Biomass productivity of *Leucaena diversifolia* and *L. leucocephala* planted in semi aris Botswana's agroforestry system.

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ABSTRACT

Leucaena diversifolia and *L. leucocephala*, were planted and evaluated for leaf, pod and wood production at Malotwana, Botswana. The trial was a 2 species x 3 spacings factorial experiment in a randomized complete block design replicated five times. The three spacings were 5 x 5, 6.3 x 5 and 8.3 x 5 m. The study was conducted over 6.5 years with the first complete plant harvest at 2.5 year and thereafter every two years. The results show that *L. leucocephala* produced significantly greater leaf, pod and wood mass at the harvest of trees aged 2.5 in 1996 ($p < 0.05$) and significantly more pods at all harvests ($p < 0.05$). Leaf and pods yields were 0.647 and 0.996 t ha^{-1} for *L. diversifolia* and 1.237 and 1.431 t ha^{-1} for *L. leucocephala* in 1996. These species can contribute to fodder for livestock as well as fuel wood production. Spacing significantly ($p < 0.05$) influenced yield per hectare of plants harvested at 2.5 years of age.

Keywords: Malotwana Botswana, *Leucaena diversifolia* and *L leucocephala*, fuel wood production.

INTRODUCTION

In Botswana livestock depend on natural pasture which is high in fibre and low in crude protein which is inadequate to sustain livestock productivity, especially in the dry season. Crop residues provide some relief post-harvest but stover is generally low in crude protein and readily trampled upon *in situ* before the dry season is over. Purposeful tree planting on cropland enhances the productivity of the land as well as improving crude protein production for livestock. Kerkhof (1990) reported that *Leucaena* has been planted widely on cropland in high rainfall areas and managed as a green manure and in hedgerows to provide wind breaks as well as to yield nutritious leaves for livestock. In Botswana limited research has been conducted to form the basis for *Leucaena* planting but where such initiatives have been taken initial growth of the species has shown much promise (Kooiman, 1992; Karachi and Lefofe, 1997). However, sustained experimentation on the growth and management of *Leucaena* over a period of time is needed as a basis for recommending species for on-farm planting.

Shelton and Brewbaker, (1994) stated that *Leucaena* can be grown in drier areas with annual rainfall as low as 300 mm. Although it is susceptible to frost, it regenerates fully once the winter is past (Karachi and Lefofe, 1997). The species produces reasonable yields of 19.7 t ha^{-1} at close spacing in semi-arid environments aided by limited watering (Bisht and Toky, 1989). The reported crude protein of the species ranges between 12 g/100 g of dry matter to 36 g/100 g of dry matter and can contribute significantly to the crude protein requirements of livestock. Additionally as a standing crop it can maintain the productivity of cropland and will reduce erosion.

The objective of the study was to evaluate *Leucaena diversifolia* and *L. leucocephala* K 28 for their agroforestry production. The study explored production of the two species at three spacings.

Material and Methods

The trial was established at Malotwana village (latitude 24° 20′ S, longitude 26° 05′

E) which falls between altitudes 940 and 950 m. a.s.l. and has a mean annual rainfall of 450 mm which occurs between September and May (Fig. 1). The soils of the site are Kgalagadi sands, poor in organic matter and nutrients, deep and excessively well drained with a pH of 4.2 ($CaCl_2$). The study was conducted between 1993 and 2000 which covers the normal cycle of drought in Botswana. Rainfall data were collected throughout the study period using a standard 5 inch rain gauge (Fig. 1)

Experimental design and treatments

The trial plot measured 4.8 hectares and was destumped and harrowed. The design of the experiment was a 2 x 3 factorial in a randomised complete block design replicated five times. The main factors were the two species, *L. diversifolia* and *L. leucocephala* and three spacings, 5 x 5, 6.3 x 5 and 8.3 x 5m. The respective tree densities were 400, 317 and 241 ha^{-1}. The land area was 4.8 hectares and each plot was 0.08 hectares. Each assessment plot comprised 16 trees, 12 and 8 trees per plot for density 400, 317 and 241ha^{-1} respectively.

The seeds used in the trial were obtained from the Agricultural Research Council – the Roodeplaat Grassland Institute, Republic of South Africa. The *L. diversifolia* seeds were issued as Prime No. 01U1, a Mexican ecotype collected above 2000 m and relatively cold-tolerant. *L. leucocephala* seeds used were K8 Prime No.01TF and some K28 Prime No.1V1 ex Tim Fenn.

