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Full Length Research Paper

Production of rape (*Brassica napus* L.) on soils amended with leguminous tree prunings: Yield responses in relation to the chemical composition of the tree prunings

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Leguminous tree leaf litter has potential as a nutrient source for smallholder vegetable production systems. However, quality of the leaf litter influences yield responses by the crops grown. Comparative yield responses of rape (*Brassica napus* L.) to legume prunings of different chemical composition were evaluated in a three block randomized complete block design (RCBD) field experiment. Prunings of *Leucaena leucocephala, Calliandra calothyrsus, Acacia angustissima* and *Acacia karoo* were applied to the soil at 5 t ha^{-1}. Two controls, 0 N and mineral N applied at 150 kg N ha^{-1}, were used. Total biomass, leaf number and size, and area were measured over a 9 week period after transplanting. The mean total biomass yields following amelioration with the various prunings ranged from 2.56 to 11.12 t DM ha^{-1}. The mean saleable leaf harvests ha^{-1} were 10.04, 7.56, 5.02, 3.00, 1.28 and 0.86 t for 150 N, *L. leucocephala*, *A. angustissima*, *C. calothyrsus*, *A. karoo* and 0 N, respectively. These results were corroborated by the resource quality of the respective organic ameliorants. The results indicated that biomass transfer technology could be used as an alternative to mineral fertilizers for vegetable production and that yields were dependent on resource quality of prunings.

Key words: Leaf litter, biomass transfer, vegetable yield.

INTRODUCTION

Diversification of crops produced by smallholder farmers in southern Africa has the potential of increasing employment and income, which in turn, permit people to purchase or otherwise acquire food to increase their food security (Dreschel and Kunze, 2001). The production of rape and other leaf vegetables for local and export markets is one such profitable agricultural enterprise (Loehr et al., 1998; Kuntashula et al., 2004). Vegetables provide household nutritional security since they are rich in vitamins, minerals and roughage, which are essentials of a balanced diet (Salunke and Kadam, 1998; Nyakudya et al., 2010). The year-round production of leaf vegetables requires land use intensification and the enterprise is only feasible and profitable when soil nutrients depleted during crop production are replenished (Kormawa et al., 1999; Losak et al., 2008).

Due to continuous cropping, most soils in sub-Saharan Africa have become deficient in soil nitrogen (N), phosphorus (P) or both (Mafongoya et al., 1998). The removal of crop residues from the fields, coupled with lower rates of macronutrient applications compared to losses, has contributed to negative nutrient balances (Stoorvogel and Smaling, 1990). Bationo et al. (2008) reported annual nitrogen losses from arable land in the sub-region to be 4.40 million tons, compared to an applied level of only 0.80 million tons. Such soils can no longer support sustainable crop production without external inputs of mineral fertilizers.

Smallholder farmers in sub-Saharan Africa appreciate

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the value of mineral fertilizers but they rarely implement the recommended fertilizer application rates (Kazombo-Phiri, 2005). The poor adoption of fertilizer use by these farmers could be attributable to the blanket recommendations that have been made by research and extension services on fertilizer application rates (Dimes et al., 2004). Mineral fertilizer recommendations for most countries in the region were geared towards large scale commercial farmers and thus overlooked the spectrum of farming objectives and returns on investments that typifies smallholder farming systems (Hikwa and Mukurumbira, 1995). These farmers fear risking their small fortunes in purchasing mineral fertilizers, especially under very variable and unreliable climatic patterns the region has been experiencing. Less than 5% of farmers commonly apply mineral fertilizer to their crops in Zimbabwe (ICRISAT, 2006).

The nutrient resource most readily available in the mixed crop-livestock systems that are characteristic of southern Africa is animal manure. However, animal manure quality varies considerably from farm to farm with N levels ranging from 0.46 to 1.98% DM (Mugwira and Mukurumbira 1985; Murwira, 2003). Considerable increases in crop yields have been reported following soil amendment with animal manure but in some cases yield reductions have been observed when nitrogen poor manure is applied due to the immobilization effect (Murwira et al., 2004; Mafongoya et al., 2006).

Biomass transfer of leguminous tree leaf material to croplands has been shown to be a sustainable means of maintaining nutrient balances in maize and vegetable-based production systems (Mafongoya et al., 2008). These biomass transfer systems include the use of green mulch, dried prunings and litter as soil ameliorants (Constantinides and Fownes, 1994). Kuntashula et al. (2004) reported that amending soils with *Gliricidia sepium* and *Leucaena leucocephala* prunings was tenable for sustaining vegetable production in seasonal wetlands. In a related study, Kazombo-Phiri (2005) reported that the nitrogen availed following the application of 10 t ha^{-1} of *L. leucocephala* leafy biomass was comparable to the application of 100 kg ha^{-1} of mineral nitrogenous fertilizer.

