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Full Length Research Paper

Productivity of maize after strip intercropping with leguminous crops under warm-temperate climate

F. S. Murungu[1]*, C. Chiduza[2] and P. Muchaonyerwa[2]

[1]Department of Agriculture, Faculty of Natural Sciences, Mangosuthu University of Technology, P. O. Box 12363, Jacobs 4026, Durban, South Africa.
[2]Department of Agronomy, Faculty of Science and Agriculture, University of Fort Hare, P. Bag X1314, Alice 5700, South Africa.

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Use of legume cover crops has been reported to improve maize productivity through various mechanisms that include improved soil mineral N supply and weed control. However, in the smallholder irrigation farming sector, where maize is the staple crop, strategies for intercropping summer legume cover crops are often a challenge for farmers. Field experiments were conducted in a warm-temperate region of South Africa during the summer season of 2007/08 and 2008/09 to investigate the effects of strip intercropping patterns (3:2; 4:2 and 6:2 patterns) on the productivity of maize (cv. PAN 6479) together with mucuna or sunnhemp. The strip-intercrop patterns did not result in improved soil mineral N or weed control. Maize yields from rows adjacent to the cover crop strips were significantly ($P < 0.01$) lower than other rows. The 3:2 strip intercropping pattern slightly depressed yields; however, yield reduction was more pronounced in the 1st season where water stress was experienced with maize partial land equivalent ratios (PLER) of 0.55 and 0.98 in the 2007/08 and 2008/09 seasons respectively. A long winter fallow period reduced the positive impact of legume cover crops on soil mineral N and weed control benefits, resulting in no observable yield increase in a subsequent maize crop. Summer legume cover crops may enhance productivity of winter food/cash crops; however, this requires further investigation.

Key words: Maize, mucuna, smallholder farms, strip-intercropping, sunnhemp.

INTRODUCTION

Conservation agriculture (CA) is being promoted as a way of reducing land degradation and foster sustainable crop production in South Africa (SA) (Allwood, 2006). The three components of CA are no tillage, residue retention in the field and crop rotation (Derpsch, 1998; FAO, 2009). Cover crops are planted to ensure a permanent soil cover in CA systems. Smallholder farmers may not necessarily adopt CA technologies to reduce land degradation; other observable benefits may persuade farmers to adopt CA. Conservation agriculture technologies have been reported to result in reduced tillage costs, timely sowing, reduced land degradation, improved weed control and water conservation as well as higher maize (*Zea mays* L.) yields (Teasdale, 1996; Derpsch, 2003; Collins, 2004; Hobbs and Gupta, 2004). Whether these benefits can be realized on smallholder farms in Sub-Saharan Africa is the subject of much debate (Giller et al., 2009). Smallholder irrigation farmers usually use a plant population of 4 plants m^{-2} (Fanadzo et al., 2010).

The low biomass yield of winter cover crops in preliminary trials has caused a shift in attention to summer cover crops (Derpsch, 2003). Summer cover crops may be desirable for their reduced irrigation costs since they are grown during the rainy season. Costs could also be reduced by considering intercropping as a strategy to incorporate cover crops. Added to this, most of the 250 000 smallholder irrigators in SA do not grow

*Corresponding author. E-mail: farayi@mut.ac.za. Tel: +27 31 907 7673. Fax: +27 86 558 5673.

