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Availability and uptake of P from organic and in organic sources of P in teak (*Tectona grandis*) using radio tracer technique

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Pot culture experiments were conducted on two bench mark soil series of Kerala (varying in available P status) at the Radiotracer Laboratory, Kerala Agricultural University, with the objectives of studying the effect of organic and inorganic sources of P on the growth of teak seedlings, uptake of P, percent P derived from fertilizer (% Pdff), P use efficiency (PUE) and A value using ^{32}P. The treatments consisted of combination of four levels of weed compost (0, 100, 150 and 200 g pot^{-1}) as organic source and three levels of inorganic P (4, 8 and 16 mg P kg^{-1}) in the form of KH_2PO_4. The experiment was laid out by adopting a factorial completely randomized block design. Results revealed that in both soils with varying levels of P, application of inorganic P at the rate of 4 mg kg^{-1} increased % Pdff and P use efficiency compared to higher levels of P application. Combined application of different levels of compost with inorganic P at the rate of 4 mg kg^{-1} resulted in significant improvement in % Pdff and P use efficiency. But shoot biomass, total P uptake and A value increased with increasing levels of inorganic P. Combined application of different levels of compost with inorganic P at 16 mg kg^{-1} also significantly improved shoot biomass, total P uptake and A value. The results in general indicated that combined application of compost with inorganic P fertilizer was more effective than application of inorganic fertilizer alone in both soils for enhanced absorption and use efficiency of P. Thus the integrated use of fertilizer and manure will enhance the productivity of teak plantation.

Key words: Phosphorus, ^{32}P, % Pdff, P use efficiency, teak.

INTRODUCTION

Vigorous teak growth requires fertile, deep, well drained soils (Kollert and Cherubini, 2012). Teak will also grow on degraded sites (Osemeobo, 1989), where it serve to rehabilitate the soil, produce timber and provide other products and services (Roshetko et al., 2013). On infertile and impoverished soil teak will not achieve its upper growth potentials. Plantations of teak have a long history in India, especially in the state of Kerala. The first teak plantation was established in Nilambur as early as 1836. However by second and third rotation the productivity of plantations stated to decrease. This decrease in productivity, to a large extend was attributed to soil

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deterioration. (Rugmini and Balagopalan, 2001; Geetha and Balagopalan, 2009). In view of low availability of land to meet the growing demand for timber the only option before teak growers is to increase productivity of per unit of land. The problems of soil degradation can be remedied to a certain extend by application of fertilizers and organic amendments. The importance of application of organic amendments to impart fertility to degrading soils has been realized not only in the agricultural sector but also in plantation forestry. Among the major nutrients, availability and absorption of phosphorus (P) in degraded lateritic soils of teak plantations in Kerala has become a major constraint due to low pH, high P fixation capacity and low to medium available P status (Suresh Kumar, 1999 and Geetha et al., 2010). Phosphatic fertilizers applied to such soils are subjected to large fixation in the soil reducing the availability to the fertilized crop. Integrated use of chemical fertilizers along with organic amendments is found to be a viable option to improve the use efficiency of applied nutrients. Accelerating prices of chemical fertilizers due to withdrawal of subsidies also created a need for alternate P sources and increasing the efficiency of phosphatic fertilizers. Even though, lots of information is available on the combined use of fertilizers and organic amendments for improving crop yields and soil fertility, the direct quantification of P extracted by teak seedlings from applied fertilizer alone and in combination with organic amendments has not yet been studied. Therefore, this study mainly intends to use ^{32}P as tracer to estimate quantitatively the P absorption and P use efficiency from applied inorganic source and the synergistic effect of organic amendment on P availability in two soil series of Kerala differing in available P status.

MATERIALS AND METHODS

In order to achieve this objective, pot culture experiments were conducted using ^{32}P to find out the rate of absorption and nutrient use efficiency in teak seedlings by growing them in two soil series in which teak is widely grown *viz.,* Velappaya and Panikkulam, having low and medium levels of available P respectively. The experiment was conducted in a green house at Radiotracer Laboratory of Kerala Agricultural University during 2007-2008 mainly to study the absorption and nutrient use efficiency of P by teak seedlings using ^{32}P labelled KH_2PO_4.

Collection of soils

Surface soils (0 to 15 cm) were collected from two bench mark soil series of Thrissur District *viz.,* Velappaya and Panikkulam from Killannoor and Panjal panchayaths respectively. Velappaya soil series was with low available P status while Panikkulam was with medium level. Soils were air dried and sieved through 2 mm sieve for laboratory analysis as well as for pot culture studies.

