EARLY RESPONSE OF SECOND ROTATION *PINUS PATULA* TO NITROGEN AND PHOSPHATE FERTILIZER AT SAO HILL AND SHUME FOREST PLANTATIONS – TANZANIA

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ABSTRACT

Forest stand fertilisation is considered to be one of the options for increasing the productivity of second rotation stands of fast growing tropical pine plantations. A fertiliser trial was initiated at one site in Shume Forest Project (NE Tanzania), and at two sites in Sao Hill Forest Project (SW Tanzania), to examine the effect of Nitrogen (N) and Phosphate (P) fertilisers on the growth of 2-year old Pinus patula. All sites were in the second rotation of the same species. Seedlings were planted in April 1997 at Shume, and in March 1998 at Sao Hill. . Treatments consisted of two rates of N (0, 60 kg N ha^{-1}) and three of P (0, 30, 60 kg P ha^{-1}) in a randomised complete block design replicated thrice. The six factorial treatments were applied in April 1998 at Shume, and April 1999 at Sao Hill. At Shume, tree heights were measured in May 1997 and May 1998; both height and diameter at breast height (DBH) in September 1998, and October 1999. Foliage samples were collected in March 1999 and analysed for N, P, K, Ca and Mg concentrations (%) and contents (mg/fascicle weight). At the Sao Hill sites tree heights were measured in November 1998 and 1999, respectively.Application of P at Shume significantly ($P<0.05$) depressed DBH from 1.68± 0.10 in the control to 1.45 ±0.14 cm in the fertilised plots, but had no significant effect on height. Measurements taken at Sao Hill in November 1998 (6 months before fertilisation), showed that tree height at the two sites in Sao Hill differed significantly (($P<0.001$), with trees at Ngwazi significantly taller (45.35±2.59cm) than at Msiwasi (36.39±4.13cm). However, these differences were no longer significant six months after fertilisation. Application of N increased stem height and height increment, but the effect was non-significant. Application of P fertiliser increased height and one-year height increment at both sites in Sao Hill, but this was only significant ($P<0.05$) at Msiwasi. Mean heights were 132.2±21.0cm in the control, 144.4±21.4cm at 30 kg P ha^{-1}, 158.7±6.2cm at 60 kg P ha^{-1}. Height increments were 94.8±19.4, 107.7±23.6, and 123.6±7.6cm. Foliar K concentration (%) was depressed by addition of P fertiliser ($P<0.05$) from 1.88 ± 0.44% in the control to 1.31± 0.06% at the highest P rate at Shume. Foliar N content was increased by P fertilisation from 1.48±0.23 (mg per fascicle weight) in the control to 1.87± 0.50 at the highest P rate.Above results, although preliminary, indicate that fertilisation with N and P may not be justified at Shume since there was no positive response two years after fertilisation. Results from Sao Hill strongly indicate a positive response to P within the first year at one site, but not in the other. This emphasises the need for developing site-specific fertiliser recommendations based on research studies.

INTRODUCTION

Pinus patula is one of the most important plantation species in East and Southern Africa where it is important for timber production, pulp and paper manufacture, particle board and wood - wool manufacture (Wormald, 1975). In Tanzania, it was first tried by the Germans at Amani (1000m altitude), and following a series of successful provenance trials large scale planting started in 1960's and by 1970 about 11,000 ha had been planted and in Kilimanjaro, Meru, West Usambara and Southern Highland at Sao Hill, Kiwira and Kawetire (Ahlback, 1988). The Sao Hill Forest Project with 49,000 ha is mostly planted to *P. patula* (Mtuy, 1995).

The growth rate and yield of *P. patula* varies considerably depending on site conditions as well as on management techniques and the genetic quality of the stock. Crop production in tropical region is often limited by low levels of soil nutrients such Nitrogen, Phosphorous, and micronutrients such as Boron and Copper. Deficiency of nutrients reduces plant growth and vigour and hence increases sensitivity to pests and diseases or adverse weather. Symptoms of nutrient deficiencies in trees include the discoloration of the foliage and sometimes stem deformities. However, often the interaction of nutrients with each other in tree growth is generally more important than the effect of a single element. For instance, when nitrogen alone was added to a phosphorus deficient soil, the growth of *P. patula* dropped behind the control (Evans, 1992).