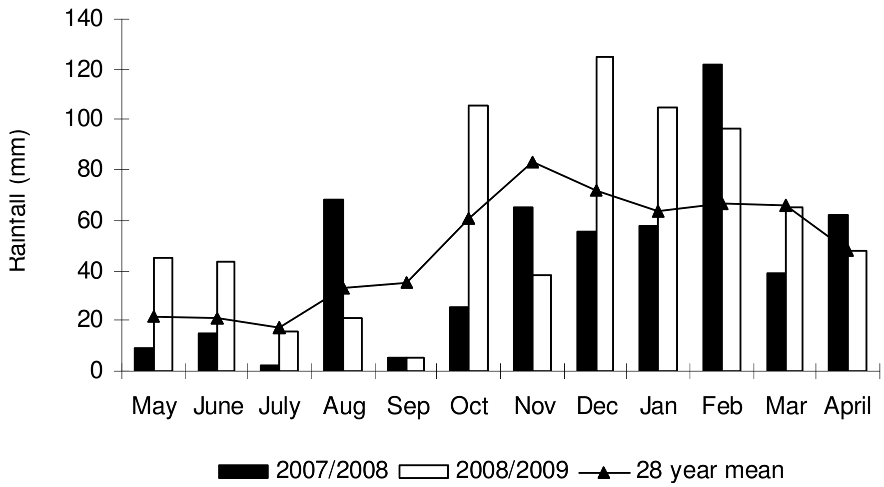

Figure 1. Monthly rainfalls at the UFH Research Farm in the 2007/08 and 2008/09 seasons as well as the 28-year mean rainfall.

winter crops or cover crops because of infrastructural deficiencies, poor management structure, and lack of financial resources (Bembridge, 2000; Fanadzo et al., 2010). Strip intercropping has been shown to be more effective in reducing competition among intercrop species (Ghaffazadeh et al., 1994). However, smallholder farmers are often not willing to sacrifice the yield of the main crop in strip-intercropping systems. The seeding rates for the main crop are normally maintained while the seeding rates for the companion crop may vary (Kankanen and Eriksson, 2007).

Information on strip intercropping of maize and cover crops is not readily available; most research has focused on strip intercropping food crops. Some research has focused on strip intercropping of maize and forage legumes. Smith and Carter (1998) reported that four-meter strips of four maize rows had the greatest maize yields, while there was a progressive decline in maize yields for the 6 and 12-m strips of maize and lucerne (*Medicago sativa* L.). Strip intercrops are usually named after the numbers of rows of component crops in the strips that are alternated. For example, in a 3:2 pattern, one crop consists of three rows, and the other crop consists of two rows. Other systems may include 3:1, 4:2 or a 6:2 pattern. In addition to the differences in number of rows per strip of the two crops, there may be slight differences in row distance (Smith and Carter, 1998). Differences in crop ratios and row distances will modify the competitive relationships and the ability of the crops to capture and utilize resources. Shifting the positions of cover crop strips in subsequent seasons may allow some maize rows to be planted on previous cover crop residues. This may bring a rotation effect in systems where crop rotations do not exist.

The type of legume species grown affects intercrop performance, while a weed-free field optimizes maize/forage legume intercrop productivity (Alford et al., 2003). Not much information is available on the most appropriate cover crop species to be grown. Low soil N and heavy weed infestation are major factors depressing yields on smallholder farms. Legume cover crops have been reported to improve soil N and making substantial nutrient contributions to maize growth (Giller, 2001; Kaizzi et al., 2006). Jeranyama et al. (2000) showed that intercropping maize with sunnhemp (*Crotalaria juncea* L.) or cowpea (*Vigna unguiculata* L.) does not provide sufficient N, and small amounts of inorganic fertilizers are required for a maize succeeding crop. Mucuna (*Mucuna pruriens* L.) is known to produce a lot of biomass and has weed suppression efficacy (Chikoye et al., 2000; Derpsch, 2003).

The objectives of this study were: (i) to determine the effect of strip intercropping patterns on maize yield, cover crop biomass yields and soil mineral N, (ii) to determine effects of shifting position of strips in a subsequent season on maize yields and weed control from different row positions in the system. It was hypothesised that maize rows growing on previous cover crop strips benefit from a higher mineral N and weed control thereby increasing productivity of the system.

MATERIALS AND METHODS

Site description

Field experiments were conducted at the University of Fort Hare (UFH) Research Farm, South Africa (32°46'S, 26°50'E). The experiment was established on 23 December 2007 and on 2 December 2008 in the 2007/08 and 2008/09 seasons respectively. The site has a warm-temperate climate, mean altitude of 535 m above sea level (m.a.s.l), and mean annual rainfall of about 575 mm (Figure 1). The soil is of alluvial parent materials and is dominated by micas in the clay fraction, with low amounts of quartz and kaolinite. The soil has 64.2% sand, 16.0% silt and 19.8% clay; pH 6.1, 0.35 g P kg^{-1}, 4.04 g K kg^{-1}, 4.25 g Ca kg^{-1} (Mandiringana et al., 2005).

