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EARLY RESPONSE OF SECOND-ROTATION *PINUS PATULA* STANDS TO NITROGEN AND PHOSPHATE FERTILIZERS AT SAO HILL FOREST PLANTATION, TANZANIA

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MTUI, E. B., MALIONDO, S. M. S., CHAMSHAMA, S. A. O., NSOLOMO, V. R., MSANYA, B. M. & MHANDO, M. L. 2005. Early response of second-rotation *Pinus patula* stands to nitrogen and phosphate fertilizers at Sao Hill forest plantation, Tanzania. An investigation into the effect of fertilization on second-rotation *Pinus patula* stands as an option for increasing growth and yield was initiated in April 1998 at two sites in the Sao Hill forest plantation, Iringa region, southwest Tanzania. Six factorial fertilizer treatments consisting of nitrogen (N) (0, 60 kg N ha^{-1}) and phosphorus (P) (0, 30, 60 kg P ha^{-1}) were assigned randomly to one-year-old *P. patula* seedlings in April 1999. Tree heights were measured at 7, 18, 22, 30 and 42 months after out-planting. Diameter at breast height (dbh) was measured from 22 months onwards. At 7 months, seedlings were significantly taller at Ngwazi (0.45 ± 0.03 m) than at Msiwasi (0.36 ± 0.04 m). In contrast, although not significant, by 42 months trees were slightly taller at Msiwasi (5.00 ± 0.37 m) than at Ngwazi (4.87 ± 0.46 m). Similarly, height increment measured at 42 months was significantly higher at Msiwasi. Msiwasi had significantly larger dbh trees (1.99 ± 0.36 cm) than Ngwazi(1.62 ± 0.0.30 cm) at 22 months, but these differences disappeared with time. Neither the application of N nor P had any effect on tree growth at Ngwazi. However, application of N depressed tree survival from 96 to 89% at Msiwasi. Application of P increased diameter and height growth at Msiwasi only. These results further stress the need for developing site-specific recommendations based on research studies.

Key words: Silviculture – plantation – *Pinus patula* – second rotation – fertilizers

MTUI, E. B., MALIONDO, S. M. S., CHAMSHAMA, S. A. O., NSOLOMO, V. R., MSANYA, B. M. & MHANDO, M. L. 2005. Respons awal dirian giliran kedua *Pinus patula* terhadap baja nitrogen dan fostat di ladang hutan Bukit Sao di Tanzania. Kajian ke atas kesan pembajaan terhadap dirian giliran kedua *Pinus patula* untuk menggalakkan pertumbuhan dan hasil dimulakan pada April 1998 di dua tapak di Ladang Hutan Bukit Sao di Wilayah Iringa, tenggara Tanzania. Enam rawatan baja faktorial terdiri daripada nitrogen (N) (0, 60 kg N ha^{-1}) dan fosforus (P) (0, 30, 60 kg P ha^{-1}) dijalankan secara rawak ke atas anak benih *P. patula* berumur 1 tahun

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pada April 1999. Ketinggian pokok diukur pada 7 bulan, 18 bulan, 22 bulan, 30 bulan dan 42 bulan selepas penanaman. Diameter pada aras dada (dbh) disukat selepas 22 bulan. Pada 7 bulan, anak benih di Ngwazi (0.45 ± 0.03 m) didapati lebih tinggi daripada anak benih di Msiwasi (0.36 ± 0.04 m). Namun, pada umur 42 bulan, pokok di Msiwasi (5.00 ± 0.37 m) lebih tinggi berbanding pokok di Ngwazi (4.87 ± 0.46 m) walaupun perbezaannya tidak bererti. Pertambahan ketinggian pokok pada 42 bulan lebih tinggi di Msiwasi. Ngwazi mempunyai dbh yang lebih besar (1.99 ± 0.36 cm) daripada Msiwasi (1.62 ± 0.03 cm) pada 22 bulan tetapi perbezaan ini hilang dengan masa. Rawatan N dan P tidak memberi kesan ke atas pertumbuhan pokok di Msiwasi daripada 96% menjadi 89%. Penggunaan P menambahkan diameter dan ketinggian pokok di Msiwasi sahaja. Keputusan ini menekankan pentingnya syor spesifik tapak berdasarkan penyelidikan.

