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Interspecific competition affects early growth of a *Eucalyptus grandis* x *E. camaldulensis* hybrid clone in Zululand, South Africa

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To determine the effects of the onset and development of vegetation competition on tree performance, a *Eucalyptus* hybrid clone (GC304) was planted in a field trial in Zululand, South Africa. Nine vegetation management treatments, imposed from planting, included a weedy control treatment, a manually weeded treatment, a chemically weeded treatment (glyphosate), a 1.2m row and a 1.2m inter-row weeding, a 0.5m radius ring weeding, a complete weeding except for a 0.5m radius ring around the tree (no ring weeding), and the use of two legume cover-crops, *Mucuna puriens* (L.) DC. (velvet bean) and *Vigna unguiculata* (L.) Walp. (cowpea). The different treatments applied during establishment resulted in the differential growth of the trees as determined by measurements of tree height and crown diameter. This occurred from as early as 60 days after planting. The degree of competition could be directly related to the type of vegetation (cover-crops or naturally occurring weeds) and its proximity to the tree. The predominant vegetation on this site, yellow nutsedge (*Cyperus esculentus* L.), was able to colonise the site rapidly, causing severe and early competition. There were strong indications that this initial competition was mainly for moisture and possibly also for nutrients, rather than competition for light. Initially, trees in those treatments that had vegetation within their immediate vicinity were most affected (weedy control, inter-row weeding and no ring weeding). With time, tree performance was more closely related to an increase in the percentage of the area kept free of vegetation. At 180 days after planting the ranking of the top five treatments in relation to the area kept free of vegetation was: manually weeded treatment (100% of area free of vegetation) > chemically weeded treatment (100% of area free of vegetation) > no ring weeding (90% of area free of vegetation) > row weeding (40% of area free of vegetation) > ring weeding (10% of area free of vegetation). The planting of cover-crops, although beneficial in terms of the suppression of competing vegetation, also caused significant tree suppression. This occurred despite the fact that their initial biomass accumulation was slower than that of the natural weed population. Of the two cover-crops, the use of a velvet bean cover-crop was not considered suitable due to its vigorous vining habit which adversely affected growth form.

Introduction

Vegetation management practiced during the establishment of eucalypt plantations is of utmost importance (Schönau 1989). Benefits include reduced seedling mortality (Dougherty and Lowery 1991), increased stem and stand uniformity (Mason and Kirongo 1998), reduced time to canopy closure (Endo and Wright 1992), increased yields (Little 1999) and reduced rotation times, as well as allowing for improved access into the compartment for various silvicultural operations. Vegetation management in the Zululand region of South Africa is even more critical due to the subtropical climate which favours an extended period of vegetation growth (Schulze 1997) and also the susceptibility of the tree species (*Eucalyptus* hybrid clones) to competition from this vegetation (Little 1999).

In Zululand *Eucalyptus* hybrid clones are grown over short rotations, ranging from six to nine years. To meet the increasing demand for pulpwood from this source, forestry companies will need to increase their timber output. This may be done either by increasing the amount of timber attainable from the existing land base, or through the acquisition of additional land (Brown and Hillis 1984, Kimmins 1994). Present and future land use policies are likely to restrict the conversion of non-afforested land to plantations. Factors influencing an increase in yield and pulpwood from an existing land base include improvements through site-species matching, tree breeding, clonal propagation, the use of interspecific hybrids and silvicultural practices.

Silvicultural management embraces those practices carried out to ensure the successful establishment of a plantation, and has been defined as the science and art of cultivating trees, the theory and practice of controlling the establishment and the growth of forests (Wenger 1984). In closely planted and fast growing eucalypt plantations in South Africa, the period of intensive silvicultural management extends from after harvesting until canopy closure. Intensive silvicultural practices are implemented during this phase in order to achieve the highest maximum yield possible on a site-sustainable basis. Schönau (1990) estimated that a 40% increase in timber yields in South Africa could be achieved through the consolidation and improvement of present silvicultural management practices, when combined with an improvement in present site-species matching and the breeding of superior trees. Of the silvicultural management practices that have been shown to increase the potential volume obtained at harvest, combinations of appropriate site preparation, fertilisation and weed control are considered to be the most important (Squire 1977, Flinn 1978, Cogliastro *et al*. 1990, Neary *et al*. 1990, Turvey 1996).

Limited information linking the impact of different vegetation management practices on tree growth could be found, especially for that of eucalypts grown in South Africa. To address this, a study relating vegetation management and *Eucalyptus* growth was undertaken in 1990 in Zululand to determine the onset of early interspecific competition from several vegetation proximity treatments and to evaluate two leguminous cover-crops for cultural vegetation control. The vegetation management practices selected for use in this trial reflected the then current (at the time of trial initiation) methods of vegetation management.