Experimental design and management

Maize (cv. PAN 6479) was strip intercropped with either mucuna or sunnhemp accessions. Planting patterns included (i) three maize rows and two cover crop rows (3:2 pattern), the sequence was repeated four times in each plot, (ii) four maize rows and two cover crop rows (4:2 pattern), sequence repeated three times in each plot and, (iii) six rows maize and two cover crop rows (6:2 pattern), sequence repeated two times in each plot. Control plots with sole crops of maize, mucuna and sunnhemp were also included. The cover crop species and intercropping patterns gave a 2 × 3 factorial plus controls laid as a randomised complete block design with three replicates. The gross plot was 10.4 × 6 m in size for all treatments. Sole maize plots had an inter-row spacing of 0.8 m and an in-row spacing of 0.31 m. In sole plots, both sunnhemp and mucuna were planted at 50 kg seed ha^{-1}, row spacing was 0.30 m. For cover crops in intercrop plots, seed density for a single row was the same as in the sole crop rows. Maize in both sole and intercrop was planted at a density of 40 000 plants ha^{-1}, in-row spacing was adjusted to achieve this density in intercrop plots. Ploughing was done in the first season only.

In the second season, position of cover crop strips was shifted, allowing some maize rows to be planted where there were cover crop strips in the previous season. Manually operated seed drilling equipment, 'matraca planters' (Farmarama, East London, SA), dropped maize seed and the required fertilizer separately at a soil depth of 4 to 5 cm. Maize fertiliser was applied at 60 kg N ha^{-1} a third of the N was applied at planting as a compound (6.7% N; 10% P; 13.3% K) and the rest as lime ammonium nitrate (LAN) (28% N) at 6 weeks after planting. Fertilizer rate mimicked farmer practice. Mucuna and sunnhemp in both sole and intercrop plots received 7 kg N ha^{-1}, 10 kg P ha^{-1} and 13 kg K ha^{-1}, applied using the same compound as earlier stated. Fertilizer rates for cover crops in intercrop were the same as for rows in the sole crops. Supplementary irrigation was applied through sprinkler irrigation based on Class A evaporation pan readings.

Weed control was done once by hand hoeing at 10 weeks in the 2007/08 season. However, in the 2008/09 season, basagran (a.i: thiadiazine 480 g L^{-1}) was applied by a knapsack sprayer at 5 L ha^{-1} at six weeks after planting to control weeds in all plots except the legume sole plots and legume strips. Control of maize stalk borer (*Busseola fusca*) was done by applying Bulldock (a.i: beta-cyfluthrin 50 g L^{-1}). All cover crops were terminated at maize harvesting. This was done by rolling the maize and cover crop and applying glyphosate at a rate of 5 L ha^{-1}.

Measurements

Maize shoot dry weights were determined at 69 days after sowing (DAS) in the first season and at 88 DAS in the second season by oven drying to a constant weight at 65°C. In the first season, maize plants were sampled separately from rows in the middle of each strip and from rows adjacent to the cover crop strips. In the second season, maize growing on previous cover crop strips was sampled separately from rows in the middle of each strip and from rows adjacent to the cover crop strips. At harvesting, the net plots were from previously undisturbed sequences in each plot. Rows of maize grown on previous cover crop strips, middle rows not growing on previous cover crop strips and maize rows adjacent to the current strips were harvested separately. Each row had an area of 0.8 × 5 m. For maize in sole plots, the net plot area was from rows 5 and 6 giving an area of 1.6 × 5 m. Maize grain yield (g $plant^{-1}$ and kg ha^{-1}) and yield components (grains $head^{-1}$ and 1000-seed weight) were also measured.

Cover crop shoot dry weights were determined on the same days as the maize sampling by cutting a row length of 0.35 m of cover crop biomass. Cover crop carbon and N concentration were determined using the LECO C/N analyser (LECO Corporation, 2003) in the 2008/09 season only. Nitrogen uptake was calculated as the product of nutrient concentration and biomass of above-ground parts of the crops. Weeds were sampled destructively from maize rows adjacent to cover crops, maize rows in the middle of the strip and maize rows in previous cover crop strips, using 35 × 35 cm quadrants and dry weight determined. In the second season, soil inorganic nitrogen was determined by extraction with 0.5 M K_2SO_4 (1:4, soil: solution) and analyzed spectrophotometrically as described by Okalebo et al. (2002) from the 0 to 20 cm depth. The sum of ammonium-N and nitrate-N is referred to as total mineral N. Soil samples were taken a week before maize planting. In each plot, samples were taken separately on rows which had cover crops and maize in the previous season.