Introduction

Pinus patula is one of the most important plantation species in east and southern Africa where it is planted for timber production, pulp and paper manufacture, particle board and wood-wool manufacture (Wormald 1975). Its growth rate and yield vary considerably depending on site conditions as well as management techniques and the genetic quality of the planting stock (Evans 1996). In Tanzania, plantation yields for pines varied from 25 to 35 $m^3 ha^{-1} year^{-1}$ during the first rotation (Ahlback 1988). In east Africa *P. patula* and *Cupressus lusitanica* are grown at a rotation varying from 25 to 35 years. Although mostly on the lower end, these yields were, however, considered acceptable under the low intensity silviculture adopted (Okama & Chamshama 1988).

After more than 45 years of industrial plantation forestry in east Africa, most of the *P. patula* plantations are in the second rotation. Although the growth and yield of the second-rotation stands have not been measured, several studies from elsewhere have compared the yields of the second rotation and the first rotation (Evans 1996). Where lower yields have been reported, they have been attributed to inherently low soil fertility, altered site conditions such as reduced soil fertility, inappropriate harvesting techniques, poor site preparation and poor tending techniques (Evans 1996, Evans & Boswell 1998). Use of seed from unimproved low yielding and poorly adapted genotypes and the emergence of new pests also lower yield. One of the major tasks ahead is therefore to look for more economical silvicultural methods that will serve to increase growth and yield of the second-rotation *P. patula* plantations.

Poor tree growth attributed to nutrient deficiency problems such as of nitrogen (N), phosphorus (P) and boron (B) has been reported by *inter alia*, Cannon (1985) and Tangwa *et al.* (1988) at Sao Hill Forest Project, southwestern Tanzania, and by Lundgren (1978) at Shume Forest Project in northeastern Tanzania. Unless judicious measures are adopted to rectify these nutrient problems, they are likely to become even more serious during subsequent rotations as nutrients are depleted through consecutive harvesting, and subsequently during the taungya phase of stand establishment (Lundgren 1978). Application of inorganic fertilizers such as N, P and B has been advocated to correct the limiting nutrients in plantations (Cannon 1985).

In some countries such as Brazil, Australia and South Africa fertilization is often used when establishing new plantations (Schonou & Herbert 1989) although it is not operationally applied in many other tropical forest plantations. Elsewhere fertilization is considered one of the most efficient ways of increasing land productivity, and can be highly profitable. For example, in Australia, fertilization of *Eucalyptus grandis* showed significant increase in merchantable volume from 165 $m^3 ha^{-1}$ in the control to 180 $m^3 ha^{-1}$ at harvest (Birk & Turner 1992). In many countries where plantation forestry is practised, it is therefore important to start preliminary trials to establish whether soil fertility status under second-rotation stands is sufficient to sustain high yields and whether fertilization of *P. patula* stands will increase yields and whether such gains are profitable.

This study was therefore undertaken to determine whether there could be improvement of yield of second-rotation *P. patula* stands in Tanzania by application of N and P fertilizers. The Sao Hill forest plantation covering 95 000 ha with about 48 000 ha mostly planted to *P. patula* was selected due to its national as well as regional significance.

Materials and methods

Site description of the study area

Sao Hill forest plantation (8°18'– 8°33' S, 35°6'–35°20' E; 1900 m asl) is located in Iringa region in the southern highlands of Tanzania. It receives a mean annual rainfall of 1000 mm falling between November and April, and has a mean annual temperature of 16 °C (Nykvist 1976). The sites selected for the fertilizer trial were Msiwasi (35°20'27" E, 8°30'50" S; 2024 m asl) and Ngwazi (35°12'4" E, 8°30'36" S; 1883 m asl).

