that, by 30th day the P release from these two sources became comparable. Further, these two sources were significantly superior to RP. The uniform release pattern of both latex sludge and SSP continued till the 90th day and thereafter the three sources became on par in their P release capacities. Similar pattern of P release on an incubation study with LS, SSP and RP was reported by George *et al.* (1991).

The three P sources registered the highest P content on 75th day followed by a decline. Such behaviour may be expected as the maximum availability limit might perhaps have reached. In view of the absence of uptake by plants under incubation conditions, the process of P fixation might have been preponderant over solubilizing ones at the maximum availability limit (Singh *et al.*, 1976).

When compared to RP, LS maintained the highest P content throughout the period of incubation. Except on the last two stages of sampling when all the three sources were on par, LS was significantly superior to RP in their P content. So, it is to be inferred that LS is a better option than RP, considering both the cost and P availability.

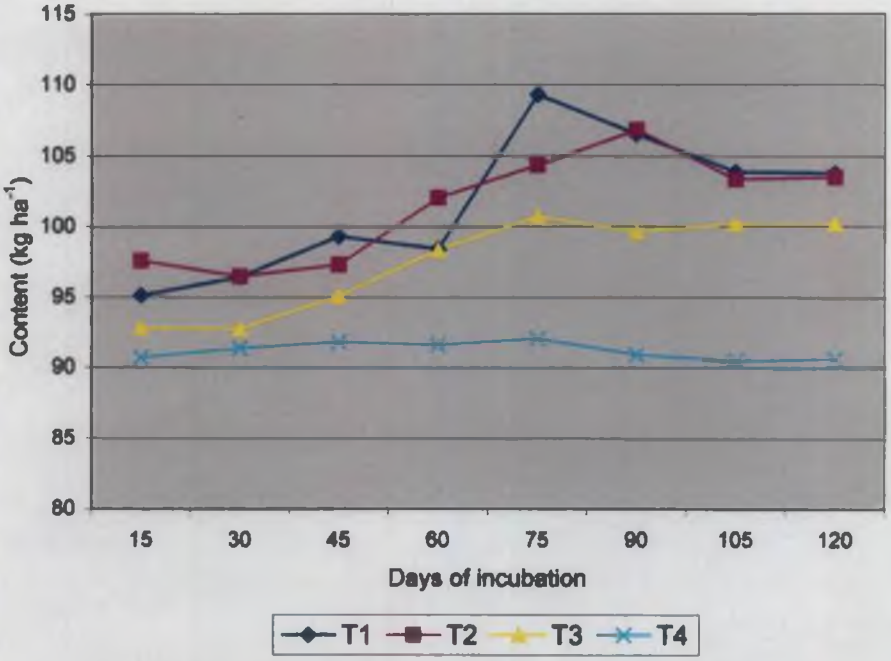


Fig. 5 Available phosphorus-incubation study

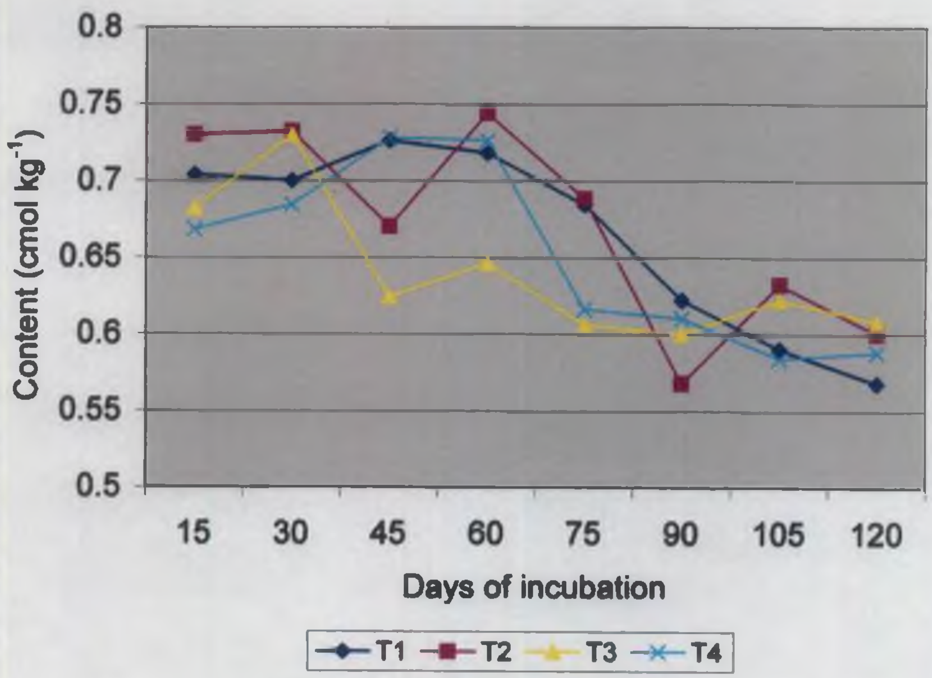


Fig. 6 Exchangeable magnesium-incubation study

5.2.6 Available Potassium

The soil available K was not significantly influenced by the application of any P source (Table 11).

The material used in the present study had a K_2O content of 0.86 per cent. Very closely agreeing value was earlier reported by George (2003). Lowe (1968) recorded 5.90 per cent K in LS while Wahab *et al.* (1979) recorded 2.49 per cent K_2O.

The inherent very low K content of LS (less than one per cent) and that too added in very small quantity might be the reason in the present incubation study, for the material having only insignificant influence on soil available K. Moreover, the soil used for study rated low in K status as indicated by initial analysis.

Singaram and Kothandaraman (1992) found that RP and SSP application in a clay loam soil did not significantly alter the soil available K.

5.2.7 Exchangeable Calcium

Perusal of the data on exchangeable Ca (Table 12) showed significant effect for various treatments from 45^{th} to 105^{th} day of incubation. The highest exchangeable Ca content was recorded by various P sources on the 45^{th} day followed by a decline. Such behaviour may be expected as the maximum availability limit might perhaps have reached. On all the days when treatment effects were significant, except 75^{th} day, LS was on par with RP in increasing soil exchangeable Ca.

The inherent very low Ca content (less than one per cent) along with its encapsulated nature might be the reason for LS not producing any significant influence on soil exchangeable content of Ca during the initial periods of incubation. Similar low Ca content in LS was earlier reported by John *et al.* (1977) and Wahab *et al.* (1979).

5.2.8 Exchangeable Magnesium

The various P sources produced significant effect on exchangeable Mg content of soil (Table 13 and Fig.6) only from 45th to 75th day of incubation. When compared between sources and stages of sampling, the release pattern showed high inconsistency. However, LS recorded the highest exchangeable Mg content on 45th day followed by a decline. Such behaviour may be expected as the maximum availability limit might perhaps have reached. In view of the absence of uptake by plants under incubation conditions, it might have become fixed in the clay lattice due to coprecipitation with $Al(OH)_3$ (Tisdale *et al*., 1997).

5.3 MAIN CROP OF CHILLI

The suitability of LS as P fertilizer for cereals like rice and maize was postulated by Lowe (1968), while George (2003) recommended the same for both mature and immature rubber.

As further elucidation of the results of the incubation studies, a pot culture experiment was undertaken with chilli (var. Jwalamukhi) as the test crop under field conditions. The feasibility of LS as a P source was compared against two conventional P sources *viz*., SSP and RP.

5.3.1 Growth Characters of Chilli

All growth characters studied *viz*., plant height, number of branches per plant, number of leaves and leaf area were significantly influenced by treatment application (Table 14 and Plate 3, 4).

With regard to the effect of various sources of P on these growth characters, the maximum values in all the cases were recorded when full P was given as SSP (T_2). And in all the four cases, they were on par with the combination treatment T_8 (½ LS + ½ RP).

The immediately available water soluble P in SSP might have given the plant an initial growth advantage, thereby recording higher values for all these growth characters. But the effect was on par with the

Plate 3. Effect of treatments on growth characters of chilli

Plate 4. Effect of treatments on growth characters of chilli

combination treatment containing P half as LS and half as RP. This might be due to the cumulative effect of water soluble P in LS as ammonium phosphate and its Mg content. Moreover, when LS was used in conjunction with RP, one third of total P becomes water soluble as indicated by George (2003). So, the adequate supply of P along with other nutrients especially N, Mg and K might have promoted chlorophyll synthesis, which in turn resulted in higher rate of photosynthesis and enhanced metabolism finally resulting in good vegetative growth of the plant.

The favourable effect of P on the growth characters of chilli was earlier reported by John (1989).

5.3.2 Yield and Yield Attributes of Chilli

The treatment application significantly enhanced the individual yield and yield attributing characters of the plant like number of days to reach first flowering, number of fruits per plant and mean weight of fruit (Table 15 and Fig.7a,7b). Agreeing results were earlier reported by John (1989).

Full P as LS (T_1) and the combination treatment ¾ LS and ¼ SSP (T_6) were the earliest to flower and was on par with T_8 (½ LS + ½ RP). Number of fruits per plant was the highest in the combination ¼ LS and ¾ RP (T_7) followed on par by T_8 and hence the same treatments recorded maximum fruit yield per plant. The highest mean fruit weight was recorded by T_8 and T_2 (full P as SSP).

So in general, yield and yield attributing characters were favourably influenced by LS when applied either alone or in combination.

In chilli, the greatest P requirement is from ten days after flowering to just before the fruits begin to ripen (Hegde, 1997) and this period coincides with 45 to 150 days after planting (Kaminwar and

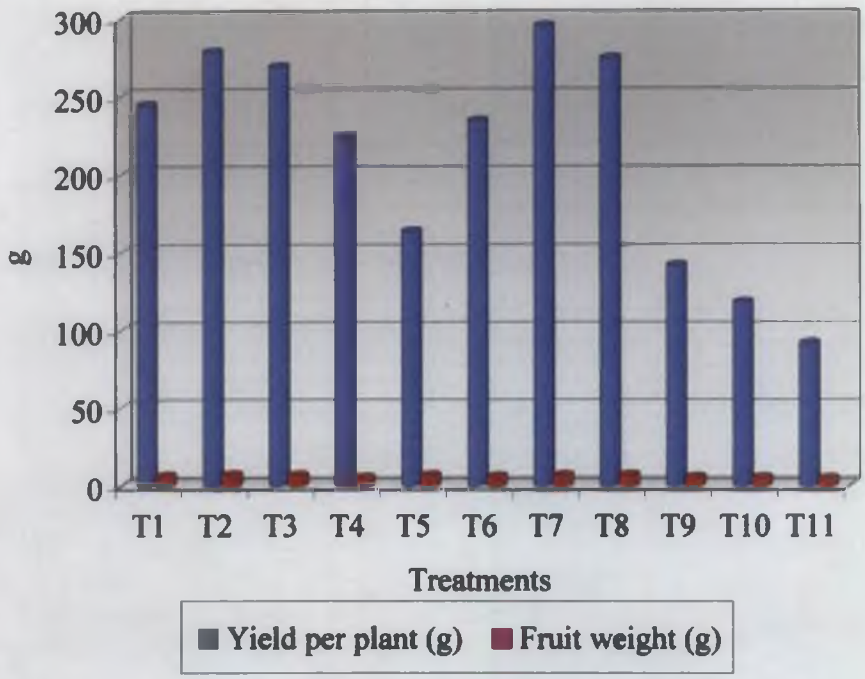


Fig. 7a Yield per plant and fruit weight - main crop

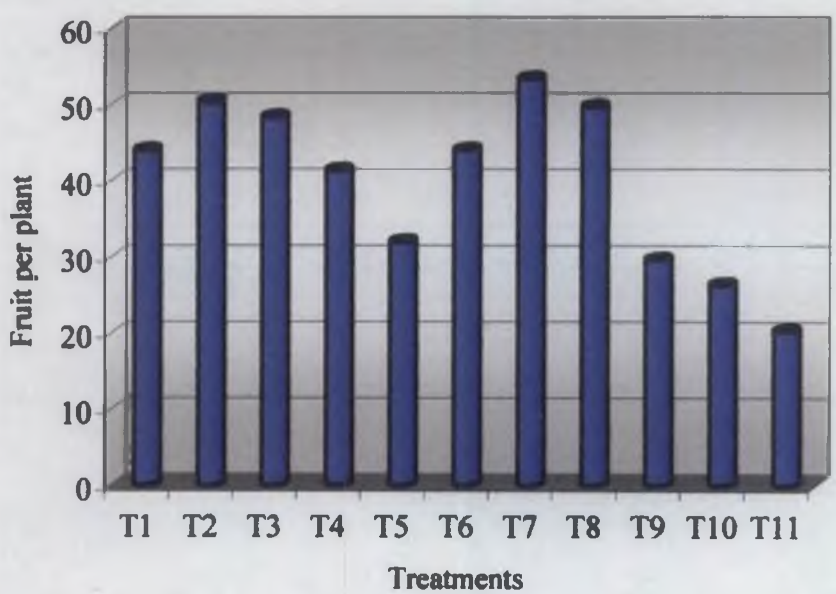


Fig. 7b Number of fruits per plant - main crop

Rajagopal, 1993). From the incubation study, it is evident that LS maintained high soil available P during this period of flowering and fruiting. So the adequate P supply might have enhanced metabolism and uptake of nutrients in general, resulting in early flowering, better partitioning of photosynthates, higher setting percentage, mean fruit weight, maximum number of fruits per plant and thereby total yield per plant. Moreover, the presence of Mg, which is required for maximal activity of almost every phosphorylating enzyme in carbohydrate metabolism (Tisdale *et al.*, 1997), might have also played a pivotal role.

The favourable effect of P on the yield and yield attributing characters of chilli was earlier reported by John (1989).

5.3.3 Quality Characters of Chilli

Significance could be observed for treatment application on quality characters of fruit like ascorbic acid, capsaicin, oleoresin and protein.

Ascorbic acid

The maximum ascorbic acid content (Table 16 and Fig.9) was recorded by T_5 (½ LS + ½ SSP) followed on par by T_8 (½ LS + ½ RP). According to Smirnoff (1996), ascorbic acid biosynthesis requires high energy P containing compounds like ATP and NADP for the activity of essential enzymes like ascorbate oxidase, monodehydro ascorbate reductase and sorbosone dehydrogenase. Moreover, some of the intermediaries are sugar phosphates. High ascorbic acid content for LS containing combination treatments indicates that it might have ensured enough availability of P for the synthesis of the various intermediary sugar phosphates and the high energy compounds resulting in enhanced ascorbic acid synthesis. The enhanced metabolism and photosynthetic activity in the plant resulting from adequate supply of P and Mg from LS might also have played a role as ascorbic acid synthesis is correlated with photosynthetic capacity and with the supply of soluble carbohydrates (Smirnoff and Pallanca, 1996). Significant effect of P on increasing the ascorbic acid content in chilli was found by Uddin and Begum (1990).