Data analyses

The aggressivity (A_{ab}) concept was employed to evaluate aggressiveness of species 'a' and 'b' in intercrop, relative to their respective sole cropping yields (Willey and Rao, 1980; Li et al., 2001):

$$A_{ab} = \frac{Y_{ia}}{Y_{sa}F_a} - \frac{Y_{ib}}{Y_{sb}F_b} \tag{1}$$

Where Y_{ia} and Y_{ib} are yields of crops 'a' and 'b' in intercropping, Y_{sa} and Y_{sb} are yields of crops 'a' and 'b' in sole cropping, F_a and F_b are the proportion of the area occupied by crops 'a' and 'b' in the intercropping. When A_{ab} is greater than 0, competitive ability of crop 'a' exceeds that of crop 'b' in intercropping. In this study, cover crops were terminated with no seed being harvested, so biomass weight was used to calculate aggressivity. Partial land equivalent ratios (PLER) were calculated using the equation:

PLER = Yij/Yii,

where Yij represented maize grain yields in intercrop and Yii represented maize grain yields in sole crop (Ofori and Stern, 1987). Treatment differences for measured variables were tested across seasons by analysis of variance (ANOVA). Inclusion of controls in the experiment resulted in an unbalanced design. Therefore, to include data analysis of controls (sole crops) in the ANOVA, an extra factor (cropping system) was added and cover crop species × intercropping pattern were nested within cropping system (Cochran and Cox, 1957; Genstat, 2007; Murungu et al., 2011). Maize cobs from different row positions were harvested on a row basis and analysed on a plant basis (g $plant^{-1}$). Row position was included as an extra factor in the analysis. Total maize dry weight and grain yield on a per hectare basis (kg ha^{-1}) was subsequently determined and analyzed. Where row position was added as a factor, ANOVA was done separately for each season because of the unbalanced nature of the data. This was necessitated by the unequal row numbers. Means and standard errors of the difference (S.E.D.) are presented with appropriate degrees of freedom (D.F.). The Genstat Statistical Package Release 7.1 was used for the analysis.

Table 1. Season, strip intercropping patterns and cover crop species effects on maize grain 1000-seed weights (g) in the 2007/08 and 2008/09 seasons.

Crop species	Sole crops (controls)	3:2 pattern	4:2 pattern	6:2 pattern
		1000-seed weight (g)		
2007/08 season				
Mucuna		245.9	246.7	254.6
Sunnhemp		207.3	246.7	234.1
Sole crop	257.4			
2008/09 season				
Mucuna		377.4	424.9	324.8
Sunnhemp		376.8	380.7	383.5
Sole crop	372.9			
S.E.D. (26 D.F.)*		59.11		

*Standard error of differences.

Table 2. Effects of row position across strip intercrop patterns with sunnhemp and mucuna on maize yield (g/plant) in the 2007/08 and 2008/09 seasons.

Row position	Maize yield (g/plant)	
	2007/08 Season	2008/09 Season
Maize rows on previous cover crop rows		176.9
Middle rows	76.0	162.8
Maize rows adjacent to cover crop species	69.7	145.5
S.E.D. (34 D.F.)*	ns	8.3

ns: Not significant (P > 0.05). *Standard error of differences to compare maize yield (g/plant) in the 2008/09 seasons.

RESULTS

Rainfall and irrigation

A total of 376.4 and 454.4 mm were received through rain and irrigation during crop growth in the 2007/08 season and 2008/09 seasons respectively (Figure 1). Failure of irrigation equipment resulted in a period of moisture stress during the critical flowering and early grain filling periods in the first season.

