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Crop Residues for Mulch, Feed Yield and Quality as Influenced by Low-Input Maize-Based Cropping Systems and N Fertilizer

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Abstract: Crop residue yield and quality in five Cropping Systems (CSs) comprising cereal-legume, cereal-cereal (CS4) and cereal-bare fallow (CS5) rotations, together with three rates of N fertilizer application on maize and barley were investigated over two consecutive 12 months cropping phases. Cereal-legume CSs were Winter field pea green manure-Summer maize (CS1), lucerne fodder bank intercropped with Winter barley and Summer maize (CS2) and Winter field pea for grain-Summer maize intercropped with cowpea (CS3). N rates were 0, 60 and 120 kg N ha^{-1} on maize and 0, 40 and 80 kg N ha^{-1} on barley. Inclusion of legumes in CSs generally increased maize stover yield and quality relative to those without legumes. The exception was CS2, in which stover DM yields were limited by competition with the lucerne in the system. Mean stover DM yield ranged from 5.3-9.5 and 6.4-7.1 ton ha^{-1} in phases 1 and 2, respectively and was consistently higher for CS1 in both phases. In general, stover quality benefits from legume inclusion were higher Crude Protein (CP), K, Mg and Ca contents. Mean stover DM yield, N content and N yield all increased with increasing N rate in both maize crop phases. Cowpea residue DM yields from CS3 increased with N application to intercropped maize but only up to 60 kg N ha^{-1} in phase 1. Significant CS×N rate interactions were only observed for barley straw yield in phase 2 where greater response to applied N was observed in CS4 than in CS2. Compared to the N control, mean straw yield in phase 1 increased by 88 and 169% for the N40 and N80 application rates, respectively. In CS3, field pea residue DM yield and N content increased with increasing N application to the preceding maize crop. Forage DM yield from lucerne in the barley-lucerne intercrop (CS2) increased with N application to barley up to 80 kg N ha^{-1}.

Key words: Residue yield, residue quality, mulch, cereals, legumes

INTRODUCTION

Crop residues (e.g., stover and haulms) after grain harvest can provide roughage for livestock feed and many be grouped by crop type, such as cereals and grain legumes. Crop species selection, cropping practices applied (e.g., double-and inter-cropping) and the level of crop inputs such as fertilizer influence residue yields (De Leeuw, 1997). In many parts of developing countries, farmers often deliberately opt for crop combinations and management practices that optimize residue production, especially from the more nutritious grain legumes (Singh and Tarawali, 1997).

In this respect, dual-purpose legumes, such as cowpea and peas are very important crops for seed and forage production (Tarawali and Mohamed-Saleem, 1995; Tarawali and Peters, 1996; Weber, 1996). In addition to their use for animal feed, crop residues are also used as mulch for soil fertility restoration and crop yield improvement (Latham, 1996; Ikpe *et al*., 1999; Hoffmann *et al*., 2001; Larbi *et al*., 2002). Green legume manures may reduce soil erosion, a major cause of land degradation in Africa and most parts of the world (Lal, 1995) and improve soil physical properties through the addition of organic matter (Wade and Sanchez, 1983; Smith *et al*., 1987). Studies have shown that when used for short-fallow improvement, legumes can reduce or in some cases eliminate, the inorganic N fertilizer requirement of a subsequent maize crop (IITA, 1996; Carsky *et al*., 1997; Muhr *et al*., 1999).

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This study compares crop residue production in terms of yield and quality from five low-input Cropping Systems (CSs). Grain yield and quality from these systems has been reported earlier (Omokanye *et al*., 2013).

MATERIALS AND METHODS

Experimental site and field experiment details: The research was conducted from 2000-2003 at Richmond (33°62'S, 150°75'E, 21 m a.s.l. elevation) near Sydney, NSW, Australia. Details of the CS and N fertilizer treatments studied, together with soil description and weather conditions during the study period were outlined in Omokanye *et al*. (2011, 2013) while a summary of the CSs is outlined in Table 1. The possible residual effects of N applied to a Summer maize crop on a following Winter crop were investigated in four of the systems. The experimental work was conducted over 2 cropping phases (Winter 2001 to Summer 2002 and Winter 2002 to Summer 2003). N fertilizer application rates were 0, 60 and 120 (N control 0, 60 and 120) kg ha^{-1} applied to maize and 0, 40 and 80 (N control, 40 and 80) kg ha^{-1} to barley (Table 1).

Crop residue harvest and yield determination: For all CSs in both phases, crop residues were harvested on the same day as grain harvest (Omokanye *et al*., 2013).

Maize (CS1-5): Maize stalk (plus husk) yield was determined from 4 m lengths of the four central rows (9.0 m^2), cut at 5 cm above ground level in each plot. The stalk was weighed then sub-sampled (1.5 kg) and sub-samples were oven-dried at 70°C for 48 h. The oven-dried sub-samples were weighed for total stover DM yield determination. After sub-sampling, the balance of the harvested residues was immediately returned and spread evenly across the harvested area of the plot from which it had been cut. Except for CS2, all maize residues were subsequently slashed and incorporated into the soil by rotavation.