Capsaicin

Capsaicin, (Table 16 and Fig.10) the most important quality trait in chilli is the condensation product of 3 – hydroxy, 4 – methoxy benzylamine and decylenic acid. Full P as LS (T_1) recorded the highest capsaicin content which was on par with T_8 (½ LS + ½ RP). Reports by Bennett and Kirby (1968) indicated that capsaicin biosynthesis begins from amino acids - phenyl alanine and valine and that high energy compounds like ATP and NADP are involved in the activation of many concerned enzymes in the biochemical pathway like 3 methyl-2-oxobutanoate dehydrogenase, capsaicinoid synthase and acyl ACP thioesterase. The favourable effect of application of LS either alone or in combination in increasing capsaicin content might be due to its beneficial role in increasing amino acid synthesis and thereby protein synthesis, favoured by the increased uptake of P and N. Moreover, adequate availability of high energy compounds in the plant system under assured P nutrition might have enhanced the activity of enzymes involved in capsaicin synthesis. Similar confirmatory reports have been put forward by Niranjana and Devi (1990).

Oleoresin

Combination treatment T_8 (½ LS + ½ RP) was on par with T_2 (full P as SSP) in the production of oleoresin (Table 16 and Fig.8). According to Lichtenthaler *et al.* (1997), isopentenyl diphosphate is the precursor of oleoresin in plants. So the adequate P supply from the combination treatment containing LS might have enhanced the biosynthesis of this precursor. Yodpetch (2000) observed that P application positively enhanced oleoresin content in cayenne pepper (*Capsicum annuum* L.).

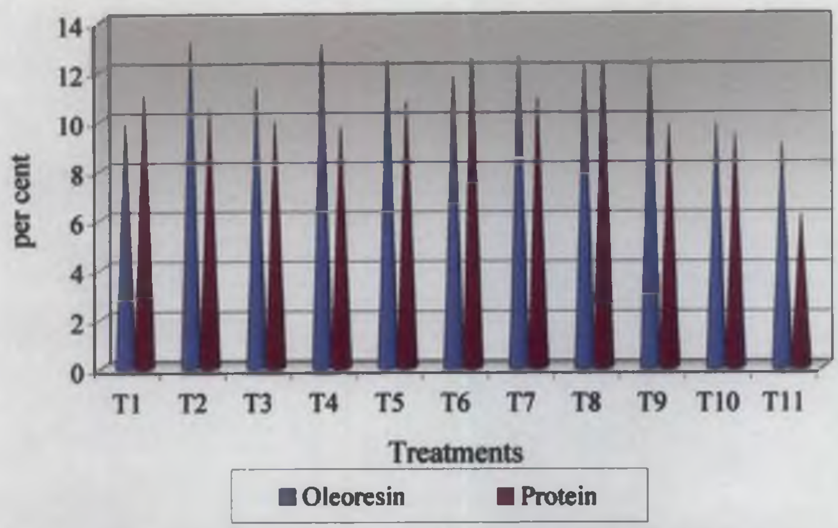


Fig. 8 Fruit oleoresin and protein content- main crop

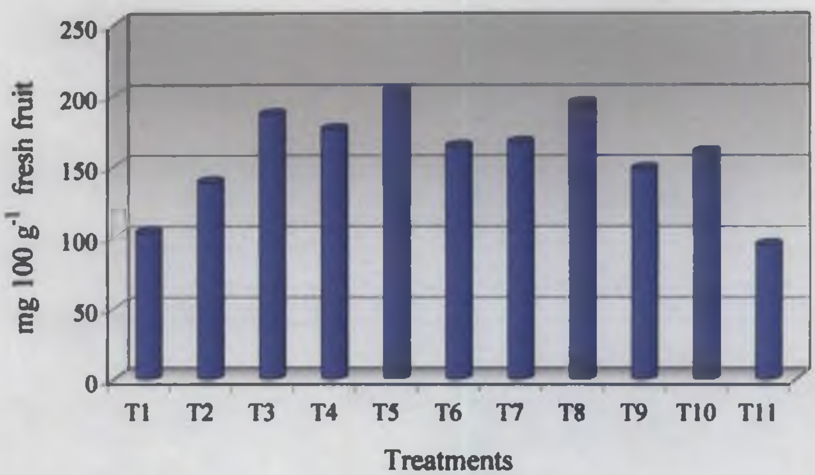


Fig. 9 Fruit ascorbic acid content-- main crop

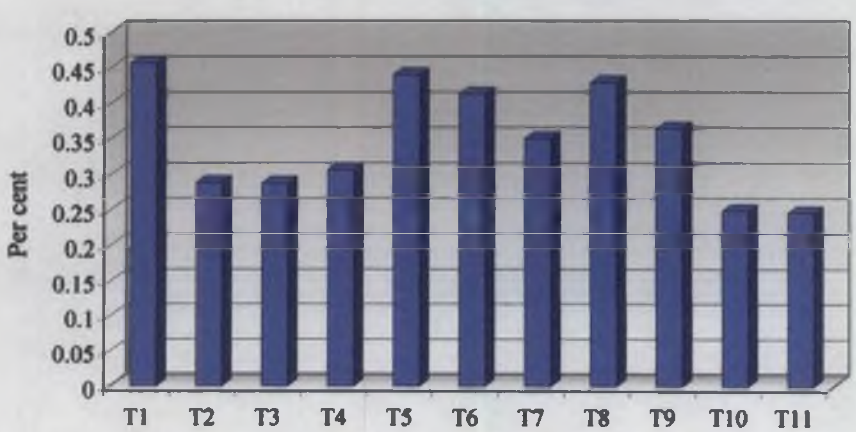


Fig. 10 Fruit capsaicin content- main crop

Proteins

The highest fruit protein content (Table 16 and Fig.8) was registered by T_6 (¾ LS + ¼ SSP) and was on par with T_8 (½ LS + ½ RP). The superior effect of LS containing combination treatments on increasing fruit protein content might be due to the easy and enhanced availability of N and P from the sludge as ammonium phosphate. This might have resulted in higher plant N content, inducing enhanced amino acid synthesis all these leading to increased protein synthesis. The fact that P is essential in the formation of effective polyribosome complex that precedes active incorporation of amino acids into protein (Lubin and Ennis, 1964) might have also played a pivotal role.

5.3.4 Total Dry Matter Production

Total dry matter production (Table 17) was significantly influenced by treatment application. When dry matter production and yields were critically observed, a close relationship was found to exist between these two. The treatment T_7 (¼ LS + ¾ RP) which gave the highest fruit yield recorded the highest dry matter production too and was on par with T_8 (½ LS + ½ RP). Such an association between dry matter and yield had been earlier reported by Datta *et al.* (1972).

Kaminwar and Rajagopal (1993) observed that dry matter production in chilli was significantly influenced by P and that it increased continuously from 45 to 150 days after planting. The favourable effect of the treatment combinations containing both LS and RP might be due to the steady and continuous P supply by virtue of the encapsulated nature of LS together with slowly available P from RP, thus ensuring adequate P supply during the flowering and fruiting periods of the crop when P requirements are the most high. Moreover, one third of total P becomes water soluble when RP and LS are used in conjunction (George, 2003). All these might have enhanced P uptake along with that of other nutrients resulting in higher rate of growth and better accumulation of photosynthates, finally resulting in increased dry matter production (Dave *et al.*, 1990).

5.3.5 Plant Nutrient Content and Uptake

Phosphorus

With regard to P content (Table 18, 19 and Fig. 11a, 12) in both bhusa and fruit, all the treatments which received P from any source, recorded significantly higher values than the treatments which received no P (T_{10} and T_{11}). The highest P content in bhusa was recorded by T_2 (full P as SSP) and that in fruit by T_9 (¾ LS + ¼ RP) and in both cases they were on par with T_8 (½ LS + ½ RP). Murugan *et al.* (2002) noted that source of P (SSP or RP) did not have any appreciable effect on the P content of chilli but the highest content was registered by SSP. Increase in P content in cereals like rice and maize with LS application was reported by Lowe (1968) while that in cover crop *Peuraria* was indicated by George *et al.* (1994). The effect of rubber effluent in increasing P content in oil palm was shown by Bachik *et al.* (1987) and that in grasses by Tan *et al.* (1975).

Full P given as SSP (T_2) recorded the highest total P uptake (Table 21 and Fig.14) and was on par with T_8 (½ LS + ½ RP). This indicates that the effect of LS and RP when present in equal amounts in increasing P uptake is comparable to that when SSP is used alone. This might be due to the cumulative effect arising from the presence of P in LS in both readily available and slowly available forms which ensure adequate P supply throughout the crop period resulting in high dry matter production in these treatments. Moreover, when LS is used in conjunction with RP, one third of total P becomes water soluble (George, 2003). This water soluble P might have favoured better root formation and initial establishment of the crop. The slowly available acid soluble P, from both LS and RP might have ensured adequate P supply and uptake during the flowering and fruiting stages of the crop when the P requirement is very high (Santiago and Goyal, 1985). Moreover, the acid soluble P from LS due to its gradual and steady release might have escaped large scale fixation reactions in the acidic red loam soil of Vellayani used for the study. The liming effect of LS attributable to its magnesium phosphate content also might have played a complementary role in reducing P fixation. Supporting evidences could be derived from the results of the present incubation study also, in which both LS and RP maintained high soil available P up to 90th day.

Aliyu (2003) indicated an increase in P uptake with the addition of P in chilli. Increased P uptake with LS application was reported in *Peuraria* by Wahab *et al.* (1979), in budded rubber stumps by George *et al.* (1991) and in immature rubber by George (2003).

Other Nutrients

The plant N content (Table 18, 19 and Fig. 11a, 12) and its uptake (Table 20 and Fig. 13) were significantly influenced by treatment application. The highest N contents in both bhusa and fruit were recorded by T_6 (¾ LS + ¼ SSP) and was on par with T_8 (½ LS + ½ RP). The highest total N uptake was for T_7 (¼ LS + ¾ RP) followed on par by T_8. A favourable effect in increasing N content and uptake was noticed for treatment combinations containing LS. This might be due to the presence of N in the sludge as ammonium phosphate and its slow release property bestowed by the encapsulation of the same by the rubber residues. The incubation study also showed a steady increase in soil available N up to 60th day when LS was applied. Moreover, the highest dry matter production was also by the same treatments. An increase in N content of both shoot and fruit of chilli with P application was noted by Aliyu (2003). Singh and Srivastava (1988) observed that N uptake in chilli was positively increased by P application. An increase in N content of pasture grass with LS application was shown by Lowe (1968). Increased N uptake with LS application in vetiver was indicated by