Seeds were pre-treated by immersing them in near-boiling water and leaving them to soak overnight. Germination occurred between 10 and 14 days after sowing. Seedlings were thinned to one seedling per pot at approximately three weeks after emergence. They were watered once a day for up to six weeks after germination while under 40% shade netting. They were moved out of the shade net for a week before planting out and watered three times in that week. Seedlings collected at the nursery were selected to be approximately the same height of 40 cm.

Management of plants

At planting 1 kg of kraal manure and 20 g of agricultural lime were applied per hole. A large basin of 50 cm radius was created around each tree to facilitate water catchment. Seedlings were provided with 10 litres of water at planting. Weeding was conducted annually through ploughing between rows and then along the row clean weeding being subsequently carried out by hand.

Trees were watered fortnightly during the dry season (June to September) throughout the study and immediately after every complete plant harvest. A total of 264 m^3 of water was used to irrigate the trees between September 1994 and completion of the trial in May 2000 corresponding to 550 litres per tree.

The season 1994 to 1995 was used to observe the response to climatic conditions in order to determine the appropriate time for pod collection. The first complete plant sampling was conducted at the end of the wet season in May 1996, when trees were aged 2.5 years. After this, complete harvesting was carried two years after the previous harvest, in 1998 and 2000. Plant harvesting involved cutting each of the four trees in the centre of the plot at the base (approximately 5-10 cm above ground) and separating the tree into leaf, pod and wood samples. Fresh masses were recorded per individual tree, immediately after separation. Where flowers occurred, they were added to the pods. In each year of complete plant sampling the pod mass from the season's collection was added to the final pod mass from the complete plant sampling to calculate the total fresh mass.

Sampling

Each year there were three pod harvestings for *L. leucocephala* but only two for *L. diversifolia*. These included complete plant harvesting for both species carried out at the end of May. When the rainfall season started in October and falls were relatively evenly distributed, seed maturity was in December or early January with the final data collection being in May. In the drought year of 1997/98, close monitoring of seed was required and more than three collections were carried out for *L. leucocephala*.

Oven-dry masses were calculated by weighing samples of pod and leaves before and after oven-drying at 70°C for 48 hours (AOAC, 1996) and then calculating the percentage dry matter (DM) for these samples. The percentage DM of pods (29%) and leaves (36%) was used to convert the green mass data obtained at harvesting to a dry matter basis for all the years of harvest.

The wood dry matter was determined by weighing bundles of fresh wood from each tree at harvest, recording the mass, and then tagging the bundle with a paper label. The labels were covered in plastic to avoid them being smudged during rain. The wood bundles were then sun-dried, with some bundles being used to test the state of dryness for their use as firewood. Well dried wood burns without spitting gum-like material (*kgakgamosi*) and emitting black smoke. Where stock borer - *Buprestidae sternocera* attack had occurred the previous week's mass was used instead of the current mass. The mass of dry wood was recorded when measurements over two successive weeks were similar. Calculated dry matter of wood was 70% of the fresh mass.

Data were entered into Microsoft Excel and analysed using General Linear Model in Statistical Analysis System (2000) because three trees in one of T_1 spacings had died because of termite attack. They were subjected to analysis of variance and means were separated using Student-Newman-Keuls Test.

The model of analysis is described by the equation:

$Y_{ijk} = \mu + B_i + S_j + T_k + TS_{jk} + e_{ijk}$, Where: Y_{ijk} = tree performance μ = expected overall mean

B_j = variation effect due to the effect of the i^{th} block I = 1,2,3,5,5

S_j = effect due to the j^{th} species j= 1, 2 T_k = effect due to using the k^{th} spacing k = 1, 2, 3