The soil at Ngwazi is described as Hapli-Chromic Lixisols (FAO 1998) or Typic Paleustults (Ultisols) (Anonymous 1999) and at Msiwasi as Hapli-Ferric Lixisols (FAO 1998) or Typic Paleustults (Ultisols) (Anonymous 1999). Some of the physico-chemical attributes of the soils of the two sites are shown in Appendix 1. The natural vegetation consists of open grasslands with scattered miombo woodland trees and shrubs dominated by *Brachystegia* and *Jurbernadia* species (Mhando *et al.* 1993).

Establishment of the trial and experimental design

The experiment was established in two second-rotation sites of Msiwasi and Ngwazi following the clear felling of the first-rotation stand of *P. patula.* Previously the logging slash was burnt and the land used for maize and beans cultivation for a few seasons. Nursery-raised seedlings of *P. patula* were planted in March 1998 at a spacing of 3 x 3 m in pits measuring 40 x 40 cm and 30 cm deep. A randomized complete block design (RCB) with three replications was adopted at each site. Each block had 9 x 18 rows of trees, and each 3 rows of 9 trees constituted a treatment plot. The plots were separated by a 4-m space. The fertilizer treatments were administered one year after planting.

The fertilizer treatments, applied at radius of 50 cm from each tree, consisted of 0 and 60 kg N ha^{-1} as urea, and triple superphosphate at 0, 30 and 60 kg P ha^{-1}. The six factorial treatments were randomly assigned to plots within each block. All plots were completely weeded manually by hoe twice a year to reduce competition from unwanted vegetation.

Data collection and analysis

Tree height was measured at 7, 18, 22, 30 and 42 months after planting. Tree diameter at breast height (dbh) was assessed from 22 months onwards. Tree height and dbh were measured using a graduated pole and a calliper respectively. Tree survival was based on counts of live trees at 42 months and expressing these as percentage of the total planted trees per plot.

The data on dbh and height were summarized using computer software procedures of the SAS 1993, version 6. 03. Plot means for each variable were subjected to analysis of variance using GLM procedure in SAS. Survival percentages were arc-sine transformed before analysis. Treatments means were considered significantly different at $p < 0.05$.

Results

Differences between sites

The combined analysis of variance showed significant site differences in tree height measured at 7 months and dbh at 30 months, as well as in the final one-year height increment. ANOVA for the final one-year height increment is shown in Table 1.

Table 1 Analysis of variance of one-year height increment (Nov. 2000–Nov. 2001) measured at the two sites in the Sao Hill Forest Project, Iringa, Tanzania

Source of variation	d.f.	SS	MS	F - ratio	Pr > F
Site	1	0.7904	0.79035	33.99	0.0001***
Treatment	5	0.1427	0.0285	1.23	0.3272ns
Site X Treatment	5	0.0516	0.0103	0.44	0.8138
Error	24	0.5581	0.5581	-	-
Total	35	1.5427	1178.1	-	-

Figures 1 and 2 show height and dbh growth trends for the two sites, indicating increasingly better growth at Msiwasi over time. At 7 months after planting trees were significantly taller at Ngwazi (0.45 ± 0.03 m) than at Msiwasi (0.36 ± 0.04 m); these differences disappeared over time and at 42 months, although not significantly different, trees were slightly taller at Msiwasi (5.00 ± 0.37 m) than at Ngwazi (4.87 ± 0.46 m).

Similarly, Msiwasi had significantly larger dbh trees (1.99 ± 0.36 cm) than Ngwazi (1.62 ± 0.0.30 cm) at 30 months, but these site differences in dbh were no longer significant at 42 months (Figure 2). By contrast, the final one-year height increment was significantly higher at Msiwasi (2.03 ± 0.17 cm) than at Ngwazi (1.74 ± 0.13 cm).