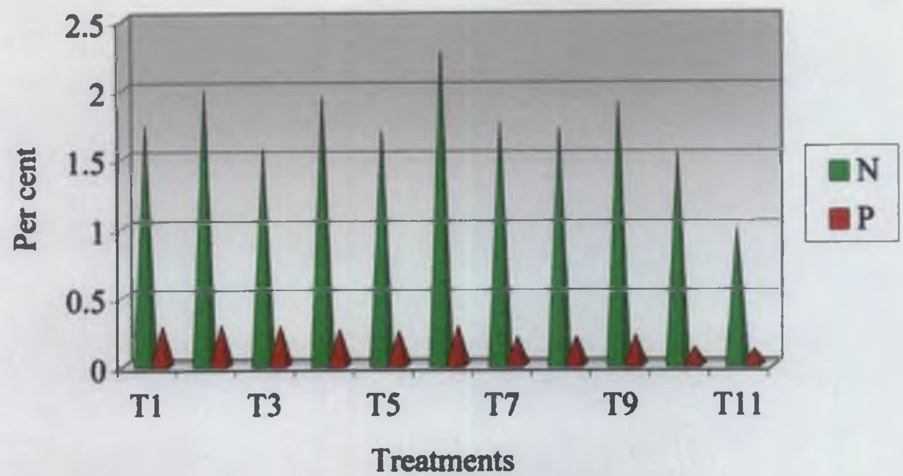


Fig. 11a Concentration of N and P in bhusa - main crop

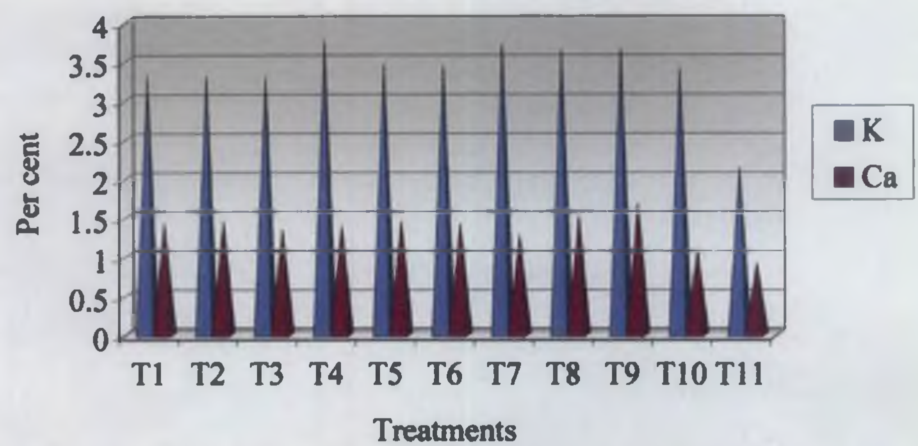


Fig. 11b Concentration of K and Ca in bhusa - main crop

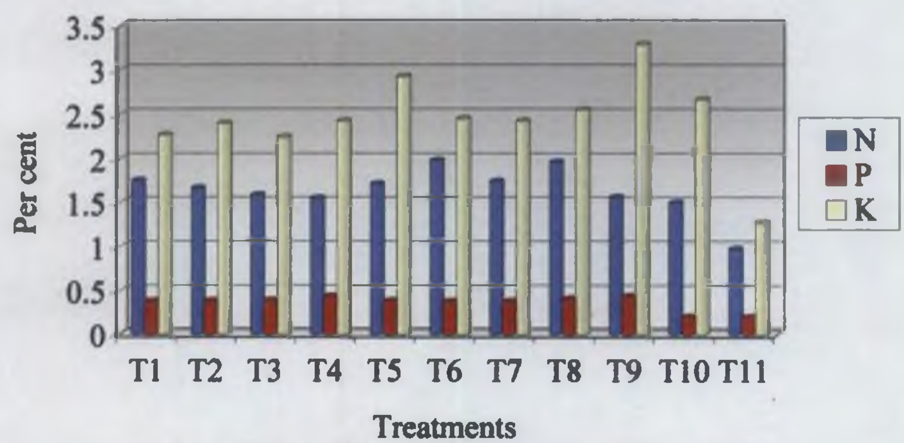


Fig. 12 Concentration of nutrients in fruit - main crop

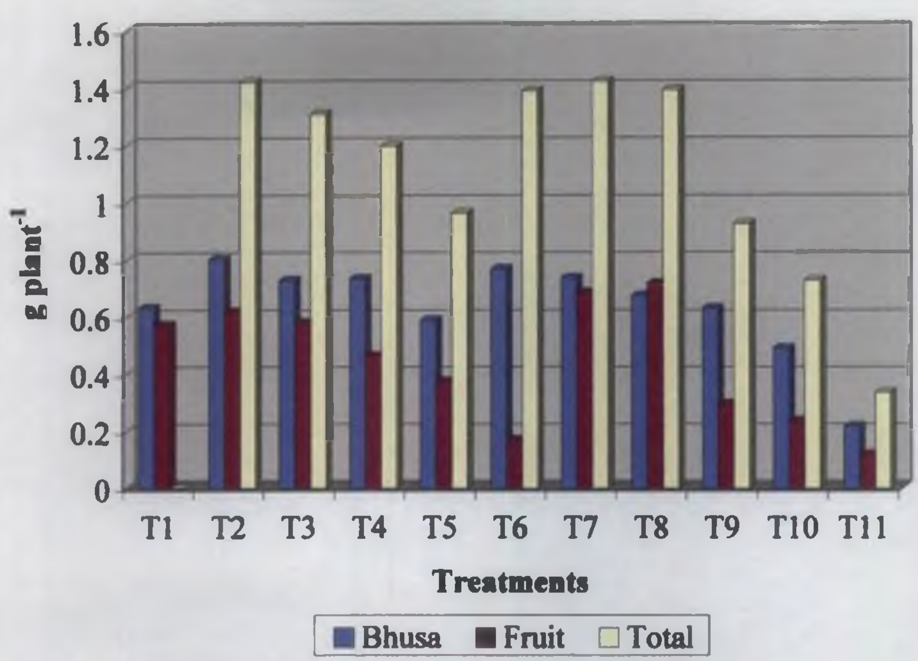


Fig. 13 Plant nitrogen uptake-main crop

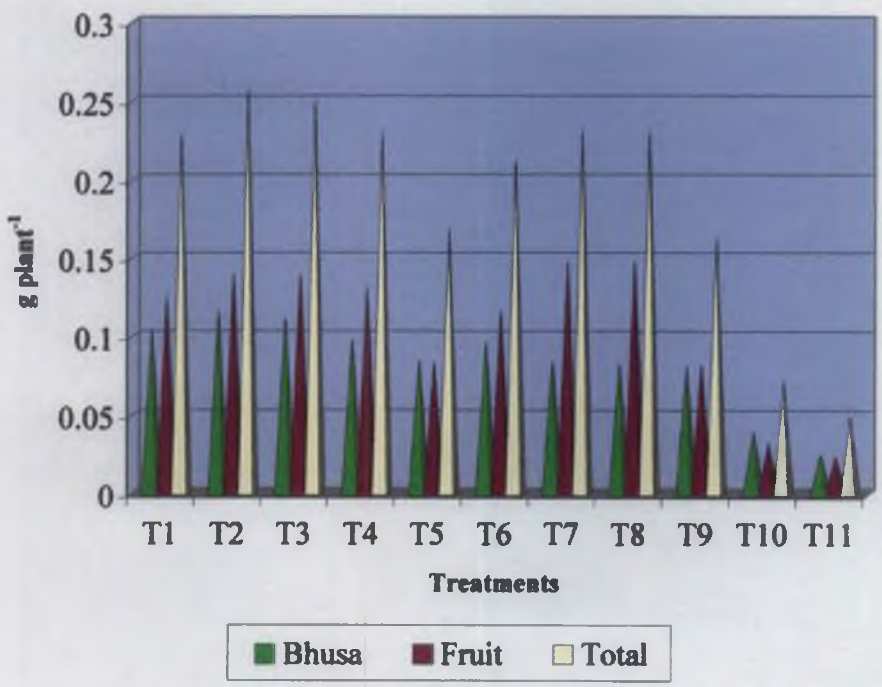


Fig. 14 Plant phosphorus uptake - main crop

Karim *et al.* (1997), in budded rubber stumps by George *et al.* (1991) and in immature rubber by George (2003).

The combination treatments involving LS recorded higher values for both bhusa and fruit K content (Table 18,19 and Fig. 11b, 12) than when SSP or RP were used alone. T_4 (¼ LS + ¾ SSP) recorded the maximum K content in bhusa while T_9 (3/4 LS + ¼ RP) that in fruit. In both cases, they were on par with T_8 (1/2 LS + ½ RP). The highest total K uptake (Table 22 and Fig. 15) was recorded by T_7 (¼ LS + ¾ RP) followed on par by T_8. Adequate P supply in these LS containing combination treatments might have increased K content and its uptake. Moreover, the high dry matter production in these treatments might also have played their own roles. Increase in K uptake with P application in chilli was indicated by Murugan *et al.* (2002). The favourable effect of LS in increasing K uptake in budded rubber stumps was reported by George *et al.* (1991) and that in immature rubber by George (2003).

The Ca content (Table 18, 19 and Fig.11b, 12) of bhusa was significantly influenced by the treatments and the highest content was recorded by T_9 (3/4 LS + ¼ RP) followed on par by T_8 (½ LS + ½ RP). But, the treatments failed to produce any significant effect on fruit Ca content which might be due to the restrictions in Ca movement to fruit even when there are sufficient concentrations within the plant (Tisdale *et al.*, 1997). The highest total Ca uptake (Table 23 and Fig. 16) was recorded by T_8 (½ LS + ½ RP) which was on par with T_7 (¼ LS + ¾ RP). A superior effect was noticed for these combination treatments as Ca supply from LS supplemented that from RP. According to Mathur and Lal (1989), RP is superior to SSP in supplying Ca to plants. The enhanced availability which increased the tissue Ca content and also better dry matter production in these treatments naturally increased uptake also. Murugan *et al.* (2002) noted that in chilli P application increased Ca uptake.

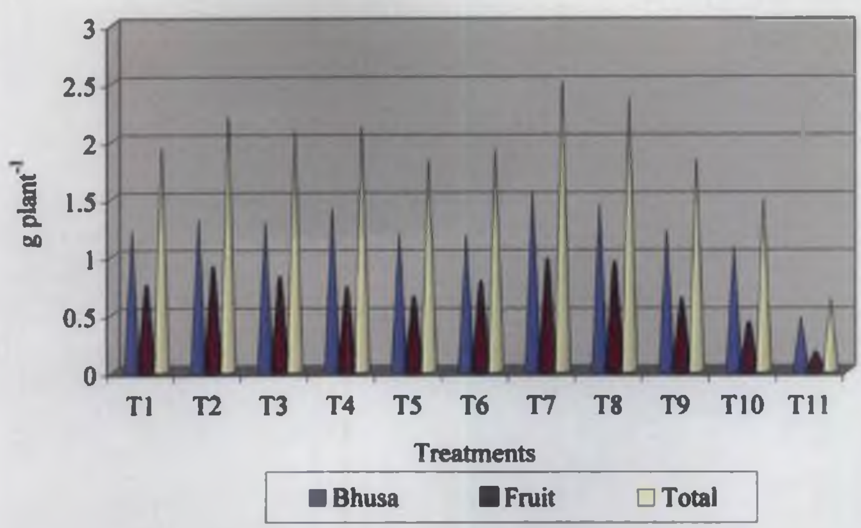


Fig. 15 Plant potassium uptake - main crop

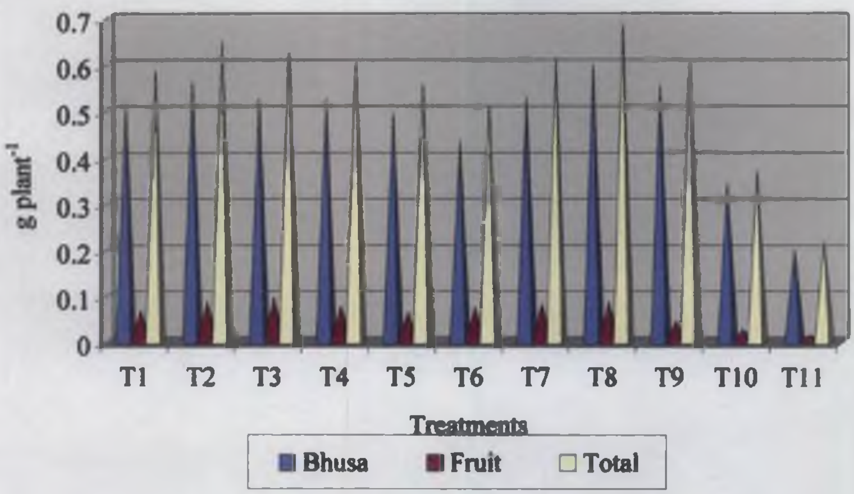


Fig. 16 Plant calcium uptake - main crop

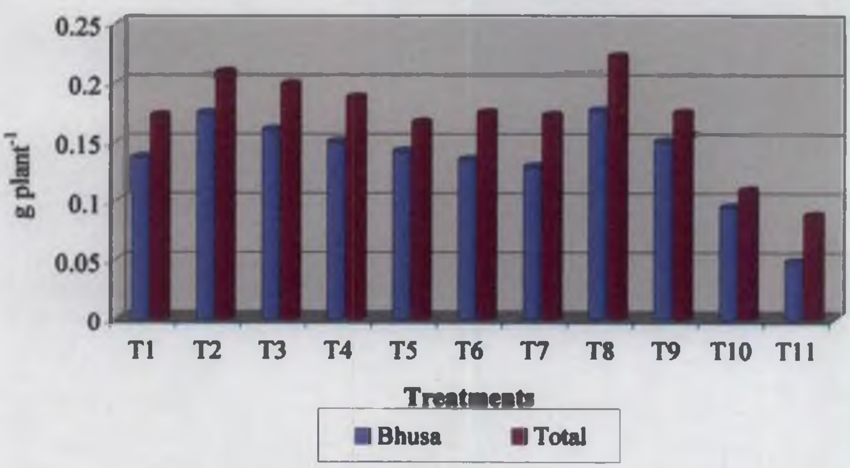


Fig. 17 Plant magnesium uptake - main crop

The treatment application failed to produce any significant effect on plant Mg content (Table 18, 19), but their effects were significant on total Mg uptake (Table 24 and Fig. 17). The maximum value for total uptake was recorded by T_8 (½ LS + ½ RP) followed by T_2 (full P as SSP). Latex sludge being a rich source of Mg resulted in the highest Mg availability as evidenced from the present incubation studies. This might have naturally increased Mg content in plant and this coupled with high dry matter production also by these treatments might have resulted in the highest uptake of the same. Murugan *et al.* (2002) observed increased Mg uptake in chilli with P application. The favourable effect of LS in increasing Mg uptake in maize, mung bean and groundnut were reported by Wahab *et al.* (1979), while that in budded rubber stumps by George *et al.* (1991), in vetiver by Karim *et al.* (1997) and in immature rubber by George (2003).

5.3.6 Soil Properties

5.3.6.1 Soil pH

The various phosphatic sources either alone or in combinations failed to bring about a significant change in pH (Table 26). The result from the present incubation study substantiates this. This might be due to the pH buffering effect of Mg phosphate present in the sludge (Lowe, 1968). George *et al.* (1994) observed no significant difference in soil pH by the application of LS continuously for three years. The insignificant effect of SSP and RP to change soil pH was indicated by Sharma and Sinha (1989) and Datta and Sharma (2001).

5.3.6.2 Electrical Conductivity

Soil EC (Table 26) was significantly influenced by treatment application. The maximum value was registered by T_8 (½ LS + ½ RP) followed by T_1 (full P as LS). The highest values in those treatment combinations containing LS might be due to high availability of P and

Mg from the material as evidenced from the analysis of soil upon crop harvest.

5.3.6.3 Available Nutrients

5.3.6.3.1 Available Phosphorus

Significant increase in soil available P (Table 27 and Fig. 18) was noticed with treatment application. The highest value was recorded by T_8 (½ LS + ½ RP) followed on par by T_7 (¼ LS + ¾ RP). Application of LS along with RP ensures slow and steady P dissolution bestowed by the encapsulated nature in the case of LS and acidic conditions of the soil used for the experiment in the case of RP. Further, liming effect on soil brought about the supply of magnesium phosphate in the case of LS and Ca in the case of RP reduces Fe and Al activity and therefore P fixation. So, these two effects cumulatively might have helped in maintaining a higher soil available P throughout the crop growth period. Increase in soil available P with P application in chilli was reported by Murugan *et al.* (2002). Significant increase in soil available P with LS application was observed by George (2003). Similar effects of rubber effluent were reported by Dolmat *et al.* (1981) and Yapa (1984).