Materials and Methods

The study was conducted near the coastal town of Mtunzini, KwaZulu-Natal (28°59'S, 31°42'E). The climate is classified as sub-tropical, with a mean annual rainfall and temperature of 1 144mm and 22°C respectively. The trial was located at an elevation of 45m on an east-facing slope. Soil parent material is of aeolin origin and is classified as an arenic lixisol and arenic kandiustult respectively. The soil texture at the 0–20cm depth interval is sandy with low organic carbon (0.23%) and clay (9%) contents. Prior to the establishment of eucalypts, the site had been used for the production of sugarcane (*Saccharum* L. spp.). As a result, the predominant weed on the site was yellow nutsedge (*Cyperus esculentus* L.). However, with the conversion to eucalypts the grass species *Panicum maximum* Jacq. became the dominant weed species.

A pre-plant spray with a non-selective herbicide (glyphosate) was undertaken prior to the establishment of *Eucalyptus grandis* x *E. camaldulensis* clonal hybrid (GC304). The use of the clone imparted a high degree of uniformity to the stand. Trees were planted on 9th October 1990 at an inter-row espacement of 3m and an intra-row spacing of 2.5m resulting in a stocking rate of 1 333 stems ha^{-1}. Each tree was fertilised at planting with 60g limestone ammonium nitrate (LAN) (28% N), applied in a 0.2m diameter ring around each tree. Nine treatments replicated four times were imposed on the stand of hybrids (Table 1). Each treatment plot consisted of 30 trees (5 rows x 6 trees in each row) with the inner net plot of 12 trees being measured (3 rows x 4 trees in each row). Each treatment plot covered an area of $225m^2$, with the total size of the trial being 8 $100m^2$.

The nine treatments were first imposed on 22nd October 1990 with the vegetation in the weedy check receiving no further control. The weed free (manual), row weeding, inter-row weeding, ring weeding and complete weeding, except for the ring (no ring weeding) treatments were kept manually weeded in their respective zones with the use of hoes. Initial weed control for the weed free (chemical) treatment was carried out with the use of glyphosate sprayed at 4l ha^{-1} through knapsack sprayers. Care was taken to protect the trees with the use of inverted plastic cones. Subsequent chemical weeding operations were carried out on the inter-row with a hand drawn shielded spray boom. The cover-crops of cowpea (*Vigna unguiculata* (L.) Walp.) and velvet bean (*Mucuna pruriens* (L.) DC.) were planted in double rows, 1m from the tree rows. The cowpea seeds were planted at an espacement of 100mm and the velvet beans at 200mm. The cover-crops were fertilised at planting with 10g 2:3:2 (N:P:K) + 0.5% Zn m^{-1} row, and were manually weeded on two occasions until a full plant cover had been established, thus reducing the need for further weed control. Vegetation control operations were carried out on a monthly basis in all the manually weeded treatments except the weedy control treatment and the cover-cropping treatments. This continued until canopy closure, after which the limited light available for growth restricted further weed development.

The tree variates of either height or crown diameter were measured at monthly intervals during the initial development of the stand. These were used to determine the performance of the different treatments over time. The mean crown diameter was calculated from two measurements taken on a horizontal plane. The first reading through the widest part of the crown, and the second reading at ninety degrees to the first, with both readings passing through the centre (stem) of the crown. From this, the growth rates for crown diameter were calculated as the difference in the growth of crown diameter over consecutive time periods.

In addition to the various tree variates measured, vegetation biomass and nutrient content, and soil moisture content were also determined at selected intervals. Above ground

Table 1: List of weeding and cover-cropping treatments

Number	Treatment	Method/species
1	Weedy control treatment	None
2	Weed free	Manual
3	Weed free	Chemical
4	Inter-row weeding (1.2m width)	Manual
5	Ring weeding (0.5m radius)	Manual
6	Complete weeding except ring[1] (0.5m radius)	Manual
7	Row weeding (1.2m width)	Manual
8	Cover-crop with weeding to establish	Cowpea
9	Cover-crop with weeding to establish	Velvet bean

[1] This treatment is described in the text and tables as a 'no ring weeding'

vegetation biomass samples were taken from a $0.5m^2$ quadrant in the weedy control and from a $1m^2$ section for the cowpea and velvet bean cover-crops. These biomass samples were taken from the border rows so as not to impact on the performance of the measured trees. One sample was collected from each treatment plot each month. The samples were oven dried for 48 hours at 60°C and their mass determined. Foliar nutrient contents were determined from the biomass samples from the weedy control (30 days after planting) and from the cover-crops (120 days after planting). From this the approximate nutrient content per hectare contained in the biomass was calculated.

