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Effects of Intercropping on Maize and Soybean Yield Performance, Land Equivalent Ratio, and Maize Leaf Area in Conservation Agriculture

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Abstract

Maize-soybean intercropping systems as a conservation farming practice are receiving increased focus from the scientific community. This is because of the advantages of intercropping, especially nutrient benefits through cereal-legume interactions, alternative sustainable methods to manage biotic stress (pests, diseases, weeds), and crop failure risk management due to erratic weather. In addition, smallholders in developing countries commonly use intercropping to produce crops. In Uganda, 40% of smallholder farmers are practicing intercropping yet no adequate location-specific information is available to inform their practice. Farmers who adopted conservation farming practices did not mulch their maize due to drudgery associated with collecting mulch. This study evaluated the effect of two tillage methods (T1 = Conventional tillage using ox drawn mould board plough, T2 = Minimum tillage using ox drawn ripper) and five soil cover practices (SC1 = Mulched Maize, SC2 = Control no mulch, SC3 = Two rows of soybean in between one row of maize, SC4 = One row of soybean in between one row of maize, SC5 = Sole soybean) on maize and soybean yield performance. The trials were established for 4 rainy seasons on a sandy loam ferrosol at National Agricultural Research Organization Institute in Lira, Uganda. Soil cover practice had a significant effect on maize and soybean crop Yield. Mulching significantly increased maize yield and LAI. The LER for both intercropping partterns were above 1.2. Tillage methods were not significantly different in determining crop performance. The practice of minimum tillage should also be adopted because it enhances the positive effects of soil cover (intercropping). We recommend farmers to adopt the intercropping pattern of one row of soybean in between maize row spaced at 75 × 30 cm for better LER, and crop performance. This intercropping pattern maximizes on available resources to deliver better output in conservation farming. Maize crop generally performed better during first season as compared to second season. We recommend farmers to utilize the first rains as the main maize production season.

Keywords: land equivalence ratio, leaf area, intercropping, conservation agriculture

1. Introduction

Intercropping is the cultivation of two or more different crops simultaneously on the same piece of land. It offers a yield advantage compared to the sole crop due to the efficient use of available resources such as light, soil nutrients and water (Bamboriya et al., 2022; Hamzei & Seyedi, 2015). Intercropping provides insurance against crop failure due to weather risks and increases diversity in an agroecosystem. Intercropping has attracted increased interest worldwide because it provides an efficient soil conservation practice and, a sustainable and more stable system of agricultural production against abiotic and biotic stress than sole cropping (Anyoni et al., 2023; Aydın et al., 2021; Santalla et al., 1999). A study found that minimum soil disturbance and crop rotation have no significant impact on yield outcomes, but that legume intercropping significantly increases yields and reduces the probability of low yields even under critical weather stress during the growing season (Arslan et al., 2015). An extensive literature review (Liebman & Dyck, 1993) reported that weed biomass in intercrops was lower than component crops in 50% of the studies, intermediate to component crops in 42% of the studies, and greater than all component crops in 8% of the studies. Similarly, Szumigalski and Van Acker (2005) concluded that annual intercrops can enhance both weed suppression and crop production compared with sole crops. Intercropping therefore can be very useful to avert pests and diseases on crops, especially under conservation agriculture for smallholder farmers in Africa. However, it may be more challenging for farmers in developed economies due to challenges in mechanizing planting and harvesting involving different crops and chemical weed control (Bamboriya et al., 2022). The land equivalent ratio has been recommended to measure the advantage of intercropping to sole cropping (Deb et al., 2022; Mead & Willey, 1980; Reddy & Chetty, 1984; Willey & Osiru, 1972).

In Uganda, farmers practicing Conservation Agriculture (CA) adopted minimum tillage and crop rotation among the three principles of CA, leaving out soil cover (Kaweesa et al., 2018). Maize legume intercropping increased the quantity of residues produced and retained as surface mulch (Ngwira et al., 2012), enhancing soil cover in conservation agriculture. Intercropping significantly increased maize yield, LAI and intercepted more light compared to sole crops (Liu et al., 2018; Matusso et al., 2013), however the intercropping parttern needs to be localized because environment and crop genotypes play a great role. It's important to note that 40 percent of farmers in Uganda practice intercropping (UBOS, 2011), hence the need to introduce it in conservation farming to be adopted as a soil cover practice. It is therefore very crucial to evaluate the intercropping compatibility among intercrops, planting pattern and their effect on land equivalent ratio, maize performance and leaf area index in conservation agricultural system.