Cowpea (CS3): All cowpea plant residues (mainly forage) within the pod-harvested two central rows (5.25 m^2) (Omokanye *et al*., 2013) were cut at 5 cm above ground level, weighed and sub-sampled (1.0 kg). Sub-samples were oven-dried at 70°C for 48 h. The balance of the harvested residues was removed from the plot along with all remaining standing plant material (cut at 5 cm above ground level). The oven-dried sub-samples were weighed for determination of residue DM yield. Husk yield was determined from the harvested pods which were air-dried and their grains extracted. Husks were then subsampled and oven dried at 70°C for 48 h.

Lucerne and barley (CS2 and CS4): Lucerne in the maize-lucerne intercrop system (CS2) was cut at 5 cm above ground level from three 1×1 m quadrats placed along the rows from which maize grain samples had been harvested and residues removed (Omokanye *et al*., 2013). Harvested lucerne was weighed and sub-sampled (1.0 kg) and sub-samples oven-dried at 70°C for 48 h then weighed for estimation of forage DM yield. After lucerne harvest, the remainder of each plot was mown to 5 cm height and all mown lucerne was removed from the plots. The lucerne was then left to grow until 2 days before direct drilling of the following Winter rotation crop (barley). About 2 days before direct drilling of barley, the lucerne was again sampled for DM yield as outlined above and all lucerne material above 5 cm removed. After barley grain harvest in November, lucerne was harvested from 1×1 m quadrats together with the intercropped barley residues, separated from the barley straw then both were weighed, subsampled (1.0 kg) and oven dried. For CS4 (sole barley), barley straw yield was also determined from three 1×1 m quadrats, weighed, subsampled (1.0 kg) and oven dried.

Table 1: Description of Cropping Systems (CSs) showing crop species, rotations, growing season and specific comments

		Period of planting			
		Cropping phase 1		Cropping phase 2	
Cropping systems	2000-01 N-F[1] (Summer)	2000 J-N (Winter)	2001-02 N-F (Summer)	2002 J-N (Winter)	2002-03 D-M (Summer)
Maize/field pea (improved fallow, CS 1)	Maize	Field pea[2]	Maize	Field pea	Maize
Maize-lucerne/barley-lucerne (legume fodder bank, CS 2)	Maize	B-L[3]	M-L[4]	B-L	M-L
Maize-cowpea/field pea (CS 3)	Maize	Field pea[5]	M-C[6]	Field pea	M-C
Maize/barley (CS 4)	Maize	Barley	Maize	Barley	Maize
Maize/bare fallow (CS 5)	Maize	Fallow	Maize	Fallow	Maize

[1]Months: N-F = November-February; J-N = June-November; D-M = December-March; [2]Field pea used as green manure for subsequent Summer maize crop; [3]B-L = Barley-Lucerne intercrop; [4]M-L = Maize-Lucerne intercrop; [5]Field pea harvested for grain; [6]M-C = Maize-Cowpea intercrop; Specific comments on CSs = CS 1. The legume (field pea-*Pisum sativum*) was incorporated as green manure into the soil at early flowering, before the subsequent maize crop was planted CS 2: Lucerne (*Medicago sativa*) was planted in Autumn 2000 after the first (baseline) maize crop to represent *Stylosanthes* sp. as a legume fodder bank or stockpile forage. The lucerne was intercropped with maize in Summer and barley in Winter; CS3 = Annual double cropping phases comprising Summer maize intercropped with cowpeas and Winter field peas grown for grain; CS4 = Continuous cereal based double cropping system; CS 5 = Maize-Winter fallow system

Field pea for incorporation as green manure (CS1): At the early (10-15%) flowering stage, three 1×1 m quadrats were harvested at 5 cm above ground level from the center of each plot. Samples were weighed, sub-sampled (1.0 kg) and oven dried at 70°C for 48 h. After sub-sampling, the balance of the harvested material was immediately returned and spread evenly across the harvested area of the plot from which it had been cut. After sampling, the remaining non-harvested field peas were killed with a herbicide (Roundup™ 360 g L^{-1} glyphosate-a.i.) at a rate of 13 mL L^{-1} of water. All field pea dry matter (except sub-samples) was subsequently spread evenly over the plot surface and then incorporated into the soil by rotavation.

Field pea for grain (CS3): Field pea residual DM (forage and husk) was determined from plants harvested for grain yield determination (Omokanye *et al*., 2013). After removing all grain from the harvested plants, residues were weighed then sub-sampled (1.0 kg) and oven-dried at 70°C for 48 h and weighed for DM yield determination. Cut samples were discarded after weighing and all remaining plant material was cut to 5 cm and removed from the plots.