TS_{jk} = the interaction due to the effect of j^{th} species and k^{th} spacing

e_{ijk} = random error effect

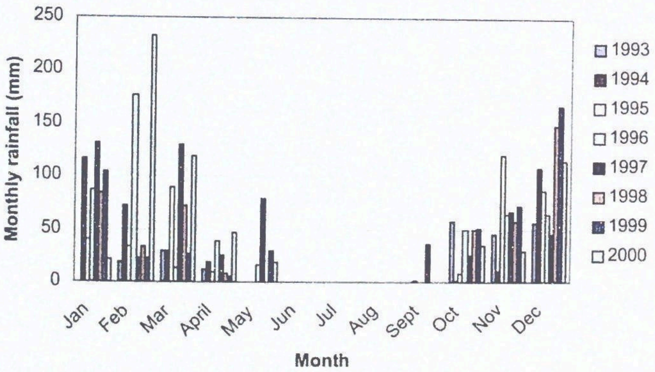

Fig. 1 Monthly rainfall recorded at the trial site for the duration of the study

Table 1 Mean tree biomass yields of *L. diversifolia* and *L. leucocephala* (kg)

Year (Age years)	Species	Spacing (m)	N	Leaves (kg)	Pod (kg)	Wood (kg)	Total (kg)
1996 (2.5)	*L. diversifolia*	5 x 5	20	2.24 ± 0.40a	3.35 ± 0.45a	8.99 ± 1.17a	14.60 ± 1.911a
		6.3 x 5	20	1.90 ± 0.39a	2.93 ± 0.45a	7.05 ± 1.17a	11.88 ± 1.911a
		8.3 x 5	17	1.81 ± 0.39a	2.99 ± 0.45a	7.12 ± 1.17a	11.92 ± 1.911a
	Mean		57	1.89 ± 0.28B	2.91 ± 0.35B	7.37 ± 0.88B	12.80 ± 1.10B
	L. leucocephala	5 x 5	20	3.97 ± 0.39a	4.37 ± 0.45a	9.28 ± 1.17a	17.63 ± 1.911a
		6.3 x 5	20	3.97 ± 0.39a	5.04 ± 0.45a	12.29 ± 1.17a	21.31 ± 1.11a
		8.3 x 5	20	3.58 ± 0.39a	3.93 ± 0.45a	8.29 ± 1.17a	15.80 ± 1.911a
	Mean		60	3.75 ± 0.28A	4.32 ± 0.33A	9.80 ± 0.88A	18.24 ± 1.10A
1998 (4.5)	*L. diversifolia*	5 x 5	20	0.49 ± 0.11a	0.23 ± 0.30a	6.25 ± 1.38a	6.94 ± 1.6299b
		6.3 x 5	20	0.34 ± 0.11a	0.67 ± 0.31a	6.67 ± 1.38a	7.54 ± 1.629ba
		8.3 x 5	17	0.49 ± 0.11a	1.27 ± 0.28a	11.68 ± 1.38a	11.66 ± 1.629a
	Mean		57	0.47 ± 0.08A	0.72 ± 0.17B	8.45 ± 1.09A	8.71 ± 0.940A
	L. leucocephala	5 x 5	20	0.43 ± 0.11a	1.17 ± 0.29a	7.27 ± 1.38a	8.75 ± 1.629a
		6.3 x 5	20	0.51± 0.11a	1.54± 0.28a	7.99± 1.38a	10.05 ± 1.63ba
		8.3 x 5	20	0.64 ± 0.11a	1.35 ± 0.29a	8.36 ± 1.38a	10.28 ± 1.629a
	Mean		60	0.48 ± 0.07A	1.44 ± 0.22A	7.44 ± 1.04A	9.69 ± 0.094A
2000 (6.5)	*L. diversifolia*	5 x 5	20	2.26 ± 0.41a	1.29 ± 0.58b	5.07 ± 1.39b	8.54 ± 2.198b
		6.3 x 5	20	2.23 ± 0.41a	1.04 ± 0.58b	6.15 ± 1.39b	9.43 ± 2.198ba
		8.3 x 5	17	3.05 ± 0.41a	3.58 ± 0.58a	10.85 ± 1.39a	17.64 ± 2.198a
	Mean		57	2.38 ± 0.34A	1.79 ± 0.46B	6.68 ± 3.84A	11.87 ± 1.27B
	L. leucocephala	5 x 5	20	2.77 ± 0.41a	4.34 ± 0.60b	8.95 ± 1.39b	15.911 ± 2.20b
		6.3 x 5	20	3.07 ± 0.41a	4.27 ± 0.58b	9.98 ± 1.39b	17.3 1± 2.20ba
		8.3 x 5	20	2.86 ± 0.41a	6.54 ± 0.58a	10.95 ± 1.39a	20.35 ± 2.198a
	Mean		60	2.76 ± 0.32A	4.43 ± 0.44A	9.46 ± 1.00A	17.86 ± 1.27A

