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Effect of different maize (Zea mays L.) – soybean (Glycine max (L.) Merrill) intercropping patterns on yields, light interception and leaf area index in Embu West and Tigania East sub counties Abstract

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Field trials were conducted at the field units of the Embu Agricultural Training Center and Kamujine Dispensary in Embu and Meru Counties, Kenya, during 2012 long rain (LR) and short rain (SR) seasons to determine the effects of different maize-soybean intercropping patterns on yields, light interception and leaf area index. The main treatments were four maize – soybean intercropping patterns (convencional-1maize:1soya; MBILI-2maize:2soya; 2maize:4soya; 2maize:6soya) and two sole crops of maize and soybean, respectively. The experimental design was a randomized complete block design with four replications, and plot size of 7.0 m by 4.5 m. The results showed that the maize-soybean intercropping patterns had significant effect on maize stover and grain yields during both seasons and sites. The MBILI treatment recorded significantly higher stover and grain yields than all other treatments. During the long rain 2012, the soybean yields were reduced by 60 and 81% due to the intercropping with maize, at Embu and Kamujine, respectively; whereas during the 2012 SR, the yields were reduced by 52 and 78% as effect of intercropping with maize at Embu and Kamujine sites, respectively. The intercropping patterns affected significantly ($p<0.0001$) the photosynthetically active radiation intercepted and the leaf area index at both sites. From the results of this study, the use of MBILI maize-soybean intercropping pattern can be recommended to the farmers of central highlands of Kenya because it gave efficient resources use and higher yields.

Key words: Intercropping patterns, maize-soybean, leaf area index (LAI), photosynthetically active radiation (PAR), central highlands, Kenya

INTRODUCTION

In intercropping system there is one main crop cultivated with one or more added crops where the main crop is of primary importance due to economic or food production reasons (Brintha and Seran, 2009). In the SSA region, cereal and grain legumes intercrop is the most practiced by smallholder farmers (Odendo, Bationo and Kimani, 2011; Sanginga and Woomer, 2009). The major reason why these farmers intercrop cereals and grain legumes is because they are particularly important human food as they are rich in protein and are sometimes sold for cash income (Odendo, Bationo and Kimani, 2011). In addition, intercrops give them the stability of the yields over several seasons (Ofori and Stern, 1987; Steiner, 1982), when one crop fails, the other might still give a reasonable yield (Prasad and Brook, 2005; Beets, 1982; Steiner, 1982). Furthermore, grain legumes help maintain and improve soil fertility due to their ability to biologically fix atmospheric nitrogen (Sanginga and Woomer, 2009; Jarenyama *et al.,* 2000). Despite that, the intercropping of cereal-legume may lead to reduction in yield of the legume component because of the adverse competitive effects (Willey *et al*., 1983).

Often, the cereal component with relatively higher growth rate, height advantage and a more extensive rooting system is favored in the competition with the associated legume crop. Thus, the greater yield loss of the minor crop is mainly due to reduced photosynthetically active radiation (PAR) reaching the lower parts of the intercrop canopy, occupied by the minor legume (Liu *et al*., 2010). The intensity and the quality of solar radiation intercepted by the canopy are important determinants of yield components and therefore yield of soybean since it is sensitive to shading (Liu *et al*., 2010; Purcell, 2000). Light levels during the late flowering to mid pod formation stages of growth have been found to be more critical than during vegetative and late reproductive periods (Liu *et al*., 2010; Schou, Jeffers and Streeter, 1978).

Therefore, any interventions that lead to increased amount of PAR interception by the minor crop have potential to increase the yield of the minor crop and increase productivity of the intercropping system (Mashingaidze, 2004). For instance, Woomer and Tungani (2003) reported that MBILI system had resulted in 20 percent more light penetration to the minor legume component when compared to the conventional intercropping pattern.Ennin, Clegg and Francis (2002) found that per cent PAR intercepted by intercrops was 4 percent greater in closer row arrangements of soybean and maize than in equally spaced 2 rows soybean: 2 rows maize. Reddy, Floyd and Willey (1980) reported that millet-groundnut intercrop system was 28 percent more efficient in light use than their monocrops, which was attributed to approximately 30 percent greater LAI of the intercrop than the sole crops. Leaf area index of a canopy is important for predicting crop growth and yields (Xinyou *et al*., 2003). A reasonable LAI is critical to maintain high photosynthetic rates and the yield (Xiaolei and Zhifeng, 2002). If the index is too low, not enough light will be absorbed and if too high, lower leaves will not receive enough light and will thus be a liability (Brintha and Seran, 2009).

On the other hand, intercropping can lead to reduction in yield of one or more of component crops due to adverse competitive effects (Willey and Rao, 1980). A review by Ofori and Stern (1987), of 40 published papers showed that the yield of the legume component declined on average by about 52 percent of the sole crop yield whereas the cereal yield was reduced by only 11 percent. The general observations from this are that yields of the legume components are significantly depressed by cereal components in intercropping, which is attributed to reduced photosynthetically active radiation (PAR) that reaches the lower parts of the maize canopy occupied by the soybean crop.

We investigated the effects of different maize-soybean intercropping patterns on yields, light interception and leaf area index. The hypotheses tested were: (i) the MBILI intercropping pattern gives significantly higher yields than conventional intercropping pattern. (ii) the 2:6 intercropping pattern of maize-soybean is more efficient in light use and gives higher leaf area index than conventional (1M:1S) intercropping pattern.

MATERIALS AND METHODS

Study area

The experiment was carried out in two sub counties of central highlands of Kenya, namely Embu West and Tigania East sub counties.

Embu West Sub County

Embu West District is located in Embu County, in the central highlands of Kenya, and occupies an area of 708 Km^2 and is bordered by Mbeere district to the East and South East, Kirinyaga to the West and Meru South to the North. The experimental site lies within N 0°31´ 4.2´´ E 37^0 27´ 20´´ and at the altitude of 1468 m above the sea level (ASL), at Embu Agricultural Staff Training College. The major agro-ecological zone (AEZ) is Upper Midland 2 (UM 2). The soils are mainly humic Nitisols and the total arable land area is 478 Km^2 with total available agricultural land area covering 371 Km^2. The average annual rainfall varies from 909 to 1230 mm with long rainy season between March and June and short rainy season between October and December, respectively (Jaetzold *et al*., 2006).