Chemical analyses: All residue sub-samples, after oven-drying and weighing were ground to pass through a 0.75 mm mesh then analyzed for N, P, K, Ca and Mg contents by a commercial laboratory (Waite Analytical Services, University of Adelaide, South Australia), according to the procedures of Colombo and Giazzi (1982) and Zarcinas *et al*. (1987). Crude protein content was determined as 6.25×N%.

Statistical analyses: Data were statistically analysed using the GLM procedure from the SAS computer package (SAS, 1997) to determine Cropping System (CS) and N fertilizer rate main and interaction effects on all parameters. Where, ANOVA indicated significant CS or N rate effects, means were compared by Least Significant Difference (LSD) using the LSD lines of SAS procedure. For CS×N rate interaction effects, LSDs were calculated using the appropriate standard error terms described by Gomez and Gomez (1984). Level of significance in the text refers to $p<0.05$. The results are presented on a phase basis, representing the phase 1 and 2 cropping cycles described in Table 1.

RESULTS

Maize stover yield and quality: Table 2 shows the mean maize stover yield (ton ha^{-1}) and mineral element contents (%) in relation to CS and N rate in phase 1 and 2. No significant interaction was observed between CS and N fertilizer rate for maize stover yield in either phase. Except for CS 2, inclusion of legumes in the rotation (CS 1 and 3) increased mean maize stover yield by 7-29% in phase 1 and 6-26% in phase 2 over CSs without legumes (CS 4 and 5). CS 1 produced significantly higher stover yield than all other CSs in both phases. Mean stover yield increased significantly with increasing N in both phases with 47 and 68% increases for N 60 and 120 over N 0 control. In phase 2, these increases were 40 and 59%, respectively.

No significant interactions between CS and N rate on mineral element composition were observed in either phase. A significant CS effect was observed for mean maize stover N and P contents as well as Ca:P ratio in both phases and for Mg content in phase 2. In phase 1, the inclusion of legumes (CS 1-3) resulted in higher mean stover N content than in those CSs without legumes (CS 4 and 5). In phase 2, CS 2 exhibited significantly higher mean stover N content than CS4 and 5 while CS1 and 3 were only significantly higher than CS4. The mean maize stover N content was significantly affected by N rate in both phases, increasing by 26 and 64% for N60 and 120 over the N 0 control, respectively in phase 1 and by 17 and 53%, respectively in phase 2. In both phases, CS2 had higher mean stover P content than CS4 and 5. All three CSs that included legumes had higher stover Ca contents than those without legumes in both phases. The resultant Ca:P ratio did not show a clear pattern in relation to CS in either phase. However, the ratio was generally higher in phase 2 than in phase 1. In phase 1, mean P, K, Mg and Ca contents and Ca:P ratio were not affected by N rate. However in phase 2, mean K content and Ca:P ratio were both significantly higher at N 60 and 120 than in the N 0 control.

Cowpea residue yield and quality (CS 3): Nitrogen fertilizer application to the intercropped maize did not significantly affect cowpea residue DM yield in the maize-cowpea intercrop (CS 3) in phase 1. However, the N 120 rate produced significantly higher forage DM yield (1.9 ton ha^{-1}) than the N 0 control (1.5 ton ha^{-1}) in phase 2. No response was evident up to N 60. Overall, mean forage DM and N yields were generally lower in phase 1 than in phase 2. In phase 1, N application to the intercropped maize did not significantly affect cowpea mineral element composition. In phase 2, only forage N content was significantly affected by the rate of applied N, being higher for the N 120 rate (1.40%) and similar for both N 0 and 60 rates (1.30%).

Table 2: Mean maize stover DM yield (t ha^{-1}) and mineral element contents (%) in relation to CS and N rate (kg N ha^{-1}) in phases 1 and 2