5.3.6.3.2 Other Nutrients

Organic C content of soil (Table 26 and Fig. 18) was significantly influenced by treatment application. Latex sludge when applied either alone or in combination significantly increased soil organic C content. The highest content was recorded by T_1 (full P as LS) and was significantly superior to all other treatments. The favourable effect of LS on organic C content of soil was evident in the incubation studies also. Application of LS promoted plant growth, enhanced soil biological activity and this might have resulted in higher organic C content. Increase in microbial activity with LS application was earlier noticed by Karim *et al.* (1997). Favourable effect of P application on soil organic C

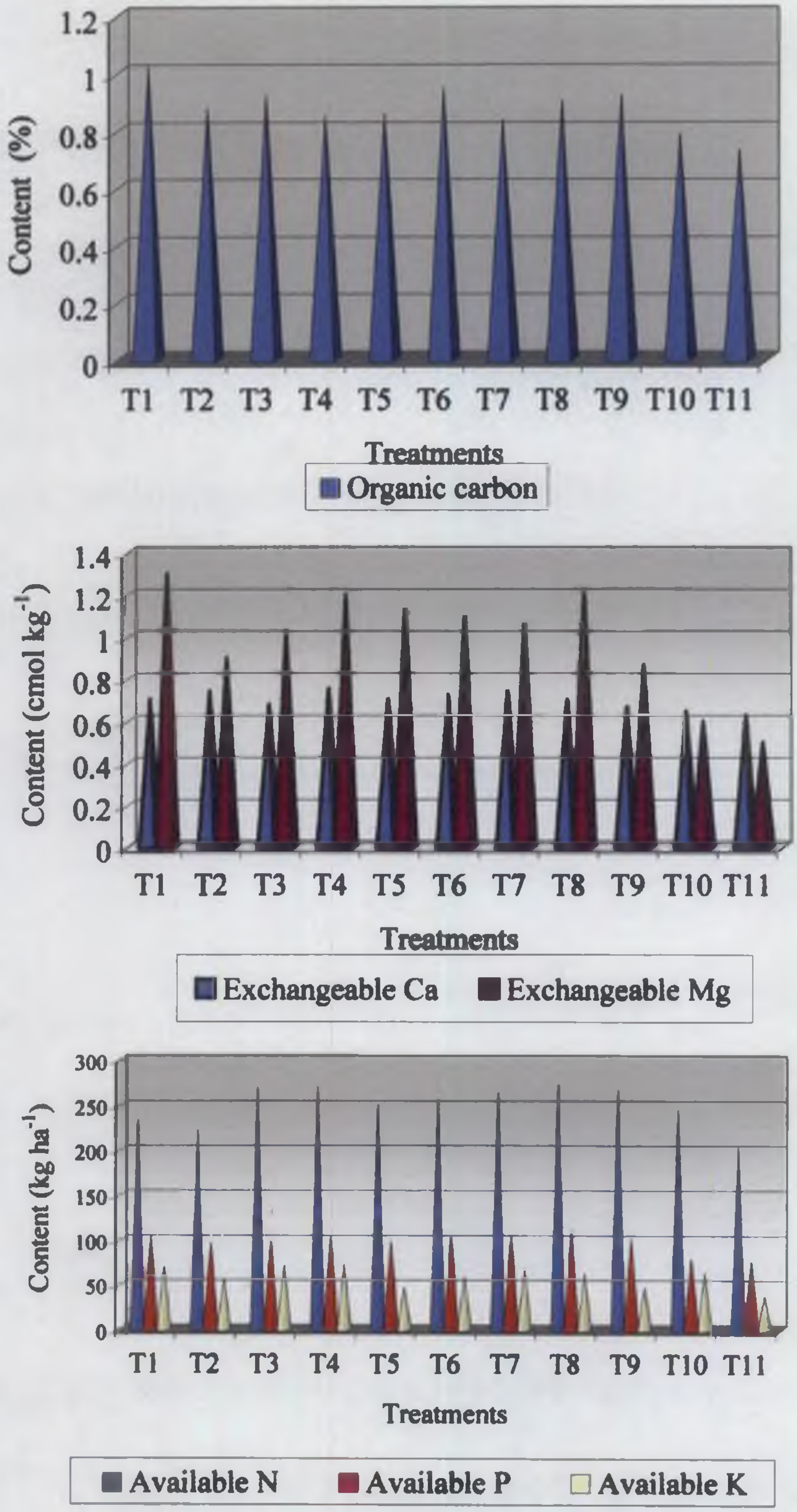


Fig. 18 Chemical analysis of soil - main crop

content was earlier indicated by De *et al.* (1984) and Subehia (1998). Increase in soil organic C with the application of rubber effluent was reported by Dolmat *et al.* (1979) and Bachik *et al.* (1987).

The treatment application significantly increased soil available N (Table 27 and Fig. 18). The highest value was recorded by T_8 (1/2 LS + ½ RP) followed on par by T_4 (¼ LS + ¾ SSP). Continuous and adequate P supply from these LS containing combination treatments might have enhanced microbial activity, which might have encouraged the build up of available N. Moreover, the slow release ammonium phosphate in LS might also have lead to soil N enrichment. According to Singaram and Kothandaraman (1992), the overall effect of P application was to encourage the build up of available N. Increase in soil available N with LS application was indicated by George (2003) while the similar effect of rubber effluent was observed by Bachik *et al.* (1987).

Soil available K (Table 27 and Fig. 18) was significantly influenced by treatment application. The highest value was recorded by T_4 (¼ LS + ¾ SSP) followed on par by T_8 (½ LS + ½ RP). However, a general trend of decrease in soil K was noticed at harvest, which might be due to increased plant uptake. Moreover, some leaching loss might also have occurred. Increase in soil available K with LS application was indicated by George (2003). Similar effect of rubber effluent was observed by Tan *et al.* (1975) and Yapa (1984).

The highest value for soil exchangeable Ca (Table 28 and Fig. 18) was registered by T_4 (¼ LS + ¾ SSP) followed on par by T_8 (½ LS + ½ RP) and T_7 (¼ LS + ¾ RP). Similar to K, exchangeable Ca content of soil decreased at harvest. This might be due to increased plant uptake. Subehia (1998) observed that exchangeable Ca build up in soil was comparable when RP and SSP were used. Increase in soil exchangeable Ca with rubber effluent application was indicated by Dolmat *et al.* (1981), Yapa (1984) and Bachik *et al.* (1987).

The treatment application significantly influenced exchangeable Mg (Table 28 and Fig. 18) content of the soil. Treatment combinations containing LS recorded higher values than when SSP or RP was used alone. The maximum value was recorded when full P was given as LS (T_1) followed on par by T_8 (½ LS + ½ RP). The encapsulated nature of LS which itself is a rich source of Mg might have resulted in continuous and steady supply of the same in accordance with crop needs. This effect might also have reduced its leaching loss. Srinivasan *et al.* (2000) showed that exchangeable Mg was maximum when P was applied in plots either as RP or SSP along with FYM. Increase in soil exchangeable Mg with LS application was indicated by George (2003). Similar effect by rubber effluent application was shown by Dolmat *et al.* (1981) and Yapa (1984).

5.4 RESIDUE CROP OF CHILLI

To study the residual effect of the treatments, another crop of chilli (Plate 5) was raised in the same pots using the same soil used for the main crop without any P addition. Urea (N), Muriate of potash (K_2O) and FYM were applied in all pots except absolute control, as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 2002).

5.4.1 Yield per Plant

The treatments significantly influenced fruit yield (Table 29 and Fig. 19) of the residue crop. The highest yield was recorded by T_8 (½ LS + ½ RP) and was on par with T_3 (full P as RP). This indicates that the residual effect when LS and RP were used in equal proportions is comparable to that when RP is used alone. LS when used in conjunction with RP might have ensured adequate P supply during the rooting, flowering and fruiting stages of the crop when P requirement is high, by virtue of their gradual and steady dissolution and the suppression of Fe and Al activity as a result of their liming effect. This might have

Plate 5. Residual effect of treatments on growth characters of chilli

enhanced metabolism and uptake of other nutrients in general, better partitioning of photosynthates and thereby higher yield. Raj and Velayudham (1995) reported that the residual effect of RP was more than that of SSP. The remarkable residual effect of LS, evident from higher yields of second and even the third crops of *Peuraria* was shown by Wahab (1976) and further corroborated by Wahab *et al.* (1979).

5.4.2 Total Dry Matter Production

The residual effect of P significantly influenced total dry matter production (Table 29). T_8 (½ LS + ½ RP) recorded the highest value followed on par by T_3 (full P as RP). As with the main crop, the treatment that gave the highest fruit yield per plant recorded the highest dry matter production. The better residual effect of LS in combination with RP might have ensured adequate P availability and this along with externally supplied N and K which promoted vegetative growth and higher fruit yield might have finally resulted in the highest total dry matter production. The higher residual effect of LS as indicated by higher dry matter yields of *Peuraria* was indicated by Wahab (1976) and further corroborated by Wahab *et al.* (1979).

5.4.3 Plant Nutrient Content and Uptake

Phosphorus

The highest P content (Table 30 and 31) in bhusa was recorded by T_8 (½ LS + ½ RP) and that in fruit by T_5 (½ LS + ½ SSP) and in both cases, they were on par with T_3 (full P as RP). The highest P uptake (Table 33 and Fig. 21) was recorded by T_8 followed on par by T_3. This might be due to the better residual effect when LS and RP were used in conjunction which ensured adequate P supply, increased plant P content and this along with high dry matter production in these treatments naturally resulted in higher uptake.

Other Nutrients

When uptake (Table 32, 34 to 36 and Fig. 20, 22 to 24) of other nutrients (N, K, Ca and Mg) was considered in general, it was seen that those treatment combinations containing both LS and RP recorded the highest values. In all cases, superiority of T_8 (½ LS + ½ RP) was evident. Adequate P supply might have resulted in better root proliferation, penetration and ramification resulting in increased nutrient absorption. The resultant enhanced dry matter production might have caused the increased uptake of these nutrients.

5.5. ECONOMICS

A critical economic analysis of the data on the costs of inputs and outputs of main as well as the residue crop (Table 25, 37 and Fig. 25) was carried out. The computed benefit-cost ratios revealed that T_8 (½ LS + ½ RP) was the most economic treatment giving a returns of Rs.2.67 and Rs.1.99 respectively for every one rupee invested. Even though, this treatment was a combination of two cheaper sources of P, it could give better yield than when costly conventional P sources were used alone and so is a better option for the farmer.