Means in a column followed by different letters abc are significantly different among spacings within species within year of assessment $p \leq 0.05$

A,B means significant differences between species within year of assessment

RESULTS

The survival of *L. diversifolia* was 87% while that of *L. leucocephala* was 97% throughout the study. The performance of each species varied under the contrasting rainfall regimes of different years. The high survival percentages of over 85% was similar to those of Kooiman (1992) in Selebi-Phikwe, Botswana in the first year after planting and those of Karachi *et al.* (1997) in Tanzania with plants aged 2.5 years

The mean tree biomass yield is presented in Table 1. Mean tree leaf yield of *L. leucocephala* was greater than that of *L. diversifolia* at the harvests in 1996 and 2000, both years had above average rainfall (Fig 1), the difference being significant in 1996 ($p<0.05$). Similarly greater yield in leaf mass of *L. leucocephala* over that of *L. diversifolia* were reported by Wickremasinghe and Gunasena (1998) in Dodangolla, Sri Lanka. In 1998 when rainfall was low there was no difference between the species due to wilting of leaves prior to harvest for both species. *L. leucocephala* produced significantly greater ($p<0.05$) pods mass than *L. diversifolia* in all years. The superiority of the species was also demonstrated in wood yield and consequently in total biomass. Pod yields differed significantly among spacings with low density planting producing more pods per tree than both medium and high densities in both species in the harvest of 2000 which had a considerably higher seasonal rainfall than either 1996 or 1998 (Fig 1). This suggests that in good years with above average rainfall competition for nutrients can be exhibited between trees even at wide spacing as in this study. Similarly mean tree wood mass of both species was significantly greater for trees at low density compared to those at medium and high density. The same trend was observed in total biomass.

Biomass yield for both species in metric tonnes are presented in Table 2. Leaf yield per hectare was greater in high density plots for both species and was significantly different ($p<0.05$) for the 1996 harvest when trees were well established and rainfall was good. For both species the contribution of pods to fodder production was greater than that of leaves except in 2000 when *L. diversifolia* which tends to accumulate foliage over an extended period and produce pods later in the season had greater yield of leaves than pods. The results show that considerable amounts of fodder can be produced in the form of pods.

Table 2 Biomass production of *L. diversifolia* and *L. leucocephala* (MT ha^{-1})

Year (Age yrs)	Species	Spacing	Leaf	Pod	Wood	Total
1996 (2.5)	*L. diversifolia*	5 x 5	0.902 ± 0.142a	1.342 ± 0.161a	3.597 ± 0.415a	5.84 ± 0.685a
		6.3 x 5	0.602 ± 0.142b	0.927 ± 0.161a	2.236 ± 0.414a	3.77 ± 0.685a
		8.3 x 5	0.438 ± 0.142c	0.720 ± 0.161b	1.715 ± 0.415b	2.87 ± 0.685b
	Mean		0.647 ± 0.082B	0.996 ± 0.093B	2.516 ± 0.239B	4.16 ± 0.395B
	L. leucocephala	5 x 5	1.589 ± 0.142a	1.748 ± 0.161a	3.714 ± 0.415a	7.05 ± 0.685a
		6.3 x 5	1.260 ± 0.142b	1.597 ± 0.161a	3.897 ± 0.415a	6.75 ± 0.685a
		8.3 x 5	0.862 ± 0.142c	0.948 ± 0.161b	1.999 ± 0.415b	3.81 ± 0.685b
	Mean		1.237 ± 0.082A	1.431 ± 0.093A	3.203 ± 0.239A	5.87 ± 0.395A
1998 (4.5)	*L. diversifolia*	5 x 5	0.197 ± 0.038a	0.081 ± 0.079a	2.498 ± 0.446a	2.78 ± 0.506a
		6.3 x 5	0.107 ± 0.038a	0.168 ± 0.079a	2.115 ± 0.446a	2.39 ± 0.506a
		8.3 x 5	0.113 ± 0.038a	0.301 ± 0.079a	2.395 ± 0.446a	2.81 ± 0.506a
	Mean		0.139 ± 0.022A	0.184 ± 0.045B	2.336 ± 0.258	2.66 ± 0.292
	L. leucocephala	5 x 5	0.174 ± 0.038a	0.420 ± 0.079a	2.907 ± 0.446a	3.50 ± 0.506a
		6.3 x 5	0.163 ± 0.038a	0.489 ± 0.079a	2.534 ± 0.446a	3.19 ± 0.506a
		8.3 x 5	0.153 ± 0.038a	0.309 ± 0.079a	2.015 ± 0.446a	2.48 ± 0.506a
	Mean		0.163 ± 0.022A	0.406 ± 0.045A	2.485 ± 0.258	3.05 ± 0.292
2000 (6.5)	*L. diversifolia*	5 x 5	0.904 ± 0.134a	0.487 ± 0.176b	2.027 ± 0.433a	3.42 ± 0.685a
		6.3 x 5	0.710 ± 0.134a	0.330 ± 0.176b	1.951 ± 0.433a	2.99 ± 0.685a
		8.3 x 5	0.741 ± 0.134a	0.865 ± 0.176a	2.644 ± 0.433a	4.25 ± 0.685a
	Mean		0.785 ± 0.077A	0.561 ± 0.102B	2.207 ± 0.25B	3.55± 0.395B
	L. leucocephala	5 x 5	1.110 ± 0.134a	1.675 ± 0.176a	3.579 ± 0.433a	6.36 ± 0.685a
		6.3 x 5	0.973 ± 0.134a	1.352 ± 0.176a	3.162 ± 0.433a	5.49 ± 0.685a
		8.3 x 5	0.690 ± 0.134a	1.577 ± 0.176a	2.638 ± 0.433a	4.91 ± 0.685a
	Mean		0.924 ± 0.077A	1.535 ± 0.101A	3.127 ± 0.250A	5.58 ± 0.395A