CS	Stover yield	Mineral element (phase 1) N	P	K	Mg	Ca	Ca:P	Stover yield	Mineral element (phase 2) N	P	K	Mg	Ca	Ca:P
CS1	9.51^{a}	0.81^{a}	0.09^{ab}	1.60	0.15	0.53^{a}	5.9^{ab}	8.85^{a}	0.70^{ab}	0.07^{b}	1.63	0.19^{ab}	0.54^{a}	7.7^{ab}
CS2	5.34^{e}	0.84^{a}	0.11^{a}	1.60	0.16	0.52^{a}	4.7^{b}	6.37^{d}	0.79^{a}	0.11^{a}	1.63	0.17^{bc}	0.53^{a}	4.8^{b}
CS3	8.47^{b}	0.91^{a}	0.09^{ab}	1.58	0.16	0.59^{a}	6.6^{a}	7.79^{b}	0.65^{ab}	0.07^{b}	1.62	0.21^{a}	0.58^{a}	8.3^{a}
CS4	7.37^{d}	0.63^{b}	0.07^{b}	1.56	0.13	0.42^{b}	6.0^{a}	7.04^{c}	0.48^{c}	0.06^{b}	1.57	0.16^{c}	0.43^{b}	7.2^{b}
CS5	7.93^{c}	0.58^{b}	0.07^{b}	1.56	0.15	0.43^{b}	6.1^{a}	7.33^{c}	0.60^{b}	0.06^{b}	1.58	0.17^{bc}	0.44^{b}	7.3^{b}
LSD	0.50	0.13	0.02	-	-	0.10	2.1	0.40	0.14	0.03	-	0.03	0.10	2.4
N rate														
0	5.58^{c}	0.58^{c}	0.10	1.58	0.15	0.60	5.7	5.62^{c}	0.53^{c}	0.09	1.57^{b}	0.18	0.51	5.7^{b}
60	8.19^{b}	0.73^{b}	0.11	1.53	0.14	0.63	6.1	7.85^{b}	0.62^{b}	0.06	1.59^{b}	0.20	0.51	8.5^{a}
120	9.39^{a}	0.95^{a}	0.10	1.57	0.15	0.59	5.9	8.93^{a}	0.81^{a}	0.07	1.70^{a}	0.17	0.52	7.4^{ab}
LSD	0.60	0.10	-	-	-	-	-	0.50	0.10	-	0.10	-	-	1.8

Mean values within a column followed by the same letter (s) are not significantly different ($p>0.05$) by LSD

In phase 1, cowpea husk DM yield was not significantly affected by N fertilizer rate but in phase 2, it was higher and similar for both N 0 and 60 (135 kg ha^{-1}) than for N 120 (120 kg ha^{-1}). This was attributed to a possible dilution effect from the higher forage dry matter yield at N 120. In both phases, cowpea husk mineral element contents were not significantly affected by N fertilizer rate.

Lucerne forage yields and mineral element contents (CS 2): Lucerne forage DM yield at maize harvest followed the same pattern in both phases, increasing significantly with the N 120 rate over the N 0 control and 60 rates on maize (Fig. 1). Forage DM yield was higher in phase 1 than in phase 2. In both phases, the mineral element content of lucerne forage at maize harvest was not significantly affected by N application to intercropped maize.

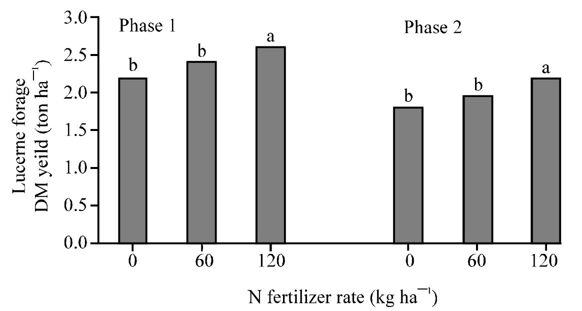

Fig. 1: Lucerne forage DM yield from the maize-lucerne intercrop (CS 2) as affected by N rate on the intercropped maize, for both phases. Bars with different letters are significantly ($p<0.05$) different according to LSD (0.3 for both phases)

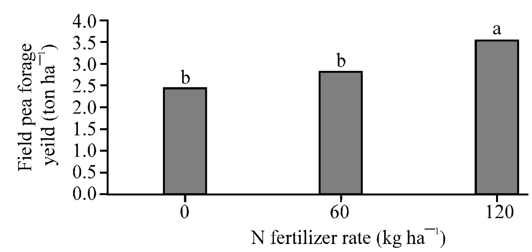

Fig. 2: Apparent carryover effects of N application to maize in the maize-cowpea intercrop on subsequent field pea forage DM yield in phase 2. Bars with different letters are significantly ($p<0.05$) different according to LSD (0.58)

Field pea forage yield, N yield and mineral element content from the short-fallow Improvement system (CS 1): The mean field pea forage DM yield, N yield and N content in phase 1 were 5.0 ton ha^{-1}, 148 kg N ha^{-1} and 3%, respectively. There were no significant apparent carryover effects of N application to the preceding maize phase 1 crop on the yield of field pea forage DM, nor on forage P, K, Ca and Mg contents. This suggests that there was little difference in residual soil N after maize, regardless of N applications to that crop of up to 120 kg ha^{-1}. No apparent carryover effects of N on any of the measured mineral elements in field pea forage were observed in phase 2.

Field pea forage yield, N yield and mineral element content (from field pea for grain, CS 3): The mean DM yield, N yield and N content of field pea residues after grain harvest were 2.45 ton ha^{-1}, 38 kg N ha^{-1} and 1.6%, respectively in phase 1. In phase 2, forage DM yield was significantly higher in plots at N 120 than those with N 0 or 60 on the preceding (phase 1) maize crop (Fig. 2). There were no apparent N carryover effects on mineral element contents in either phase. Mean husk dry matter yield, N yield and N content were 265 kg ha^{-1}, 3.1 kg N ha^{-1} and 1.2%, respectively for phase 1 and 268 kg ha^{-1}, 3.2 kg N ha^{-1} and 1.2%, respectively in phase 2. No apparent carryover effects were observed from N application to the preceding phase 1 maize crop on DM yield and mineral contents of field pea husks in phase 2.