On four occasions from January 1991 to April 1991 gravimetric soil moisture measurements were taken from treatments in the first replicate. A CPN 503DR Hydroprobe® was used by taking count ratios (measured count/standard count) at six soil depths up to 0.8m and correlating these with gravimetric soil moisture determinations.

Before comparisons between individual treatment means were made, an *F*-test was carried out. The *F*-test is an overall test of the significance of the differences that have been observed between the means of all the treatments in the experiment (Mead and Curnow 1983). Only if the *F*-value was significant were treatment differences further investigated using least significant differences (LSDs). Comparisons between the tree variates were analysed as a randomised complete blocks design with the use of Genstat® for Windows™ (Lane and Payne 1996). In addition, Bartlett's test (Snedcor and Cochran 1956) was used to test the assumption of homogeneity of variance in order for a valid analysis of variance to be performed.

Results and Discussion

Vegetation growth and the onset of interspecific competition

Relative to the manually weeded treatment, initial tree suppression was detected from the time the first measurements were taken (58 days after planting), for both the tree variates of height and crown diameter (Figures 1 and 2). There is often a delay between the onset of vegetation-induced stress in trees and the detection of this stress in the form of reduced growth for the tree variates measured. As the degree of suppression at this stage was already significant it indicates that suppression occurred at some stage earlier than that recorded. The early suppression of trees in this trial could be a result of the initial type of vegetation occurring on this site, that is yellow nutsedge. Little and Schumann (1996) detected vegetation-induced (predominantly yellow nutsedge) tree suppression 30 days after planting in an *Eucalyptus* weeding trial, also on an ex-sugarcane field in Zululand.

The type of vegetation occurring on ex-agricultural lands is often a reflection of the crop previously grown on the site, combined with the vegetation management practised. As sugarcane was grown on the site prior to the conversion to plantations, its management as the primary crop meant that

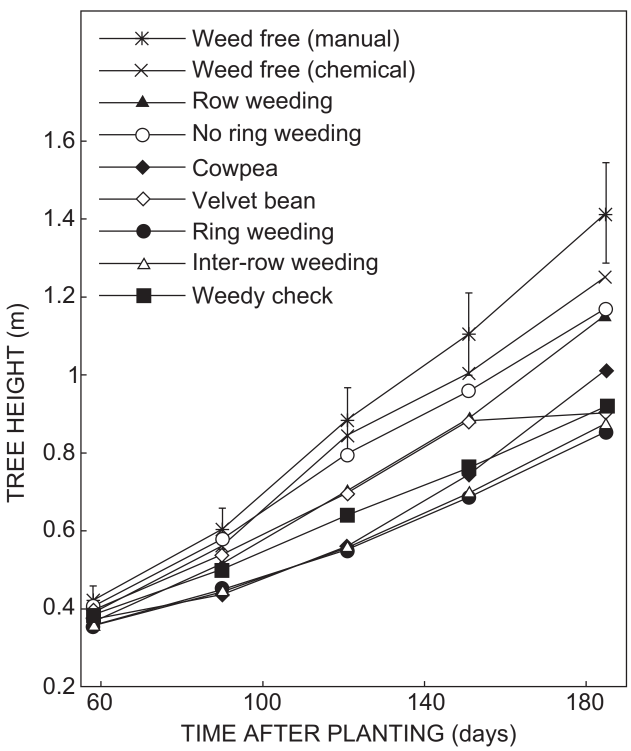

Figure 1: Initial development of tree height with time. The no ring weeding treatment refers to complete weeding except in a 0.5m radius around the tree