Tigania East Sub County

Tigania East Sub County is located in Meru County, in

Table 1: Treatments in the two sites (ATC-Embu and Kamujine)

Treatment	Cropping system	Treatment	Cropping system
T1	Sole maize	T4	Maize-Soybean (2:2)
T2	Sole soybean	T5	Maize-Soybean (2:4)
T3	Maize-Soybean (1:1)	T6	Maize-Soybean (2:6)

the central highlands of Kenya and it occupies 108.6 km^2. The experimental site lies within N 0° 6´ 19.5´´ E 037°64´ 39.6´´ and at the altitude of 935 m above the sea level (ASL), at Kamujine Dispensary in Mikinduri Division. The major agro-ecological zones are Lower Midlands 3 and Upper Midland 3 (LM 3 and UM 3), the soils are mainly eutric Nitisols and humic Cambisols. The annual average temperature varies from 19.2 °C to 22.9 °C.The average annual rainfall varies from 1000 to 2200 mm with long rainy season between March and June and short rainy season between October and December, respectively (Jaetzold*et al.*, 2006).

Experiment design and treatments

The experiment in this study was established in Embu-ATC (Embu West district) and in Kamujine (Tigania East district) in March 2012 and it was laid out as a randomized complete block design (RCBD). There were four replicate blocks and plot sizes measuring 7 m x 4.5 m The cropping system was of sole maize (*Zea mays* L.), sole soybean (*Glycine max* (L.) Merrill) and maize (M) – soybean (S) intercropping with cropping patterns (Table 1).

Management of the experiment

The fields were ploughed using hand hoe and left as such for two weeks. Plots measuring 7.0 x 4.5 m were marked just before planting. Pathways measuring 3.0 m and 2.0 m were left between the blocks and plots, respectively. At Embu-ATC, planting was done on the 23rd of March and 12th of October 2012 for the 1st and 2nd seasons, respectively. At Kamujine, planting was done on the 26th of March and 15th of October 2012 for the 1st and 2nd seasons, respectively. The sole maize (*Zea mays* L.) var. DK 8031 was planted at a spacing of 0.75 m 0.50 m inter and intra-row, respectively. The number of hills per row was 10 with three seeds per hill in order to ensure maximum plant population and to account for germination failure; and two weeks after germination the excess plants were thinned out to remain with two plants per hill. The sole soybean (*Glycine max* (L.) Merrill) var. Gazelle was hand drilled at a spacing of 0.45 m × 0.10 m in inter and intra – row spacing resulting to 62 plants per row to ensure maximum germination/population and the excess plants were thinned out to remain with the recommended population of 31 plants per row after 2 weeks of emergence. The following external nutrient replenishment inputs were applied per plot: 6kg of manure equivalent to 30 kg N ha^{-1}, applied two weeks before planting; 94.5 grams of CAN as source of N, equivalent to 30 kg N ha^{-1}, for soybean the Nitrogen (starter N) was applied at sowing while for maize it was applied when the crop had six leaves, as topdressing; 189 grams of TSP as source of P, equivalent to 60 kg P ha^{-1}, which was applied at sowing. The fertilizers were applied accordingly to the recommendation. Management practices were the same for both the monocrop and the maize – soybean intercrop.

Maize and soybean harvest and yields

Maize and soybean grain and stover was harvested at maturity from a net area of each treatment demarcated after leaving out two rows on each side of the plot and the first two and the last two maize/soybean plants on each row to minimize the edge effect. The entire plants on the plots was harvested by cutting at the ground level and weighted to represent the total fresh weight. Maize/Soybean cobs/pods were manually separated from the stover, sun-dried, and packed in sacks before threshing. After threshing, moisture content of the grains was determined using a moisture meter and grain yield adjusted to 12 percent moisture content using the following formula. Similarly, the yields were calculated using the following formulas.

$$Adjusted\ yield = measured\ yield * \frac{(100 - sample\ moisture\ content)}{(100 - s\tan dard\ moisture\ content)} \quad (1)$$

$$Yield\ (t/ha) = 10 * \frac{Dry\ weight\ (kg/m^2)}{Net\ area\ (m^2)} \quad (2)$$

Table 2: Effect of intercropping pattern on maize yields (grain and stover yields) during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Treatment	Stover yield (t/ha)		Grain yield (t/ha)	
		2012 LR	2013 SR	2012 LR	2013 SR
Embu	Sole maize	11.73	8.14	4.95	4.58
	Maize-Soybean (1M:1S)	12.64	7.74	5.49	5.16
	Maize-Soybean (2M:2S)	13.12	7.62	6.11	5.62
	Maize-Soybean (2M:4S)	8.89	4.91	4.05	3.48
	Maize-Soybean (2M:6S)	5.26	4.45	2.74	3.16
p-value		0.0001***	<0.0001***	<0.0001***	0.0467*
$LSD_{(0.05)}$		2.59	1.31	0.87	1.79
Kamujine	Sole maize	3.81	6.00	3.36	2.98
	Maize-Soybean (1M:1S)	3.87	6.34	3.09	3.44
	Maize-Soybean (2M:2S)	2.95	6.55	3.07	3.55
	Maize-Soybean (2M:4S)	2.59	4.83	2.47	2.86
	Maize-Soybean (2M:6S)	1.90	3.97	1.9	1.82
p-value		0.0461*	0.0005***	0.0704ns	0.0006***
$LSD_{(0.05)}$		1.43	1.00	1.07	0.64

ns – not significant; *significant at $p \leq 0.05$; **significant at $p < 0.01$; ***significant at $p < 0.001$.

Determination of light interception and leaf area index

Radiation interception of photosynthetically active radiation was measured in both the sole crop and the different intercropping patterns using a Sunfleck Ceptometer. The measurements were taken between 11.30 am and 01:30 pm (local time) at an interval of fourteen days. The PAR intercepted was then calculated according to Goudriaan (1988) as follows;

$$\%\,PAR\ intercepted = \frac{(PAR_a - PAR_b)}{PAR_a} * 100 \qquad (3)$$

Where, PAR_a = PAR above the canopy and PAR_b = PAR below the canopy.

The determination of LAI was done using the inversion of transmitted PAR, as indicated in the equation according to Goudriaan (1988)

$$L = \frac{\left[\left(1 - \frac{1}{2K}\right) f_b - 1\right] \ln \tau}{A(1 - 0.47 f_b)} \qquad (4)$$

Where, L is leaf area index; K is the extinction coefficient for the canopy, given as $k = \frac{1}{2 cos\theta}$ with ϴ the zenith angle of the sun; f_b is the fraction of incident PAR; τ is the ration of PAR measured below the canopy to PAR above the canopy; A is given as $A = 0.283 + 0.785a - 0.159a^2$, with a the leaf absorptivity in the PAR band (typically around 0.9).

Data analysis

Data of maize and soybean yields, PAR and LAI were subjected to analysis of variance using SAS version 8. To test for significant differences between different cropping pattern and conventional intercropping systems, the yields were subjected to *t-student* test at 95 percent of significance level ($p < 0.05$).