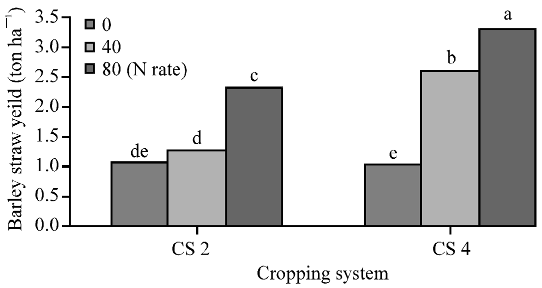

Fig. 3: Barley straw DM yield in relation to CS and N fertilizer rate in phase 2. Bars with different letters are significantly ($p<0.05$) different according to LSD (0.23)

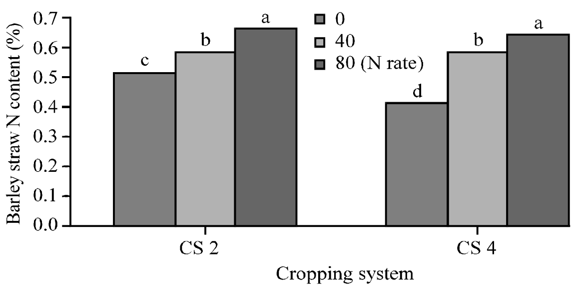

Fig. 4: Barley straw N content in relation to CS and N fertilizer rate in phase 2. Bars with different letters are significantly ($p<0.05$) different according to LSD (0.05)

Barley straw yield and quality (CS 2 and 4): Significant CS×N rate interactions were observed only for barley straw yield in phase 2. In phase 1, mean straw yield was significantly lower in CS 2 (1.59 ton ha^{-1}) than in CS 4 (2.3 ton ha^{-1}). Mean straw yield increased significantly with increasing N rate in phase 1. Compared to the N 0 control, mean straw yield increased by 88 and 169% for N40 and 80, respectively. In phase 2, there was a significantly greater straw yield response to applied N in CS4 than in CS2 (Fig. 3). Yields of both systems were similar for the N 0 control.

Significant CS×N rate interaction effects were observed only for straw N and Ca contents in phase 2. No significant CS×N rate interactions were observed for the other mineral elements or for Ca:P ratios in either phase. In phase 1, only mean N content was affected by CS being significantly higher in barley intercropped with lucerne (CS2-0.62%) than in barley alone (CS4-0.56%). In phase 2, the effect of CS and N rate on straw N content is shown in Fig. 4 where both CSs showed significant increases with increasing N application rate up to N 80. Straw N content was higher in CS 2 than in CS 4 for N 0 control.

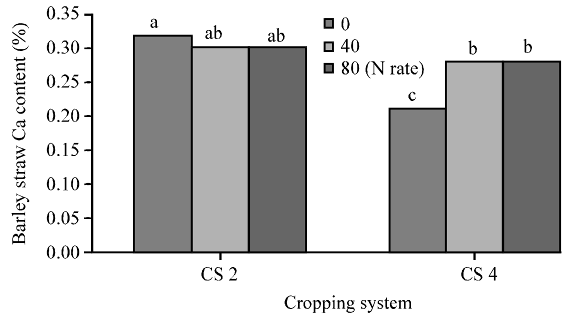

Fig. 5: Barley straw Ca content in relation to CS and N fertilizer rate in phase 2. Bars with different letters are significantly ($p<0.05$) different according to LSD (0.05)

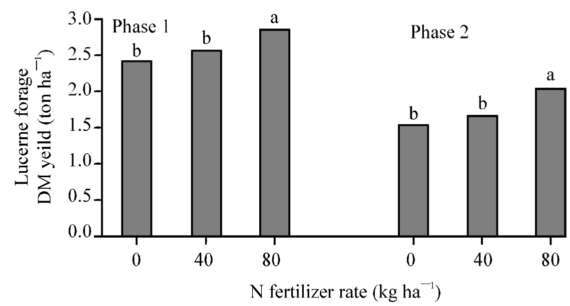

Fig. 6: Lucerne forage DM yield from the barley-lucerne intercrop system (CS 2) in relation to N fertilizer rate in phases 1 and 2. Bars with different letters are significantly ($p<0.05$) different according to LSD (0.25-phase 1; 0.37-phase 2)

CS did not affect barley straw P, K or Mg contents in either phase. Mean Ca:P ratio was not affected by CS in phase 1 but was significantly higher for CS 2 (2.42) than CS 4 (1.83) in phase 2. Mean straw N content increased significantly with increasing N but only up to N 40 in phase 1. N application did not affect mean P, K and Mg contents in either phase. In both phases, mean Ca:P ratio was the same for both N 0 and 40 (2.0) but was significantly higher in both phases with an increase to N 80. In phase 2, straw Ca content was only influenced by N rate in CS 4 with a significant increase in Ca content at N 60 and 120 relative to the N 0 control (Fig. 5).