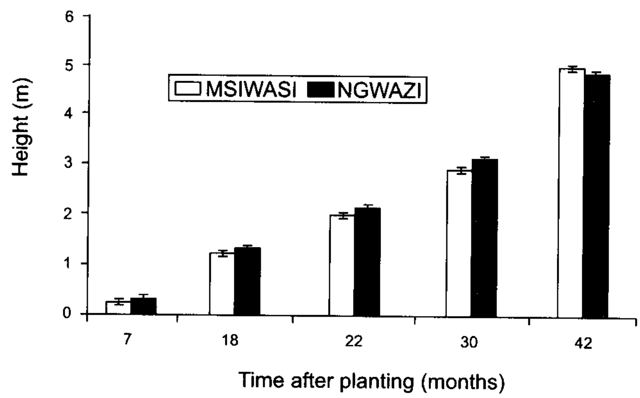

Figure 1 Height growth at Msiwasi and Ngwazi sites at Sao Hill forest plantation, Iringa, Tanzania

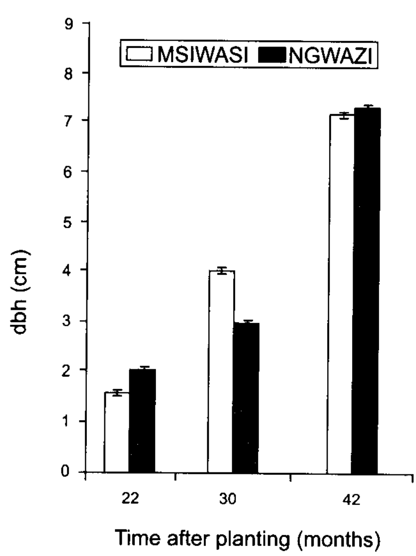

Figure 2 Diameter growth at Msiwasi and Ngwazi in Sao Hill forest plantation, Iringa, Tanzania

Within-site treatment differences

Both height and dbh attributes were significantly affected by blocking at each site indicating that it was effective. Neither N nor P fertilizer significantly affected any of the tree growth attributes at Ngwazi. At Msiwasi by contrast, application of N significantly depressed tree survival at 42 months from 95.9 $\pm$ 3.4 % in the control to 89.3 $\pm$ 9.2 % at 60 kg N ha^{-1} (Table 2).

The effect of P fertilization at Msiwasi was highly significant on height measured at 42 months (Table 3), dbh measured at 30 and 42 months (Table 4), as well as on the final one-year height (Table 5) and 20-month dbh increment (Table 6). Table 5 shows the positive effect of P addition on height growth but which was only significant at 42 months, whereby height increased from 4.72 $\pm$ 0.39 m in the control to 5.28 $\pm$ 0.28 m at 60 kg P ha^{-1}. The corresponding figures for the final one-year height increment were 1.95 $\pm$ 0.09 m and 2.11 $\pm$ 0.23 m (Table 5).

Table 2 Analysis of variance of tree survival at 42 months at Msiwasi, Sao Hill Forest Project, Iringa, Tanzania

Source of variation	d.f.	SS	MS	F - ratio	Pr > F
Block	2	0.2912	0.1456	5.01	0.031*
N	1	0.1476	0.1476	5.08	0.048*
P	2	0.0460	0.0230	0.79	0.480 ns
NP	2	0.0778	0.0389	1.34	0.306 ns
Error	10	0.2905	0.0291	-	
Total	17	0.8530	-	-	

Table 3 Analysis of variance of tree height measured at 42 months at Msiwasi, Sao Hill Forest Project, Iringa, Tanzania

Source of variation	d.f.	SS	MS	F - ratio	Pr > F
Block	2	0.1247	0.0624	0.53	0.60 ns
N	1	0.0545	0.0545	0.47	0.51 ns
P	2	0.9583	0.4791	4.07	0.05*
NP	2	0.0787	0.0394	0.33	0.72 ns
Error	10	1.1772	0.1177	-	
Total	17	2.3934	-	-	