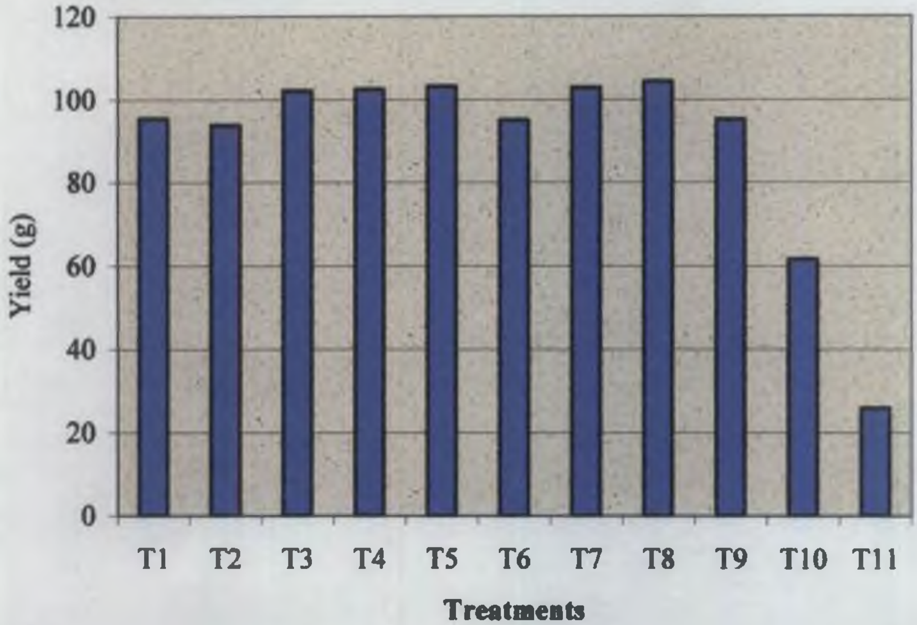


Fig. 19 Yield per plant - residue crop

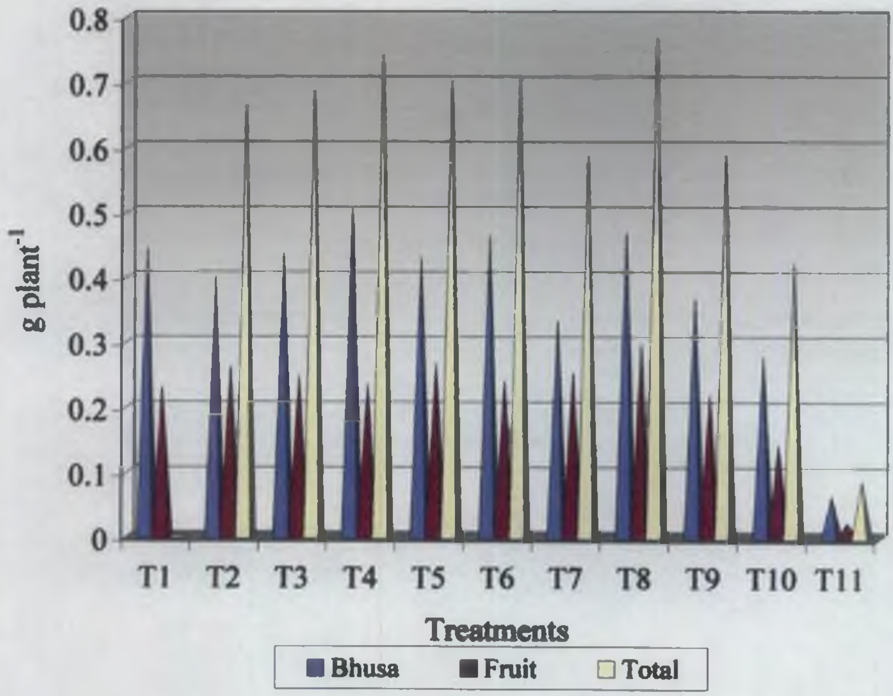


Fig. 20 Plant nitrogen uptake - residue crop

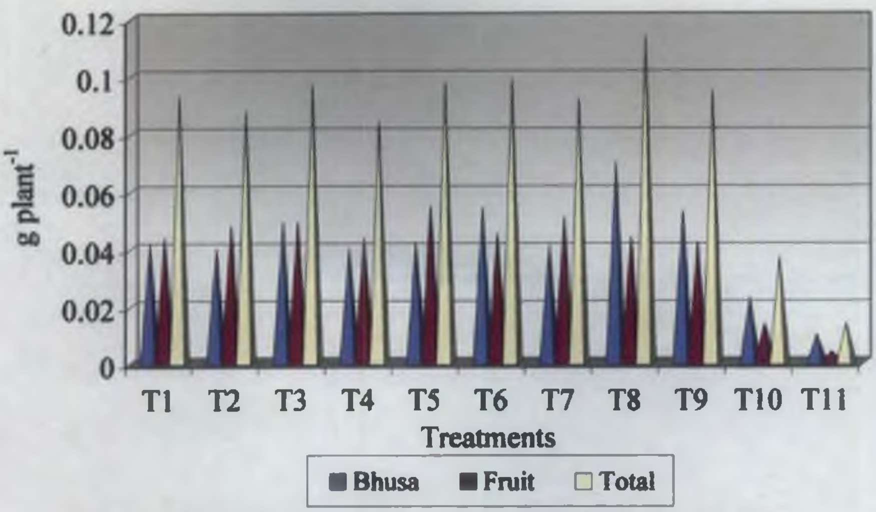


Fig. 21 Plant phosphorus uptake - residue crop

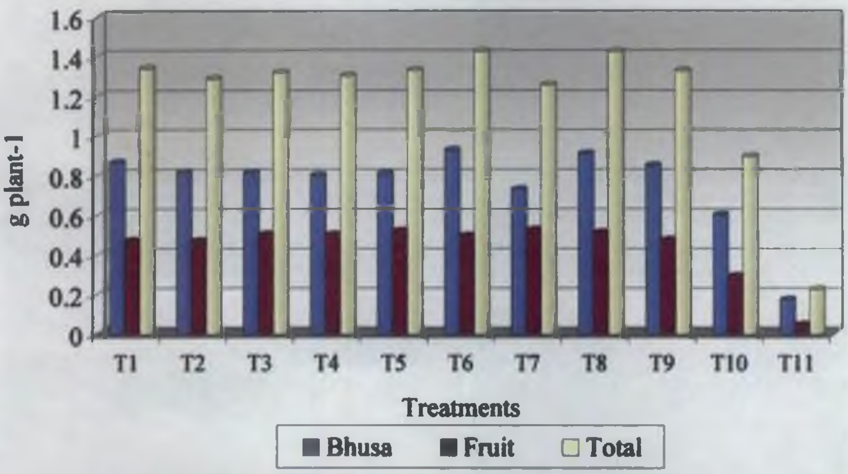


Fig. 22 Plant potassium uptake - residue crop

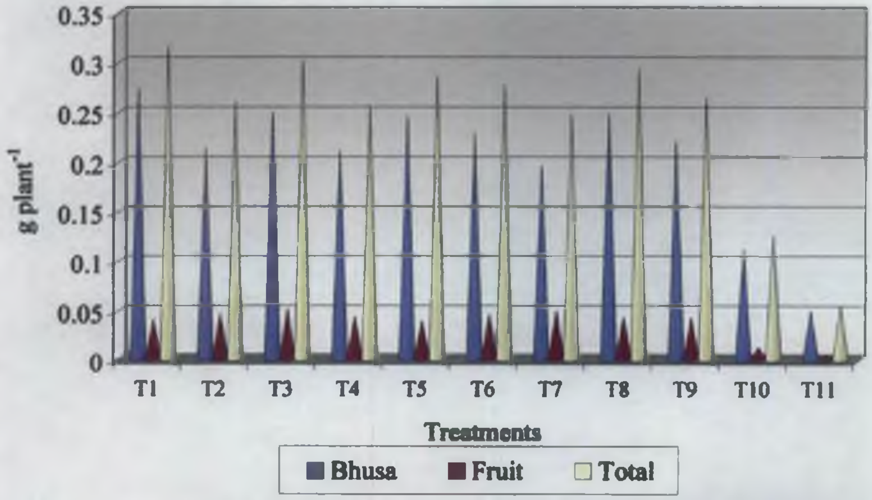


Fig. 23 Plant calcium uptake - residue crop

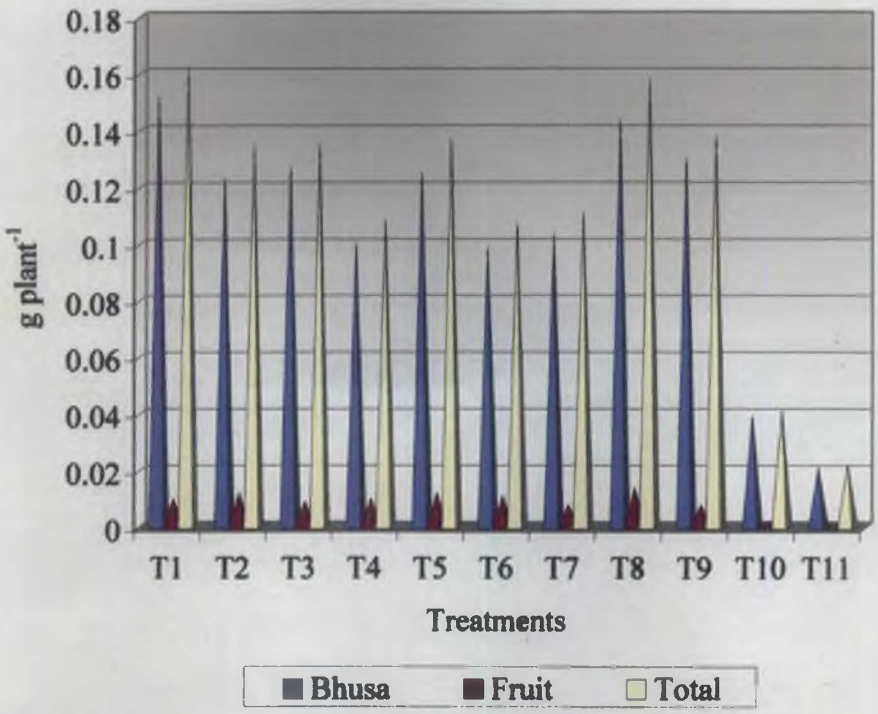


Fig. 24 Plant magnesium uptake - residue crop

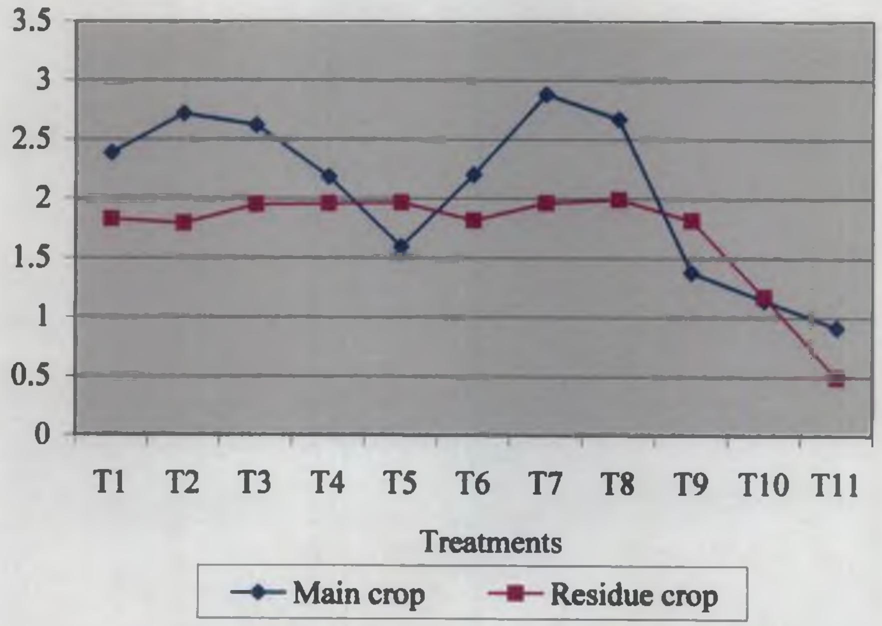


Fig. 25 Benefit : Cost ratios-main and residue crop

SUMMARY

6. SUMMARY

Latex sludge, the inevitable byproduct of latex concentration process in natural rubber industry is currently considered by environmentalists and industrialists alike as a waste material posing problems of handling and disposal. Chemically, it is magnesium ammonium phosphate formed on addition of diammonium hydrogen phosphate to field latex prior to centrifugation for lowering its high Mg content which otherwise will adversely affect its stability on further processing. About 800 tonnes of this material are produced annually in Kerala by 110 latex processing factories. Reports of its promising agronomic efficiency in some cover crops and rubber have already been observed. However, not much research has been carried out using this material.

The present study was an attempt to evaluate the feasibility of using latex sludge, a cheap or 'no cost' material at present as a source of P in crop production, the results of which if positive can be a major breakthrough for farmers in reducing their costs of cultivation. Summarized below are the salient findings, which were generated out of detailed investigations, carried out at laboratory and field levels for characterizing this material and studying its soil and crop effects.

A critical appraisal of the analytical profile of latex sludge showed that the material was near neutral in reaction (pH 6.49) with organic C content of 5.09 per cent. The N and Mg contents were quite substantial, 6.05 and 6.86 per cent respectively, but both K and Ca contents registered negligible values, less than one per cent.

The total P content in latex sludge was 35.98 per cent grading it superior to rock phosphates now popular in market as commercial fertilizers. Of the total P, 13 per cent was water soluble and 36 per cent citrate soluble, together accounting for nearly half of the gross P content. The balance fraction which though is citrate insoluble has got the possibility of becoming soluble in mineral acids that may occur in soil due to certain microbial biochemical reactions and hence plant available. All these facts are clearly suggestive that latex sludge can serve as a P source to short and long duration crops equally by virtue of its potential for staggered release of the nutrient.

A detailed laboratory incubation study with soil for 120 days duration was undertaken to monitor and compare at fortnightly intervals the release of plant nutrients from latex sludge in comparison with that from two conventionally used P sources – SSP and RP against a no P applied control (soil alone). The soil used belonged to Vellayani series (*Typic Kandiustult*) and was sandy loam in texture; acidic in reaction (pH 5.63), high in organic C and available P but low in available N and K rating.

At any stage of incubation, the various phosphatic sources could not bring about a significant change in soil pH.

At all stages of incubation, except on the 90th and 105th day, the soil EC did not differ significantly among the various sources of P, even though there was significant variation when compared to control.

Organic C content was significantly influenced by the treatments from the 30th DOI onwards. The superiority of latex sludge in increasing this soil attribute was evident, the values gradually increasing to a maximum by the 75th day followed by a slow decline.

The available N values were the highest for latex sludge applied soil throughout the incubation period except on the 105th day. From the 30th to the 90th day, these values were significantly superior to those for SSP and RP applied soils.

The different P sources exerted significant influence on soil available P contents throughout the incubation period. On the 15th day when all the treatments were significantly different from each other in their P dissolution capacities, SSP was the most superior. Latex sludge which ranked next, was significantly superior to RP. But from the 30th day onwards, P release from latex sludge and SSP became statistically comparable and significantly superior to that from RP. The uniform release pattern of both latex sludge and SSP continued till the 90th day and thereafter, the three sources became on par in their P release capacities. All the above facts are strong supporting evidence in favour of latex sludge for being used as an alternate P source to plants since, this material becomes as good as or even better than the conventional P sources in increasing the soil available P.

The available K levels in soil remained unaffected throughout the incubation period despite P application in different forms.

The exchangeable Ca and Mg levels showed significant variations under P application through different sources from the 45th DOI only. The treatments continued their effects up to the 105th day on Ca, but ceased by the 75th day on Mg. During this period, latex sludge was as effective as RP in increasing and maintaining the exchangeable Ca levels in soil and making them plant available, while Mg release pattern showed high inconsistency.

For further elucidation and field confirmation of the laboratory results, a pot culture with chilli (*Capsicum annuum* L.) var. Jwalamukhi was conducted. The selection of this crop was based on its relative high P demand. The treatments were fixed so as to compare the P supply to the crop from latex sludge against that from two other conventional P sources - SSP and RP when each one was used singly or when LS was used in different combinations with the other two.

The growth characters of the crop *viz.*, plant height, branches per plant, number of leaves and leaf area registered the maximum value when full P was given as SSP (T_2). But the effects were statistically on par with the treatment combination T_8 (½ LS and ½ RP).

Yield and yield attributing characters in general were favourably influenced by LS when applied alone or in combination with other P sources. The sole treatment T_1 (full P as LS) and the combination treatment T_6 (¾ LS + ¼ SSP) were the earliest to flower, the first flowering by both being on the same period. This favourable trait was also exhibited by T_8 (½ LS + ½ RP). The number of fruits per plant and fruit yield per plant were the highest for T_7 (¼ LS + ¾ RP), which was on par with T_8 (½ LS + ½ RP). The mean fruit weight also was the highest for T_8 and for T_2 (full P as SSP).

The quality traits of chilli *viz.*, the contents of ascorbic acid, capsaicin, oleoresin and protein also testified the suitability of latex sludge as an alternate P source. The treatment combination T_8 (½ LS + ½ RP) registered values, which were either the highest or on par with the highest.

The plant uptake of nutrients, a major yield contributing factor also showed trends in favour of latex sludge. The uptake of N, P, K, Ca and Mg, which were significantly influenced by the treatments were the highest or on par with the highest for the treatment combination T_8 (½ LS + ½ RP).

Chemical analysis of soil upon crop harvest for the contents of organic C, N, P, K, Ca and Mg and subsequent statistical scrutiny of the data showed that the treatments caused significant variations in their available levels. The highest organic C content was recorded by T_1 (full P as LS), which was significantly higher than all other treatments. In general, higher values of available N and P and exchangeable Mg were shown by T_8 (½ LS + ½ RP). A general trend of decrease in soil available K and exchangeable Ca was noticed at harvest.

The residual effects of the treatments were studied by a subsequent crop of same variety of chilli in the same pots using the same soil following all the cultural operations as for the previous main crop except addition of any P.

Experimental conditions all being uniform for the residue crop, the maximum residual effect of P was exhibited by the combination treatment T_8 (½ LS + ½ RP) manifested by recording statistically the highest values for important traits contributing to yield and quality like dry matter contents of bhusa and fruit, content and uptake of P by bhusa and uptake of N and Mg by fruit. Even though not the highest, the values registered by this treatment for other similar traits (bhusa content and uptake of N, K, Ca and Mg; fruit contents of N, P and K and fruit uptake of P, K and Ca) were statistically on par with the highest values recorded by other treatments. The favourable disposition of all these factors towards this treatment cumulatively reflected on the fruit yield also which was significantly the highest.

The benefit-cost ratios worked out for the various treatments showed that for the main crop, treatment combination T_7 (¼ LS + ¾ RP)) was found to be the most profitable giving returns of Rs.2.67 for every one rupee invested and was on par with T_8 (½ LS + ½ RP). For the residue crop, T_8 was found to be the most profitable giving returns of Rs.1.99 for every one rupee invested.

Epitomizing the foregoing findings, the use of latex sludge as an alternate cheap source of P to crops can undoubtedly be advocated on the basis of quantitative, qualitative and monetary aspects of yield. The use of this material in conjunction with RP to provide the plant its P requirement in quantitatively equivalent basis registered values, which were either the highest or the next highest, but statistically on par with it for most of the characters studied, of the main as well as the residue crop. Moreover, use of this apparently ecofriendly material in crop production will be a boon in terms of its disposal also.

Inspired by the results so far generated further investigations on the material in the following lines are suggested.

- Extrapolation of these laboratory and pot culture results by large scale field trials.
- Composting using bio agents like earthworms.
- Reinforcement using bio-activators like P solubilizing and cellulolytic microorganisms.
- Controlled partial acidulation to increase the nutrient release efficiency.
- Pre incubation with soil with or without the above, prior to direct application in field.

It is hoped that in the present age when the progress of the nation is at stake in the face of calamities like natural havocs, population explosion and dwindling natural resources, a study of this nature shall be "not a giant leap, but a small step forward for mankind" in the challenging task of developing agriculture into a sustainable vibrant economy.