Lucerne forage yield and mineral element contents: The mean lucerne forage DM yield followed the same pattern in both phases, increasing significantly with N application up to N 80 on barley (Fig. 6). Forage DM yield was lower overall in phase 2 than in phase 1. N application had no significant effects on forage mineral element content in either phase.

DISCUSSION

Choice of cereal and legume species and N fertilizer application rate had significant effects on DM yield and N content of crop residues in the cropping systems investigated. Dry matter yield and N content were generally increased by the inclusion of legumes and the application of N fertilizer.

Summer season crops

Maize: The inclusion of legumes in rotations increased maize stover yields over the cereal-based (CS 4) and cereal-bare fallow (CS 5) systems. However, the benefit of inclusion of legumes was significantly higher where the legume biomass was retained in the system by incorporation into the soil (CS 1) compared to systems where the legume biomass was completely removed (CS 2 and 3) at harvest. The lower stover yields in the latter systems probably reflect direct competition effects on maize from intercropped lucerne (CS 2) and cowpea (CS 3). This is consistent with the effects reported earlier for maize grain yield (Omokanye *et al*., 2013). Higher maize stover yields have been reported in maize-cowpea intercrops in other studies (Ofori *et al*., 1987; Stern, 1993; Olasantan, 1998). The higher stover yields from CS 3 compared to CS 2 probably reflect a lower level of competition from the intercropped cowpea than from the established lucerne in CS 2.

The expected benefits of using a lucerne-ley intercropped with maize were not evident in this study, as reported earlier for maize grain yield (Omokanye *et al*., 2013). The relatively poor yield performance of maize in CS 2 was attributed to consistent draining of available soil water by lucerne which has been reported to reduce successful establishment of maize (Dalgliesh *et al*., 2001) and maize grain yield. N content of maize stover in CS 2 was significantly higher than in CS 1 and 3 and was attributed to a yield dilution effect from the higher stover yields obtained in CS 1 and 3.

The gradual decline in maize stover N content with time in the cereal-based systems indicates that they will be unlikely to sustain adequate maize yields without applied N fertilizer. The results from this study confirm earlier reports that rotation with legumes increased maize growth, dry matter and N accumulation (Carsky *et al*., 1999).

From a livestock nutrition perspective for an animal under normal feeding conditions and in a state of good health, the Crude Protein (CP) (6.25×%N) content of maize stover from all CSs and N rates (2.8-5.7% CP) was below the critical values of 6-8% CP in cattle diets. Below these critical values, digestibility and voluntary intake of forage are likely to be reduced (Humphreys, 1991). However, if the maize stover is grazed *in situ*, the presence of lucerne forage (CS 2) and cowpea residues (CS 3) may allow satisfactory CP intake, as compared to the cereal-based (CS 4) and cereal-bare fallow (CS 5) systems.

Some reported critical minimum values for essential dietary elements for ruminant livestock are outlined in Table 3 and the following discussion on the dietary adequacy of the various elements in residues is based on these values. Besides higher N and CP levels, cropping legumes in rotation with maize also improved the Ca content of maize stover in both phases to well above the minimum adult cattle requirement (Table 3) while those CSs without legumes barely met the minimum requirement. However for young growing calves, only the Winter grain legume/maize-cowpea intercrop system (CS 3) met the minimum Ca requirement. Calcium contents for all CSs and N rates were within the ranges required by adult sheep. In phase 2, only CS 2 (maize-lucerne) had a higher maize stover P content than the other systems which was attributed to a yield dilution effect from their higher stover yields. However, P contents in stover from all cropping systems and at all N rates were clearly below the critical minimum requirement for young calves and young growing cattle (Table 3). The resulting maize stover Ca:P ratios of 5-7:1 and 5-8:1 far exceeded the generally accepted critical ratio of 1-2:1 Ca:P (Underwood, 1981). These values reflect the low stover P content found in all CS and N rate treatments. The provision of a diet to sheep with a high level of Ca and a low level of P results in a more rapid decrease in food intake and Plasma Inorganic P (PIP) than when the Ca level is normal (Field *et al*., 1975; Ternouth and Sevilla, 1990a). When the level of dietary P is extremely low but Ca is high, P absorption is reduced. Later research with the same sheep has shown that repletion with Ca but not P results in a further decrease in PIP and food intake (Ternouth and Sevilla, 1990b). Thus, extreme Ca:P ratios may result in an exacerbation of the effects of P deficiency. Potassium contents of maize

Table 3: Critical minimum content of essential elements and optimal Ca:P ratio in dry matter to meet ruminant livestock nutritional requirements