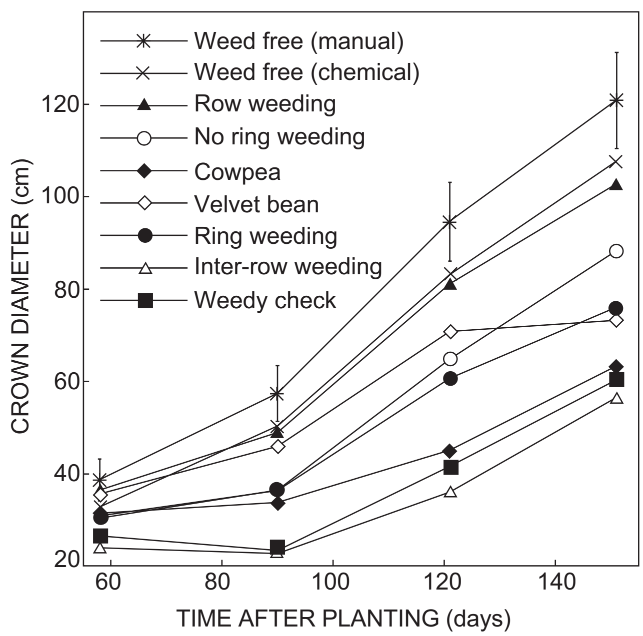

Figure 2: Initial development of tree crown diameter with time. The no ring weeding treatment refers to complete weeding except in a 0.5m radius around a tree

all other vegetation types were targeted for control by manual hoeing or with either selective or non-selective herbicides. One vegetation type that proved to be resilient to most of the forms of control was yellow nutsedge. Yellow nutsedge is a weed characteristic of ex-agricultural lands and its competitiveness may be due to a number of factors. Although it is able to propagate itself by seed, the main form of reproduction is by underground vegetative structures (corms and tubers) (Thullen and Keeley 1975, Schippers *et al*. 1993). This development from vegetative structures would provide an advantage over those competitors that grow from seed, as the species is able to develop almost immediately after conditions for growth become suitable. Initial development of the vegetation biomass in the weedy control treatment was rapid, with an increase from 0.7 tons ha^{-1} to 3.0 tons ha^{-1} being recorded for the first two months of growth (Figure 3). This rapid growth often coincides with the development of the young seedlings, the stage at which they are most vulnerable to interspecific competition. Another problem was the variability in the timing of the sprouting and resprouting habits of yellow nutsedge which makes control difficult. The herbicides used for the control of vegetation as a pre-plant spray, in this case glyphosate spayed at 4l ha^{-1}, did not provide effective yellow nutsedge control due to this variability in sprouting times. Schippers *et al*. (1993) found that yellow nutsedge is still able to grow even with 90% herbicide efficacy. This means that although the growth of the yellow nutsedge plants may be delayed, rapid recovery and growth follows.

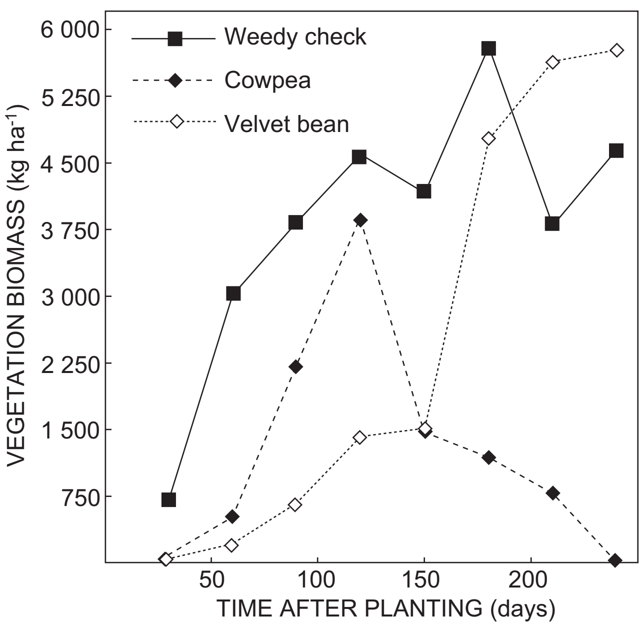

Figure 3: Development of 'dry above ground' vegetation biomass with time

It was unlikely that competition for light would have played a major role in limiting tree growth initially, as the height of the poorest performing treatment at 58 days after planting (inter-row weeding) was already 35.5cm. Yellow nutsedge on these sites very seldom attains a height of over 30cm. Relative to its proximity to trees, yellow nutsedge may have either restricted the initial above ground development of the trees through below-ground competition for moisture and nutrients, or alternatively provided a physical barrier for the development of a larger tree crown. Thus the trees with the smallest crown diameters at 58 days after planting were those treatment plots in which the vegetation was retained in the immediate proximity of the trees. These were the weedy control (26.6cm), the inter-row weeding (23.9cm) and the no ring weeding (30.4) treatments (Figure 2).