RESULTS AND DISCUSSION

Effects of maize-soybean intercropping patterns on maize and soybean yields

Maize yields

At Embu during both seasons, maize stover and grain yields were significantly affected by the intercropping pattern (Table 2). For instance, during 2012 LR the MBILI treatment recorded significantly higher stover and grain yields (13.12 t ha^{-1}, p=0.0001 and 6.11 t ha^{-1}, $p < 0.0001$, respectively) than all the other treatments. During the 2012 SR, similar trend emerged with the MBILI treatment recording significantly the highest stover and grain yield 7.62 t ha^{-1}, $p < 0.0001$ and 5.62 t $ha^{-1}$$p$=0.0467, respectively (Table 2).

During both seasons at Kamujine site, maize stover yield was significantly ($p \leq 0.05$) affected by the intercropping pattern. For instance, during 2012 LR the conventional treatment produced significantly the highest stover yield (3.87 t ha^{-1}, p=0.0461). During this season, the grain yield was not significantly affected by the intercropping patterns (p=0.0704); however, the sole maize treatment recorded numerically the highest value of 3.36 t ha^{-1} while and 2M:6S treatment recorded the lowest yield. The lower maize yields under 2M:6S treatment could be related to the lower plant density compared to other treatments. During the 2012 SR, the MBILI treatment recorded significantly the highest stover and grain yield (6.55 t ha^{-1}, p=0.0005 and 3.55 t $ha^{-1}$$p$=0.0006, respectively) than all the other treatments, except sole maize and conventional treatments (Table 2).

Similar results of increased maize yield under MBILI treatment found at Embu site were also reported by Undie *et al.* (2012) in Nigeria under maize-soybean intercrop, Mucheru-Muna *et al.* (2010) in the central highlands of Kenya and Woomer *et al.* (2004) in western Kenya with maize-beans, and Solanki *et al.* (2011) in India with maize-blackgram. This could be due to the fact that the MBILI intercrop arrangement offer better opportunities to the components to utilize available resources more effectively than the conventional (1M:1S) intercropping pattern. Rajat De and Singh (1979) stated that the modified 2M:2S system affords a better solar energy harvest than the 1M:1S crop arrangement, because the former might have provided sufficient light to the lower leaves to continue photosynthesis. Furthermore, Brintha and Seran (2009) stated that productivity rates increases with LAI because of increased total light interception, but larger LAI values often cause no more increases and then decreases on a ground basis, probably due to respiratory CO_2 loss from heavily shaded leaves and stems. However, when the plant population is different the yield difference is determined by population density rather than crop arrangement (Rajat De and Singh, 1979), which was not the case in this particular situation. Similarly, Sikirou and Wydra (2008), Dapaah *et al.* (2008), Mpairwe *et al.* (2002) and Olufemi *et al.* (2001) reported higher cereal grain yield under intercropping system compared to its sole crop. Maize grain yield differs with different legume species and intercropping produces higher maize grain yield than in pure stand (Sikirou and Wydra, 2008).

On the other hand, Thobatsi (2009) in South Africa, Silwana and Lucas (2002) also observed reduction in aize yield under intercropping system compared to its monocrop, under similar environment of limited rainfall conditions, as it was observed at Kamujine site during 2012 LR. In this site it was necessary to supplement with irrigation water because the crop had started to suffer from water stress due to lack of rainfall during flowering period, as it can be seen in the Figure 3. Amede (1995) stated that one of the factors that reduces maize grain yield is dry conditions that occur specially during the flowering period. Higher populations under intercrops compared to monocrop under stress conditions might result in intercrop yields being lower than sole crop yields due to increased competition for moisture (Natarajan and Willey, 1986). Yield reductions involving one or all intercropping components in intercropping could be associated to inter-specific competition for nutrients, moisture and/or space (Adaniyan *et al.*, 2007). Moreover, Kamujine has a light texture soil, which has low moisture holding capacity (Jaetzold *et al*., 2006), resulting therefore in reduced yields under intercropping (Natarajan and Willey, 1986).

The efficiency of a crop variety to convert the dry matter into economic yield is determined by its harvest index. The higher the value, the higher will be dry matter conversion efficiency. The absence of significant differences in HI of maize observed during 2012 SR at Embu and Kamujine sites agrees with results by Haseeb-ur-Rehman *et al*. (2010) and Egbe, Alibo and Nwueze (2010) in maize-cowpea intercropping; Saleem *et al.* (2011) in maize-legume intercropping systems; and, Carruthers *et al.* (2000) in maize-soybean intercropping who reported that the intercropping systems did not affect the harvest index of maize component.

Soybean yields and components

During both seasons in both sites, the soybean yield was significantly affected by the intercropping pattern. During the 2012 LR, the yields were reduced by 60 and 81 percent due to the intercropping with maize, at Embu and Kamujine, respectively; whereas, during the 2012 SR, the yields were reduced by 52 and 78 percent as a result of intercropping with maize, at Embu and Kamujine, respectively (Table 3). At Embu, during 2012 LR, the sole soybean observed significantly the highest stover yield (1.41 t ha^{-1}, p=0.0015) than all the intercropping patterns, followed by the 2M:6S intercrop pattern with 1.03 t ha^{-1} which was statistically different from MBILI (0.53 t ha^{-1}, p = 0.0015) and conventional (0.40 t ha^{-1}, p = 0.0015) intercropping patterns, but not significantly different from the 2M:4S intercropping pattern. Also, the sole soybean treatment gave statistically the highest grain yield (1.44 t ha^{-1}, p=0.0002) than all the intercropping patterns, followed again by the 2M:6S treatment (0.88 t ha^{-1}, p=0.0002), which was significantly different from other intercropping patterns (conventional, MBILI and 2M:4S). Similar results were obtained during 2012 SR, where sole soybean treatment recorded statistically the highest stover yield (1.45 t ha^{-1}, p<0.0001) than all the other

Table 3: Effect of intercropping pattern on soybean yields (stover and grain yields) during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Treatment	Stover yield (t ha^{-1})		Grain yield (t ha^{-1})	
		2012 LR	2012 SR	2012 LR	2012 SR
Embu	Sole soybean	1.41	1.45	1.44	1.65
	Maize-Soybean (1M:1S)	0.40	0.76	0.26	0.41
	Maize-Soybean (2M:2S)	0.53	0.55	0.35	0.42
	Maize-Soybean (2M:4S)	0.60	0.83	0.46	0.76
	Maize-Soybean (2M:6S)	1.03	1.17	0.88	1.01
p-value		0.0015**	0.0001***	0.0002***	< 0.0001***
$LSD_{(0.05)}$		0.43	0.28	0.39	0.18
Kamujine	Sole soybean	1.09	1.27	0.56	0.72
	Maize-Soybean (1M:1S)	0.18	0.21	0.05	0.07
	Maize-Soybean (2M:2S)	0.19	0.24	0.04	0.08
	Maize-Soybean (2M:4S)	0.52	0.58	0.17	0.30
	Maize-Soybean (2M:6S)	0.78	0.83	0.24	0.37
p-value		< 0.0001***	0.0004***	0.0007***	<0.0001***
$LSD_{(0.05)}$		0.13	0.39	0.20	0.08

ns – not significant; *significant at $p \leq 0.05$; **significant at $p<0.01$; ***significant at $p<0.001$.