Maize yield and yield components

The 2007/08 season had much lower 1000-seed weights compared to the 2008/09 season. However, strip intercropping maize with sunnhemp in the 3:2 pattern, reduced 1000-seed weights in the 2007/08 season while there were no significant differences in the 2008/09 season across the different strip-intercrop patterns (Table 1). The second season had a significantly ($P < 0.01$) higher number of grains/cob than the first season with 353.3 and 520.6 grains cob^{-1} for the first and second seasons, respectively. Row position had no significant ($P > 0.05$) effect on the number of grains cob^{-1} in both seasons. With respect to yield (g plant^{-1}), intercropping pattern, cover crop species and row position did not significantly ($P > 0.05$) affect the yield of individual plants in the first season. However, in the second season, maize plants adjacent to cover crop strips had significantly ($P < 0.01$) lower grain yield (g) plant^{-1} compared to the other row positions. Maize rows, planted on previous cover crops rows had a similar yield as the maize grown on rows that were not planted to cover crops the previous season (Table 2).

With respect to final yield (kg ha^{-1}), there was a significant ($P < 0.05$) season × intercropping pattern interaction. The second season had higher yields than the first. The 3:2 pattern resulted in lower yields in both seasons compared to the other cropping patterns. However, the differences in yield between the 3:2 pattern and the other cropping patterns were much greater in the 2007/08 season (Table 3). While PLER was similar across strip intercropping patterns in the 2008/09 season, the 3:2 pattern resulted in significantly lower maize PLER in the 2007/08 season (Table 4). Cover crop species was

Table 3. Effects of season and strip intercropping patterns on maize yield (t/ha) in the 2007/08 and 2008/09 seasons.

Season	Sole crops (Controls)	3:2 pattern	4:2 pattern	6:2 pattern
		Maize yield (t/ha)		
2007/08 season	4.8	2.6	4.9	4.1
2008/09 season	7.0	6.9	7.9	7.3
Standard error				
S.E.D.$_a$ (28 D.F.)		0.8		
S.E.D.$_b$ (28 D.F.)		0.7		
S.E.D.$_c$ (28 D.F.)		0.6		

S.E.D.$_a$: Standard error of differences for sole plot to sole plot comparisons only, minimum replications; S.E.D.$_b$: standard error of differences for comparisons of sole plot yields with other treatments, controls vs. strip-intercrop yields; and S.E.D.$_c$: standard error of differences for treatment comparisons only, for comparing strip-intercrop plots only.

Table 4. Effects of season and strip intercropping patterns on maize partial land equivalent ratios (PLER) in the 2007/08 and 2008/09 seasons.

Season	3:2 pattern	4:2 pattern	6:2 pattern
	Partial land equivalent ratios (PLER)		
2007/08 season	0.55	1.02	0.85
2008/09 season	0.98	1.13	1.04
Standard error			
S.E.D. (20 D.F.)*		0.09	

*Standard error of differences to compare PLER between the different strip-intercropping patterns in across both seasons.

the only factor that significantly ($P < 0.05$) affected agressivity, with sunnhemp ($A_{ab} = -0.18$) being more aggressive than maize, while maize was more aggressive than mucuna ($A_{ab} = 0.13$).

Cover crop shoot dry weight, N uptake and soil mineral N

Cover crop dry weight was highest in sole crops while dry weight for strip-intercropped cover crops was less than 4.5 t ha^{-1} except for sunnhemp in the 3:2 pattern (Figure 2). Nitrogen concentration was significantly ($P < 0.01$) higher in mucuna (4.9%) compared to sunnhemp (2.6%). The C:N ratio was lower for mucuna (9.1) compared to sunnhemp (16.2). However, sunnhemp had a significantly higher N uptake than mucuna, differences in N uptake were much greater for sole cropping and the 3:2 pattern compared to the 4:2 and 6:2 pattern (Table 5). In the second season, all cropping patterns had similar soil mineral N levels at planting, with a mean of 48 mg N kg^{-1} except for sole sunnhemp plots, which had 82 mg N kg^{-1}. There were no significant ($P > 0.05$) differences in soil mineral N for rows previously planted to maize or cover crops.