	Element content as % of dry matter							
Livestock category	N	CP	Ca	P	Mg	K	Ca:P	References
Cattle-young calves				0.4-0.7	0.07-0.10			NRC (2001)
Growing	1.8	11.25	0.6-1.0	0.12	1-2:1		1-2:1	Little (1980), NRC (2001), Minson *et al*. (1976) and Underwood (1981)
Adult	0.96-1.28	6.0-8.0	0.43					Humphreys (1991) and ARC (1980)
Sheep-adult			0.20-0.82		0.12-0.18			NRC (1980)
Ruminants						0.5-0.8		NRC (1980), ADAS *et al*. (1984) and NRC (2001)

stover from all CSs and N rates were above the limiting values for ruminant livestock while those of Mg were above the minimum requirements for young calves and sheep.

Cowpea: Cowpea residue DM yield in CS3 with 120 kg N ha^{-1} averaged 1.7 ton DM ha^{-1} over the 2 phases and was similar to that of 1.5 ton DM ha^{-1} reported for a maize-cowpea intercrop with 60 kg N ha^{-1} in a 2 years trial (Olasantan, 1998). These yields are much higher than the 0.2-0.7 ton DM ha^{-1} reported for a cowpea variety-millet intercrop trial (Singh and Emachebe, 1998). All cowpea forage mineral element contents, including Ca:P ratios were sufficient to meet the requirements of ruminant livestock outlined in Table 3. On a CP basis, residual cowpea forage from all N rates in the maize-cowpea intercrop was within the critical range of 6-8% CP for cattle diets (Humphreys, 1991).

Cowpea husk N, K, Ca and Mg contents and Ca:P ratios all met the requirements of adult ruminant livestock. However, P content was limiting for young calves but double the critical value for young growing cattle. Adeloye (1995) found that goats on a cowpea husk diet exhibited higher growth rates, dry matter feed intake and feed conversion ratios than those on a control diet (40:60 concentrate: grass mixture).

Lucerne: Although, lucerne DM yield increased with an increase in applied N to intercropped maize, the mineral element contents were similar for all rates of applied N. In this study, soil moisture was consistently low under the cereal-lucerne intercrop system throughout the experimental period. The forage N contents (3.3-3.7%) were well above the critical levels suggested by Minson *et al.* (1976) for young beef cattle (Humphreys, 1991). Ca contents were well above the requirements of adult cattle, young growing calves and sheep. With lower DM yields in phase 2, Ca and Mg contents were 56 and 44% higher, respectively than in phase 1 which was attributed to a yield dilution effect. P contents (0.23-0.28%) were clearly below the requirements of young calves but met the critical values for young growing cattle. K contents (2.6-2.8%) were well above the limiting values for ruminant livestock. The forage Ca:P ratios of 4.9-5.7:1 from the three N rates far exceeded the generally assumed critical ratio of 1-2:1 (Underwood, 1981). Mg contents (0.21-0.24%) were adequate for young calves and sheep (NRC, 1980). Generally, the mineral element contents recorded for lucerne were adequate for ruminants and in a crop-livestock system, this would offset the deficiencies of some mineral elements in maize stover from the maize-lucerne intercrop, thereby reducing farmer costs for mineral supplementation of livestock.

Winter season crops

Field peas: The absence of residual effects from N application to the preceding maize crop on field pea residue DM yield in both phases for CS 1 and in phase 1 for CS 3 was attributed to maize uptake of available N and to nitrification of any residual fertilizer N in the interval (c.a. 3 months) between maize harvest and planting of field pea. The increase in field pea forage DM yield in phase 2 compared to phase 1 suggests a steady increase in N availability with successive cropping phases. Over a longer period steady improvement in field pea yields and quality may be expected over time. For CS 1, 149 and 166 kg N ha^{-1} from above-ground field pea biomass was incorporated into the soil in phase 1 and 2, respectively prior to sowing the subsequent maize crop. In contrast, removal of all field pea residues in CS 3 resulted in an average N loss to the system of 42 kg N/ha/year. Increasing yield of the maize crop is a major objective of the CS 1 improved fallow system. Aggarwal stated that legume residue incorporation may sustain N content in arable soils more effectively over time than where residues were removed and is an important method for managing soil fertility. Nitrogen availability for a succeeding crop from green manure is gradual, in contrast to the rapid N release from inorganic N fertilizers (Groffman *et al.*, 1987).

Where a farmer cuts and removes the field pea forage as livestock feed or allows *in situ* grazing instead of incorporating residues into the soil, the forage N (2.9-3.2%), K (2.77-2.90%), Ca (0.74-0.77%) and Mg (0.21%) contents and Ca:P ratios (2.53-2.92) at the early flowering stage were sufficient for the requirements of cattle and sheep (Table 3). P contents (0.25-0.31%) were marginal for young calves but adequate for young growing cattle (Little, 1980). Whether, the opportunity cost of foregoing the benefits of green manure incorporation on maize yield and quality compared to their retention for livestock production warrants further studies which would assist farmer decision making in these integrated crop-livestock systems.