Beyond the environmental physico-chemical characteristics the resource quality plays an important role in regulating decomposition (Mafongoya et al., 1997). A direct relationship is known to exist between decomposition rate and initial nitrogen or lignin and soluble polyphenols in leguminous litter. High initial nitrogen, low C: N, low (lignin + soluble polyphenol)-to-nitrogen or low polyphenol-to-nitrogen ratios generally favour high rates of decomposition of leguminous leaves (Zaharah et al., 2008). Prunings that differ in these quality considerations would therefore support different levels of crop production. Characterisation of the resultant crop production levels is required to assist decision making by smallholder farmers. The objective of this study was to evaluate yield responses of a leaf vegetable grown on soils amended with prunings of different leguminous tree species.

MATERIALS AND METHODS

Study area

The study was conducted at Hatfield Experimental Farm of the University of Pretoria, Pretoria, South Africa (28° 45' S and 28° 16' E and 1372 m a.s.l). The farm receives an annual rainfall of 670 mm spread over October and March and experiences monthly average maximum temperatures of 30°C in January and average minimum temperatures of 1.5°C in July (Meteorological Office, South Africa, 2008). The site has a free draining sandy clay loam (Hutton, South African Soil Classification Working Group, 1991), with a pH (water) of 5.70 and a carbon content of 16.70 g kg^{-1}. Before planting, the soil's macronutrient composition was 555.00, 27.90 and 46.00 mg kg^{-1} of N, P and K, respectively.

Cultural practices

Seedlings were produced by planting two to three seeds of rape (*Brassica napus* L. cv. English Giant (Afrigro Seed Company, South Africa)) in 200 cavity seedling trays containing a peat based potting medium, Hygromix (Hygrotech Seed Company, South Africa) in a glasshouse. To reduce competition, seedlings were thinned out seven days after planting ensuring one healthy seedling remained per cavity. Once seedlings germinated, they were irrigated with a nutrient solution once every two days (for the first week) and on a daily basis for the last three weeks in the nursery. The nutrient solution was made by dissolving 2.5 g of Multiseed Classic soluble fertilizer in one litre of water, availing 0.48, 0.21 and 0.39 g of N, P and K respectively, in every litre used for irrigation. The seedlings were transplanted to the field 28 days after germination.

Before transplanting single super phosphate (34 kg ha^{-1}), potassium chloride (31 kg ha^{-1}) and lime (5 t ha^{-1}) were applied during land preparation. Seedlings were sprayed for aphids with a solution of Methomex (active ingredient: methomyl) three days after transplanting and once every two weeks thereafter. The experimental plots were hand weeded at three and six weeks after transplanting to control weeds. During the course of the experiment the plots received supplementary irrigation, dependent on the prevailing weather conditions and the crop requirements using a sprinkler system. Two separate experiments were conducted, the first between March and May 2009 and the second between December 2009 and February 2010, being the local autumn and summer seasons.

Treatments and design

The yield responses of rape were assessed in a field experiment arranged in a randomised complete block design with three blocks in both seasons. Each of the three blocks consisted of six plots (measuring 4.0 m x 3.5 m) corresponding to the treatments, four prunings and two controls. Ten rows of four week old seedlings were planted with an inter-row spacing of 0.40 m and intra-row spacing of 0.35 m, giving a plot population of 100 plants. The sun-dried prunings of *L. leucocephala, C. calothyrsus, A. angustissima* and *A. karoo* were applied at 5 t DM ha^{-1} just before the seedlings were transplanted. Incorporation of the prunings was achieved by applying the mulch on the surface and mixing it within the 0 to 0.15 m layer of the soil using hand hoes. There were two control treatments, a true control where no N (0 N, except for the antecedent N in the soil) was applied and 150 kg N ha^{-1} (150 N), the conventional recommendation for rape. Mineral fertilizer was applied as limestone ammonium nitrate (28% N) in three equal dressings, at planting, 3 and 6 weeks after transplanting. The six treatments were denoted as *L. leucocephala, C. calothyrsus, A. angustissima* and *A. karoo,* and the controls as 0 and 150 N.