Green house experiment

Air dried soils of the soil series mentioned above were used to fill 36 plastic pots of uniform size and 1 kg capacity. Weed compost containing 2.3% N, 1.23% P and 1.83% K was air dried, sieved through 2 mm sieve and used as organic amendment in the experiment. The treatments consisted of combination of four levels of weed compost (0, 100, 150 and 200 g pot^{-1}) and three levels of inorganic P (4, 8 and 16 mg P kg^{-1}). The experiment was laid out by adopting a factorial Completely Randomized Block Design and continued up to 30 days.

Organic P: 4 levels
Inorganic P: 3 levels
Total treatment combination : 4 × 3 = 12
Replication: 3
Total no. of pots in one soil series: 12 × 3 = 36
No. of soil series: 2
Total no. of pots in the experiment: 36 × 2 = 72

Weed compost was applied in each pot as per the treatment and mixed with the soil to a uniform consistence, one week prior to the planting of teak seedlings. Nitrogen and potassium were applied in the form of urea and muriate of potash as per Package of Practices Recommendations (KAU, 2007). Teak seedlings were raised in the nursery for three months and then transplanted to the pot. Each pot was planted with two seedlings.

The isotope ^{32}P (t1/2- 14.3 days; E max: 1.71 Mev) obtained as ^{32}P in dilute hydrochloric acid (HCl) medium from the Board of Radiation and Isotope Technology (BRIT), Mumbai was used for the study. The source of inorganic P, KH_2PO_4 was labelled with the above ^{32}P so as to get a specific activity of 2.0 mCi / mg of P. This solution was used as the source of inorganic P. This solution was placed in band around seedlings. Regular watering was done daily to maintain optimum soil moisture.

Seedlings were maintained in the pots for one month. Plant samples collected 30 days after planting were oven dried at 65°C ± 5 to a constant weight, powdered and kept ready for analysis. Samples were then digested with diacid mixture nitric- perchloric acid (2:1) and P in this solution was determined by vanado-molybdate yellow colour method (Piper, 1966) and the intensity was measured in a spectrophotometer.

Radio assay

The radioactive P in the above digest was determined following Cerenkov counting (Wahid et al., 1985). The counts per minute (cpm) of ^{32}P in all the samples were recorded and corrected for back ground and decay. The specific activity in the applied fertilizer and that in plant samples were computed using counts rates (cpm g^{-1}) in the fertilizer and plant samples. The data from radio assay was used to compute percent P derived from fertilizer (% Pdff), percent P derived from soil (% Pdfs), A values and P use efficiency as suggested by Fried and Dean (1952). A value is the availability index of the nutrient from soil. Banded application of fertilizer ensures accurate A values.

$$\%\ \text{Pdff} = \frac{\text{Specific activity in plant sample}}{\text{Specific activity in fertilizer}} \times 100$$

$$\%\ \text{Pdfs} = 100 - \%\ \text{Pdff}$$

$$\text{Uptake of P from fertilizer (mg P pot}^{-1}) = \frac{\%\ \text{Pdff}}{100} \times \text{Total P uptake (mg P pot}^{-1})$$

$$\text{A value (mg P 100 g}^{-1}\text{ soil)} = \frac{\%\ \text{Pdfs}}{\%\ \text{Pdff}} \times \text{P applied (mg P 100 g}^{-1}\text{ soil)}$$

Table 1. Effect of combined application of inorganic P and compost on % Pdff by teak seedlings grown in soils with varying levels of P.

Treatment	Inorganic P (mgkg^{-1})		
Compost (g pot^{-1})	4	8	16
		Velappaya series (low P)	
0	9.51^{b}	8.02^{c}	5.56^{d}
100	10.46^{a}	6.05^{d}	5.74^{d}
150	9.33^{b}	6.13^{d}	6.39^{d}
200	7.53^{c}	5.92^{d}	5.75^{d}
F Value		9.838**	
		Panikkulam series (medium P)	
0	6.24^{ab}	5.11^{cd}	3.98^{efg}
100	6.67^{a}	4.35^{def}	3.13^{g}
150	5.56^{bc}	3.88^{efg}	3.17^{g}
200	4.66^{cde}	3.90^{efg}	3.46^{fg}
F Value		2.764*	

Means with same letter as super script are homogeneous, ns- nonsignificance, ** - significant at P= 0.01,*- significant at P= 0.05.

$$\text{P use efficiency (\%) (PUE)} = \frac{\text{\% Pdff} \times \text{Total P uptake (mg P pot}^{-1})}{\text{Fertilizer P added (mg pot}^{-1})}$$

Statistical analysis

The data obtained in the experiment was subjected to analysis of variance using the statistical package SPSS (Norusis, 1988). Mean comparisons between treatment means were done using Duncan Multiple Range Test (DMRT).