In East Africa, especially in Tanzania, several reports have indicated soil fertility problems in first rotation *P. patula* stands (Procter, 1968; Cannon, 1985; Tangwa *et al.*, 1988). Results from few fertiliser trials and soil analysis suggested nutrient deficiencies especially in latosol at Sao Hill (Procter, 1968). Procter (1967) reported a Boron (B) deficiency problem in the fertile volcanic soil of the Southern Highland of Tanzania, as well as in soils derived from the basement complex rocks. The latter soils are usually loose to friable, highly leached and deficient in nutrients. Sao Hill Forest Project, the largest forest plantation in Tanzania, is located on such soil. Interestingly, Boron deficiency appeared to affect the growth of *P. elliottii* much more than that of *P. patula*. The die-back of *E. grandis* and *E. saligna* in Zambia has also been attributed to B deficiency Cannon (1985). This fertility problem can sometimes be corrected by application of borax at time of planting (Procter, 1967).

Whereas fertilisation has been shown to be one of the most efficient ways of increasing land productivity and can be highly profitable, nevertheless this practice is not common in tropical plantation forestry. For most tropical developing countries, inorganic fertilisers are considered too expensive for agriculture including plantation forestry. Other factors limiting adoption of fertilisation include losses due to leaching, surface run off, volatilisation, immobilisation and P fixation. It is clear that just as in agriculture, preliminary trials will be required to establish if forest stand yields will be increased through fertilisation, and whether such gains are profiTable.

This study was undertaken with the broad objective to improve the yield of *P. patula* plantation in Tanzania through site amelioration. The specific objective was to study the effect N and P fertilisers on the growth of *P. patula*.

MATERIAL AND METHODS

Site Description of the Study Areas

Shume

The field experiment was established in Gologolo within the Shume Forest Project (4^{0} 40'S, 38^{o}16$^{'}$É; 1700 m a.s.l.) in West Usambara Mountains, Tanzania. Rainfall is distributed in two seasons; long rains during March – May, and short rains from November to December. Mean annual rainfall ranges from 600 mm to more than 1200mm (Msangi, 1990). The mean annual temperature varies with altitude: at 500m it is the 25 – 27^{o}C, while on the plateau at 1500 - 1800m, it ranges from 17 - 18^{0}C (Wiersum et. al., 1985). A low temperature of 3.1^{0}C has been recorded at Shume (Moreau, 1935). The soils are classified as *Eutric* - *Nitisols* developed from basement complex parent geological material in FAO/UNESCO World Soil Map. Soil texture varies from sand loam to clay; the top soil colours are normally dark due to organic matter, while subsoil are red, yellowish-red, brownish-red and yellow (Lundgren, 1978). The natural vegetation comprised of *Juniperus excelsa*, *Ocotea usambarensis*, *Macaranga kilimandscharica* and other montane forest species.

Sao Hill

Sao Hill Forest Plantation (8° 18’S to 8° 33’s and 35° 6’E to 35° 20’E, 1900m a.s.l.) is located in Iringa region in the Southern highlands of Tanzania. It receives a mean annual rainfall of 1000mm falling between November and April; mean annual temperature is 16°C (Nykvist, 1976). According to Nykivist (1976), the soils are relatively homogenous and are mainly ***dystric Nitisols*** associated with *orthic acrisols*. The clay minerals are mainly kaolinitic type with low cation exchange capacity, low base saturation and acidic. The natural vegetation varies from open grasslands with scattered trees and shrubs dominated by *Brachystegia* and *Jurbernadia* species (Mhando *et al.*, 1993).

Nursery Techniques

Pinus patula seedlings were raised in the nursery before field planting using standard methods for raising conifer seedlings (Anonymous, 1982).