Measurements

Biomass yields

For the determination of biomass accumulation, two rape plants per plot were randomly selected for destructive sampling from the two rows next to each outer border row at 2, 4, 6, 8 and 9 weeks after transplanting. Following the removal of excess soil adhering to the root system, the uprooted plants were separated into shoot and root components. Following the recording of the composite shoot fresh weight and to allow for the determination of leaf number, size and area, individual leaves of the shoot were plucked. Leaf area was determined by passing the individual leaves through the LI 3100 belt driven leaf area meter (LiCor, Lincoln, NE, USA). Leaf length and width were measured with a ruler. The leaf samples were then oven dried at 60°C to constant weight for determination of dry matter. Individual root systems were weighed to determine fresh weight and then oven dried at 60°C to a constant weight. The total accumulated biomass of rape was calculated by combining weight of the shoot and root for each plot at week 9.

Saleable leaf yield

The weekly saleable leaf yield of rape was determined through the plucking of mature leaves from a net plot of three middle rows from week 4 through to 9 after transplanting. Following plucking the leaves was weighed to determine fresh weight. The weekly saleable leaf yields for each treatment over the six weeks of harvesting were summed up as the total saleable leaf yield after 9 weeks.

Chemical analysis

Leguminous prunings were analysed for initial C, N, P, S, soluble condensed tannins and lignin. The initial N content of the various prunings was analysed using a Kjeldahl auto-analyzer. The butanol-HCl assay as described by Makkar (1995) without the Fe^{3+} in the reagent was used to determine soluble condensed tannins, using quebracho as the reference. The concentrations of the soluble condensed tannins in the extracts were estimated from the regression equation:

$$y = 0.793x – 0.022; r^2 = 0.996$$

Where y is the absorbance read at 550nm and x is the concentration of quebracho in mg ml^{-1}. The results for the soluble condensed tannins were expressed as g kg^{-1} DM Quebracho Tannin Equivalent. Lignin was determined by the acid detergent fibre method (Goering and van Soest, 1970).

Statistical analysis

Data collected for leaf number and size, leaf area, root and shoot dry mass, total biomass and saleable leaf yields on all sampling dates were subjected to analysis of variance (ANOVA). Treatment means were compared using the least significant difference (LSD) test at 0.05 probability level. All statistics were conducted using SAS Procedures (SAS, 2010).

RESULTS AND DISCUSSION

The mean monthly minimum and maximum temperatures during the experimental periods are presented in Figure 1. Higher temperatures were experienced in summer (December 2009 to February 2010) than during autumn (March to May 2009). The average monthly temperatures recorded for March, April and May were 22, 17 and 11°C, respectively, compared to 24, 23 and 25°C recorded for December, January and February, respectively.

Chemical composition of prunings

The initial chemical composition of the various prunings used as soil amendments are summarized in Table 1. There were significant differences among the prunings with respect to most of the chemical fractions which were analyzed, indicative of differences in pruning quality. Nitrogen contents of the prunings were significantly different (P > 0.05), ranging from 25.00 g N kg^{-1} DM (*A. karoo*) to 39.80 g N kg^{-1} DM (*L. leucocephala*). Carbon content was highest in prunings of *L. leucocephala* and the C: N ratio of these prunings was 20. The respective C: N ratios of the other prunings were: *A. angustissima*: 18, *C. calothyrsus*: 15 and *A. karoo*: 11. Phosphorus content of prunings ranged from 17.10 to 27.40 g P kg^{-1} DM, being lowest in prunings of *A. karoo* and highest in *L. leucocephala* prunings. The pattern shown by prunings with respect to lignin concentration was the reverse of that shown for N concentration. Prunings of *L. leucocephala* had the lowest lignin content (151.00 g kg^{-1} DM) and those of *A. karoo* had the highest lignin content (283.00 g kg^{-1} DM). A similar trend was shown for soluble condensed tannins. The general ranking of prunings based on soluble condensed tannins was *A. karoo* > *C. calothyrsus* > *A. angustissima* = *L. leucocephala*.

The soluble condensed tannin contents of prunings that were reported are comparable to those reported by Hove et al. (2001), where sun-dried prunings of *C. calothyrsus*, *A. angustissima* and *L. leucocephala* had soluble condensed tannin contents of 196.00, 134.00 and 33.00 g kg^{-1} DM, respectively (quebracho tannin equivalent). The differences in the soluble condensed tannin contents of prunings of *A. angustissima* that we are reporting and those reported by Hove et al. (2001) could be attributable to the different growth conditions, time of harvesting and parts of the plant used. Mafongoya et al. (1998) reported C: N ratios of 16.00, 17.60 and 17.60 for prunings of L. *leucocephala*, *A. angustissima* and *C. calothyrsus,* respectively, and their findings are comparable to the findings that we are reporting. A direct relationship is known to exist between decomposition and N release rates and the chemical composition of the prunings. Thus the differences in quality of the four prunings would imply different decomposition and nutrient release patterns, which in turn have a strong bearing to crop growth and yield.

