SOIL WATER ENERGY RELATIONS AND NITROGEN MINERALISATION IN FOREST STANDS OF *PINUS PATULA, EUCALYPTUS SALIGNA* AND *PINE-EUCALYPTS* MIXTURE AT SAOHILL FOREST PLANTATION PROJECT, TANZANIA

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ABSTRACT

This study evaluated the effect of 17-year old monoculture stand of Pinus patula and mixed stand of P. patula - Eucalyptus saligna stand on soil water energy relations, bulk density (BD) and hence soil porosity, soil organic Carbon (OC) content and nitrogen mineralisation. The stands were on the same soil type. In each stand, a soil profile was excavated and soil core samples were collected from three depths for BD estimation, and for determining soil moisture retention at different matric potentials by the pressure chamber method. Soil OC was determined on composite samples from each depth. Nitrogen mineralisation and nitrification of topsoil samples from each stand were estimated from a 14-day aerobic incubation method.The pine stand had significantly higher BD (1.6-g cm^{-3}) than the other two stands (1.4-g cm^{-3}) and consequently, lower soil porosity (41% and 47%). Soil OC was slightly but non-significantly higher in the mixed stand (3.2%) than in the monoculture stands (2.9%). The effect of species on the pattern of volumetric moisture retention curves differed with depth. By combining data from the three horizons, the effect of the three stands was clearly separated. Volumetric available water holding capacity was similar under the Eucalyptus and mixed stands (31%), but much higher than in the pine monoculture (16%). These results indicate that the pine monoculture had inferior soil moisture relations than the Eucalyptus monoculture, but that these soil moisture properties can be improved by mixing pine with Eucalyptus. In contrast, nitrogen mineralisation and nitrification were significantly lower in the soil from the pure eucalyptus stand, suggesting soil fertility problems in this second rotation coppice stand. Despite the positive soil attributes recorded in the mixed stands over pure stands, silvicultural prescriptions for species mixtures are not yet available and need to be developed.

INTRODUCTION

Tropical monoculture forest plantations of fast growing tree species are highly productive and mature at shorter rotations than indigenous forests. Yields for pines and cypress vary from 25-35 to over 40 $m^3 ha^{-1} yr^{-1}$ for Eucalyptus (Zobel *et al.*, 1987). The wood produced from these plantations has many uses, both industrial and domestic. Furthermore, the plantations usually cover large areas hence making mechanical logging worthwhile. In Tanzania, industrial plantations cover over 100,000 ha (Mtuy, 1996). The Sao Hill Forest Project in Southern Tanzania has about 48,000ha mainly planted with *Pinus patula* and *Eucalyptus saligna* and was established to supply a pulp and paper mill and a large-scale sawmill. It also caters for several small-scale mobile sawmills located within the plantations.

Despite the high yields from these plantations of exotic species, concerns have been expressed on the long-term sustainability of these monoculture plantations. Monoculture plantations are considered to be ecologically unsTable. Potential concerns include environmental degradation due to inappropriate establishment and harvesting methods (Lundgren, 1978; Raison and Crane, 1986; Maliondo and Chamshama, 1996), emergency of new pests and diseases (Nsolomo et *al*., 1999), unfavourable hydrological influences (Mhando, 1991) and reduced biodiversity.

It has been argued that plantations of species mixtures are ecologically more sTable and resilient than monoculture stands. By careful selection of species to be planted and the planting configuration, plantations of mixed species may be more resilient. For example they may be more resistant to pest attack. Synergistic associations such as soil fertility improvement by a companion species may increase the productivity of the partner species. For example DeBell *et al.* (1989) and Binkley *et al.* (1992) reported increased productivity of Eucalyptus planted with Albizia, an N-Fixing species, in Hawaii. Of prime importance is that the species are compatible, either spatially or sequentially.

Plantations of species mixtures of exotic species have rarely been tried in the tropics. A stand of *Eucalyptus saligna* and *Pinus patula* grown in mixture was established in 1982 at Sao Hill Forest Plantation Project in SW Tanzania. Monoculture stands of each species were also established at the same time. The pure *Eucalyptus saligna* stand was clear-felled in 1991 and harvested for transmission poles, and is now a second rotation coppice stand. Fortunately, part of species-mix stand and the pine monoculture still exist, and since they are located on the same soil type, this provided a rare opportunity to study the effect of these stands on some important soil properties such as nutrient and soil moisture properties which affect site productivity. We hypothesised that soil properties in the pure stands would not differ significantly from those in the mixed stand. We specifically wanted to examine the effect of 20-year old monoculture stands of *Pinus patula*, *Eucalyptus saligna* (now a coppice stand), and a mixed stand on soil water energy relations, soil pH, bulk density (BD) and soil porosity, soil organic Carbon (OC) content and nitrogen mineralisation.