treatments, followed by the 2M:6S treatment (1.17 t ha^{-1}, *p*<0.0001), which was statistically different from the rest of the intercropping patterns. Although the conventional treatment observed 28 per cent higher stover yield than the MBILI treatment, they were not statistically different among them. The monocropped soybean observed also the highest grain yield (1.65 t ha^{-1}, *p*<0.0001) than all other treatments, followed by the 2M:6S treatment with 1.01 t ha^{-1} (*p*<0.0001), which significantly differed from the rest of the treatments. At Kamujine during 2012 LR, the sole soybean treatment gave statistically the highest stover and grain yields (1.09 t ha^{-1}, *p*<0.0001 and 0.56 t ha^{-1}, *p*=0.0007, respectively) than all the other treatments, followed by the 2M:6S treatment with 0.78 t ha^{-1} for the stover yield, which was significantly different (*p*<0.0001) from the other intercropping patterns. During the 2012 LR season, there was significant positive correlation between the soybean grain yield and, and soil mineral N, with *r*=0.73 (*p*=0.0002) and *r*=0.76 (*p*<0.0001), respectively. During 2012 SR, monocropped soybean treatment observed also significantly the highest stover yield (1.27 t ha^{-1}, *p*=0.0004) than all the other treatments. Similarly, sole soybean treatment recorded the highest grain yield of 0.72 t ha^{-1} (*p*<0.0001) than all the other treatments. In general, the yields increased with about 23 and 26 percent in the second season compared to the first season, at Embu and Kamujine, respectively. Probably due to the cumulative effects of the goat manure that was applied in the first and second seasons, and also due to root and nodule senescence (Table 3).

At Embu during the 2012 LR, there were significant differences in soybean stover yield (*p*=0.0278) among the rows in 2M:4S treatment, where the row next to the maize plant observed 16.7 percent lower yield than the row far away from the maize plant. For the grain yield, the row far away from the maize plant gave 20 percent significantly higher (*p*=0.0009) yield than the row next to maize plant. During the 2012 SR, the soybean stover and grain yields were 9.5 and 14.8 percent significantly (*p*=0.0113 and *p*=0.0108, respectively) higher in the middle row than in the row next to the maize plant, respectively. At Kamujine during the 2012 LR, there were no significant differences (*p*=0.7292) on soybean stover yield between the middle row and the row next to the maize plant; whereas the grain yield in the middle row was 21 percent significantly (*p*=0.0251) higher than in the row next to the maize plant. During the 2012 SR, the soybean stover and grain yields were 22.2 and 25.9 percent significantly (*p*=0.0088 and *p*=0.0085, respectively) lower in the closer row than in the middle row, respectively (Table 4).

At Embu during the 2012 LR, there were significant differences in soybean stover yield (*p*=0.0179) among rows in 2M:6S intercropping pattern. The middle row recorded about 27.3 percent higher yield than the row next to the maize row. For the grain yield, the middle row observed 30 per cent significantly higher (*p*=0.0236) than the row closer to maize plant. During the 2012 SR, the soybean stover yield did not show significant differences (*p*=0.1008) between the row next to the maize plant and one in the middle row; however, it was numerically 7.7 percent higher in the middle row than in the row next to the maize plant. The grain yield was 25 percent significantly (*p*=0.0297) higher in middle row than in the

Table 4: Shading effect on soybean yield in the 2M:4S during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Row position	Maize-Soybean (2M:4S)			
		Stover yield (t/ha)		Grain yield (t/ha)	
		2012 LR	2012 SR	2012 LR	2012 SR
Embu	Middle	0.07	0.095a	0.05	0.061a
	Closer	0.06	0.086b	0.04	0.052b
p-value		0.0278*	0.0113**	0.0009***	0.0108**
LSD$_{(0.05)}$		0.01	0.007	0.01	0.007
Kamujine	Middle	0.05	0.066	0.019	0.034
	Closer	0.05	0.054	0.015	0.027
p-value		0.7292	0.0088**	0.0251*	0.0085**
LSD $_{(0.05)}$		0.01	0.009	0.004	0.005

ns – not significant; *significant at $p \leq 0.05$; **significant at $p < 0.01$; ***significant at $p < 0.001$.

Table 5: Shading effect on soybean yield in the 2M:6S treatment during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Row position	Maize-Soybean (2M:6S)			
		Stover yield (t/ha)		Grain yield (t/ha)	
		2012 LR	2012 SR	2012 LR	2012 SR
Embu	Middle	0.11	0.13a	0.10	0.12a
	Closer	0.08	0.12a	0.07	0.09b
p-value		0.0179*	0.1008	0.0236*	0.0297*
LSD$_{(0.05)}$		0.03	0.02	0.03	0.02
Kamujine	Middle	0.086	0.10a	0.024	0.065a
	Closer	0.066	0.060b	0.016	0.036b
p-value		0.1049	0.0051**	0.0305*	0.0017**
LSD $_{(0.05)}$		0.025	0.03	0.007	0.02

ns – not significant; *significant at $p \leq 0.05$; **significant at $p < 0.01$; ***significant at $p < 0.001$.

closer row. At Kamujine during the 2012 LR, there were no significant differences (*p*=0.1049) on soybean stover yield between the row middle row and the row closer to the maize plant; whereas the grain yield in the middle row was 33.3 per cent significantly (*p*=0.0305) higher than in the closer row. During the 2012 SR, the soybean stover and grain yields were 40.0 and 44.6 percent significantly (*p*=0.0051 and *p*=0.0017, respectively) higher in the middle row than in the closer row, respectively (Table 5).

At Embu site, during the 2012 SR there was statistically significant strong positive correlation between soybean grain yields of the middle row and PAR intercepted (*r*=0.998; *p*=0.0019) and LAI (*r*=0.992; *p*=0.0078), at 49 DAP (Figure 1).