RESULTS

Results obtained were % P derived from fertilizer (% Pdff), 'A' value, P use efficiency, shoot biomass and uptake of P. All results are discussed below and summarized in Tables 1 to 5.

Percent P derived from fertilizer (% Pdff)

Statistical analysis of % Pdff data (Table 1) revealed significant interaction between two factors, inorganic P and compost, as well as significant variation between treatments in the both soils series.

In low P soils, % Pdff varied from 5.56 to 10.46. Application of inorganic P at 4 mg kg^{-1} along with compost at 100 g pot^{-1} resulted in maximum % Pdff in this soil. Data also indicated a general decreasing trend in % Pdff with increase in the rate of inorganic P applied.

In medium P soils, % Pdff varied from 3.13 to 6.67. As seen in low P soil, application of inorganic P at 4 mg kg^{-1} along with compost at 100 g pot^{-1} resulted in maximum % Pdff and this was on par with the treatment P at 4 mg kg^{-1} alone. Data also indicated a general decreasing trend in % Pdff with increase in the rate of inorganic P applied.

A value

Statistical analysis of 'A' value data (Table 2) revealed significant interaction between two factors inorganic P and compost, as well as significant variation between treatments in both the soil series.

In both low and medium P soils, treatments varied significantly with respect to A value. In low P soil, A value varied from 3.43 to 27.28. Application of inorganic P at 16 mg kg^{-1} without compost resulted in maximum A value and this was on par with the treatment P at 16 mg kg^{-1} with 100 and 200 g pot^{-1} of compost. In general, A value increased with every successive rate of inorganic P applied. In medium P soil, A value ranged from 5.65 to 49.81. Significantly higher A value was recorded in the treatment inorganic P at 16 mg kg^{-1} along with 100 and 150 g compost.

Phosphorus use efficiency

Statistical analysis of the P use efficiency data (Table 3) revealed significant interaction between two factors, inorganic P and compost, as well as significant variation between treatments in both the soil series.

In low P soil, P use efficiency ranged from 0.76 to 2.67. Application of inorganic P at 4 mg kg^{-1} along with compost at 200, 150 and 100 g pot^{-1} recorded significantly

Table 2. Influence of combined application of inorganic P and compost on A value (mg 100 g $^{-1}$ of soil) of soils with varying level of P.

Treatment	Inorganic P (mgkg^{-1})		
Compost (g pot^{-1})	4	8	16
		Velappaya series (low P)	
0	3.82^{d}	9.24^{d}	27.28^{a}
100	3.43^{d}	12.56^{c}	26.43^{a}
150	3.89^{d}	12.31^{c}	23.51^{b}
200	4.92^{d}	12.71^{c}	26.23^{a}
F Value		3.940**	
		Panikkulam series (medium P)	
0	6.10^{g}	14.90^{f}	38.61^{c}
100	5.65^{g}	17.66^{ef}	49.81^{a}
150	6.80^{g}	19.83^{d}	49.03^{a}
200	8.58^{g}	19.70^{d}	44.71^{b}
F Value		5.422**	

Means with similar letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01,*- significant at P= 0.05.

Table 3. Influence of combined application of inorganic P and compost on phosphorus use efficiency (%) of soils with varying level of P.

Treatment	Inorganic P (mgkg^{-1})		
Compost (g pot^{-1})	4	8	16
		Velappaya series (low P)	
0	1.82^{b}	1.08^{ef}	0.83^{h}
100	2.50^{a}	1.22^{de}	0.76^{h}
150	2.67^{a}	1.41^{cd}	0.93^{gh}
200	2.62^{a}	1.44^{c}	0.94^{gh}
F Value		8.467**	
		Panikkulam series (medium P)	
0	1.68^{b}	1.30^{c}	0.63^{f}
100	1.95^{a}	0.86^{de}	0.64^{ef}
150	1.88^{ab}	0.88^{d}	0.58^{f}
200	1.91^{a}	1.18^{c}	0.70^{def}
F Value		4.988**	

Means with similar letter as superscript are homogeneous, ns-nonsignificant, ** -significant at P= 0.01, *-significant at P= 0.05.

high P use efficiency compared to other treatments. In medium P soil, P use efficiency ranged from 0.58 to 1.95. As seen in low P soil, application of inorganic P at 4 mg pot^{-1} along with compost at 200 and 100 g pot^{-1} resulted in maximum P use efficiency. While, P at 4 mg pot^{-1} along with compost at 150 g pot^{-1} was on par with the above treatment. Similarly, application of higher rates of inorganic P also resulted in a decrease of P use efficiency in this soil.