MATERIAL AND METHODS

Site Description of the Study Area

This study was conducted in November 1999 in Gulusilo Range within the Sao Hill Forest Plantations Project.

Location, topography, vegetation, soil and climate

Sao Hill Forest Plantations (8°18'S to 8° 33's and 35° 6'E to 35°20'E, 1900m a.s.l.) are located in Iringa region in the Southern highlands of Tanzania. The area receives a mean annual rainfall of 1000mm falling between November and April; mean annual temperature is 16°C (Nykvist, 1976). According to Nykivist (1976) and FAO-UNESCO (1977) 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 are acidic. The natural vegetation varies from open grasslands with scattered trees and shrubs dominated by *Brachystegia* and *Jurbernadia* species (Mhando *et al.*, 1993).

Stand Types

Three stands located close to each other were selected at Gulusilo Range, Division I. Before afforestation the stands were the typical Sao Hill grassland sites with scattered bushes, and the land was used by villagers as a small settlement and for cultivation of grains (maize and finger millet), potatoes, and homestead groves of *Oxytenanthera braunii*.

The stands were two separate pure stands of Pinus *patula* and *Eucalyptus saligna* and a mixed stand of the two species. Both the pine and mixed stands were established in 1978 using nursery-raised seedlings, planted at a spacing of 2.5 x 2.5 m. The pure eucalyptus stand was planted in 1980 and clear cut in 1991, and then put under a coppice management regime. The stands are on the same soil type with undulating slope ranging from 1 to 10%. Part of the mixed stand had just been harvested before the start of this study.

Stand Characterisation

A stratified random sampling design was used. Three positions along a soil catena (i.e. upper, middle, lower) were identified in each stand, and at each position five sample plots, each measuring 15 x 15 m, were randomly sited. This gave a total of 15 sample plots per stand.

The breast height diameters (DBH) of all trees in each plot were measured at a height 1.3 m above the ground level using a calliper. The height of five largest trees in each plot, i.e. dominant trees, were estimated using a Suunto hypsometer.

Soil Sampling

Topsoil sub-samples were collected from six points randomly selected within each plot. The sub-samples were then thoroughly mixed to get a composite sample for laboratory analysis.

In addition, a point was selected at the centre of each stand and a soil pit was dug to at least 1-m depth, and the exposed soil profile was described in the field using methods according to FAO guidelines. Soil texture was determined by 'feel method' and soil colour using a Munsel colour chart. Three soil samples were separately collected from each of the three depths selected according to soil colour changes. Three soil cores were collected from each of the three depths using a steel core cylinder.

Laboratory methods

One set of the soil cores was weighed and oven-dried at 105 °C to constant weight for bulk density determination. The other sets were used to characterise the soil water potential using the pressure-chamber method.

The loose soil samples were passed through a 2-mm sieve, and a portion of each soil sample was weighed fresh and then oven-dried for 16 hr at 105 °C to determine oven dry weight. Soil pH was measured on field moist soils using water and 0.01M $CaCl_2$ (2.5:1 ratio) using a pH meter. Soil texture was determined using a hydrometer. Standard methods as described by Anderson and Ingram (1992) were adopted to determine %OC using Black and Walkley method; total Nitrogen by the micro Kjeldahl method; available P by the Bray I method.

A 14-day aerobic incubation method as described by Anderson and Ingram (1992) was used to measure nitrogen mineralisation. To estimate the initial inorganic N (NH_4^+ and NO_3^-), a fresh sample was extracted with 2M K_2SO_4. Net N mineralisation was calculated as the difference between the amount of inorganic N measured after 14 days and that measured initially. Nitrification was similarly calculated.

Data analysis

The data collected for stand attributes (stocking, DBH and height) and soil characteristics were summarised using computer software procedures of the Statistical Analysis System Programme (SAS, 1985). Plot means for each variable were subjected to the analysis of variance using the GLM procedure for unequal sample sizes. Those means, which were significantly different, were further separated using Student - Newman - Keuls (SNK) Multiple Range Test.

RESULTS AND DISCUSSION

General Observations

The monoculture Eucalyptus saligna stand consists of coppices developed after the first stand was cleared 8 years ago. Compared to the other two stands, this stand was more open, hence had more undergrowth vegetation, and less forest floor and a thinner organic soil horizon.

Stand Attributes

The stands differed in stocking (Table 1) with the pine stand being more densely stocked (1084 trees/ha) than mixed stand (767 trees/ha), with 63% of the mixed stand consisting of pine trees. If the number of coppices per stool is disregarded, the number of eucalyptus trees in the mixed stand were only 40% of those in the pure stand. However, in the eucalyptus coppice stand, 62% of the tree had two coppices. Despite the higher stocking, pine trees in the monoculture stand were significantly taller and had larger DBH than in the mixed stand (Figure 1).