REFERENCES

7. REFERENCES

Achari, M.S., Moorthy, M.D. and Arunachalam, G. 1998. Effect of paper factory effluent on physico-chemical properties of soil. *Madras agric. J.* 85: 464-465

Achari, M.S., Moorthy, M.D. and Arunachalam, G. 1999. Studies on the influence of paper mill effluents on the yield, availability and uptake of nutrients in rice. *J. Indian Soc. Soil Sci.* 47: 276–280

Ahmad, A., Inam, A., Ahmad, I., Hayat, S., Azam, Z.M. and Samiullah. 2003. Response of sugarcane to treated wastewater of oil refinery. *J. Environ. Biol.* 24: 141–146

Ahmed, N. and Tanki, M.I. 1991. Response of chilli (*Capsicum annuum* L.) to nitrogen and phosphorus. *Haryana J. Hort. Sci.* 20: 114–118

Aliyu, L. 2002. Growth and yield of pepper (*Capsicum annuum* L.) as affected by nitrogen and phosphorus application and plant density. *Crop Res.* 23: 467-475

Aliyu, L. 2003. Effect of nitrogen and phosphorus fertilizers on the chemical composition and uptake of mineral elements by pepper (*Capsicum annuum* L.). *Crop Res.* 25: 272–279

AOAC. 1960. *Official Methods of Analysis.* Ninth edition. Association of Official Agricultural Chemists, Washington D.C., 832 p.

Augusthy, P.O. and Mani, A. S. 2001. Effect of rubber factory effluent on seed germination and seedling growth of *Vigna radiatus* L. *J. Environ. Biol.* 22: 137–139

Awasthi, P.K. 1990. Marketing of rock phosphate as direct phosphatic fertilizer. *Fertil. News* 35(4): 91–96

Bachik, A.T., Karim, M.Z., Chin, P.Y., Huan, L.C. and John, C.K. 1987. Application of rubber factory effluent on land. *Plrs' Bull.* 192: 63–81

*Baevre, O.A. and Gislerod, H.R. 1990. Phosphorus fertilization and liming of peat for raising plants. *Norsk Landbruksforsking* 4: 7–14

Bajaj, K.L., Kaur, G., Singh, J. and Brar, J.S. 1979. Effect of nitrogen and phosphorus levels on nutritive values of sweet pepper (*Capsicum annuum* L.) fruits. *Qualitas Pl.* 28: 287–292

Balakrishnan, K. 1999. Studies on nutrient deficiency symptoms in chilli (*Capsicum annuum* L.). *Indian J. Pl. Physiol.* 4: 229–231

Basak, R.K. 1999. *Fertilizers a Text Book.* Kalyani Publishers, Ludhiana, 265 p.

Bennett, D.J. and Kirby, G.W. 1968. Constitution and biosynthesis of capsaicin. *J. chem. Soc.* 44: 442–446

Bergmann, W. 1992. *Nutritional Disorders of Plants–Development, Visual and Analytical Diagnosis.* Third edition. VCH Publishers Inc., Florida, 741 p.

Bhatia, A., Pathak, H. and Joshi, H.C. 2001. Use of sewage as a source of plant nutrients: Potentials and problems. *Fertil. News* 46 (3): 55–64

Black, C.A., Evans, D.D., Ensminger, L.E., White, J.L. and Clark, F.E. 1965. *Methods of Soil Analysis.* American Society of Agronomy Inc., Madison, 1569 p.

Brien, O.T.A., Herbert, S.J. and Barker, A.V. 2002. Growth of corn in varying mixtures of paper mill sludge and soil. *Commun. Soil Sci. Pl. Analysis* 33: 635–646

Chatterjee, A., Joshi, H.C. and Pathak, H. 2003. Impact of distillery and paper mill effluent irrigation on yield of rice and soil fertility. *J. Indian Soc. Soil Sci.* 51: 564–566

Chougule, A.B. and Mahajan, P.R. 1979. Effect of varying levels of plant population, nitrogen, phosphorus and potash on growth and yield of chilli. *Veg. Sci.* 6: 73–80

Cochran, W.G. and Cox, G.M. 1965. *Experimental Designs*. John Willey and Sons Inc., New York, 182 p.

Damke, M.M., Kawarkhe, V.J. and Patil, C.V. 1988. Effect of P and K on growth and yield of chilli. *PKV Res. J.* 12: 110–114

Das, T.K. and Rath, B.S. 1992. Effect of different levels of N and P on the yield of transplanted (irrigated) chilli (*Capsicum annuum* L.). *Orissa J. agric. Res.* 5: 194–196

Datta, N. and Sharma, C.M. 2001. Evaluation of rock phosphate – sulphur mixtures as sources of phosphorus to soybean. *J. Indian Soc. Soil Sci.* 49: 449–456

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

Datta, S.P., Biswas, D.R., Saharan, N., Ghosh, S.K. and Rattan, R.K. 2000. Effect of long term application of sewage effluents on organic carbon, bioavailable phosphorus, potassium and heavy metal status of soils and content of heavy metals in crops grown thereon. *J. Indian Soc. Soil Sci.* 48: 836–839

Dave, S.K., Katrodia, J.S. and Patel, M.L. 1990. Nutrition and growth of banana cv. Basrai in deep black soils of South Gujarat. *Fertil. News* 35 (3) : 19-26

De, S.K., Singh, L. and Shanker, J. 1984. Effect of mussoorie rock phosphate on certain soil properties. *Indian J. agric. Chem.* 17: 227–229

Debnath, N. C. and Basak, R. K. 1986. Effect of rock phosphate and basic slag on available phosphorus in acid soils in relation to soil characteristics, seasons and moisture regimes. *J. Indian Soc. Soil Sci.* 34: 464–470

Devarajan, L. and Oblisami, G. 1995. Effect of distillery effluent on soil properties, yield and quality of sugarcane. *Madras agric. J.* 82: 397–399

Devlin, R.M. and Witham, F.H. 1983. *Plant Physiology*. Fourth edition. CBS Publishers and Distributors, New Delhi, 577 p.

Dhaliwal, R.S. and Malik, R.S. 1999. Physical and chemical composition of organic effluents of the industries situated in semi arid India. *Indian J. agric. Chem.* 32: 37–43

Dharmatti, P.R. and Kulkarni, G.N. 1988. Effect of nutrition, spacing and pickings on seed yield and seed quality in bell pepper. *Seed Res.* 16: 148–151

Dolmat, M.T. 1978. Agricultural utilization of rubber factory effluent-A review of its potential. International Rubber Research and Development Board Symposium, 2–4 March 1978. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract*: 10

Dolmat, M.T., Isa, Z., Karim, M.Z. and Lam, L.A. 1981. Land disposal of rubber effluent: Soil-plant system as a pollutant remover. Planter's Conference, 23-26 May 1981. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract* : 364

Dolmat, M.T., Karim, M.Z., Isa, Z. and Pillai, K.R. 1979. Land disposal of rubber factory effluent: Its effect on soil properties and performance of rubber and oil palm. Planter's Conference, 24–27 May 1979. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract* : 436

Dutta, S.K. and Boissya, C.L. 1999. Effect of paper mill effluent on growth, yield and N. P. K. contents of transplanted rice (*Oryza sativa* L.) var. Mahsuri. *J. Environ. Biol.* 20: 29–32

Farooqui, A. 1994. Effect of tannery effluent on growth, morphology and yield of *Lens culinaris* Medic. *Madras agric. J.* 81: 26–29

Gagnon, B., Simard, R.R., Lalande, R. and Lafond, J. 2003. Improvement of soil properties and fruit yield of native low bush blue berry by paper mill sludge addition. *Can. J. Soil Sci.* 83: 1–9

Gare, B.N., More, S.M., Jadhav, M.G. and Burli, A.V. 2001. Effect of spacing and fertilizer on yield of rainfed chilli in sub-montane zone of Maharashtra. *J. Maharashtra agric. Univ.* 25: 270-271

Gautam, D.D., Kumar, K. and Bishnoi, S. 1992. Effect of dairy effluent on seed germination of some rabi and kharif crop plants. *J. Environ. Biol.* 13: 7–12

George, E.S. 2003. Centrifuge Factory Sludge - Pazhvasthuvil Ninnum Valum. *Rubber* 447: 19–20

George, E.S., Amma, M.K. and Mathew, M. 1991. Evaluation of bowl sludge as fertilizer for immature rubber and cover crop. *J. Plantn. Crops* 18: 179–183

George, E.S., George, K.T., Mathew, M. and Joseph, T. 1994. Commercial application of latex sludge as fertilizer- A preliminary assessment. *Indian J. Natural Rubb. Res.* 7: 46–50

Ghosh, P.C. 1999. *Chemistry and Agronomic Evaluation of Phosphatic Fertilizers*. Agrotech Publishing Academy, Udaipur, 368 p.

Gonzalez, A. and Beale, A. 1987. N and P fertilizers and growth and yield of sweet pepper. *J. agric. Univ. Puerto Rico* 71: 209–215

Goswami, M. and Naik, M. L. 1992. Effect of a fertilizer effluent on chlorophyll contents of *Cyamopsis tetragonoloba* Taub. *J. Environ. Biol.* 13: 169 – 174

Habib, I. 1995. Irrigational impact of rubber factory effluent on elemental bioaccumulation and metabolite concentration in *Triticum aestivum*. *Res. Bull. Punjab Univ. Sci.* 45: 67–72

Haron, K. and Zakaria, Z.Z. 1994. Land application of palm oil mill effluent (POME) on oil palm using a tractor-tanker and flat bed system. *PORIM Bull.* 28: 20–29

Hegde, D.M. 1997. Nutrient requirements of solanaceous vegetable crops. *Ext. Bull. ASPAC*. 441: 9-12

Hesse, P.R. 1971. *A Textbook of Soil Chemical Analysis*. William Clowes and Sons, London, 513 p.

Hossain, M.M., Mohanty, B.K. and Nanda, S.K. 2001. Effect of nitrogen, phosphorus and potash on growth and yield of chilli cv. Pusa Jwala. *Hort. J.* 14: 69-74

Igbokwe, P.E. and Tiwari, S.C. 1985. Use of basic slag in sweet pepper production. *J. Miss. Acad. Sci.* 30: 83–91

Isa, Z. and Ibrahim, A. 1988. Effluent from rubber glove manufacturing. International Rubber Technology Conference, 12 – 14 November 1988. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract*: 518

Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi, 498 p.

Jadi, A.W.M. 1983. Land application of rubber effluent. Seminar on Land Application of Oil palm and Rubber Factory Effluents, 12–14 March 1983. Malaysian Society of Soil Science, Serdang. *Abstract* :28

Jayaraj, T., Jaquline, A., Selvaraj, A. and Pappaiah, M. 1999. Effect of spacing and manurial treatments on seed yield and its seed quality attributes in PLR–1 chillies. *S. Indian Hort.* 47: 273–274

Jeyabal, A., Arivazhagan, K. and Thanunathan, K. 2000. Utilization of lignite fly ash as source of plant nutrients for rice. *Fertil. News* 45(7): 55–58

John, C.K., Ang, S.H. and Broughton, W.J. 1976. Effect of rubber factory effluents on soil properties and growth of *Hevea brasiliensis*. Symposium on Soil Microbiology and Plant Nutrition, 7–9 August 1976. Malaysian Society of Soil Science, Kuala Lumpur. *Abstract*: 120

John, C.K., Mahmud, H.J., Wahab, A., Karim, M.Z. and Pushparajah, E. 1977. Utilization of wastes from natural rubber producing factories. *Planter* 53: 449 – 467

John, S. 1989. Nutrient management in vegetable chilli (*Capsicum annuum* L.) var. Jwalasakhi. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 90 p.

Joseph, P. A. 1982. Effect of nitrogen, phosphorus and potassium on the growth and yield of chilli var. Pant C-1. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 108 p.

Joseph, P.A. and Pillai, P.B. 1985. Effect of nitrogen, phosphorus and potassium on the growth and yield of chilli var. Pant C-1. *Agric. Res. J. Kerala* 23: 75–82

Joshi, H.C., Pathak, H., Choudhary, A. and Kalra, N. 1996. Distillery effluent as a source of plant nutrients: Prospects and problems. *Fertil. News* 41(11): 41–47

Jothimani, P. and Bhaskaran, A. 2002. Effects of dilution and dynamics of physical factors during factory effluent irrigation. *J. Ecotoxicology and Environmental Monitoring* 12: 255 – 261

Kaminwar, S.P. and Rajagopal, V. 1993. Fertilizer response and nutrient requirements of rainfed chillies in Andhra Pradesh. *Fertil. News* 38(7): 23–26

Kanapathy, K. 1968. A survey of the quality of some paddy irrigation water in Malaya and its interpretations. *Malaysian agric. J.* 46: 286–297

Kanapathy, K., Jorgensen, H.K. and Singh, G. 1983. Preparation and utilization of dried palm oil mill effluent (POME). National Workshop on Oil palm By- Product Utilization, 9-11 September 1983. Palm Oil Research Institute, Malaysia. *Abstract*: 7

Kannan, K. and Oblisami, G. 1992. Effect of paper mill effluent irrigation on dry matter accumulation in groundnut. *Madras agric. J.* 79: 59–61

Kanwar, R.S. and Kapur, J. 1987. Direct and residual effects of sulphitation and carbonation press mud cakes on the yield, quality and nutrition of sugarcane (*Saccharum officinarum*). *Indian Sug. Crops J.* 13(4): 1–5

Karim, M.Z. and Bachik, A.T. 1989. Comparative study of rubber effluent and an inorganic fertilizer as sources of plant nutrients for Hevea and their effects on soil properties. *J. Natural Rubb. Res.* 4: 260–272

Karim, M.Z.A., Sudin, M.N., Bakti, N.A.K., Hamzah, Z. and Isa, Z. 1997. Land application of sludge from latex product manufacturing: A preliminary study. International Rubber Conference, 2–5 March 1997. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract* : 1049

KAU. 2002. *Package of Practices Recommendations 'Crops'*. Twelfth edition. Directorate of Extension, Kerala Agricultural University, Thrissur, 278 p.