Shoot biomass

Statistical analysis on shoot biomass data (Table 4) revealed significant interaction between two factors, inorganic P and compost, as well as significant variation between treatments in both the soil series.

In low P soil, significantly higher biomass was obtained due to the application of higher level of inorganic P (16 mg kg^{-1}). Even though shoot biomass significantly

Table 4. Influence of combined application of inorganic P and compost on shoot biomass of teak seedlings (g pot^{-1}).

Treatment	Inorganic P levels (mgkg^{-1})		
Compost (g pot^{-1})	4	8	16
		Velappaya series (low P)	
0	3.23^{d}	3.40^{cd}	4.44^{ab}
100	3.29^{d}	3.67^{c}	4.11^{b}
150	3.37^{cd}	4.10^{b}	4.15^{ab}
200	3.46^{cd}	4.30^{ab}	4.51^{a}
F Value		4.013**	
		Panikkulam series (medium P)	
0	4.49^{cde}	4.81^{c}	4.56^{cd}
100	4.70^{c}	4.16^{e}	5.81^{a}
150	4.84^{c}	4.29^{de}	5.24^{b}
200	4.62^{cd}	5.36^{b}	5.24^{b}
F Value		20.230**	

Means with similar letter as superscript are homogeneous, ns-nonsignificant, **- significant at P= 0.01, *-significant at P= 0.05.

Table 5. Influence of combined application of inorganic P and compost on uptake of P (mg P kg^{-1}) of teak seedlings.

Treatment	Inorganic P levels (mgkg^{-1})		
Compost (g pot^{-1})	4	8	16
		Velappaya series (low P)	
0	0.77^{j}	1.08^{i}	2.40^{ab}
100	0.96^{ij}	1.64^{fg}	2.12^{cd}
150	1.15^{hi}	1.84^{ef}	2.34^{bc}
200	1.39^{gh}	1.95^{e}	2.63^{a}
F Value		4.839**	
		Panikkulam series (medium P)	
0	1.09^{h}	2.03^{d}	2.54^{c}
100	1.18^{gh}	1.58^{f}	3.27^{a}
150	1.36^{g}	1.81^{e}	2.95^{b}
200	1.66^{ef}	2.43^{c}	3.25^{a}
F Value		14.138**	

Means with similar letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01, *-significant at P= 0.05.

increased with increased rates of compost at lower levels of inorganic P (4 and 8 mg kg^{-1}), the data were on par at higher level of P (16 mg kg^{-1}) irrespective of the quantity of compost applied. The results in general revealed that application of high levels of inorganic P alone and in combination with compost increased shoot biomass.

Compared to low P soils, shoot biomass was significantly higher in medium P soils and the data ranged from 4.49 to 5.81 g pot^{-1}. Here also significantly higher biomass was obtained due to application of higher level of inorganic P (16 mg kg^{-1}). Unlike in the case of medium P, the compost applied at 100 g pot^{-1} was found significantly superior at higher level of P.

Uptake of P

Statistical analysis of P uptake data by teak plants revealed significant interaction between compost and inorganic P in both the soil series (Table 5). Significant variation between treatments was also observed in both soils.

In low P soil, uptake of P ranged from 0.77 to 2.63 mg kg^{-1}.

Uptake of P increased with higher application rates of inorganic P as well as compost. Maximum uptake of P was observed in the treatment inorganic P at 16 mg kg^{-1} + 200 g pot^{-1} of compost. Application of inorganic P alone at 16 mg kg^{-1} also resulted in higher uptake and this was on par with the treatment (16 mg kg^{-1} + 200 g pot^{-1} of compost) which gave maximum uptake. In medium P soil, uptake of P varied from 1.09 to 3.27 mg kg^{-1}. As observed in low P soil, uptake of P was increasing with increase in the rate of inorganic P as well as compost. Maximum uptake of P was in the treatments with higher rate of inorganic P (16 mg pot^{-1}) along with compost at 100 and 200 g pot^{-1}. The higher shoot biomass and uptake of P in medium P soil could be attributed to the relatively higher soil pH coupled with higher quantity of plant extractable P in soil.