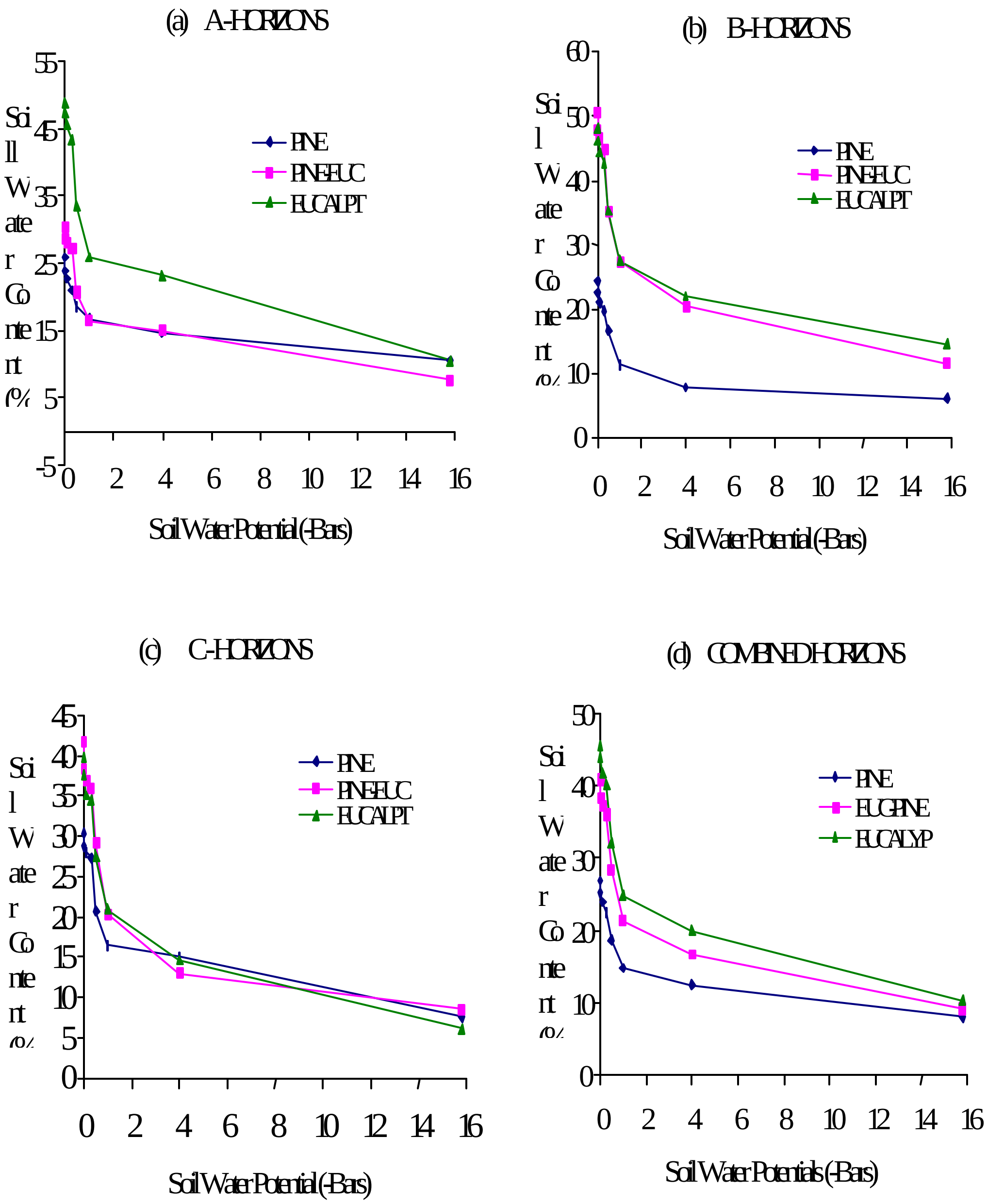

Figure 1. Effect of Species Type on Soil Water Energy Relations (a) A-Horizons
(b) B-Horizons (c) C-Horizons (d) Combined Horizons

Table 1: Stand attributes of the monoculture *P. patula* and P. *patula -E. saligna* mixed stands

Stand Type	Stand Density	Diameter at Breast Height (cm)	Height (m)
P. patula	1084±241	22.62±1.09	28.02±1.05
E. saligna	726±84	13.91±0.36	25.18±1.32
Mixed			
P. patula	478±105	16.26±0..90	21.14±1.30
E. saligna	289±109	26.00±1.16	33.07±1.15

Variation of Selected Soil Properties

The soil texture in the three stands was sandy clay with clay averaging 42% and sand 52%. The soil under the pure pine stand had a significantly higher bulk density (Table 2) and consequently significantly lower porosity than the other two soils. Although soil pH and %OC were lower in the pine than in other two soils the difference was non-significant (Table 2).