At Kamujine site, during 2012 SR also middle rows showed existence of significant correlation between soybean yields and light intercepted and Leaf area index, at 63 DAP. For instance, soybean stover yield was strongly positive correlated with the PAR intercepted (*r*=0.95; *p*=0.0463) and LAI (*r*=0.99; *p*=0.0088), as indicated by the Figure 2. Similarly, there was strong positive correlation between soybean grain yield with the amount of light intercepted (*r*=0.997; *p*=0.0027) and LAI (*r*=0.99; *p*=0.0085) (Figure 3)

Effect of maize-soybean intercropping patterns on light interception and Leaf Area Index

At Embu during the 2012 SR, significant differences

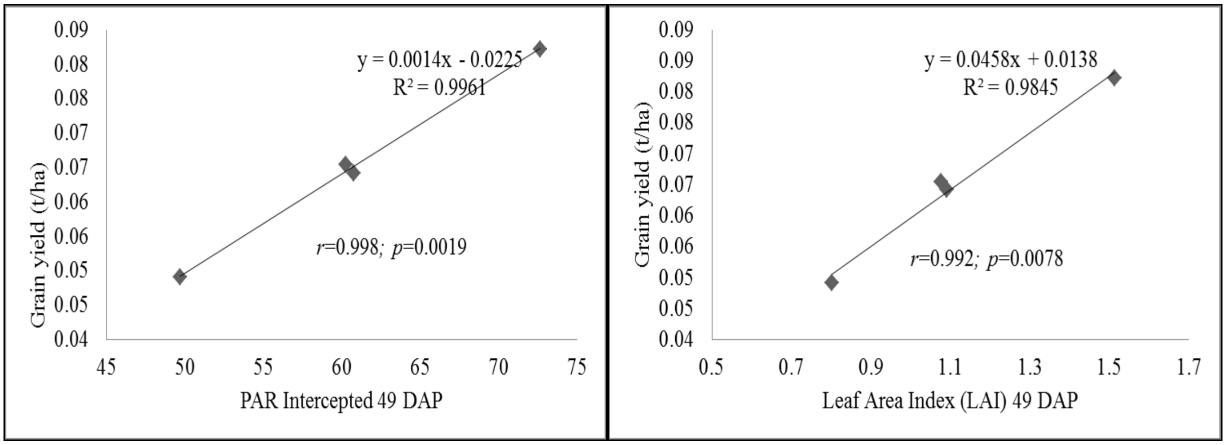

Figure 1. Relationship between soybean grain yield with PAR intercepted and LAI in middle rows during 2012 SR at Embu site.

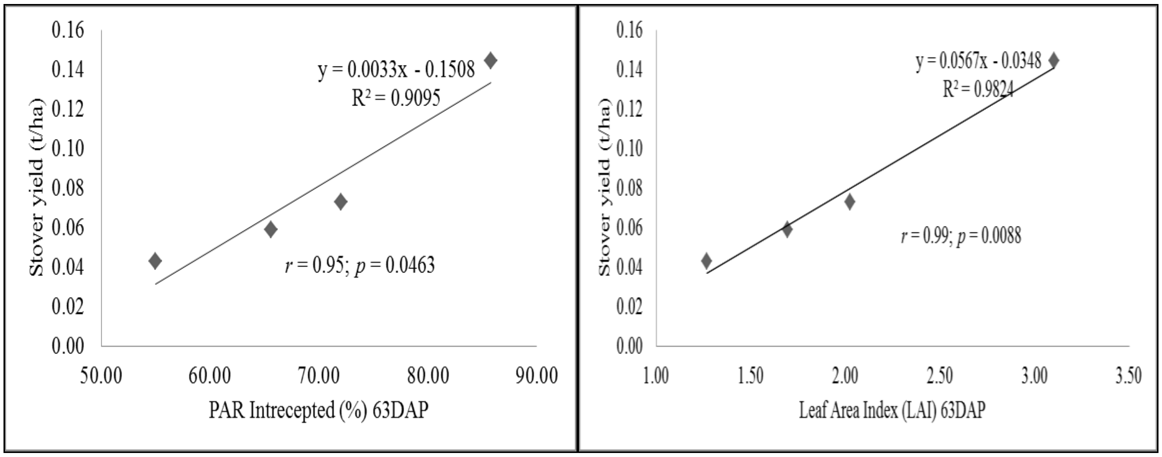

Figure 2. Relationship between soybean stover yield with PAR intercepted and LAI in middle rows during 2012 SR at Kamujine site

(*p*<0.001 and *p*<0.05) were observed in light interception (PAR) and leaf area index (LAI) for maize and soybean during the sampling period as affected by the intercropping patterns, except during 49 days after planting (DAP). For instance, during the 35 DAP sole soybean intercepted significantly (*p*=0.0002) more light (58.23 percent) and leaf area index (LAI) of 1.03 (*p*=0.0003) than all other treatments and/or crop, excluding sole maize, soybean in 2M:2S, 2M:4S and in 2M:6S treatments. In this period only soybean under MBILI treatment showed existence of significant strong correlation between grain yield and PAR intercepted (*r*=0.98; *p* =0.0254) and LAI (*r*=0.97; *p*=0.0324), as shown by the Figure 3. While at 63 DAP the soybean in MBILI treatment observed statistically (*p* = 0.0310) the highest light interception (84.15 percent) than sole soybean, maize and soybean under 2M:4S, and maize under 2M:6S treatments (Table 6). At Kamujine site during the same sampling period, where both PAR and LAI were significantly (35 DAP with *p*<0.0001 and *p*<0.0001; and, 49 DAP with *p*=0.0476 and *p*=0.0342, respectively) affected by the intercropping patterns. At 35 DAP the sole soybean recorded statistically the highest PAR of 62.08 per cent (*p*<0.0001) and LAI of 1.18 (*p*<0.0001) compared to all other treatments. Whereas, during the time of 49 DAP maize under MBILI treatment intercepted significantly more light (80.69 per cent, *p*=0.0476) than all other treatments, excluding sole soybean, sole maize, soybean under MBILI and maize under 2M:6S treatments. In the same period (49 DAP

Table 6: Effect of intercropping patterns on PAR and LAI of maize and soybean during 2012 SR at Embu and Kamujine sites

Location	Treatment	Crop	35 DAP		49 DAP		63 DAP	
			PAR%	**LAI**	**PAR%**	**LAI**	**PAR%**	**LAI**
Embu	Sole maize	Maize	57.23	1.03	66.50	1.28	83.40	3.61
	Sole soybean	Soybean	58.23	1.09	54.97	1.00	73.12	2.87
	Maize-Soybean (1M:1S)	Maize	32.41	0.47	56.55	0.99	74.19	2.74
		Soybean	41.65	0.66	56.67	0.99	78.05	3.06
	Maize-Soybean (2M:2S)	Maize	45.88	0.74	61.00	1.24	74.10	3.21
		Soybean	53.70	0.95	66.92	1.45	84.15	4.26
	Maize-Soybean (2M:4S)	Maize	42.67	0.70	55.58	0.95	69.05	2.34
		Soybean	55.89	1.00	48.74	0.87	68.24	2.40
	Maize-Soybean (2M:6S)	Maize	46.34	0.75	51.38	0.87	66.95	2.23
		Soybean	53.82	0.95	59.13	1.10	77.73	3.35
p – value			0.0002***	0.0003***	0.2850	0.3564	0.0310*	0.0962
LSD$_{(0.05)}$			10.10	0.25	14.97	0.52	10.95	1.33
Kamujine	Sole maize	Maize	49.86	0.85	69.39	1.52	76.47	2.28
	Sole soybean	Soybean	62.08	1.18	75.72	1.67	80.93	2.65
	Maize-Soybean (1M:1S)	Maize	36.24	0.55	67.17	1.37	78.90	2.54
		Soybean	32.51	0.48	54.79	0.95	67.68	1.89
	Maize-Soybean (2M:2S)	Maize	43.71	0.71	80.69	2.06	84.23	3.24
		Soybean	41.66	0.66	70.60	1.46	79.48	2.60
	Maize-Soybean (2M:4S)	Maize	37.44	0.57	64.10	1.21	71.74	2.08
		Soybean	41.38	0.66	65.62	1.38	73.57	2.00
	Maize-Soybean (2M:6S)	Maize	48.87	0.82	67.97	1.37	76.84	2.34
		Soybean	23.26	0.33	65.17	1.37	80.98	2.48
p – value			<0.0001***	<0.0001***	0.0476*	0.0342*	0.1417	0.2026
LSD$_{(0.05)}$			8.83	0.20	13.35	0.54	11.05	0.93