In contrast where Winter field pea was grown for grain (CS 3), significant apparent residual effects of N applied to the preceding maize crop were obtained in both forage DM and N yields in phase 2. This suggests that some applied fertilizer N was carried over from the maize crop. However, it is more likely that this reflected a significant N contribution from the phase 1 cowpea intercrop from both N fixation, as well as breakdown of cowpea root biomass retained in the soil. After grain harvest, the mineral composition of the residual field pea forage and husk that was harvested and removed in CS 3 would have met only the K, Mg, Ca and Ca:P ratio requirements of ruminant livestock (Table 3). P content would only meet the critical value of 0.12% for young growing cattle (Little, 1980) while N content was lower than the 1.8% minimum requirement suggested by Minson *et al*. (1976). However, CP content was adequate for young beef cattle diets and probably would not limit digestibility and voluntary intake (Humphreys, 1991).

Barley: The lower straw yields recorded in the barley-lucerne intercrop (CS 2) compared to sole barley (CS 4) could be attributed to low soil moisture content (Omokanye *et al*., 2011) which probably inhibited N uptake by the intercropped barley. Evidence of lucerne competing for applied N in CS 2 was obvious at both N 40 and 80, as barley straw yield was lower than from CS 4 at both N rates. The straw N yield from CS2 at N80 was similar to that from CS 4 at N 40. As expected, barley straw N content increased with an increase in N rate in both systems in both phases. However, when no fertilizer was applied, barley straw N content from CS 2 was higher than that from CS 4 indicating some N contribution from lucerne in CS2.

Harvested straw had a lower average N content than the critical levels suggested for livestock feed (Minson *et al*., 1976), indicating probable low digestibility and voluntary intake if fed to livestock (Humphreys, 1991) because of lower CP content (generally below 6%). P contents were barely adequate to meet the critical value of 0.12% for young growing cattle and were generally below the requirement of 0.40-0.70% for young calves. On the other hand, the K contents were well above the minimum values for ruminant livestock of 0.5-0.8% (Table 3). Calcium content was below the requirement for adult cattle and young growing calves but adequate for sheep in both phases. Calcium content was lower in CS 4 than in CS 2 in both phases. However, Ca contents in both phases were within the ranges of 0.2-0.82% required by sheep (NRC, 1980). The higher straw Ca level in the barley-lucerne intercrop (CS 2) further confirms the greater availability of Ca in legume systems, even when no fertilizer was applied. This was also reflected in the higher Ca:P ratio in CS 2. However, with the exception of CS 4 in phase 2, the Ca:P ratios of the two systems and all N treatments were above the generally assumed critical ratio of maximum 1-2:1 (Underwood, 1981). Mg contents were sufficient for young calves (NRC, 2001) and sheep (NRC, 1980).

With the exception of P content which was adequate only for young growing cattle, lucerne forage contained adequate amounts of the other elements tested (N, K, Ca and Mg and Ca:P ratio) for satisfactory ruminant animal production.

CONCLUSION

The results of this study have shown that Winter legume incorporation (CS 1) and growing Winter legumes for grain (CS 3) both provided benefits to maize stover productivity and quality. CS 1 was consistently better than CS 3 in this regard.

Even with applied N, maize stover CP content was still below the critical levels required for satisfactory animal nutrition. However, if the maize stover is grazed *in situ* by animals, the presence of lucerne forage in the maize-lucerne intercrop (CS 2) and cowpea residues in the maize-cowpea intercrop (CS 3) would probably allow satisfactory CP intake from those systems, as compared to the cereal-based (CS 4) and cereal-bare fallow (CS 5) systems or where the Winter legume was soil-incorporated as green manure (CS 1). Thus, the combination of a higher N source, such as legume residues with maize stover would be required for adequate nutrition of grazing or housed animals. Maize stover Ca content was consistently higher with legume inclusion in the rotation than in those systems without legumes, even when no N fertilizer was applied.

All cowpea forage mineral element contents, including Ca:P ratios were adequate to meet the nutritional requirements of ruminant livestock. Generally, the mineral element contents recorded for lucerne were adequate for ruminants and in a crop-livestock system, this would offset the deficiencies of some mineral elements in maize stover from the maize-lucerne intercrop (CS 2), thereby reducing farmer costs for mineral supplementation of livestock.

As expected, barley straw N content increased with an increase in N rate in both systems in both phases. However when no fertilizer was applied, barley straw N content from the barley-lucerne intercrop (CS 2) was higher than that from the sole barley (CS 4) crop, indicating some N contribution from the lucerne in CS 2. The higher barley straw Ca content in CS 2 further confirms the greater availability of Ca in legume systems, even when no fertilizer was applied. This was also reflected in the higher Ca:P ratio in CS 2.

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