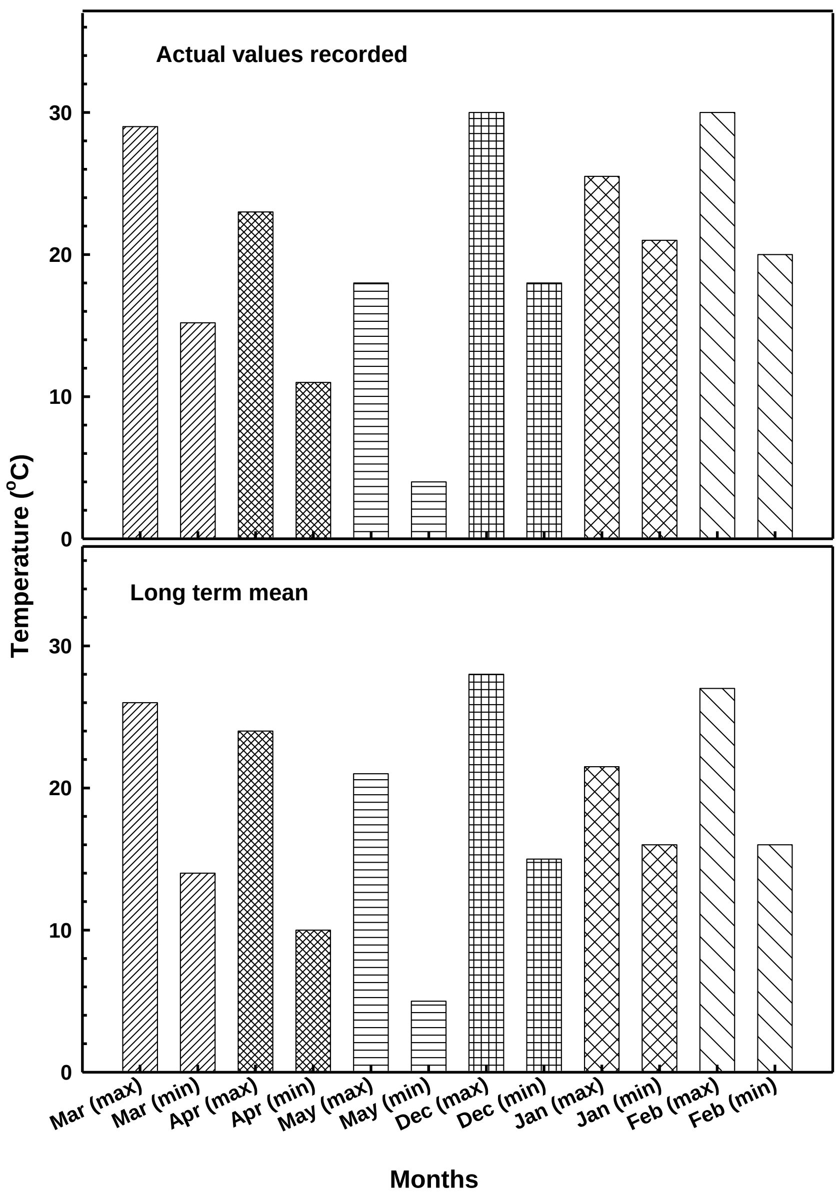

Figure 1. Average maximum and minimum temperatures during the March – May 2009 and December 2009 – February 2010 seasons mirrored against the long term means recorded at the Hatfield Experimental Farm, Pretoria, SA.

Table 1. Chemical composition of MPT prunings applied as soil ameliorants during the March to May 2009 and December 2009 to February 2010 growing seasons at the Hatfield Experimental Farm, Pretoria, SA.