ns – not significant; *significant at $p \leq 0.05$; **significant at $p<0.01$; ***significant at $p<0.001$.

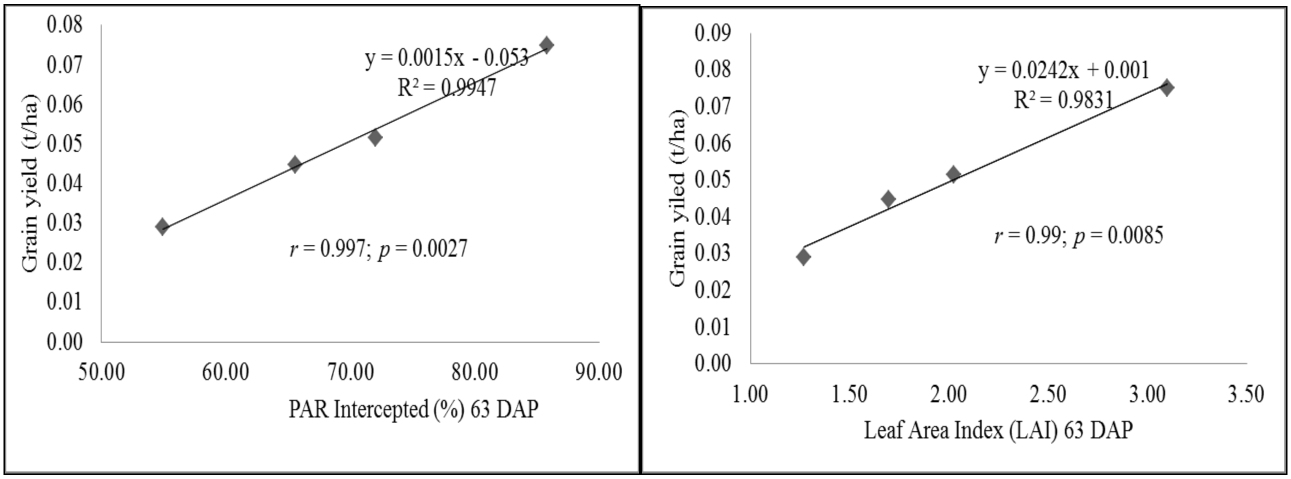

Figure 3. Relationship between soybean grain yield with PAR intercepted and LAI in middle rows during 2012 SR at Kamujine site

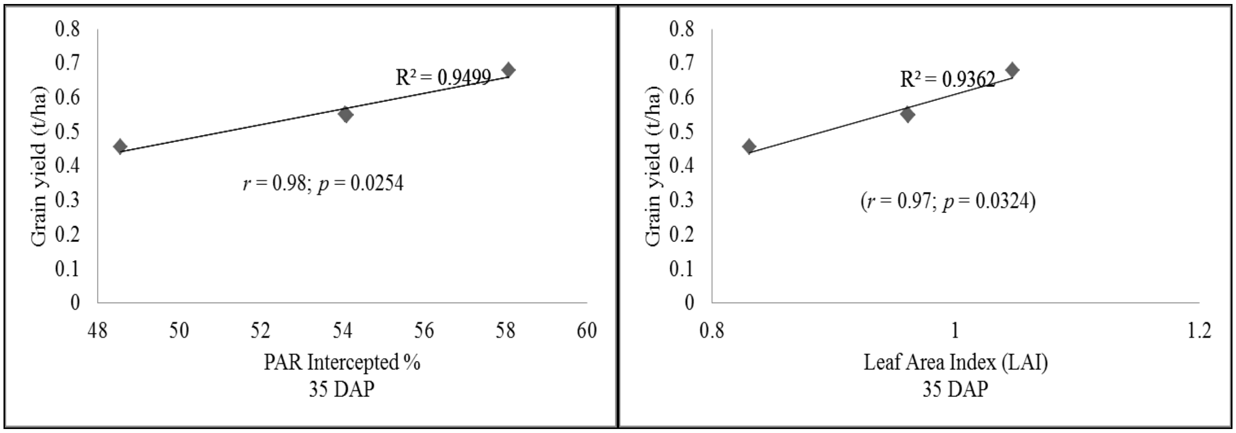

Figure 4. Relation between sobean grain yield under MBILI treatment with PAR and LAI during 2012 SR at Embu site

still maize under MBILI treatment showed the highest LAI of 2.06 than all other treatments, except soybean under monocrop (Table 6 and Figure 4).

The higher light interception showed by sole soybean treatment at Embu and Kamujine sites was also reported by Ghanbari, Dahmardeh, Siahsar and Ramroudi (2010), who observed that the cowpea-maize intercropping and maize sole crop had showed a lower light interception compared to cowpea sole crop. Studying wheat-faba bean intercropping, Eskandari (2011) found that the mean of PAR interception averaged over sampling dates by sole cropped bean was significantly higher than that for sole cropped wheat. Studying maize-peas intercropping, Kanton and Dennett (2008) found that at 36 DAP the sole peas were intercepting 30 per cent more light than sole maize. Studying maize-bean intercropping, Tsubo *et al.* (2001) found that sole beans showed higher PAR intercepted than sole maize. Studying southern pea-sweet corn intercropping system, Francis and Decoteau (1993) found that monocropped southern pea had intercepted more light than monocropped sweet corn 52 and 66 DAP. Solanki *et al.* (2011) reported that sole soybean intercepted more light as compared to maize+soybean and sole maize at 75 DAP.