Establishment of the trial and experimental design

The present study was conducted in second rotation sites following the clear felling of a first rotation stand of *P. patula*. The logging slash was burnt and the land used for maize and beans cultivation using the Taungya system (Chamshama *et al.*, 1992). The site was prepared by complete cultivation and nursery-raised seedlings of *P. patula* planted at a spacing of 3m x 3m. A Randomised Complete Block Design (RCBD) with three replications was adopted at each site. Each block had 9 x 18 rows of trees with each 3 rows of 9trees forming treatment plot; the plots were separated by a 4-m space. Planting at Shume was done in April 1997 and at Sao Hill in March 1998.

At each site, fertilisers were applied one year after planting. The treatments included application of Nitrogen at 0 and 60 kg/ha as urea, and phosphorous at 0, 30 and 60 kg/ha, as triple super phosphate, each applied at radius of 50 cm from each tree. The 6 treatments randomly assigned within each block were applied to all trees in plots measuring 21 m x 24 m. All plots were completely weeded manually by hoe twice per year to reduce competition from unwanted vegetation.

Data Collection

Assessment of survival, tree height and diameter at breast height

All trees in each plot were measured for diameter at breast height (DBH) using a calliper and height by using graduated pole. Survival was calculated by counting the remaining seedlings.

At Shume, tree heights were measured in May 1997 and 1998, September 1998, and October 1999. DBH was measured in September 1998 and October 1999. At the Sao Hill sites, tree heights were measured in November 1998 and 1999, respectively.

Foliage sampling

Foliage samples were collected at Shume, in March 1999 (about one year after fertiliser application), to monitor tree nutritional status. Foliage samples were collected from each from 3 dominant trees selected randomly within each plot. Fully-grown needles were taken from 10 fascicles from the second major whorl in the upper crown of each tree. The needles were begged and transported immediately to the laboratory.

Laboratory analysis

Foliar samples were oven dried at 80^{o} C before chemical analysis. A portion of the dried sample for each tree was dry-ashed at 450^{o} C. The ash was dissolved in IM HCl and K, Ca, and Mg concentration in the aliquot were determined by Atomic Absorption Spectrophotometer, while P concentration was measured colorimetrically using a spectrophotometer. Another dried sub sample was analysed for total N by the Micro-Kjeldahl method. Foliar nutrient contents were obtained by multiplying nutrient concentrations by the average fascicle/weight for each plot.

Data Analysis

The survival, DBH, height and foliar analysis data were summarised using computer software procedures of the Statistical Analysis System Programme (SAS, 1985). Plot means for each variable were subjected to GLM procedure for unequal sample sizes, and those means which were significantly different, were further separated using Student - Newman - Keuls (SNK) Test. Survival % was transformed to Arc-sine numbers before being analysed. Significant effects were judged at $P<0.05$.

RESULTS

Shume Site

Effect of fertiliser application on tree growth

Table 1a shows that tree height was increased by N fertiliser, but the effect was not significant; similarly, the addition of P fertiliser had no significant effect on height.
Addition of P fertiliser significantly decreased DBH at 5 months after application, but this effect had disappeared one year later (Table 1b). The effect of N on DBH was not significant.

Table 1a: Effect of N and P fertiliser on height growth at Gologolo,Shume Forest Project

Fertiliser (kg/ha)	May 1997	May 1998	September 1999	October 1999
		Height, cm		
Nitrogen				
0	34.7±7.0a[ϒ]	156.9±37.0a	190.1±43.6a	376.7±64.4a
60	36.4±6.6a	164.9±31.8a	199.3±36.6a	381.8±36.6a
Phosphorus				
0	35.6±6.8a	164.2±39.8a	202.9±45.5a	384.7±72.9a
30	35.6±6.8a	159.0±30.9a	190.5±36.9a	383.5±61.2a
60	35.4±7.0a	160.3±38.8a	192.8±39.0a	369.9±56.7a

[ϒ]Means followed by the same letter in a column are not significantly different ($P<0.05$)

Table 1b: Effect of N and P fertiliser on DBH growth at Gologolo, Shume Forest Project