Constituent	*L. leucocephala*	*A. angustissima*	*C. calothyrsus*	*A. karoo*	LSD (0.05)	CV (%)
Nitrogen (g kg^{-1} DM)	39.80[a]	31.00[b]	29.40[c]	25.00[d]	2.77	4.42
Carbon (g kg^{-1} DM)	796.41[a]	558.91[b]	441.28[c]	275.31[d]	9.57	0.92
Phosphorus (g kg^{-1} DM)	27.40[a]	24.83[b]	21.40[c]	17.10[d]	1.25	2.76
Sulphur (g kg^{-1} DM)	2.34[a]	2.07[ab]	1.71b[c]	1.43[c]	0.52	13.69
Lignin (g kg^{-1} DM)	151.10[d]	206.89[c]	244.89[b]	283.17[a]	6.16	1.39
Soluble Condensed Tannin (g kg^{-1} DM, Quebracho Equivalent)	132.40[c]	145.85[c]	180.32[b]	203.86[a]	18.11	5.47

Means in the same row followed by different letters differ significantly (P <0.05) using LSD test.

Table 2. Partitioning of biomass to different plant tissues of rape at week 9 during the March to May 2009 and December 2009 to February 2010 growing seasons.

Treatment	Total biomass (t DM ha^{-1})		Shoot biomass (t DM ha^{-1})		Root biomass (t DM ha^{-1})	
	Mar-May	Dec-Feb	Mar-May	Dec-Feb	Mar-May	Dec-Feb
L. leucocephala	11.50^{b}	10.73^{b}	10.58^{b}	9.87^{b}	0.92^{b}	0.86^{b}
A. angustissima	7.95^{c}	6.48^{c}	7.31^{c}	5.96^{c}	0.64^{c}	0.52^{c}
C. calothyrsus	5.02^{d}	4.07^{d}	4.62^{d}	3.74^{d}	0.40^{d}	0.33^{d}
A. karoo	3.12^{e}	2.00^{e}	2.87^{e}	1.84^{e}	0.25^{e}	0.16^{e}
150 kg N ha^{-1}	16.40^{a}	15.26^{a}	15.08^{a}	14.03^{a}	1.32^{a}	1.23^{a}
0 N	1.74^{f}	1.39^{f}	1.60^{f}	1.27^{f}	0.14^{f}	0.12^{f}
LSD (0.05)	0.14	0.26	0.47	0.28	0.04	0.06
CV (%)	1.03	2.16	3.72	2.40	10.32	8.42

Means in the same column followed by different letters differ significantly ($P < 0.05$) using LSD test.

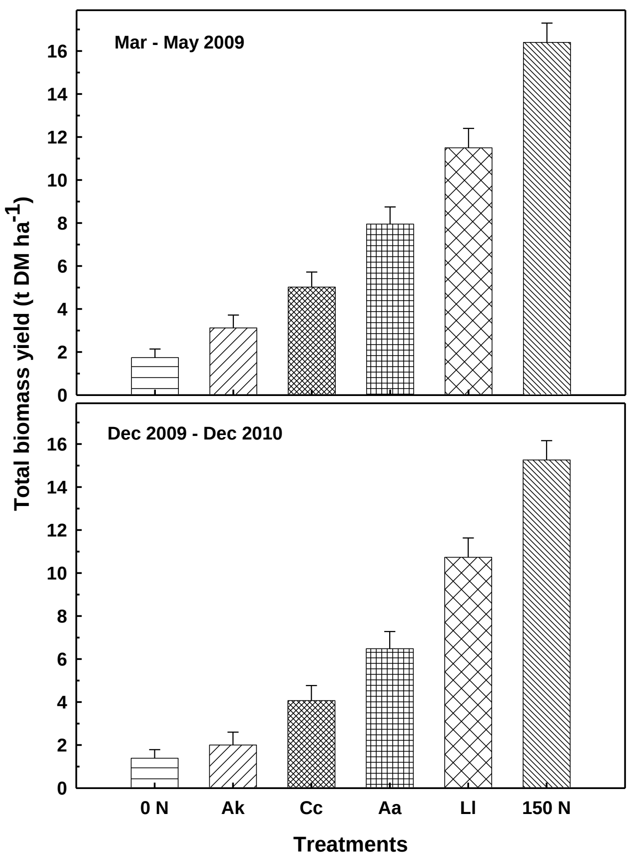

Figure 2. Mean total biomass yields of rape, 9 weeks after transplanting during the March to May 2009 and December 2009 to February 2010 growing seasons. Error bars denote standard error of the mean.

Biomass yields

Application of the various leguminous prunings increased biomass yields of rape relative to the non-fertilized treatment (Table 2). Yields from plots ameliorated with leguminous prunings reflected differences in chemical composition of the prunings. Prunings of *L. leucocephala* were of high quality due to their high N content and low concentrations of lignin and soluble condensed tannins. The general ranking for treatments based on total

Table 3. Total number of leaves and the maximum leaf lengths and widths per plant of rape at week 9 during the March to May 2009 and December 2009 to February 2010 growing seasons.