Varies studies, particularly in tropical, have shown that intercrops intercept more PAR than sole crops, for example, Sivakumar and Virmani (1980) with maize-pigeon pea, Bandy-opadhyay (1988) with sorghum-mung bean, and Tsubo *et al.* (2001) with maize-bean intercrops. The present study confirmed that MBILI treatment capture more radiant energy than sole crops, but the differences between this treatment and the sole maize crop (at Embu site) or soybean crop (at Kamujine site) were relatively small and not significant. This might be probably due to the differences in agro-ecological zonation and rainfall patterns between the two sites, where at Embu site (upper midland) had received more rainfall which made the maize crop to respond positively as it allowed faster leaf area growth and plant height, and therefore more light was intercepted; whereas, at Kamujine site (lower midland) had received less rainfall which made the maize crop to retard its initial growth rate compared to soybean and not being able to cover the soil surface very early resulting in lower interception of PAR compared to soybean. Also, Soybean plants, being deep rooted, can to some extent withstand dry periods (Prasad and Brook, 2005).

Environmental factors such as limited moisture, influences the leaf area development (Afuakwa and Crookston, 1984). Tsubo *et al.* (2001) stated that faster leaf area growth can cause higher PAR intercepted during the vegetative stage. Radiation interception varies from seedling emergence to crop harvest (Natarajan and Willey, 1980; Sivakumar and Virmani, 1980) and depends largely on the canopy leaf area (Tsubo *et al*., 2001). The higher PAR conversion efficiencies of intercrop systems relative to the sole crops may be due to spread of light over greater leaf area, and more efficient distribution of light in their canopies during early stages of growth (Addo-Quaye *et al*., 2011). Keating and Carberry (1993) concluded that cereal and legume can differ in PAR interception because of differences in their vertical arrangement of foliage and canopy architecture and can therefore intercept more PAR compared to sole crops. Moreover, it has been found by several investigators (Reddy and Willey, 1981; Sivakumar and Virmani, 1984; Watiki *et al*., 1993) that LAI patterns follow the patterns of radiation interception.

The higher LAI observed during 49 DAP with intercropped maize at Kamujine agrees with the results of

Table 7: Effects of maize shade on PAR intercepted of soybean during 2012 SR at Embu and Kamujine sites

Location	Row position	35 DAP		49 DAP		63 DAP	
		2M:4S	2M:6S	2M:4S	2M:6S	2M:4S	2M:6S
		PAR	PAR	PAR	PAR	PAR	PAR
Embu	Middle	63.94	61.71	66.87	68.68	78.03	87.05
	Closer	43.97	42.71	47.75	49.23	66.05	71.25
p – value		0.001***	<0.0001***	<0.0001***	0.0029**	0.0001***	0.0092**
$LSD_{(0.05)}$		9.13	6.16	7.12	11.58	5.59	11.24
Kamujine	Middle	48.82	53.23	61.69	69.08	75.55	84.51
	Closer	31.61	46.44	47.11	49.18	63.15	63.41
p – value		<0.0001***	0.012*	0.0051**	0.0021**	0.0027**	<0.0001***
$LSD_{(0.05)}$		5.31	5.05	9.85	11.36	7.74	6.53

ns – not significant; *significant at $p \le 0.05$; **significant at $p<0.01$; ***significant at $p<0.001$.

Baldé *et al.* (2011) who found that maize intercropped with pigeonpea or brachiria had higher LAI than sole maize crop; and, Thobatsi (2009) who found maize intercropped with cowpea long duration cultivar had significantly higher LAI of 2.23 compared to medium season cultivars. Higher maize LAI when intercropped with soybean during 2013 SR could have been attributed to sufficient rainfall at the beginning of the season that stimulated maize leaf growth.

Similarly, the reductions of maize LAI under intercropping systems in both sites (Embu and Kamujine) have been also reported by other researchers (Thobatsi, 2009; Zegada-Lizarazu, Izumi and Ijima, 2006; Bilalis *et al.*, 2005). The absence of differences in maize LAI between all treatments in both sites (Embu and Kamujine) at 63 DAP and at 49 DAP in Embu site correspond with results of Filho (2000) who did not find any significant differences between sole maize and maize intercropped with cowpea. Twala and Ossom (2004) also did not find any significant differences in LAI between maize monocrop and maize intercropped with sugar beans or groundnuts. These results support the fact that different climatic conditions will result in different leaf development patterns of maize, with or without intercropping.

In general, at Embu site monocropped maize and the MBILI treatments intercepted numerically more light than all other treatments, with averages of 69.04 and 64.29 percent during the sampling period, respectively. The MBILI treatment intercepted 10.43 per cent more light than the conventional treatment (Figure 5). While, at Kamujine site monocropped soybean and the MBILI treatment intercepted numerically more light than all other treatments, with averages of 72.91 and 66.73 percent, respectively. The PAR intercepted by the MBILI treatment was 15.66 percent above the one that the conventional treatment had intercepted (Figure 5).

Similar results were also reported by Woomer and Tungani (2003) who found that beans had intercepted 20 per cent more light under MBILI treatment than under conventional crop arrangement. These findings demonstrate the advantages of light penetration to the MBILI intercropping pattern which offer realizable potential for smallholder farmers to improve the performance of their maize-legume enterprise (Woomer and Tungani, 2003).

The Table 7 shows that in both sites (Embu and Kamujine) the amount of light intercepted by the legume component and LAI were significantly ($p<0.05$) affected by maize shade. For instance at Embu site, 35 DAP the middle row intercepted significantly ($p=0.001$ and $p<0.0001$) 19.97 and 19.0 per cent more light than the closer row, in the 2M:4S and 2M:6S treatments, respectively. During the time of 49 DAP, the closer row had significantly ($p<0.0001$ and $p=0.0029$) intercepted 19.12 and 19.45 percent less light than the middle row, in the 2M:4S and 2M:6S treatments, respectively. And at 63 DAP, the PAR intercerped by the middle row was 11.98 and 15.80 percent statistically ($p=0.0001$ and $p=0.0029$) higher than the one that was intercepted by the closer row, in the 2M:4S and 2M:6S treatments, respectively. Similarly, at Kamujine the closer row had significantly ($p<0.0001$ and $p=0.012$) intercepted 17.21 and 6.79 percent less light than the middle row, in the 2M:4S and 2M:6S treatments, respectively, at the time of 35 DAP. During the time of 49 DAP, the middle row had significantly ($p=0.0051$ and $p=0.0021$) intercepted 14.58 and 19.90 percent more light than the closer row, in the