The biomass of the vegetation in the weedy control plots developed rapidly until 120 days after planting, after which the rate of development remained fairly constant (Figure 3). Although yellow nutsedge still remained on the site, it was succeeded by annual herbaceous broadleaved species and perennial grasses, of which *Panicum maximum* was the most abundant. Although taller than nutsedge, the delayed development of these species meant that competition remained below-ground for resources, rather than for light, in all but the most suppressed trees. Evidence supporting competition for below-ground resources was provided by four sets of gravimetric soil moisture records measured at different depths with a Hydroprobe® from January 1991 to April 1991 (Figure 4). It is clear that the plots in those treatments containing some form of vegetation cover have lower soil water contents than those without competing vegetation. Similar results were reported by Christie (1994) and Yeiser and Barnett (1991). Christie (1994) found a decrease in soil moisture content with an increasing abundance of *Setaria megaphylla* (Steud.) Dur and Schinz. Yeiser and Barnett (1991) found that soil moisture was greatest and fascicle water potential was least negative for *Pinus echinata* Mill. trees receiving complete control by herbicide, compared with trees receiving partial herbicide application or no weed

Table 2: Foliar nutrient contents contained in the biomass of the weeds and cover-crops

Element	Weeds (30 day biomass)	Velvet bean (120 day biomass)	Cowpea (120 day biomass)
Nitrogen (%)	1.2	3.12	3.17
Phosphorus (%)	0.46	0.93	0.72
Potassium (%)	1.17	2.66	2.05
Calcium (%)	0.42	1.83	1.49
Magnesium (%)	0.44	0.88	0.57
Sodium (%)	0.05	0.08	0.03
Iron (mg kg^{-1})	690	504	496
Zinc (mg kg^{-1})	21	80	72
Copper (mg kg^{-1})	4	7	7