Treatment	Total number of leaves		Maximum leaf length (cm)		Maximum leaf width (cm)	
	Mar-May	Dec-Feb	Mar-May	Dec-Feb	Mar-May	Dec-Feb
L. leucocephala	22.33[b]	20.00[b]	26.53[b]	22.87[b]	19.18[b]	17.93[b]
A. angustissima	18.67[c]	15.67[c]	21.87[c]	18.37[c]	17.18[c]	14.59[c]
C. calothyrsus	16.33[d]	13.00[d]	17.11[d]	14.68[d]	14.66[d]	11.47[d]
A. karoo	13.67[e]	11.00[e]	15.71[e]	12.56[e]	10.62[e]	9.76[e]
150 kg N ha^{-1}	25.33[a]	23.33[a]	28.47[a]	25.76[a]	21.07[a]	19.06[a]
0 N	11.00[f]	9.33[f]	12.21[f]	10.25[f]	9.03[f]	8.47[f]
LSD (0.05)	1.04	0.98	1.11	1.01	0.89	0.75
CV (%)	3.84	5.88	9.82	10.56	5.14	4.79

Means in the same column followed by different letters differ significantly (P < 0.05) using LSD test.

biomass yields was: 150 N > *L. leucocephala* > *A. angustissima* > *C. calothyrsus* > *A. karoo* > 0 N. Biomass yields were generally higher during the March to May season than during the December to February season (Figure 2). The season x treatment interaction was significant (P < 0.05) due to the differences in absolute yields among the treatments.

Application of prunings of *A. karoo* increased total biomass yield of rape by 1.38 t DM ha^{-1} relative to the biomass yield of non-fertilized plots (1.74 t DM ha^{-1}) during the March to May season. Meanwhile amelioration with prunings of *C. calothyrsus, A. angustissima* and *L. leucocephala* during the same period produced yields that were 1.9, 3.5 and 5.5 fold, respectively, relative to the yield of the 0N treatment. During the December to February season, the absolute total biomass increases over the non-fertilized plots following soil amelioration with prunings of *A. karoo, C. calothyrsus, A. angustissima* and *L. leucocephala* were 0.61, 2.68, 5.09 and 9.34 t DM ha^{-1}, respectively. Averaged across the two seasons, the total biomass yields at week 9 following amelioration with prunings of *A. karoo, C. calothyrsus, A. angustissima* and *L. leucocephala* were 2.56, 4.55, 7.22 and 11.15 t DM ha^{-1}, and were lower than 15.8 t DM ha^{-1} realized after soil amendment with mineral fertilizer at 150 kg N ha^{-1}. A constant shoot-to-root ratio was observed across all treatments and averaged 10.42 (Table 2).

Rape is an all-year-round crop which is particularly suited to the cooler period of the year and its season of maximum growth is during autumn (Smith, 1995). It is a difficult crop during summer when temperatures are high and plants become infested with cabbage aphids (*Brevicoryne brassicae*) which necessitate frequent spraying for control (DAFF, 2010). Seasonal temperature differences and higher incidences of aphid infestation during the December to February season account for the higher biomass yields observed during the March to May season. Differences in biomass yields of rape from plots ameliorated with the different leguminous tree prunings could be explained by differences in their chemical composition.

The higher biomass yields of rape grown in soils ameliorated with the different leguminous prunings over the non-fertilized plants is evidence that leguminous tree prunings can be used as a source of N for vegetable production. The incorporation of prunings not only gives greater rates of decomposition and N mineralization but provides better synchrony between N availability and demand (Gaskell and Smith, 2007). Snapp et al. (1998) reported 3.20, 3.60, 5.10 and 5.10 fold increases in maize yields following soil amendment with leaves of *C. calothyrsus*, *A. angustissima*, *L. leucocephala* and *C. cajan*, respectively, relative to the yield of non-fertilized maize (1.1 t DM ha^{-1}). Chanyowedza and Chivinge (2002) also reported increase in the yield of 43 and 77% sorghum following soil amelioration with prunings of *Acacia nilotica* and *A. karoo*, respectively.