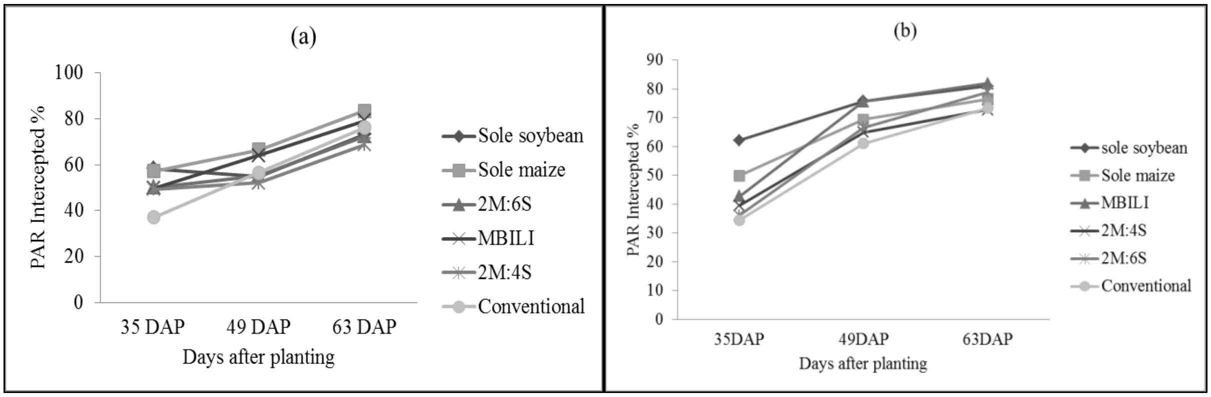

Figure 5. PAR Intercepted (%) during 2013 SR at Embu (a) and Kamujine (b) sites

Table 8: Effects of maize shade on LAI of soybean during 2012 SR at Embu and Kamujine sites

Location	Row position	35 DAP		49 DAP		63 DAP	
		2M:4S	2M:6S	2M:4S	2M:6S	2M:4S	2M:6S
		LAI	LAI	LAI	LAI	LAI	LAI
Embu	Middle	1.24	1.17	1.33	1.38	3.23	4.20
	Closer	0.71	0.67	0.81	0.83	2.19	2.73
p – value		0.001**	0.001**	<0.001	0.0028	0.001	0.0078
$LSD_{(0.05)}$		0.25	0.20	0.17	0.33	0.58	1.02
Kamujine	Middle	0.82	0.93	1.17	1.40	2.43	3.04
	Closer	0.46	0.76	0.80	0.83	1.62	1.62
p – value		<0.0001***	0.0124	0.008	0.0017	0.001	<0.0001
$LSD_{(0.05)}$		0.11	0.13	0.27	0.32	0.45	0.43

ns – not significant; *significant at $p \leq 0.05$; **significant at $p<0.01$; ***significant at $p<0.001$.

2M:4S and 2M:6S treatments, respectively. At 63 DAP, the PAR interceped by the closer row was 12.40 and 21.10 percent statistically (*p*=0.0027 and *p*<0.0001) lower than the one that was intercepted by the middle row, in the 2M:4S and 2M:6S treatments, respectively (Table 7).

At Embu site during 2012 SR, at 35 DAP the middle row observed significantly (*p*=0.001 and *p*<0.001) 1.24 and 1.17 higher LAI than the closer row with 0.71 and 0.67, in the 2M:4S and 2M:6S treatments, respectively. During the time of 49 DAP, the closer row had significantly (*p*<0.0001 and *p*=0.0029) recorded 0.52 and 0.55 lower LAI than the middle row, in the 2M:4S and 2M:6S treatments, respectively. At 63 DAP, the LAI observed by the middle row was 1.04 and 1.47 statistically (*p*=0.001 and *p*=0.0078, respectively) higher than the one that was recorded by the closer row, in the 2M:4S and 2M:6S treatments, respectively (Table 8).

At Kamujine site, during 35 DAP the closer row had significantly (*p*<0.0001 and *p*=0.0124) observed lower LAI with values of 0.46 and 0.76 than the middle row (0.82 and 0.93), in the 2M:4S and 2M:6S treatments, respectively. During the time of 49 DAP, the middle row had significantly (*p*=0.008 and *p*=0.0017) recorded higher LAI with values of 1.17 and 1.40 than the closer row that observed 0.80 and 0.83, in the 2M:4S and 2M:6S treatments, respectively. At 63 DAP, the LAI recorded by the closer row was 0.81 and 1.42 statistically (*p*=0.001 and *p*<0.0001) lower than the one that was showed by the middle row, in the 2M:4S and 2M:6S treatments, respectively (Table 4). Similar effects of shading on legume component have been reported by several authors (Hang *et al.*, 1984; Stirling *at al.*, 1990; Ali, Jeffers and Henderlong (2003). For instance, Ali *et al.* (2003) found that alternate row of soybean had intercepted 31 percent more PAR than alternate narrow rows at 74 DAP.

The reduction of soybean yields under intercropping with maize or sorghum has also been reported by several researchers (Ijoyah and Fanen, 2012; Muoneke *et al.*, 2007; Muneer *et al.*, 2004; Heibsch *et al.,* 1995; Olufajo, 1992; Pal, Oseni, and Norman, 1992; Neupane, 1983). This reduction in soybean yields under intercropping could be due to interspecific competition between the intercrop components for water, light, air and nutrients, and also the aggressive effects maize (C_4 species) on soybean, a C_3 species (Muoneke *et al.,* 2007). According to Heibsch *et al.* (1995), crops with C_4 photosynthetic pathways have been known to be dominant when intercropped with C_3 species like soybean. The shading of soybean by the maize plants (taller) may also have contributed to the reduction of the yields of intercropped soybean. Olufajo (1992) reported that shading by the taller plants in mixture could reduce the photosynthetic rate of the lower growing plants and thereby reduce their yields. This observation was confirmed in this study where lower soybean yields were recorded in the rows next to the maize plant compared to the middle row, and the yields positively correlated with the PAR intercepted. In addition, Lesoing and Francis (1999) stated that water stress and shading were probably the two major factors, which contribute to reduced legume component yield under intercropping. Moreover, Natarajan and Willey (1980) and Sivakumar and Virmani (1980) reported that stover yield often shows a positive correlation with the amount of radiation intercepted by crops in intercropping systems. However in the current this study there was a positive correlation between grain yield with the amount of radiation intercepted by crops in intercropping treatments.

The reduction of harvest index of the legume component observed in this study was also reported by other researchers (Alhassan, Kalu and Egbe, 2012). The reduction was mainly due to maize shading effects on soybean, which caused the legume component to allocate its photosynthates to vegetative growth and height increasing for competing with taller maize. On the other hand, the findings of this study at Kamujine site are in agreement with Carruthers *et al*. (2000) who reported that the HI for intercrop soybean was not significantly different from monocrop soybean.

CONCLUSION

The maize-soybean intercropping patterns had significant effect on maize stover and grain yields during both seasons and sites. The MBILI treatment recorded significantly the highest maize stover and grain yields.During both seasons in both sites, the soybean yield was significantly affected by the intercropping pattern. During the 2012 LR, the yields were reduced by 60 and 81 percent and during the 2012 SR, the yields were reduced by 52 and 78 percent as a result of intercropping with maize.The intercropping patterns affected significantly the PAR intercepted and the leaf area index at both sites. The soybean sole crop intercepted significantly more light and leaf area index (LAI) than all other treatments and/or crop. Towards the end of the season, the soybean in MBILI treatment observed statistically the highest light interception than other treatments.

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