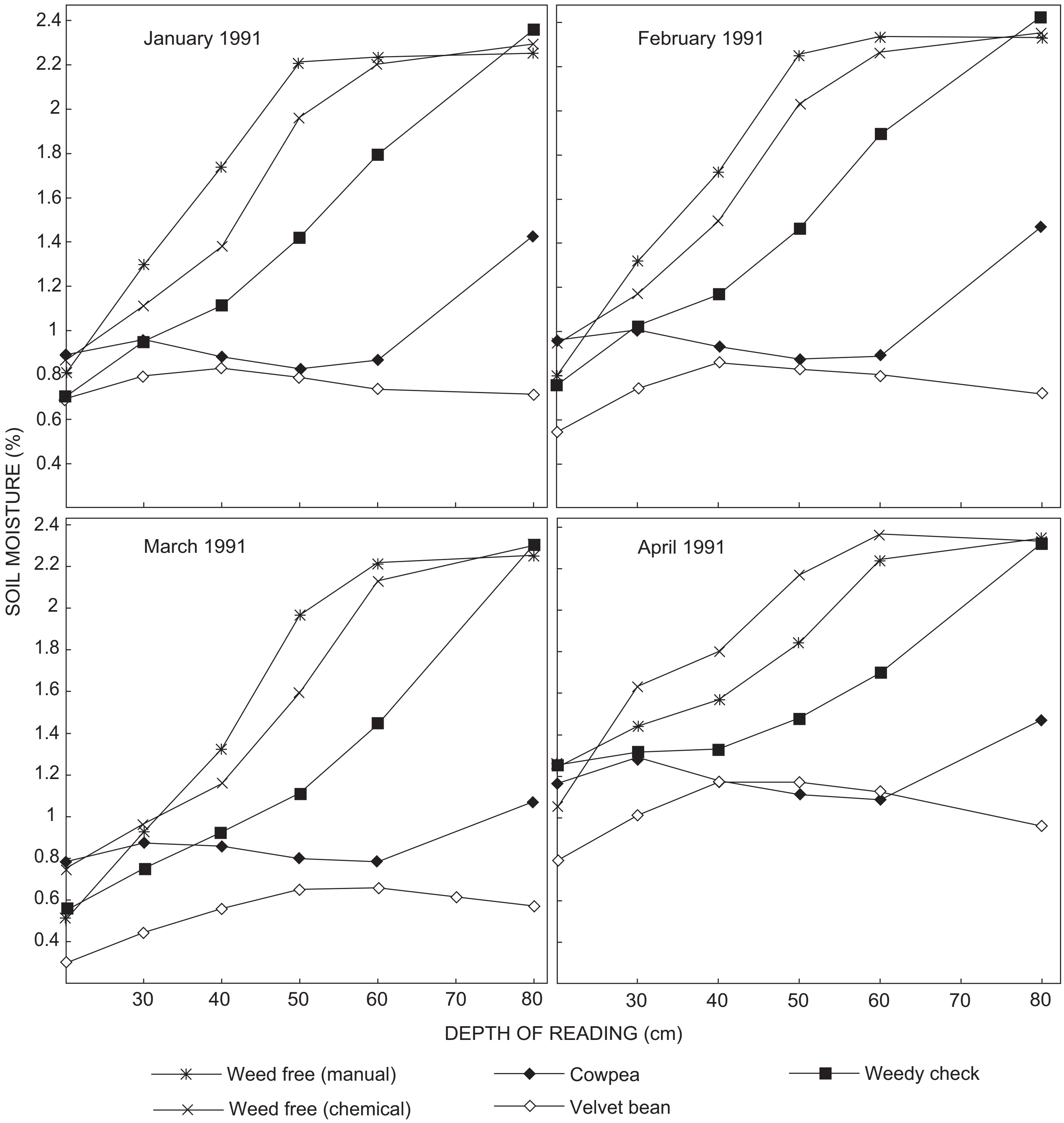

Figure 4: Changes in gravimetric soil moisture content with depth from four selected treatments

control. Combined with this lower soil water content would be the reduced ability of the trees for nutrient uptake (Gonclaves *et al*. 1997). This would be further exacerbated by the uptake of nutrients by the competing vegetation. Ellis *et al*. (1985) reported that the removal of competing vegetation as opposed to leaving it on the site resulted in higher foliar concentrations of nitrogen in trees of *Eucalyptus delegatensis* (R.T. Baker). Foliar nutrient content of the different types of vegetation cover are presented in Table 2. Thirty days after planting, the vegetation in the weedy control contained an approximate equivalent of 8kg ha^{-1} of nitrogen. This level would continue to rise with increasing levels of vegetation biomass, although the nitrogen only becomes available to the plants through decomposition after a weeding event or through natural mortality. As foliar nutrient samples were not taken from the trees it would be difficult to quantify the effect of this release of nutrients on tree performance.

The continued development of the vegetation meant that competition for the site's resources would remain until the trees became dominant and more tolerant to interspecific competition. Increased tree growth rates for crown diameter from 90 days after planting in all but the velvet bean treatment indicated that trees were increasingly able to tolerate interspecific competition (Figure 5).

Treatment responses to interspecific competition

Inter-row and complete weeding except within 0.5m of the tree (no ring weeding)

The relative position of the vegetation as reflected by its proximity to the trees, resulted in the continued divergence of the treatments over time (Figures 1 and 2). Tree height and crown diameter growth were as low for the inter-row weeding treatment, as for the weedy control treatment. The removal of 40% of the total vegetation between the tree rows did not result in additional resources becoming available to the plant for improved growth. The potential to develop a root system extending beyond the 0.9m weed infested row was inhibited by the small size of the suppressed tree. The growth rate of the crown diameters was negative for both the weedy control and inter-row weeding treatments between the first two measurement dates (Figure 5). There was an improvement in the growth rate for the inter-row weeding treatment between 121 days and 151 days after planting, over that of the weedy control. This could possibly be associated with the development of the tree roots of the inter-row weeding treatment into the vegetation-free zone. Although not significant, this difference was to be maintained through to felling.

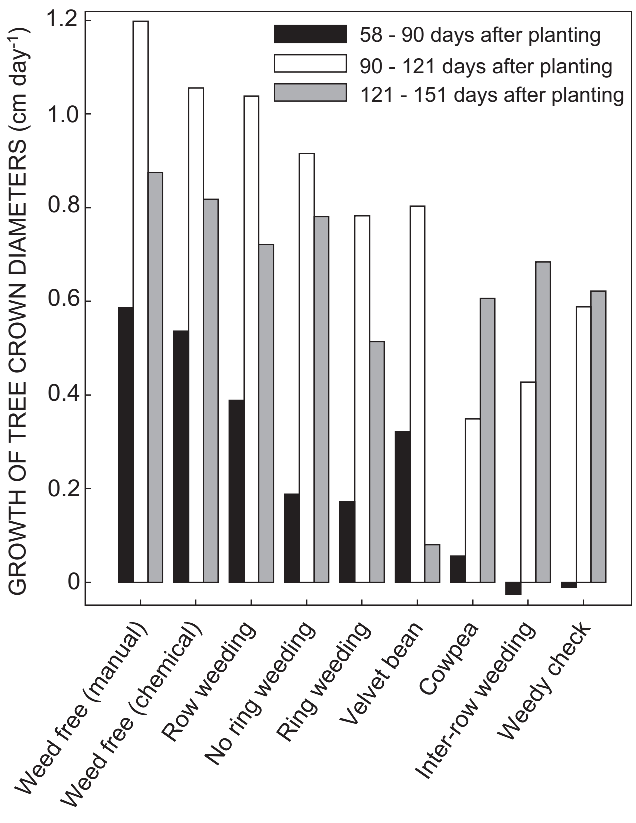

Figure 5: Growth rate of tree crown diameters. The no ring weeding treatment refers to complete weeding except in a 0.5m radius around the tree