Leaf development

Total leaf numbers per plant increased linearly regardless of the sampling date for the various treatments. The season x treatment interaction was significant (P < 0.05) and therefore total leaf numbers are presented by season in Table 3. Plants that received mineral fertilizer at 150 kg N ha^{-1} had the highest total leaf numbers of 25 and 23 leaves plant^{-1} during the March to May and December to February seasons, respectively. The total leaf number for the non-fertilized plants averaged 10 leaves plant^{-1} for the two seasons, ranking lowest across both seasons. Plants grown in soils amended with the various prunings had total leaf numbers that were 2 and 11 leaves plant^{-1} more than those of the unfertilized plants during the two seasons. Plants grown in soils ameliorated with prunings of *A. angustissima*, *C. calothyrsus* and *A. karoo* had total leaf numbers that were on average 4, 6 and 9 leaves plant^{-1}, respectively, less than the total leaf numbers for plants grown following the application of *L. leucocephala* prunings during both seasons. Meanwhile plants grown

Table 4. Maximum leaf area per plant (at week 9) and weekly rate of change of leaf area for rape grown during the March – May 2009 and December 2009 – February 2010 growing seasons.

Treatment	Maximum leaf area (cm^2) $plant^{-1}$		Rate of change of leaf area (cm^2) $week^{-1}$ $plot^{-1}$	
	Mar-May	Dec-Feb	Mar-May	Dec-Feb
L. leucocephala	3,842.11b*	3,307.12b	419.80b	360.77b
A. angustissima	2,480.76c	2,200.15c	267.04c	235.41c
C. calothyrsus	2,014.53d	1.893.41d	227.09d	198.91d
A. karoo	1,604.28e	1,342.71e	176.07e	131.76e
150 kg N ha^{-1}	4,001.21a	3,604.12a	440.09a	390.76a
0 N	1,002.12f	856.41f	106.07f	90.02f
LSD (0.05)	112.25	101.23	15.6	10.45
CV (%)	12.56	11.47	13.75	14.12

Means in the same column followed by different letters differ significantly ($P < 0.05$) using LSD test.

following the application of the various prunings had on average 3 and 12 leaves $plant^{-1}$ less than plants that received mineral fertilizer during both seasons. The general ranking of treatments based on total leaf numbers was: 150 N > *L. leucocephala* > *A. angustissima* > *C. calothyrsus* > *A. karoo* > 0 N.

The increases in leaf numbers as N content of prunings increased that we are reporting are comparable to those reported by Semuli (2005), where the higher nitrogen rates increased the total leaf count of cabbage relative to lower rates. Nyakudya et al. (2010) also reported significant variation in leaf count $plant^{-1}$ when rape was grown in soils amended with the recommended mineral fertilizer, *miombo* leaf litter and green leaf biomass of *Acacia polyacantha*. The highest leaf number was obtained following the application of the recommended mineral fertilizer.

The maximum leaf length and width of the various treatments are also presented in Table 3. The leaf lengths of plants that received mineral fertilizer at 150 kg N ha^{-1} were 2.30 and 2.50 times longer than the leaf lengths of non-fertilized plants during the March to May and December to February seasons, respectively. Averaged across the two seasons the maximum leaf widths of plants grown in soils ameliorated with the different prunings were 1.16 (*A. karoo*) – 2.12 (*L. leucocephala*) times wider than leaves of plants that received no amelioration. The increases in leaf length and width with increasing N availability we are reporting are comparable to those reported by Pavlou et al. (2007) in lettuce. The application of higher levels of N (2.08 to 3.38 g N $plant^{-1}$) gave lettuce plants that had leaf lengths and widths that were 1.10 and 2.30 times that of lettuce plants that did not receive any N. Maximum leaf area was highest in plants that received mineral fertilizer at 150 kg N ha^{-1} and lowest in the non-fertilized plants during both seasons (Table 4). Comparison of the maximum leaf area attained following the application of mineral fertilizer and that of plants that did not receive any amendment revealed that application of fertilizer increased leaf area by 3,000 and 2,748 cm^2 $plant^{-1}$ during the March to May and December to February seasons, respectively. Amelioration with prunings of *A. karoo*, *C. calothyrsus*, *A. angustissima* and *L. leucocephala* during the March to May season increased leaf area by 604, 1,014, 1,480 and 2,842 cm^2 $plant^{-1}$ over the 0N treatment. The respective increases during the December to February season were 486, 1,037, 1,344 and 2,451 cm^2 $plant^{-1}$. Maximum leaf area attained following the application of prunings of *L. leucocephala* was 96 and 92% of the maximum leaf area attained by plants that received mineral N during the March to May and December to February seasons, respectively. Averaged over the two seasons, amelioration with prunings of *A. karoo*, *C. calothyrsus* and *A. angustissima* resulted in 39, 51 and 62% of the maximum leaf area attained following the application of mineral fertilizer at 150 kg N ha^{-1}.