Fertiliser (kg/ha)	September 1998	October 1999
	DBH, cm	
Nitrogen		
0	1.5±0.2a[ϒ]	4.8±1.4a
60	1.6±0.2a	5.0±1.3a
Phosphorus		
0	1.7±0.1a	5.0±1.4a
30	1.4±0.1b	4.9±1.4a
60	1.5±0.1b	4.8±1.3a

[ϒ]Means followed by the same letter in a column are not significantly different ($P<0.05$)

Effect of fertiliser application on foliar nutrients

Foliar analysis showed that application of fertiliser had no statistically significant effect on concentration of foliar nitrogen, phosphorous, sodium, calcium and magnesium. However, application of P fertiliser significantly decreased potassium concentration (Table 2a). Addition of N-fertiliser also non- significantly reduced K concentration.

Application of N fertiliser did not significantly affect foliar contents of nitrogen, calcium, phosphorous, potassium and magnesium. But the application of P-fertiliser increased the foliar N content (Table 2b).

Table 2a: Effect of N and P fertiliser rates on foliar element concentrations of *P. patula* at Gologolo, Shume Forest Project

Element concentration (%)	Fertiliser Rates				
	No 0 kg/ha	N1 60kg/ha	Po 0 kg/ha	P1 30 kg/ha	P2 60 kg/ha
K	1.67 ±0.45a♣	1.51±0.21a	1.88±0.44a	1.57±0.17ab	1.31±0.06b
N	1.36 ± 0.26a	1.49±0.24a	1.40±0.25a	1.31±0.24a	1.57±0.23a
P	0.15 ± 0.03a	0.14±0.02a	0.16±0.03a	0.14±0.02a	0.14±0.02a
Na	0.13 ± 0.05a	0.19±0.12a	0.15±0.09a	0.17±0.42a	0.16±0.05a
Ca	2.26 ±0.26a	2.35±0.43a	2.23±0.45a	2.39±0.34a	2.32±0.29a
Mg	0.18 ± 0.03a	0.13±0.60a	0.18±0.04a	0.19±0.07a	0.16±0.02a

♣Means followed by the same letter in a row under a given fertiliser are not significantly different (P<0.05)

Table 2b: Effect of N and P fertilisers on foliar element contents *P. patula* at Gologolo, Shume Forest Project

Element contents mg/fascicle	Fertiliser Rates				
	N0 0 kg/ha	N1 60 kg/ha	P0 0 kg/ha	P1 30 kg/ha	P2 60 kg/ha
N	1.43 ± 0.37a♣	1.65 ± 0.45a	1.48±0.23ab	1.26 ± 0.26b	1.87 ± 0.50a
P	0.15 ± 0.04a	0.15 ± 0.03a	0.17 ± 0.03a	0.13 ± 0.02a	0.16 ± 0.04a
K	1.67 ± 0.51a	1.51 ± 0.21a	2.00 ± 0.48a	1.54 ± 0.16a	1.55 ± 0.29a
Ca	2.26 ± 0.52a	2.35 ± 0.39a	2.38 ± 0.54a	2.33 ± 0.30a	2.71 ± 0.46a
Na	0.13 ± 0.07a	0.19 ± 0.13a	0.16 ± 0.09a	0.18 ± 0.06a	0.19 ± 0.08a
Mg	0.18 ± 0.04a	0.18 ± 6.05a	0.20 ± 0.51a	0.19 ± 0.06a	0.19 ± 0.02a

♣Means followed by the same letter in a row under a given fertiliser are not significantly different (P<0.05)

There was a significant N-P interaction needle Mg content. This was due the decrease in Mg content when P was added without N, while the application of both increased it.

Sao Hill Sites

Differences between sites

Stem height at the two sites in Sao Hill differed significantly during 1998 with a mean of 36.4 ± 4.1cm at Msiwasi and 45.4 ± 2.6cm at Ngwazi. By May 1999 trees were taller at Msiwasi (154.6 ± 25.4cm) than at Ngwazi (145.08 ± 20.04 cm), but these differences were not significant. Site differences in height increment over the period were also not significant i.e., 108 ± 20.92 at Msiwasi and 109.20 ± 24.29 at Ngwazi.