DISCUSSION

Percent P derived from fertilizer (% Pdff)

In low P soils a decreasing trend in % Pdff with increase in the rate of inorganic P was due to the immediate adsorption of applied P by the Al and Fe hydrous oxides present in the soils. These hydroxides have the ability to absorb P on their surfaces and thus much of the added P is ‘fixed’ instead of being made available for crop use (Akinrinde, 2006). It was also noted that application of compost at higher levels resulted in a decrease of % Pdff at all levels of inorganic P. This would mean that higher levels of compost application resulted in more P absorption from soil pool rather than from fertilizer pool. It is assumed that rather than working directly by plants as a nutrient source, compost improves the soil properties and makes more P available from the native soil pool. The above results established the fact that teak plants showed a preference for native P over the fertilizer P especially with compost application. Comparatively low values of % Pdff observed in teak plants might be due to its perennial nature. Karanja et al. (1999) also reported low % Pdff (3 to 6%) in *Grevelia robusta* at three month after transplanting.

A value

Increased A value with every successive rate of inorganic P applied was due to the increase in the available P caused by the direct application of inorganic (Sharpley et al., 1987) also found that continued fertilizer P applications caused decreasing P-sorption thereby increasing the available P levels. Results also revealed that combined application of compost along with inorganic P increased A value. This increase might be due to the release of organic acids during the decomposition of compost, which delay the crystallization and formation of Ca-P complexes and Ca-P minerals. At the same time, it may form complexes with iron (Fe) and aluminium (Al) and thus reduce the number of sites for P sorption. Illmer and Schinner (1995) also emphasized on the role of organic manures in the release of P as well as mobilization of native soil P into the soil matrix.

In general, it was seen that A value was high in medium P soil compared to low P soil. Medium P soil contains more soil organic carbon and this being an energy source for microbes, and their activity may be partly responsible in part for increased levels of labile P (Lee et al., 1990) in addition to its relatively higher level of inherent soil P.

Phosphorus use efficiency

Phosphorus use efficiency was found to be high in compost applied treatments. El-Ghamry et al. (2009) also reported higher P use efficiency due to application of increased rate of humic acid in faba bean. Results also indicated significant decrease of P use efficiency with increasing rate of inorganic P. This is due to at low levels of P, roots will compete for more P and this in turn leads to efficient use of P from applied P source in this soil. Similar observations were also made by Shrivastava et al. (2007). In general, low P use efficiency was seen in medium P soil compared to low P soil and this is attributed to relatively higher content of native P in this soil.

Shoot biomass

Fagbenro and Aluko (1987) also found positive correlations between rates of inorganic and organic fertilizer application and growth of leucaena and gliricidia in acid soils of Nigeria. Russo and Berlyn (1990) and Ulukan (2008) also reported that humates (granular and liquid forms) could reduce plant stress and enhance plant nutrient uptake.

Uptake of P

Results in general revealed the importance of inorganic P as well as compost application in both soil series. The low response of teak seedlings to compost application in low P soil might be due to the inadequate quantity of P coupled with slow decomposition of applied compost to elevate the inherent low level of available P pool to an optimum needed for easy absorption by plants. But in medium P soils, native soil P as well as applied compost might have been sufficient to get the desired level of available P pool for enhanced absorption by the plants. Integration of organic amendment with P fertilizers is reported to increase P in labile pools and may have potential to enhance the availability in soil (Sanchez et al., 1997). Similar findings on enhanced dry matter yield and P uptake by rock phosphate enriched compost inoculated with fungus have been reported by Biswas and Narayanasamy (2006). Hence, the results in general indicated that application of inorganic P alone and in combination with compost resulted in enhanced P uptake. This can be attributed to increased P availability (Yasin et al., 2012) and a decrease in P sorption due to presence of the decomposition products of organic matter (Iyamuremye and Dick, 1996). This is in line with the finding of Rajan et al. (1991) that higher pH and low Al content in soil increased yield and P uptake in rye grass.

Conclusion

Results from the radiotracer investigation using ^{32}P revealed that in both soils with varying levels of P, application of inorganic P at 4 mg kg^{-1} increased % Pdff and P use efficiency compared to higher levels. Combined application of different levels of compost with inorganic P at 4 mg kg^{-1} resulted in significant improvement in % Pdff and P use efficiency. But shoot biomass, total P uptake and A value increased with increasing levels of inorganic P. Combined application of different levels of compost with inorganic P at 16 mg kg^{-1} also significantly improved shoot biomass, total P uptake and A value. From the above study it is concluded that combined application of compost with inorganic P fertilizer was more effective than application of inorganic fertilizer alone for enhanced absorption and use efficiency of P in teak seedlings. The findings of the study will help teak growers to make informed decision about integrated use of fertilizer and organic manure to improve productivity.

Conflict of Interest

The authors have not declared any conflict of interest.

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