Total green leaf area per plant is the integrated value of the number of green leaves and the size of each leaf (Biemond, 1995). Plants grown in soils ameliorated with the various leguminous prunings had higher leaf area compared to plants that did not have any amendment. An increase in the amount of N availed by the prunings increased leaf area, leaf number and vegetative growth of plants, thus increasing the photosynthetic capacity and consequently the high biomass yields produced. The general increases in leaf area with increasing N availed by the prunings that we are reporting are comparable to those reported by Semuli (2005), where increasing N from 0 to 120 mg l^{-1} increased leaf area of cabbage to 59.68 cm^2 compared to 5.72 cm^2 in control plants. The higher leaf area attained following soil amendment with mineral fertilizer and leguminous prunings suggests more vigorous growth which is desirable for higher leaf yields and the bigger leaf sizes are a quality attribute, determining the desirability of leaf vegetables on the market

Table 5. Mean total saleable leaf yield of rape (t fresh weight ha^{-1}) 9 weeks after transplanting during the March – May 2009 and December 2009 to February 2010 growing seasons.

Treatment	Mar – May	Dec - Feb	Mean
L. leucocephala	8.01[b]	7.11[b]	7.56[b]
A. angustissima	5.64[c]	4.41[c]	5.02[c]
C. calothyrsus	3.34[d]	2.66[d]	3.00[d]
A. karoo	1.60[e]	0.96[e]	1.28[e]
150 kg N ha^{-1}	10.94[a]	9.15[a]	10.04[a]
0 N	0.98[f]	0.74[f]	0.86[f]
LSD (0.05)	0.33	0.11	0.37
CV (%)	9.46	7.45	8.23

Means in the same column followed by different letters differ significantly ($P < 0.05$) using LSD test.

(Masinde et al., 2009).

Saleable leaf yield

The season x treatment interaction was significant and therefore total saleable leaf yields are presented by season in Table 5. Higher total saleable leaf yields were realized during the March to May season than during the December to February season. Plants grown following the application of mineral fertilizer had the highest saleable leaf yields of 10.94 and 9.15 t fresh weight ha^{-1} during the March to May and December to February seasons, respectively. On the other hand, plants that received no amelioration had the lowest total saleable leaf yields of 0.98 and 0.74 t fresh weight ha^{-1} during the March to May and December to February seasons, respectively.

During the March to May season, soil amelioration with prunings of *A. karoo, C. calothyrsus*, *A. angustissima* and *L. leucocephala* increased the saleable leaf yield of rape by 0.62, 2.36, 4.66 and 7.03 t fresh weight ha^{-1}, respectively, over the 0 N treatment. The corresponding increases in saleable leaf yield over the 0N treatment during the December to February season were 0.22, 1.92, 3.67 and 6.37 t fresh weight ha^{-1}, respectively. However, averaged across the two seasons, soil amelioration with prunings of *A. karoo*, *C. calothyrsus*, *A. angustissima* and *L. leucocephala* gave total saleable leaf yields that were 8.76, 3.00, 5.02 and 2.48 t fresh weight ha^{-1}, respectively, and these were lower than the total saleable leaf yield attained from the 150 N plants.

Saleable leaf yields increased with an increase in the amount of N availed by prunings. Ghanti et al. (1982) attributed the increases in leaf yield with increasing N availability to the fact that N favoured more vegetative growth producing plants with a higher leaf count and subsequently higher total green leaf area per plant. Increases in the growth parameters in turn synthesized more plant metabolites thereby increasing leaf yields (Kumar and Rawat, 2002). The application of mineral fertilizer at 150 and 300 kg N ha^{-1} was reported to have increased the leaf yield of spinach by 1,144 and 1,501 g m^{-2} compared to that realized from the unfertilized control (Elia et al., 1998).

Conclusion

Prunings of leguminous tree species can be used as a source of N for vegetable production as evidenced by the higher yields realized following amendment of soil with the various prunings relative to the unfertilized plants. The large variation observed in dry matter accumulation, leaf development and saleable leaf yields could largely be interpreted based on the resource quality of the leguminous prunings. It would seem resource quality affected the synchrony between crop demand and N supply in the soil and ultimately growth rates. However, even yields from *A. karoo*, the species of least quality, indicate considerable potential for smallholder vegetable production.

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