Effect of Nitrogen fertiliser

There was no significant increase in height in 1999 due to fertilisation at any of the two sites although growth was slightly higher at Ngwazi when N was added. For example, fertilised trees had a mean height increment of 113±18 cm compared to 106±30 in the control.

Effect of Phosphate fertiliser

Table 3a shows that the effect of P application on mean stem heights and height increment averaged across the two sites were highly significant. In each case, the highest rate of P differed significantly from the control. Although mean tree height at Ngwazi increased from 150±29 cm in the control to 160±16 cm at highest P rate (60 kg ha^{-1}), this effect was statistically non-significant. The corresponding height increments were 105±27 and 114 ±14 cm.

Table 3a: Effect of P fertiliser on mean height growth of *P. patula* at two sites in Sao Hill Forest Project

P rate ($kgha^{-1}$)	Height (1998)	Height (1999)	Height Increment
		cm	
0	41.2 ± 5.0a	141.0 ± 25.7b[Ξ]	99.8± 23.2b
30	41.1 ± 5.6a	149.1 ± 26.8ab	108.1 ± 26.6ab
60	40.3 ± 6.8a	159.3 ± 11.5a	118.9 ± 12.1a

[¶]Means followed by the same letter in a column are not significantly different (P<0.05)

Table 3b: Effect of P fertiliser on mean height growth of *P. patula* at Msiwasi, Sao Hill Forest Project

P rate ($kgha^{-1}$)	Height (1998)	Height (1999)	Height Increment
		cm	
0	37.4 ± 3.9a	132.2 ± 21.0b[Ξ]	94.8 ± 19.4a
30	36.7 ± 3.7a	144.4 ± 21.4ab	107.7 ± 23.6ab
60	35.1± 5.1a	158.7± 6.3a	123.6 ± 7.6a

[¶]Means followed by the same letter in a column are not significantly different (P<0.05)

However, the effect of P was on height at Msiwasi was highly significant (Table 3b). Although trees had similar heights during the year 1998, the application of P significantly increased tree mean height and height increment whereby trees in the highest P fertiliser rate differed significantly from those in the control (Table 3b).

DISCUSSION

Effect of Fertiliser Application on Tree Growth

Tree growth is a function of climate, soil genetic potential and silvicultural practice adopted. For any species, the main re-course open to silviculturist for increasing yield is to exploit the full site potential by improving soil conditions particularly at time of planting. Soil moisture and nutrient availability are the most critical factors during early stand establishment phase. Soil moisture availability is usually regulated by minimising competition by weeding out unwanted plants. Fertilisation at planting or soon thereafter, aims at providing a sufficient amount of nutrients to ensure unimpeded and rapid establishment of roots. Also fertilisers ensure sufficient available nutrients for rapid root development and hence maintain optimum ratio with other elements especial N and K.

Response to fertiliser application at Shume

From the results of the present study, all treatments seemed to be effective in ensuring high seedling survival and growth at Shume. The survival rate is about 99.5% which exceeds the minimum accepTable survival rate (80%) for most plantations in Tanzania (Anonymous, 1982; Mhando *et al.,* 1993). Application of N-fertiliser had no significant effect on DBH and height. This is in contrast to the results reported by Cromer *et al.* (1981) which showed that height and DBH growth of *Eucalyptus obligua* in Tasmania responded to application of N-fertiliser. Also there is some evidence from other studies that nitrogen fertiliser will assist in the growth recovery of the stand after planting. The results from Shume are also in contrast with those from similar studies which examined nitrogen fertiliser treatment in the central North Island pumice plateau and showed that growth response of *Pinus radiata* was 30 - 60 m^3/ha when other nutrients were not limiting (Hunter *et al.*, 1985).

Application of P-fertiliser to the trees resulted in negative early growth response which is in contrast with the results reported by Maltos and Macier (1984) which showed that there was a growth response of *E. grandis* and *E. saligna* 18 months after application of P fertiliser.