Complete weeding except within a 0.5m radius of the tree, resulted in the significant ($P < 0.05$) initial suppression of the tree height and crown diameter growth in comparison to the manually weeded treatment. The vegetation in the immediate proximity to the tree had a negative impact on growth. This is reflected in the low growth rate for crown diameter measurements between days 58 and 90 (Figure 5). Subsequent growth rates were much improved, indicating that the additional resources available for tree growth from the area beyond the 0.5m radius were being utilised for growth.

Ring and row weeding

Compared to the manually weeded treatment, the 1m ring weeding treatment resulted in the significant suppression of tree performance from the time of the first measurement. Ninety percent of the competing vegetation was retained on the site for the ring weeding treatment as opposed to the no ring weeding treatment where 90% of the vegetation was removed. The difference in vegetation cover between these two treatments is reflected in the increased growth rates for crown diameter from 14.5% (between 90 and 121 days after planting) to 34% (between 121 and 151 days after planting) (Figure 5). A 1m ring weeding would only be expected to give some degree of benefit for tree growth up to 60 days on this site. Below, rather than above ground competition for the site's resources would have played a role in the restriction of growth in this treatment. In a comparison between the rooting of *Eucalyptus globulus* Labill. cuttings and seedlings, Sasse and Sands (1997) found that cuttings had no tap root, but rather formed adventitious roots during the propagation phase. The mean primary root length was 30cm eight weeks after planting, indicating a zone of influence of greater than 60cm in diameter. If the root growth of the vegetation is also taken into account, assuming a similar rate of growth and lateral spread, then the roots of the vegetation and trees would be competing in the same zone within two months after planting. Due to the low soil strength properties associated with the sandy soils in this trial, the growth of the roots of both the weeds and trees could be expected to be higher than average, resulting in larger zones of influence. Misra and Gibbons (1996) found a 71% and 31% reduction in the lengths of primary and lateral roots respectively with an increase in penetrometer resistance from 0.4Mpa to 4.2Mpa in 17-day-old *Eucalyptus nitens* (Deane and Maiden) Maiden. seedlings.

In a trial to determine the development of minimum row weeding requirements with time (also with eucalypts on ex-sugarcane land in Zululand), Little and Schumann (1996) found that the minimum row weeding requirements increased from a 1.5m row weeding 59 days after planting to a 2.5m row weeding 92 days after planting. Endo and Wright (1992) compared the 22-month growth of *Eucalyptus grandis* W. Hill ex Maiden under different levels of competing vegetation control in Columbia. Of the treatments imposed, they found that the more intensive the vegetation control, the better the performance, with the 1m row, 1m ring and low intensity weeding producing successively poorer growth. They attributed the response of these treatments to varying degrees of competition for moisture. Similar trials investigating the effect of increasing row or ring weeding areas on tree performance all indicate increased tree performance with an increase in the area that is kept free of vegetation (Tiarks and Haywood 1981, Constantini 1989, Dougherty and Lowery 1991, Richardson *et al*. 1995, Little and Schumann 1996).

The 1.2m row weeding (60cm weeded on either side of the tree) resulted in a 40% removal of the vegetation from this treatment. This increased removal of vegetation, when compared to the ring weeding treatment, benefited tree height and crown diameter growth from the time that the first measurements were taken. As with the ring weeding treatment there was a significant reduction in tree height from 58 days after planting, and crown diameter from 91 days after planting when compared to the manually weeded treatment (Figures 1 and 2). This suggests that although an improvement on the 50cm ring weeding, the 1.2 row weeding would still need to be increased from between 58 and 90 days after planting in order for optimum growth to be maintained.

Cover-crops

Initial biomass accumulation for both the cowpeas and velvet beans was not as rapid as that for the naturally occurring vegetation (Figure 3). The cowpeas and velvet beans grew from seeds, whereas the majority of yellow nutsedge development was from vegetative structures (tubers), a far more rapid means of growth. The initial biomass development of the cowpea cover-crop was more rapid than that of the velvet bean cover-crop resulting in the suppression of tree growth from an earlier age. A reduction in the growth of the crown diameter occurred between 58 days and 90 days after planting when the dry above ground biomass increased from 0.5 tons ha^{-1} to 2.2 tons ha^{-1}. As the cowpeas were planted in the inter-row, the reduction in initial tree performance could be attributed to competition for below-ground resources rather than for light. The low gravimetric soil moisture content for cowpeas shown in Figure 4 indicates that competition is most likely to be for moisture.