Kayalvizhi, C., Gopal, H., Baskar, M., Bose, S. C. M. and Sivanandham, M. 2001. Recycling of distillery effluent in agriculture – effect on soil properties and sugarcane yield. 63rd Annual Convention, 25 – 27 August 2001. Sugar Technologists Association, Jaipur. *Abstract*: 146

Khan, M.A.R. and Suryanarayana, V. 1977. Effect of N, P and K on flowering, fruit size and yield of chilli var. NP. 46A. *Veg. Sci.* 4: 53–60

Kumar, A., Sarkar, A.K., Singh, R.P. and Sharma, V.N. 1999. Effect of fly ash and fertilizer levels on yield and trace metal uptake by soybean and wheat crops. *J. Indian Soc. Soil Sci.* 47: 744–748

Kumar, V. and Mishra, B. 1991. Effect of two types of press mud cake on growth of rice, maize and soil properties. *J. Indian Soc. Soil Sci.* 39: 342–344

Lal, J.K., Mishra, B., Sarkar, A.K. and Lal, S. 1996. Effect of fly ash on growth and nutrition of soybean. *J. Indian Soc. Soil Sci.* 44: 310–313

Lichtenthaler, H.K., Rohmer, M. and Schwender, J. 1997. Two independent biochemical pathways for isopentenyl diphosphate and isoprenoid synthesis in higher plants. *Physiol. Pl.* 101:643–652

Lim, C.H. and P'ng, T.C. 1984. Land application of rubber factory effluent on oil palm and rubber. International Conference on Soils and Nutrition of Perennial Crops, 23–25 July 1984. Malaysian Society of Soil Science, Kuala Lumpur. *Abstract*: 307

Lim, K. H. 1988. Integrated systems for treating and utilizing plantation effluents: palm oil mill effluent as a specific example. International Symposium on Anaerobic Digestion, 22–26 May 1988. Palm Oil Research Institute, Malaysia. *Abstract* : 10

Lowe, J.S. 1968. Bowl sludge as a fertilizer. *Plrs' Bull.* 96: 91-95

Lubin, M. and Ennis, H.L. 1964. On the role of intracellular K in protein synthesis. *Biochem. Biophys. Acta.* 80: 614-631

Maiti, S.S., Mukhopadhyay, M., Gupta, S.K. and Banerjee, S.K. 1990. Evaluation of fly ash as a useful material in agriculture. *J. Indian Soc. Soil Sci.* 38: 342–344

Mathew, A.G., Nambudiri, E.S., Ananthakrishna, S.M., Murthy, K.N. and Lewis, Y.S. 1971. An improved method for estimation of capsaicin in capsicum oleoresin. *Laboratory Practice* 1: 23–26

Mathur, B.S. 1980. Use of indigenous rock phosphate as a source of phosphate for acidic soils of Chotanagpur plateau, Bihar. Symposium on Increasing Productivity of Acid Soils in the Eastern Region, 7–9 April 1980. Fertilizer Association of India, Calcutta. *Abstract*: 63

Mathur, B.S. 1995. Utilization of basic slags in agriculture. *Recycling of Crop, Animal,Human and Industrial wastes in Agriculture* (ed. Tandon, H.L.S.). Fertilizer Development and Consultation Organization, New Delhi, pp. 150–157

Mathur, B.S. and Lal, S. 1989. Effect of graded levels of rock phosphate on plant nutrition on an alfisol. *J. Indian Soc. Soil Sci.* 37: 491–494

Maya, P., Natarajan, S. and Thamburaj, S. 1999. Effect of plant density and nutrients on certain physiological parameters in sweet pepper. *S. Indian Hort.* 47: 237-239

Medhi, R. P., Singh, B. and Parthasarathy, V. A. 1993. Effect of varying levels of nitrogen, phosphorus and potassium on chillies. *Prog. Hort.* 22: 173–175

Mehrotra, O.N., Saxena, H.K. and Mishra, P. H. 1968. Effect of NPK deficiencies in chillies. *Fertil. News* 13 (3): 34-36

Mitra, A. and Gupta, S.K. 1999. Effect of sewage water irrigation on essential plant nutrient and pollutant element status in a vegetable growing area around Calcutta. *J. Indian Soc. Soil Sci.* 47: 99–105

Mohandas, S. and Appavu, K. 2001. Direct and residual effect of combined application of basic slag with green leaf manure on soil available nutrients and yield of rice. *Madras agric. J.* 88: 53-56

Mohanty, B.K., Hossain, M.M. and Nanda, S.K. 2001. Response of chilli cv. Utkal Rashmi to nitrogen, phosphorus and potash. *Orissa J. Hort.* 29: 51–53

Mongia, A.D., Chhabra, R. and Lal, K. 2003. Possibility of using fly ash as a source of silica for increasing rice productivity on a reclaimed alkali soil. *J. Indian Soc. Soil Sci.* 51: 89–91

Mukhopadhyay, T.P. 2004. Crop management of chillies. *Spice India* 17: 13–18

Murugan, M. 2001. Quality of chilli (*Capsicum annuum* L.) variety Co-3 as influenced by levels and sources of phosphorus and levels of nitrogen. *J. Spices Aromatic Crops* 10: 1–5

Murugan, M., Backyiarani, S., Kumar, A.J. and Subbiah, A. 2002. Yield and nutrient content of chilli (*Capsicum annuum* L.) in response to sources of P and levels of P and N. *J. Spices Aromatic Crops* 11: 13–17

Muthumanickam, D. 2003. Influence of different phosphorus sources and zinc spray on the yield and quality of black pepper (*Piper nigrum* L.) under acid soils. *J. Spices Aromatic Crops* 12: 15–18

Naeidhe, M.F.S. 2001. Effect of application of basic slag and super phosphate on herbage yield and on soil and herbage concentrations of phosphorus in organic grassland. *Biological Agric. Hort.* 19: 231–245

Nasreen, S. and Islam, M.S. 1989. Response of chilli to NPK and S fertilization. *Bangladesh Hort.* 17: 5–9

Nazeeb, M., Lim, K.H., Loong, S. G. and Ho, C.Y. 1983. Trial on rubber factory effluent on oil palm. Seminar on Land Application of Oil palm and Rubber Factory Effluents, 12–14 March 1983. Malaysian Society of Soil Science, Serdang. *Abstract* : 61

Nazeeb, M., Lim, K.H., Loong, S. G. and Ho, C.Y. 1984. Trial on the effects of rubber factory effluent on oil palm. Seminar on Land Application of Oil palm and Rubber Factory Effluents, 11–13 March 1984. Malaysian Society of Soil Science, Serdang. *Abstract* : 61

Niranjana, K.V. and Devi, L.S. 1990. Influence of P and S on yield and quality of chillies. *Curr. Res. Univ. agric. Sci.* 19: 93–94

Oviasogie, P.O. and Aghimien, A. E. 2003. Macronutrient status and specification of Cu, Fe, Zn and Pb in soil containing palm oil mill effluent. *Global J. Pure appl. Sci.* 9: 71-79

Palaniswami, C. and Sriramalu, U.S. 1994. Effects of continuous irrigation with paper factory effluent on soil properties. *J. Indian Soc. Soil Sci.* 42: 139–140

Patil, G.D and Chaudhari, R.D. 2002. Effect of levels of spent wash on CO_2 evolution, yield and uptake of nutrients by maize (*Zea mays* L.). *Madras agric. J.* 89: 726–729

Patil, K.B. and Biradar, D.P. 2002. Nutrient uptake of chilli as influenced by plant population and integrated nutrient levels in vertisols. *J. Maharashtra agric. Univ.* 26: 337–339

Patil, S.P. and Kale, S.P. 1983. Residual effect of press mud cake (PMC) on: II. Chemical properties of soil and uptake of nutrients in sugarcane (*Saccharum officinarum* L.). *Indian Sug.* 33: 91–95

Patra, S.K., Padhi, A.K. and Mishra, S.N. 1989. Effect of press mud cake and fertilizer phosphorus on the yield and economics of potato and cabbage. *Environ. Ecol.* 7: 899–901

Pillai, K.R. 1977. A note on application of mixed rubber factory effluent to mature rubber. *Planter* 53: 468-469

Piper, C.S. 1967. *Soil and Plant Analysis.* Asia Publishing House, Bombay, 368 p.

Prabhakar, B.S., Srinivas, K. and Shukla, V. 1987. Growth and yield response of green chilli to nitrogen and phosphorus fertilization. *Indian Cocoa Arecanut Spices J.* 11: 12 – 14

Pratt, P.F. 1965. *Potassium in Methods of Soil Analysis.* Second edition. American Society of Agronomy, Madison, 1019 p.

Pundir, J.P.S. and Porwal, R. 1999. Effect of spacings and fertilizers on growth, yield and physical fruit quality of chilli (*Capsicum annuum* L.) cultivars. *J. Spices Aromatic Crops* 8: 23–27

Pushparajah, E., Haridas, G. and Soong, N.K. 1976. Utilization of effluent and bowl sludge from natural rubber processing. Agro-industrial Wastes Symposium, 12–14 February 1976. Malaysian Society of Soil Science, Kuala Lumpur. *Abstract*: 170

Pushparajah, E., Haridas, G. and Soong, N.K. and Zeid, P. 1975. Utilization of effluent and bowl sludge from natural rubber processing factories. Agro-industrial Wastes Symposium, 11– 13 February 1975. Malaysian Society of Soil Science, Kuala Lumpur. *Abstract*: 117

Raj, N.J.P. and Velayudham, K. 1995. Direct and residual effect of mussoorie rock phosphate, organic manures and phosphobacteria in rice-black gram system. *Madras agric. J.* 82: 220–221

Raja, M.I. and Raj, D. 1979. Effect of press mud application on physical chemical and biological characteristics of some common soils. I. Laboratory studies. *Madras agric. J.* 66: 538–545

Rajan, A.R.and Sriramalu, U.S. 1987. Influence of sewage wastes on dry matter yield of crops. *Indian J. agric. Chem.* 20: 243–250

Ram, S., Patnaik, N.C., Mohapatra, A.K.B., Sahoo, S. and Samal, K.C. 1996. Effects of fertility levels and chilli varieties on the yields of green chillies and incidence of chilli thrips *Sciothrips dorsalis* Hood. in Eastern ghat Highland zones of Orissa. *Environ. Ecol.* 14: 642–645

Raman, S., Patel, A.M., Shah, G.B. and Kaswala, R.R. 1996. Feasibility of some industrial wastes for soil improvement and crop production. *J. Indian Soc. Soil Sci.* 44: 147–150

Raman, S., Patil, R.G. and Zalawadia, N.M. 1999. Press mud as a potential source of nutrient, amendment and wax. *Fertil. News* 44 (11): 25-31

Ramesh, V. and Chhonkar, P.K. 2001. Growth and uptake of nutrients by rice and lettuce grown on an acid sulphate soil amended with fly ash and lime. *J. Indian Soc. Soil Sci.* 49: 222–225

Rao, K.J. and Shantaram, M.V. 1996. Effect of urban solid wastes on dry matter yield, uptake of micronutrients and heavy metals by maize plant. *J. Environ. Biol.* 17: 25–32

Reddy, G.R. and Rao, K.J. 2000. Impact of sewage irrigation on macro-nutrient status of soils. *Andhra agric. J.* 47: 218–223

Roychoudhury, A., Chatterjee, R. and Mitra, S.K. 1990. Effect of different doses of nitrogen, phosphorus, potassium, magnesium, calcium and iron on growth and development in chilli. *Indian Cocoa Arecanut Spices J.* 13: 96-99

RRIM. 1976. *Annual Report 1975-76.* Rubber Research Institute of Malaysia, Kuala Lumpur, 120 p.

Sadasivam, S. and Manickam, A. 1992. *Biochemical Methods for Agricultural Sciences.* Wiley eastern Ltd., Madras, 246 p.

Saga, K. 1973. Studies on the pungency of red pepper fruit – The effect of mineral nutrition specially phosphorus nutrition. *Bull. Fac. Agric. Hirosaki Univ.* 18 : 96 - 106

Santiago, C.L. and Goyal, M.R. 1985. Nutrient uptake and solute movement in drip irrigated summer peppers. *J. agric. Univ. Puerto Rico* 69: 63–68

Sharma, B.R., Chadha, A.P.S. and Bajpai, H.K. 1996. Response of chilli (*Capsicum annuum* Linn.) to nitrogen and phosphorus levels under irrigated condition. *Adv. Pl. Sci.* 9: 213–214

Sharma, R.N. and Singh, D.P. 1994. Studies on the fertilizer requirement of chilli. *Bharatiya Krishi Anusandhan Patrika* 9: 225–231

Sharma, U.C. and Sinha, H. 1989. Residual effect of phosphatic sources in a rice-gram rotation on acid soil. *J. Indian Soc. Soil Sci.* 37: 190–192

Shukla, V., Srinivas, K. and Prabhakar, B.S. 1987. Response of bell pepper to nitrogen, phosphorus and potassium fertilization. *Indian J. Hort.* 44: 81 – 84

Simpson, J. R., Adair, C.R., Kohlr, G.O., Dawson, E.N., Debald, H. A., Klister, E.B. and Klick, J.I. 1965. *Quality evaluation studies of foreign and domestic rice*. Technical Bulletin No. 1331. United States Department of Agriculture, Washington D.C., 250 p.

Singaram, P. and Kothandaraman, G.V. 1992. Effect of residual phosphorus on availability of nutrients by different sources and levels of phosphorus in a cropping system. *Madras agric. J.* 79: 579–582

Singh, A., Agrawal, S.B., Rai, J.P.N. and Singh, P. 2002. Assessment of the pulp and paper mill effluent on growth, yield and nutrient quality of wheat (*Triticum aestivum* L.). *J. Environ. Biol.* 23: 283–288

Singh, D., Mannikar, N.D. and Srivas, N.C. 1976. Fertilizer value of indigenous rock phosphates compared with single super phosphate : Laboratory incubation studies with farm yard manure. *J. Indian Soc. Soil Sci.* 24: 78-80

Singh, K. and Srivastava, B.K. 1988. Effect of various levels of nitrogen and phosphorus on growth and yield of chilli (*Capsicum annuum* L.). *Indian J. Hort.* 45: 319–324

Singh, R.V. and Naik, L.B. 1990. Response of different vegetable crops to NPK levels and spacing in Chotanagpur region. *Fertil. News* 35(11): 35–39

Singh, T., Singh, P.N. and Yadav, D.V. 2001. Effect of application of fertilizers and manures on sugarcane productivity and soil fertility changes under a sugarcane based cropping system. *Indian J. Sugarcane Technol.* 16: 1–8

Singh, Y. and Bahadur, R. 1998. Effect of application of distillery effluent on maize (*Zea mays*) crop and soil properties. *Indian J. agric. Sci.* 68: 70–74

Sinha, R.K. and Sinha, E.A.K. 2000. *Waste Management.* INA Shree Publishers, Jaipur, 319 p.

Sivanadyan, K. 1992. Natural rubber latex serum concentrate: its agronomic potential. *Pltrs' Bull.* 210: 3-8

Sivanadyan, K. and Asokumar, A. 1989. Agronomic potential of natural rubber serum powder. Rubber Grower's Conference, 4–7 January 1989. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract*: 548

Smirnoff, N. 1996. The function and metabolism of ascorbic acid in plants. *Ann. Bot.* 78 : 661–669

Smirnoff, N. and Pallanca, J.E. 1996. Ascorbate metabolism in relation to oxidative stress. *Biochemical Soc. Trans.* 24 : 472-478

Snedecor, G.W. and Cochran, W.G. 1967. *Statistical Methods.* Sixth edition. Oxford and IBH Publishing Co., Calcutta, 206 p.