The lack of N X P fertiliser interaction on growth was different from that reported by Cromer *et al.* (1981), but similar to that reported by Schutz (1982). Therefore the application of fertiliser did not improve the growth of 2-year-old *Pinus patula* probably due to loss of fertiliser by soil surface run off and leaching caused by frequent rainfall as rains continued up the end of June.

Response to fertiliser application at Sao Hill

Unlike in Shume, addition of P fertiliser, but not N, increased height growth at both sites in Sao Hill, although the effect was only significant at Msiwasi. Soil fertility problems were reported previously at Sao Hill during the first rotation stands (Procter, 1968; Cannon, 1985; Tangwa et al., 1988). The current results support the findings of Mhando et al. (1993) that reported positive response of 8-year old E. saligna to complete cultivation during site preparation in conjunction with NPK and B fertiliser application. The response to P addition is expected as both trials are located on strongly acidic soils with low native P availability and high fixation capacity of added fertiliser P. The duration of response will thus depend on the amount of P that is fixed, and can be released from the fixed pool, as well as mineralisation of organically-bound P.

In South Africa, the use of fertilisers was considered as a major option for improving soil characteristics for early growth and hence volume production of P. patula which at 7 years age increased by 31% due to fertiliser application (Schutz, 1976). SAPI Forest (Pty) Ltd. initiated three trials testing the effect of increasing phosphate levels on P. elliotii, P. patula and P. taeda. After nearly 9 years of growth all three pines had responded significantly to fertiliser application provided weed growth was controlled. Pinus patula in particular failed to respond if not weeded (Mackenzie and Donald, 1982). In 1979, a trial on reforestation with P. patula was conducted in Golboa plantation in Natal, to compare spot and circle fertiliser application. After four years, DBH was significantly improved by fertiliser application, and spot application gave a bigger DBH than circle application (Morris, 1981).

Work undertaken by the Usutu pulp Co. from 1965 to 1981 which was summarised by Morris (1984), indicated that phosphate gives the most consistent growth response when applied to P. patula at planting but potash was also beneficial. Nitrogen with P or P and K improved growth but alone or when not balanced by P depressed growth. A trial In Swaziland indicated the advantage of both cultivating and fertilising young P. patula (Evans, 1994). Although it appeared that the effect of fertiliser (NPK) was longer lasting than that of cultivation. Second rotation P. patula also appeared to have better growth than in the first rotation (Germishursen, 1974).

Effect Of Fertiliser Application on Foliar Nutrients

The various fertiliser treatments did not significantly affect the concentration of any foliar nutrient, presumably because of the young age of the stand. The results showed that the effect of N-fertiliser application on foliar concentration of N, K P Ca and Mg (Table 4b,c, d) contradicts those reported by Mead et al. (1984). Mead reported that potassium was the element most frequently related to tree size in P. radiata followed by calcium, nitrogen, phosphorous and finally magnesium. Foliage nitrogen concentration less than 1.2% are low enough to ensure economic of fertiliser response with growth being restricted, but further application of 150 kg N/ha at age 7 of P. radiata resulted in statistically significant nitrogen - phosphorous interaction for the nitrogen foliage level (Will, 1985).

The reduction of potassium concentration following the application of P-fertiliser is similar to those reported by Smeathurst et al. (1993), and perhaps reflects a dilution effect. In contrast to the results reported by Adam and Allen (1985), application of P - fertiliser also showed significant effect on N – concentration. The lack of N and P fertiliser interaction differs from those reported by Will (1985).

CONCLUSION AND RECOMMENDATION

The results reported here indicate that the use of fertiliser N and P to enhance early growth at the Shume site may not be justified, as there was no response even at two years after fertilisation. In contrast, results from Sao Hill strongly indicate a positive response to P application within the first year.

As the data used in this study were collected one year after the soil fertility amelioration treatments were imposed, it is therefore too early to make firm conclusions and the trials should be monitored over a longer period. Future assessments will reveal whether the positive response to P at Sao Hill will be sustained Finally, these results from the three sites stress the need for developing site-specific fertiliser recommendations based on research trials.

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