Maize and weed dry weights

In the 2007/08 season, maize rows adjacent to sunnhemp strips produced significantly lower dry weights compared to maize rows adjacent to mucuna strips (Figure 3). In the 2008/09 season, maize rows growing on previous cover crop strips had similar dry weights to maize grown where there were no cover crop strips in the first season (Figure 3B). With respect to maize dry weight per hectare, the 2007/08 season had significantly ($P < 0.05$) lower maize dry weights (6.8 t ha^{-1}) compared to the 2008/09 season (8.4 t ha^{-1}). The 3:2 and 4:2 patterns resulted in significantly ($P < 0.05$) lower maize dry weights per hectare compared to the 6:2 pattern and the control (Table 6).

Weed biomass (t ha^{-1}) was similar between the two seasons. Weed biomass was also similar across the strip

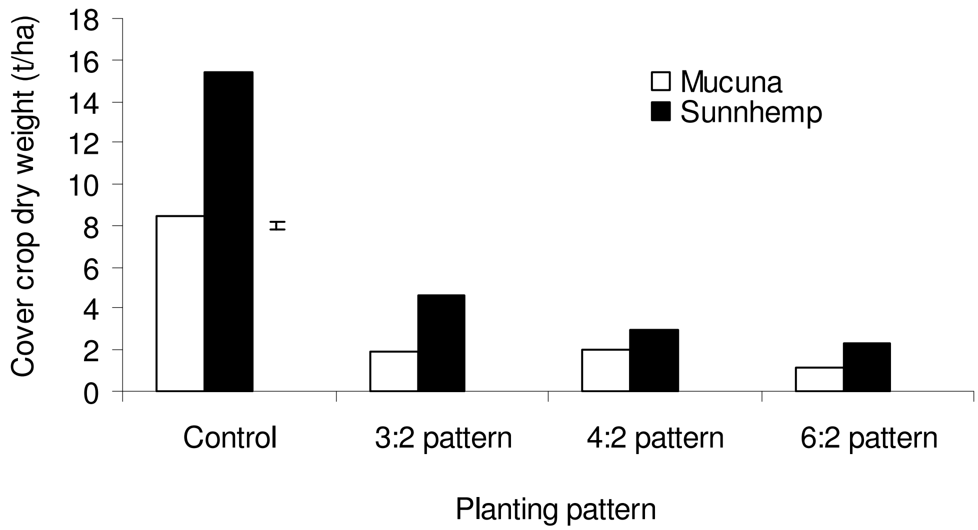

Figure 2. Effects of strip intercropping patterns on mucuna and sunnhemp dry weights, means across the two seasons. Error bar represents the standard error of differences (28 D.F.).

Table 5. Effects of strip intercropping patterns and cover crop species (mucuna and sunnhemp) on N uptake (kg N/ha) in the 2008/09 season.

Cover crop species	Control	3:2 pattern	4:2 pattern	6:2 pattern
	N uptake (kg/ha)			
Mucuna	441.8	92.5	63.4	48
Sunnhemp	401.1	131.3	71.5	57.1
Standard error				
S.E.D. (14 D.F.)*		13.1		

*Standard error of differences to compare N uptake between the different strip-intercropping patterns in across both cover crops.