Soong, N. K. and Yeoh, C. S. 1974. The use of NR emulsion for stabilizing sandy soils. Planter's Conference, 23–26 May 1974. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract*: 127

Soyza, S., Yogaratnam, N. and Yapa, P.A.J. 1994. Use of rubber factory effluents as a fertilizer for young Hevea plants. *J. Rubb. Res. Inst. Srilanka* 74: 1–9

Srinivas, K. 1983. Response of green chilli to nitrogen and phosphorus fertilization. *S. Indian Hort.* 31: 37-39

Srinivasan, K., Veeraragavathatham, D., Kanthaswamy, V. and Thiruvudainambi, S. 1999. Effect of nitrogen and phosphorus on the yield and economics of hybrid capsicum. *S. Indian Hort.* 47: 57– 60

Srinivasan, V., Sadanandan, A.K. and Hamza, S. 2000. Efficiency of rock phosphate sources on ginger and turmeric in an Ustic Humitropept. *J. Indian Soc. Soil Sci.* 48: 532–536

Srivastava, A. and Chhonkar, P.K. 2000. Effect of fly ash on uptake of phosphorus, potassium and sulphur by sudan grass and oats grown on an acid soil. *J. Indian Soc. Soil Sci.* 48: 850–853

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for estimation of available nitrogen in soils. *Curr. Sci.* 25: 259–260

Subbiah, K., Helkiah, J. and Rajagopal, C. K. 1980. Effect of nitrogen, phosphorus and potassium on capsaicin content of MDU-1 chilli. *S. Indian Hort.* 28: 103–104

Subbiah, K., Helkiah, J., Ravikumar, V. and Rajagopal, C.K. 1982. Effect of combined application of organic and inorganic fertilizer on yield and nutrient uptake of MDU-1 chilli. *S. Indian Hort.* 30 :45-47

Subehia, S.K. 1998. Effect of rock phosphate on some chemical properties of soil. *Crop Res.* 15: 37–42

Sukanya, T.S., Meli, S.S. and Patil, R.H. 2002. Effect of spent wash as irrigation water on performance of maize (*Zea mays*) and soil fertility. *Indian J. agric. Sci.* 72: 736–738

Swaminathan, K. and Vaidheeswaram, P. 1991. Effect of dyeing factory effluents on seed germination and seedling development of groundnut (*Arachis hypogea*). *J. Environ. Biol.* 12: 353–358

Tan, H. T. and Pillai, K. R. 1976. Possible utilization of factory effluent on oil palm and other crops. Oil Palm Seminar, 23–25 November 1976. Palm Oil Research Institute, Malaysia. *Abstract*: 248

Tan, H.T., Pillai, K.R. and Barry, D.J. 1975. Possible utilization of rubber factory effluent on crop land. International Rubber Conference, 2–5 March 1975. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract*: 158

Tan, H.T., Pillai, K.R., and Yeow, K.H. 1973. *Report on Crop Diversification Research and Effluent Trials in Chemera.* Chemera Research Station, Seremban, Malaysia, 108 p.

Tapia, M.L. and Dabed, R. 1984. Nutrient uptake by sweet pepper grown in quartz. Sixth International Congress on Soil less Culture, 7–9 August 1984. Wageningen University, Netherlands. *Abstract*: 683

Teoh, K.C. and Chew, P.S. 1984. Use of palm oil sludge cake in oil palm and cocoa poly bag nurseries. Seminar on Land Application of Oil palm and Rubber Factory Effluents, 11–13 March 1984. Malaysian Society of Soil Science, Serdang. *Abstract*: 9

Tewari, D.D., Srivastava, A. and Pandey, Y. N. 2003. Effect of rubber factory effluent on growth of *Pisum sativum* (var. Auricle). *J. Living Wld* 10: 7–11

Thangavel, P. 2002. Interaction effect of raw and diluted tannery effluent and amendments on nutrient status and SAR of soil. *Indian J. agric. Chem.* 35: 77-86

Thawale, P.R., Juwarkar, A.S., Kulkarni, A.B. and Juwarkar, A.A. 1999. Lysimeter studies for evaluation of changes in soil properties and crop yield using wastewater. *Intl. J. trop. Agric.* 17: 231–244

The Rubber Board. 2001. *Rubber Grower's Companion*. Rubber Board, Kottayam, 135 p.

Thiagarajan, C. P. 1990. Influence of NPK on the yield and quality of chilli seed. *S. Indian Hort.* 38: 159–160

Thomas, L. and Gopinathan, R.2002. Organic meals from KCPL slurry – A breakthrough in industrial waste utilization for sustainable agriculture. *Proceedings of Fourteenth Kerala Science Congress, January 29 – 31, 2002* (ed. Das, M.R.). Kerala State Committee on Science, Technology and Environment, Thiruvananthapuram, pp. 253 -257

Tisdale, S. L., Nelson, W.L., Beaton, J.D. and Havlin, J. L. 1997. *Soil Fertility and Fertilizers*. Fifth edition. Mc Millan Publishing Co., New York, 634 p.

Tiwari, R.C., Saraswat, P.K. and Agrawal, H.P. 2003. Changes in macronutrient status of soils irrigated with treated sewage water and tube well water. *J. Indian Soc. Soil Sci.* 51: 150–152

Uddin, M.M. and Begum, S. 1990. Effect of fertilizers on vitamin C content of green chilli (*Capsicum* sp.) *Bangladesh J. scient. ind. Res.* 25: 118–124

Varadan, K.M., Satyanarayana, T. and Havanagi, G.V. 1977. Some phosphate studies on ragi. *J. Indian Soc. Soil Sci.* 25: 380–390

Wahab, M.B.H.A. 1976. Sources of phosphate for rubber and associated crops – Preliminary studies. Planter's Conference, 24–27 May 1976. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract*: 75

Wahab, M.B.H.A., Dolmat, M.T. and Isa, Z. 1979. Bowl sludge–A potential fertilizer. *Pltrs' Bull.* 159 : 41–53

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37: 29–34

Wood, B.J. 1977. A review of current methods for dealing with rubber factory effluent. *Planter* 53: 477-495

Wood, B.J. and Lim, K.H. 1989. Developments in the utilization of palm oil and rubber factory effluents. *Planter* 65: 81–98

Yapa, P.A.J. 1984. Effluent disposal and environmental pollution in rubber plantations in Srilanka. International Rubber Conference, 3–6 March 1984. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract*: 391

Yapa, P.A.J. 1987. A study on fertilizer value of rubber factory effluents on young Hevea plants. Science Asian Conference, 21–23 June 1987. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract*: 141

Yeow, K.H. 1983. Treatment methods, fertilizer values and land application systems of oil palm and rubber effluents. Seminar on Land Application of Oil palm and Rubber Factory Effluents, 12–14 March 1983. Malaysian Society of Soil Science, Serdang. *Abstract*: 213

Yeow, K.H. and Yeop, A.K. 1983. The present status of effluent utilization in Malaysia. Planter's Conference, 23–26 May 1983. Rubber Research Institute of Malaysia, Kuala Lumpur. *Abstract*: 347

*Yodpetch, C. 2000. Study on the optimum fertilizer rates on yield and quality of three long cayenne peppers (*Capsicum annuum* L.). *Kasetsart J. Natl. Sci.* 32: 37–45

Zalawadia, N.M., Raman, S. and Patil, R.G. 1997. Influence of diluted spent wash of sugar industries application on yield and nutrient uptake by sugarcane and changes in soil properties. *J. Indian Soc. Soil Sci.* 45: 767–769

*Original not seen

EVALUATION OF LATEX SLUDGE AS A PHOSPHORUS SOURCE IN CROP PRODUCTION

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ABSTRACT

A detailed investigation entitled 'Evaluation of latex sludge as a phosphorus source in crop production' was carried out at College of Agriculture, Vellayani, with chilli (*Capsicum annuum* L.) as the test crop. Preliminary studies in both India and abroad had shown this waste product of latex concentrate industry to be a rich source of plant nutrients especially P.

Initially the basic physico-chemical properties of this sludge material were estimated followed by an incubation study in which its P release pattern was compared with that of two conventional P sources -SSP and RP. Then pot culture experiments were undertaken to study its direct and residual effects on the growth and yield characters of chilli var. Jwalamukhi.

Chemically, latex sludge is magnesium ammonium phosphate. Analytical studies revealed it to be near neutral (pH 6.49) in reaction which is mainly due to the pH buffering effect of its magnesium phosphate component. So, no significant variation in soil pH was observed both in the incubation study as well as in the pot culture experiments and in this respect it is comparable with the conventional P sources- SSP and RP.

The total P content is 35.98 per cent grading it superior to rock phosphates now popular in market as commercial fertilizers. Of the total P, 13 per cent is water soluble and 36 per cent citrate soluble, together accounting for nearly half of the gross P content. The presence of both fractions gives latex sludge an added advantage over SSP and RP, in that it can provide both readily available and slowly available forms of P, making it suitable for a wide range of crops and soils.

Another positive property of latex sludge is the presence of Mg (6.86 per cent) and N (6.05 per cent) in it. Mg has been found to be required by many plants in about the same quantities as P to increase their photosynthetic efficiency. The N is present in readily available form too *ie*., as ammonium phosphate.

The presence of about five per cent organic C is another advantage as it enhances phosphate dissolution capacity of the material. In addition, it can supply minute quantities of K and Ca (less than one per cent). On the basis of its chemical profile, latex sludge can be considered more or less as a complete complex fertilizer.

The greatest advantage is its ability to act as a slow release fertilizer, a property bestowed on it by the encapsulation of nutrients by rubber residues present in low concentration.

The dynamics of important soil chemical properties on incubation with latex sludge (T_1), SSP (T_2) and RP (T_3) were studied against a control (T_4, soil alone) for a period of 120 days. These sources were applied to one kg soil taken in plastic containers, to provide P @ 40 kg ha^{-1} and the soil was maintained at field capacity.

The superiority of latex sludge in increasing the soil organic C content was very much evident from the incubation study, even though there was an initial delay. From the 30^{th} day onwards latex sludge was significantly superior to RP and SSP, the values gradually increasing to a maximum by the 75^{th} day followed by a slow decline.

The available N values were the highest for latex sludge applied soil throughout the incubation period except on the 105^{th} day. From 30^{th} to the 90^{th} day these values were significantly superior to those for SSP and RP applied soils.

The different P sources exerted significant influence on soil available P contents throughout the incubation period. On the 15^{th} day, the water soluble phosphates of SSP maintained its superiority by recording a value significantly higher than that of all other sources. The next highest value was recorded by latex sludge and was significantly superior to RP. But from the 30^{th} day onwards, P release from latex sludge and SSP became statistically comparable and significantly superior to that from RP. The uniform release pattern of both latex sludge and SSP continued till the 90^{th} day and thereafter the three sources became on par in their P release capacities. The superior effect of latex sludge in maintaining a high soil available P till about 90th day is therefore very much evident and is mainly due to the presence of both water and citrate soluble P fractions in it.

The available K levels in soil remained unaffected throughout the incubation period despite P application in different forms.

The various P sources could produce significant variations in soil exchangeable Ca and Mg levels only towards the middle period of the incubation. In general, latex sludge was seen on par with RP in increasing soil exchangeable Ca but the Mg release pattern showed high inconsistency.

The agronomic efficiency of latex sludge was evaluated by conducting pot culture experiments laid out in CRD with a main and a residue crop of chilli var. Jwalamukhi. The treatments included T_1 (full P as LS), T_2 (full P as SSP), T_3 (full P as RP), T_4 (¼ LS + ¾ SSP), T_5 (½ LS + ½ SSP), T_6 (¾ LS + ¼ SSP), T_7 (¼ LS + ¾ RP), T_8 (½ LS + ½ RP), T_9 (¾ LS + ¼ RP), T_{10} (No P) and T_{11} (absolute control). Urea, muriate of potash and FYM were applied uniformly to all treatments except absolute control, as per Package of Practices Recommendations of Kerala Agricultural University. The P fertilizers were applied as per treatment schedule.

The growth characters of chilli registered the maximum values when full P was given as SSP (T_2). But, the effects were statistically on par with the combination treatment T_8 (½ LS + ½ RP).

Yield in general was favourably enhanced when latex sludge was applied along with RP. The highest yield was recorded by T_7 (¼ LS + ¾ RP) but it was on par with T_8 (½ LS + ½ RP). The economic analysis (benefit-cost ratio) also showed the same trend of yield.

The quality traits of chilli also testified the suitability of latex sludge as an alternate P source. The treatment combination T_8 (½ LS + ½ RP) registered values which were either the highest or on par with the highest.

The plant uptake of nutrients, a major yield contributing factor, also showed trends in favour of latex sludge. The uptake of N, P, K, Ca and Mg which were significantly influenced by the treatments were the highest or on par with the highest for the combination treatment, T_8.

Chemical analysis of soil upon crop harvest indicated that the combination treatment T_8 (½ LS + ½ RP) could maintain higher levels of available N, P and exchangeable Mg. Full P as latex sludge (T_1) recorded the highest organic C content and was significantly higher than all other treatments.

The residual effects of the treatments were studied by raising another crop of same variety of chilli in the same pots using the same soil following all the cultural operations as for the main crop except P addition.

The highest residual effect of P was exhibited by the combination treatment T_8 (½ LS + ½ RP) manifested by recording the highest fruit yield and thereby the highest returns.

The high residual effect of T_8 (½ LS + ½ RP) was also evident from its highest P uptake indicating adequate P availability inspite of its lack of application to the current crop. Moreover, the uptake of other nutrients was either the highest or on par with the highest value for the same treatment (T_8).

The present investigation, therefore, undoubtedly proves that latex sludge can be used as an alternate and cheap source of P in crop production. The combination treatment T_8 (½ LS + ½ RP) emerges superior on the basis of its direct and residual effects on growth, yield and quality characters of chilli. Economic analysis substantiates this further. Moreover, use of this apparently ecofriendly material in crop production will be a boon in terms of its disposal also.

APPENDIX

APPENDIX - I

Weather parameters during the cropping period

Main crop – August to December 2003

Residue crop – January to April 2004

Fortnight	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rain fall (mm)	Evaporation (mm)
August I	30.96	24.26	80.90	35.50	3.69
August II	30.72	24.25	80.75	65.00	4.01
September I	30.92	23.55	76.46	10.30	4.70
September II	31.92	24.30	73.56	0.00	5.20
October I	30.60	23.50	84.13	242.0	3.60
October II	30.20	22.90	83.87	273.9	2.10
November I	30.00	23.40	83.73	165.9	2.70
November II	30.90	20.70	81.11	3.50	2.45
December I	31.00	22.10	74.43	0.00	2.60
December II	31.40	20.90	77.68	0.00	3.33
January I	31.50	22.30	76.43	0.00	3.45
January II	31.80	22.90	77.37	6.80	3.65
February I	32.00	21.30	77.35	0.40	4.05
February II	32.10	24.50	74.35	0.00	4.30
March I	33.10	24.70	75.95	0.00	4.60
March II	32.70	24.50	77.15	1.20	4.56
April I	33.50	24.70	74.96	67.7	4.40