Table 4 Analysis of variance of tree diameter at breast height (dbh) measured at 42 months at Msiwasi, Sao Hill Forest Project, Iringa, Tanzania

Source of variation	d.f.	SS	MS	F - ratio	Pr > F
Block	2	4.9159	2.4579	5.62	0.02*
N	1	0.1225	0.1225	0.28	0.61 ns
P	2	4.1838	2.0919	4.79	0.03*
NP	2	0.4487	0.2244	0.51	0.61 ns
Error	10	4.3703	4.3703	-	
Total	17	14.0412	-	-	

Table 5 Effect of P fertilizer on height growth of *Pinus patula* at Msiwasi in the Sao Hill Forest Project, Iringa, Tanzania

P rate kg ha^{-1}	Tree height (m)					Final one-year height increment
	Age (months after planting)					
	7	18	22	30	42	30–42
0	0.37 ± 0.04	1.32 ± 0.21	1.92 ± 0.27	2.77 ± 0.37	4.72 ± 0.39	1.95 ± 0.09
30	0.37 ± 0.04	1.44 ± 0.21	2.05 ± 0.27	2.95 ± 0.31	4.99 ± 0.24	2.04 ± 0.14
60	0.35 ± 0.05	1.59 ± 0.06	2.20 ± 0.07	3.17 ± 0.16	5.28 ± 0.28	2.11 ± 0.23

Table 6 Effect of P fertilizer on dbh growth of *P. patula* at Msiwasi in the Sao Hill Forest Project, Iringa, Tanzania

P rate kg ha^{-1}	Tree diameter (dbh) (cm)			Final 20-month diameter increment
	Age (months after planting)			
	22	30	42	22–42
0	1.51 ± 0.28	3.57 ± 0.74	7.09 ± 1.04	5.57 ± 0.76
30	1.59 ± 0.39	4.06 ± 0.60	7.56 ± 0.68	5.97 ± 0.33
60	1.75 ± 0.17	4.43 ± 0.31	8.26 ± 0.65	6.51 ± 0.53

Tree dbh at 42 months was increased from 7.09 ± 1.04 cm in the control to 8.26 ± 0.65 cm at 60 kg P ha^{-1}, and the corresponding figures for the final 20-month dbh increment were 5.57 ± 0.76 cm and 6.51 ± 0.53 cm (Table 6).

Discussion

According to Cannon (1985) and Tangwa *et al.* (1988), the Sao Hill Forest Plantation Project had been facing soil fertility problems even during the first rotation, and the use of inorganic fertilizer was recommended from these studies. Later, field fertilizer trials involving the use of N, P, B and K tested with various tillage treatments revealed that some combinations increased the growth of *P. patula* (Kalaghe & Manssy 1989) and *E. saligna* (Mhando *et al.* 1993). The current results, though of a shorter period, further underpin the beneficial effects of P but not of N on the early growth of *P. patula* at Sao Hill. These results support the findings of Evans (1984, 1996) that fertilization can increase the yield of the *P. patula* stands during the second rotation. The significant and positive effect of P fertilizer on tree growth of *P. patula* at Msiwasi persisted for 2.5 years after application. In Brazil, Maltos and Macier (1984) also reported a significant growth response by *E. grandis* and *E. saligna* 18 months after application of P fertilizer.

Except for the depressed survival at Msiwasi at 42 months, there was no growth response to N at either site. By contrast, Evans (1984) reported growth depression by N when applied to P-deficient soils in Swaziland. Goncalves *et al.* (1999), however, stressed the rare response of eucalypt plantations to N fertilization under tropical and subtropical conditions, suggesting that organic N mineralization may be sufficient to meet tree demands.