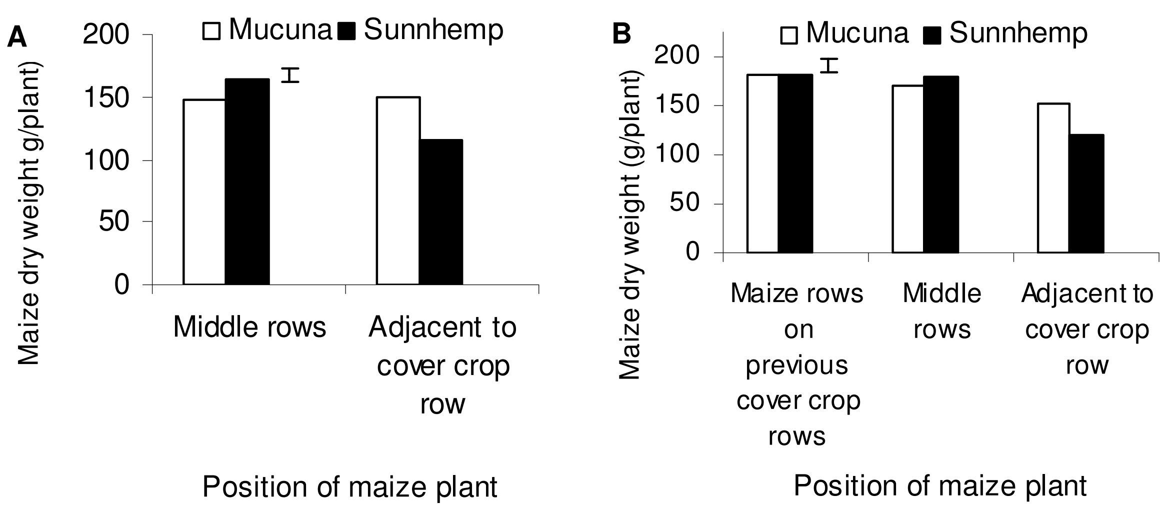

Figure 3. Effects of cover crop species and row position on maize dry weight (g/plant) in the 2007/08 (A, 22 D.F.) and 2008/09 (B, 34 D.F.) seasons. Error bars represent the standard error of differences.

Table 6. Strip intercropping pattern effects on maize dry weights (t/ha), means across the 2007/08 and the 2008/09 seasons are presented.

Standard error	Control	3:2 Pattern	4:2 pattern	6:2 pattern
	Maize dry weight (t/ha)			
	8.4	**7.0**	**7.3**	**8.1**
S.E.D.$_a$ (24 D.F.)		0.4		
S.E.D.$_b$ (24 D.F.)		0.3		

S.E.D.$_a$: Standard error of differences for comparisons of sole plot yield with other treatments, control vs. strip-intercrop yields; and S.E.D.$_b$: standard error of differences for treatment comparisons only, for comparing strip-intercrop plots only.

Table 7. Effects of strip intercropping pattern and cover crops species on weed dry weights (t/ha) means across the 2007/08 and 208/09 seasons are presented.

Cover crop species	3:2 pattern	4:2 pattern	6:2 pattern	Control
	Weed dry weights (t/ha)			
Mucuna	3.5	3.5	3.6	3.0
Sunnhemp	4.1	3.9	3.3	1.1
Standard error				
S.E.D.$_a$ (28 D.F.)		0.8		
S.E.D.$_b$ (28 D.F.)		0.7		
S.E.D.$_c$ (28 D.F.)		0.4		

S.E.D.$_a$: Standard error of differences for sole plot to sole plot comparisons only, minimum replications; S.E.D.$_b$: standard error of differences for comparisons of sole plot weed dry weights with other treatments, controls vs. strip-intercrop yields; and S.E.D.$_c$: standard error of differences for treatment comparisons only, for comparing strip-intercrop plots only.

intercropping patterns irrespective of cover crop species. However, the sunnhemp sole crop had significantly ($P < 0.05$) lower weed biomass compared to the other plots (Table 7). In the second season, there were no significant ($P > 0.05$) differences in weed dry weights for strips previously planted to maize or cover crops in the first year.

DISCUSSION

The lower maize yields in the first season compared to the second season may be explained by water deficits experienced during critical periods such as the flowering and grain filling in the first season. Late weed control in the first season compared to the second season could also explain the yield differences between the two seasons. The yield reduction in the 3:2 pattern was much greater in the relatively drier 2007/08 season. Increased competition from cover crops may have reduced maize productivity (lower 1000 seed weights, final yield and PLER) in the 3:2 pattern. Zegada-Lizarazu et al. (2006) showed that under limited water environments, competition for soil water between intercropped plants may be strong thereby reducing the overall performance of the intercrop system. In the absence of water stress, the 3:2 pattern would maximise sunnhemp biomass production without negatively affecting maize yields as shown by a high maize PLER (0.98) in the second season. Farmers are often not willing to compromise yield of the staple crop, when cover crops are strip intercropped with maize. Sunnhemp was more aggressive than maize in this study, if equal proportions of land area had been used for sunnhemp and maize in the intercrop, maize yields may have been drastically reduced.