Table 2: Effect of tree species on selected soil properties at Sao Hill Forest Plantation Project

SPECIES TYPE	pH	OC (%)	BD (cm3mg-1)	FC (%)	PWP (%)	AVWHC (%)
Pine alone	4.4±0.1a	2.9±0.9a	1.6±0.04a	23.9±2.8b	8.0±1.6b	15.9±3.1b
Pine-Ecalypti	4.6±0.3a	3.1±0.5a	1.4±0.1b	41.6±3.4a	10.9±1.6a	30.7±3.0a
Eucalypti alone	4.6±0.2a	3.1±0.5a	1.4±0.1b	41.7±4.4a	9.4±3.4a	31.4±2.6a

Mean±SD[#]
Mean followed by the same letter in a column are not significantly (NS) different at $P<0.05$.

Table 2 also shows that the soils of the three stand types differed significantly in soil moisture retention at field capacity and in available water holding capacity, with the soil under pine having 50% of the values of the other two soils. The effect of stands on the pattern of volumetric moisture retention curves (Fig. a, b, c) differed with depth, but in general Eucalyptus stand retained more water, and pine stand the least. The mixture curve was intermediate. This trend was particularly evident when data from the three depths were combined (Fig. 2d). The significantly poor water relations in the pine soil is explained by the lower soil porosity as compared to the soil in the other two stands.

Soil Nitrogen Mineralisation

Net N mineralisation was significantly lower in the monoculture Eucalyptus stand, releasing about 45% of the N released by the other two stands (Fig. 3). Nitrification was similarly lower under the Eucalyptus stand indicating that the stand is less fertile than the others (Table 3). Possible reasons accounting for the lower fertility include nutrient losses that occurred during and after harvesting. Nutrients are lost from the site when tree parts are harvested and exported. Also changes in microclimate conditions following canopy removal often accelerate forest floor and soil organic matter decomposition, and unless plant roots intercept the released nutrients they become susceptible to leaching losses. The aggrading Eucalyptus coppice stand, and the dense undergrowth vegetation of indigenous grass, herbs, shrubs and trees might also have sequestered a substantial amount of stand N capital which was thus not measured in the soil.

Table 3: Effect of tree species ammonification, nitrification and net mineralisation surface soil s at Sao Hill Forest Plantations Project after 14-days incubation

SPECIES TYPE	NH_4-N ($mgNkg^{-1}$)	NO_3-N ($mgNkg^{-1}$)	Net N Mineralisation ($mgNkg^{-1}$)
Pine alone	4.37±1.96a#	2.85±1.66a	7.22±2.50a
Pine-Eucalyptus	4.45±1.34a	2.70±1.83a	7.15±0.98a
Eucalyptus alone	1.48±0.46b	1.78±0.39a	3.25±1.69b
F-Probability	0.0086	NS	0.0025

Mean ± SD#

Mean followed by the same letter in a column are not significantly (NS) different at P<0.05.

Higher N availability in mixed stands than in pure stand of certain species has been reported previously in several studies. Richards (1962) reported that different pine species improved the growth of Hoop pine (*Araucaria cunnnghamii* Aik) because of improved N supply brought by pine. In N-limited peat soil, the growth and N status of spruce was enhanced by the presence of larch, due to improved net N mineralisation (Carlyle and Malcom, 1986). Possible reasons were better substrate quality, decomposer community and mycorrhizosphere in the larch litter (Carlyle and Malcom, 1986). Williams (1992) similarly reported enhanced mineral and organic N beneath a 15-year-old Sitka Spruce - Scots Pine than beneath a pure Scots Pine stand. There were indications that beneath Sitka Spruce - Scots Pine, N had been transferred from the underlying soil. The mechanism accounting for the higher N availability under the mixed Pine-Eucalyptus in the present study is yet to be established.

CONCLUSIONS AND RECOMMENDATIONS

The results obtained from this study indicate that soil moisture properties were similar under pure Eucalyptus and Pine-Eucalyptus stands, but significantly higher than in pine stand. In contrast, net mineralisation and hence fertility was similar under pure Pine and Pine-

Eucalyptus stands, and significantly higher than in the eucalyptus stand. Thus the mixed stand of the two species appears superior with respect to soil fertility and soil water relations. However, considering that the study involved three unreplicated stands within one small area, these results should be treated as preliminary. In addition, silvicultural prescriptions for these mixtures including planting configuration do not currently exist, and require further research.

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