Up to the time of last measurement, the positive effect of P on tree growth was only significant at one site (Msiwasi) but not at the other (Ngwazi). This might reflect site differences in soil fertility, suggesting Msiwasi to be a poorer site than Ngwazi. Soil analytical data for the two sites (Appendix 1), however, suggest similarity in soil texture, pH, CEC and total N, but lower base saturation and higher Al saturation for Msiwasi than Ngwazi site. Low base saturation and high Al saturation reduce microbial activity, affecting organic N and P mineralization. High Al activity in the soil solution also fixes soil P in a less readily available form. In addition, Msiwasi site is located on a steeper slope (9%) than Ngwazi (5%), suggesting more erosion of the top soil from the former site. The apparently superior fertility attributes of Ngwazi might therefore explain the lack of strong response to NP fertilizer.

Despite the early response of P fertilizer at Msiwasi, it is, however, not clear how long the response will last considering the high fixation capacity of the added P fertilizer (Tairo *et al.* 2002). The duration of the response will depend on the amount of P that is fixed and released from the fixed pool as well as the mineralization of organically bound P.

The longevity of response can perhaps be enhanced by adherence to good silvicultural practices such as complete cultivation during site preparation, frequent weeding to reduce competition for water, space and nutrients, pruning and timely thinning. For example, Mackenzie and Donald (1982) reported poor response of *P. patula* to fertilizer where weed growth was not controlled, while Evans (1996) reported positive response to both cultivation and fertilizing of young *P. patula*, though the effect of fertilizer was longer lasting than that of cultivation.

The ultimate question asked when considering use of inorganic fertilizers in forestry, particularly in poor countries, is whether it can be justified at all. Ultimately justification must be based on cost/benefit ratio based on field studies. Studies like this one, if monitored over long periods, can provide useful information to that end. As pointed out by many workers, however, fertilization of forest plantations must be in support of good silviculture (Evans 1996, Evans & Boswell 1998).

Conclusions

The use of N and P fertilizers to enhance early growth and yield of second-rotation *P. patula* at Sao Hill strongly indicates a positive response to P-fertilizer application but not the interaction of N with P. Application of N significantly depressed dbh growth at Ngwazi.

The data used in this study only covered three years post-fertilization, and hence the results should be treated as preliminary, and await future assessment to reveal whether the positive response to P will be sustained. The results from this trial, however, further stress the need for developing site-specific fertilizer recommendations based on research trials.

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Appendix 1a Selected soil properties for the Ngwazi site, Sao Hill Forest Project, Iringa, Tanzania

Soil depth (cm)	pH	Clay (%)	C (%)	N (%)	Avail. P (mg kg^{-1})	CEC (cmol kg^{-1})	Base saturation (%)	Al saturation (%)
0–15	5.0	35.4	5.00	0.22	4.62	18.7	22.2	40
15–30	5.0	46.4	1.40	0.11	2.94	12.0	19.5	59
30–50	5.1	54.4	0.80	0.08	1.65	9.6	11.8	76
50–75	5.2	57.8	0.73	0.05	1.14	8.4	10.8	81
75–140	4.9	57.6	0.60	0.06	0.63	7.2	12.8	38
140–180+	4.8	59.6	040	0.05	0.60	6.9	14.1	nd

nd – not determined.

Appendix 1b Selected soil properties for the Msiwasi site, Sao Hill Forest Project, Iringa, Tanzania

Soil depth (cm)	pH	Clay (%)	C (%)	N (%)	Avail. P (mg kg^{-1})	CEC (cmol kg^{-1})	Base saturation (%)	Al saturation (%)
0–8	5.1	29.6	3.50	0.20	2.5	17.1	6.5	85.6
8–36	4.9	50.8	3.10	0.07	6.7	12.9	5.4	88.3
36–128	4.5	63.6	0.94	0.07	1.87	10.9	4.6	43.1
128–183	5.1	58.2	0.60	0.04	2.94	9.5	5.8	nd
183+	5.1	55.4	0.34	0.04	2.19	10.2	8.0	nd

nd – not determined.