The lack of difference in soil mineral N between rows which were previously planted to maize or the legume cover crops could be the result of land being left fallow during winter, as practiced in most smallholder irrigation farms (Fanadzo et al., 2010). A fallow of 5 to 6 months could have allowed enough time for the legume cover crops to decompose and release nutrients and allowed weeds to grow, which may have taken up nutrients, compromising the efficiency of the system with respect to nutrient contributions to the next maize crop. Nutrient release from decaying plant materials must be synchronized with nutrient uptake by a follow-up crop. Rain received (255 mm) during the fallow period may also leach nutrients such as N. The lack of better productivity (maize dry weight, yield and yield components) for maize growing on previous cover crop rows than on other maize rows, may be explained by similar inorganic N levels in these rows. Growing summer legume cover crops with view of planting winter food/cash crops may offer better prospects for optimizing nutrient release and uptake by crops in smallholder cropping systems. However, more research on this may be required. From the results of this study, strip-intercropping cover crops with maize may not increase maize productivity or reduce the N fertilizer requirements of the next maize crop.

The significantly higher soil mineral N in sole plots grown to sunnhemp may be explained by the higher biomass yields and overall N uptake from sunnhemp compared to the other plots. This may benefit winter cash/food crops that may be planted on decaying sunnhemp residues resulting in improved productivity. Legume cover crops have been reported to improve soil N levels, with substantial nutrient contributions to maize growth in Nigeria and Tanzania (Kalumuna et al., 2001; Ibewiro et al., 2004). In these farming systems, the rainfall pattern is bimodal, having a shorter rain season followed by a longer rain season. Fast growing cover crops are usually planted in the short season with maize being planted immediately on arrival of the long season. This may explain why in these systems, summer cover crops contribute substantially to maize growth since the period from cover crop termination to maize planting is much shorter. In situations with a unimodal rainfall pattern, like in the present study, growing winter cash crops under irrigation may maximise nutrient uptake by crops from decomposing summer grown cover crops.

Higher biomass yields by the sole crops compared to the strip-intercropped cover crops may largely be explained by the much higher cover crop density per unit area in the sole crops. The higher cover crop density for the 3:2 pattern also explains the higher biomass yield compared with the 4:2 and 6:2 patterns. Comparisons in cover crop biomass yield were made on total cover crop biomass produced in the whole plot, regardless of the strip-intercrop pattern to mimic the actual biomass yields that would be realised if each system was used by farmers. However, when biomass yields were compared on equal area basis across strip-intercrop patterns, cover crop species was the only factor affecting final biomass yields. The low biomass yields obtained by the 6:2 pattern (< 2 t ha^{-1}) may not make any meaningful contribution to the overall performance of the system.

Sunnhemp lowered the dry weights of maize growing adjacent to it much more than mucuna. This may be explained by the more vigorous growth of sunnhemp compared to mucuna. Sunnhemp was better at competing for growth resources than mucuna. The much lower maize dry weights per unit area for the 3:2 may be explained by the increased cover crop strips per unit area, which may have increased competition for resources compared to the other strip patterns. Strip intercropping maize with mucuna or sunnhemp did not lower weed dry weight, while the sunnhemp sole crop reduced weed dry weights. The aggressive nature and fast growing ability of sunnhemp explains this. Reduced sunnhemp density in strip intercrops may also explain why sunnhemp was unable to reduce weed growth in strip intercrop systems. Mucuna was not as vigorous as in other studies, since mucuna is known to out-compete weeds and can drastically reduce maize yields when grown in association with maize (Udensi et al., 1999; Caamal-Maldonado et al., 2001).

Conclusions

Sunnhemp produces more dry weight than mucuna especially, when planted as a sole crop or when strip intercropped with maize in the 3:2 pattern compared to the 4:2 and 6:2 patterns. However, strip intercropping maize with these summer cover crops does not improve soil mineral N levels or maize yield in a system where there is a long winter fallow period. Legume strips failed to improve soil mineral N in the following summer season. Growing winter food/cash crops after a summer legume cover crop may offer better prospects for optimizing nutrient release and uptake by crops in smallholder cropping systems.

However, more research on this may be required in the future. Maize productivity was not reduced by strip intercropping with sunnhemp or mucuna using the 3:2; 4:2 or the 6:2 patterns. Shifting maize rows in a subsequent season, so that maize grew on previous cover crop rows, did not improve maize productivity.

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