After maximum biomass accumulation at 120 days after planting, rapid senescence followed, and nil survival at 180 days after planting. This resulted in an increase in the height growth rate, in comparison to the weedy control, from –15.4% between 90–121 days after planting to 34.4% between 121–151 days after planting. This may be attributed to a combination of a release from competition and the release of nutrients from decomposing plant matter. Foliar nutrient contents for cowpeas were determined 120 days after planting and are shown in Table 2. There would be a substantial release of nitrogen (approximately 122kg ha^{-1}) following senescence that may have benefited tree growth on these nutrient-deficient soils.

Initial development of the velvet bean as a cover-crop was not as rapid as that of the cowpeas, and velvet bean biomass reached a competitive level only 121 days after planting. This coincided with a rapid increase in dry above ground biomass of the velvet beans from 0.6 tons ha^{-1} to 1.4 tons ha^{-1} over the same period. Unlike the cowpeas, velvet bean biomass continued to increase over time providing sustained tree suppression late into the first season. This is visible in Figures 1 and 2 where the rate of tree growth after 120 days is negligible. The vining habit of the velvet bean also caused physical damage to the trees in the form of bent stems. Although these were removed from the trees, the effects were to be maintained through to harvest.

Chemically and manually weeded treatments

Tree height for the chemically weeded treatment was significantly lower than for the manually weeded control from 58 days after planting (Figure 1). This significance was maintained until 18 months after planting, after which no further significant differences between these two treatments for any of the measured tree variates were recorded. As extra care was taken to protect the trees from accidental spray drift during spraying operations it is unlikely that herbicide damage caused this suppression in tree growth. Rather the enhanced tree performance of the manually weed control could be attributed to increased nutrient mineralisation resulting from the manual weeding operations. Manual hoeing is not as effective for vegetation control as is the spraying of herbicides, resulting in competitive vegetation growth that was far more vigorous (albeit sub-competitive) in these plots. Four manual weed control operations were required as opposed to the two for the chemically weeded control. Foliar nutrient contents for the competing vegetation that had grown over a 30 day period give an approximate indication of the nutrients that would be released into the soil in the manually weed plots if weeded on a monthly basis (Table 2). Although not as high in nutrient content as the cover-crops, the release of nutrients after manual weeding operations, especially on highly leached soils with a low organic carbon content, may have resulted in improved conditions for tree growth. As foliar nutrient samples were not taken from the trees it would be difficult to quantify the effect of this release of nutrients on tree performance. Schönau (1983) found that the application of fertilisers high in nitrogen resulted in the beneficial growth of eucalypts on the sandy soils in South Africa. Woods *et al.* (1992) demonstrated that the presence of weeds significantly enhanced the uptake of nitrogen from the site by plant biomass, thereby improving nitrogen retention on the site. By timing the vegetation control events such that tree suppression did not occur, these nutrients would be released into the soil. The use of manual hoeing would have also incorporated some of this vegetation into the soil, increasing the rate of nutrient mineralisation.

Conclusions

The different vegetation management treatments applied during establishment resulted in the differential growth of the trees. This occurred from as early as 60 days after planting. The degree of competition could be directly related to either the use of cover-crops or naturally occurring vegetation and its proximity to the tree. The predominant vegetation on this site, yellow nutsedge, was able to colonise the site rapidly, causing severe and early competition. There were strong indications that this initial competition was mainly for moisture and possibly also for nutrients, rather than competition for light. Initially, trees in those treatments that had vegetation within their immediate vicinity were most affected (weedy control, inter-row weeding and no ring weeding). With time, tree performance was more closely related to an increase in the percentage of the area kept free of vegetation. At 180 days after planting the ranking of the top five treatments in relation to the area kept free of vegetation was: manually weeded treatment (100% of area free of vegetation) > chemically weeded treatment (100% of area free of vegetation) > no ring weeding (90% of area free of vegetation) > row weeding (40% of area free of vegetation) > ring weeding (10% of area free of vegetation). The planting of cover-crops, although beneficial in suppressing competing vegetation, also caused significant tree suppression. This occurred despite the fact that their initial biomass accumulation was slower than that of the natural vegetation. Of the two cover-crops, the use of a velvet bean cover-crop is not advisable due to its vigorous vining habit which adversely affected tree growth form.

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