Means in a column followed by different letters abc are significantly different among spacings within species within year of assessment $p \leq 0.05$

A,B means significant differences between species within year of assessment

DISCUSSION

In all harvesting years *L. leucocephala* produced a significantly greater ($p<0.05$) mean pod mass than *L. diversifolia*, indicating the greater potential *of L. leucocephala* for producing feed both as leaves and especially as pods. This also indicates the potential of *L. leucocephala* to become weedy unless regular harvests of pods are employed to increase fodder and avoid weediness on-farm. Total biomass yields of *L. leucocephala* significantly exceeded those for *L. diversifolia* in years with high rainfall 1996 and 2000 but in the year of poor rainfall both species were comparable.

When trees were allowed to grow for 2.5 years compared to two years there were significant differences between yield at different establishment densities for all parameters ($p<0.05$). High density trees produced the greatest yield per hectare compared to those at both medium and low density. This can be ascribed to the greater number of stems per hectare leading to more complete site utilization, and hence a higher yield. These results agree with those of Maghembe *et al.* (1986) and those of Gathaara *et al.* (1991) who found greater biomass yields at high tree densities in 3 and 4 year old stands. In this study the highest yields per hectare for *L. leucocephala* and *L. diversifolia* were also in the highest density plantings with significantly lower yields in lower density plots. Greater yields at high densities were also recorded in 2000 when the rainfall was well above average and again can be attributed to higher stem numbers per hectare. However when the rotation was shortened there were no significant differences in yields between spacings both for the year with low rainfall

(1998) and one with high rainfall (2000) (Fig. 1). The greater number of stems per hectare can therefore be exploited to increase agroforestry products in both species. The study shows that considerable amount of fodder can be produced in the form of leaf mass for *L leucocephala* (1.6 t ha^{-1}) and *L. diversifolia* (0.9 t ha^{-1}). This can contribute valuable dry season fodder. On the other hand, pods can yield considerably more biomass than leaves with values of 1.7 and 1.3 t ha^{-1} for *L. leucocephala* and *L. diversifolia* respectively under average rainfall as shown in 1996. Woodfuel of 3.6 t ha^{-1} produced by each species met farm needs and reduced labour employed to collect such products.

CONCLUSION

These results show that in Botswana where there is a considerable shortage of dry season feed, tree fodder from *Leucaena lecucocephala* and *L. diversifolia* planting can contribute to crude protein availability through leaves and pods. Equally important through tree planting, woodfuel can be made available to households thus reducing extraction from natural woodland and time spent collecting wood by women and children.

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