2. Materials and Method

2.1 Study Site

The study was done on-station at Ngetta Zonal Agricultural Research and Development Institute (Ngetta ZARDI) located in northern Uganda at 02°.29573′N; 032°.92092′E; 1, and at 101 meters above sea level (masl). Average daily temperature is 25 °C; while maximum temperature is 29 °C. The climate is moist, sub-humid, with a mean annual rainfall of 1,639.1 mm that is bi-modally distributed from March-June and August-December (Kumakech et al., 2014). This site is characterized by sandy loam texture (ferrosols) with pH of (6.0-6.7), Organic matter ranges from 2-3%, Phosphorus (10-30 ppm), Calcium (800-1500 ppm), magnesium (200-600), potassium (400-800 ppm) soil nutrient data as measured at National Agricultural Research Laboratories (NARL), Kawanda.).

2.2 Study Design and Field Lay Out

The experiment was laid out as a randomized complete block design with a split plot arrangement and three replications per treatment (Table 1). The study was repeated for four seasons 2019B, 2020A, 2020B and 2021A. Plots were 4 × 4 m wide with a 2 m border in between plots. Main plot blocks were 2.5 m between blocks. Guard rows were established at plot borders. The main plot factors were type of tillage: T1 (Ox plough), T2 (rip line). The subplot factors were soil cover applied in five sub-plot treatments: SC1: Sole maize mulched at 6 t/ha, SC2: Sole maize with no mulch, SC3: Intercropping maize and soybean (2 rows of soybean in between), SC4: Intercropping maize with soybean (1 row of soybean in between) and SC5: Sole soybean (Table 2). Maize and soybean crop were planted at the same time. Crop rotation was done by rotation of crops in subsequent seasons involving maize replaced with soybean and vice versa, apart from intercropped plots. Tillage with ox-plough consisted of land preparation using inversion-type moldboard, ploughing (two times) at a depth of 15-25 cm, followed by harrowing and planting using a hand hoe. Weeding was performed two times per season using a hand hoe for conventional tillage. Depth of hoeing is 18-20 cm during harrowing and down to 10-15 cm during weeding. Mulch consisted of grass cuttings collected from a mowed compound at the institute, 9.6 kg were applied per 16 m^2 plot, this is equivalent to 6 t/ha.

Table 1. Experimental lay out

Ox tillage	Minimum tillage ripline	Ox tillage	Minimum tillage ripline	Ox tillage	Minimum tillage ripline
Replicate 1	Replicate 1	Replicate 2	Replicate 2	Replicate 3	Replicate 3
SC3	SC2	SC3	SC5	SC4	SC1
SC4	SC1	SC4	SC1	SC1	SC2
SC2	SC5	SC5	SC2	SC3	SC4
SC1	SC3	SC1	SC3	SC5	SC5
SC5	SC4	SC2	SC4	SC2	SC3

Note. SC 1 = Mulched Maize, SC2 = Control no mulch, SC3 = Two rows of soybean in between one row of maize, SC4 = One row of soybean in between one row of maize, SC5 = Sole soybean).

Table 2. Detailed subplot treatments

Subplot treatment	Spacing	Justification for variety and spacing ** Experimental plot size is 16 m^2
1	75 × 30 cm	6t/ha of mulch is the recommended rate (Uwah, 2011). WEMA maize varieties are drought tolerant. This is the recommended spacing from the maize breeding programme at NARO (44,444 plants/ha, equivalent to 71plants/plot).
2	75 × 30 cm	WEMA maize varieties are drought tolerant. This is the recommended spacing from the maize breeding programme at NARO (44,444 plants/ha, equivalent to 71 plants/plot).
3	2 rows of soybean in-between maize row (90 × 30 cm)	As recommended for legunes (Mubiru et al., 2017, 2018; Mubiru & Coyne, 2009), (Maize 37,000/ha or 59 plants/plot and soybean 256 plants/plot or 160,000 plants/ha).
4	1 row of soybean in-between maize row (75 × 30 cm)	As recommended by the NARO maize breeding programme (Maize 44,444 plants/ha or 71 plants per plot and beans 128 plants/plot or 80,000 plants/ha).
5	50 × 10 cm for conventional tillage and 75 × 10 cm for minimum tillage	Recommended spacing by Makerere soybean breeding programme. Variety Maksoy 3N. Quick maturing (320,000 plants/ha or 384/plot for conventional and 260,000 plants/ha or 213/plot, under minimum tillage).

Note. NARO (National Agricultural Research Orgarnisation).

Ripping was done with an ox-ripper during dry season in July and December at a depth of 30-40 cm and inter row spacing of 75 cm. This was done after slashing and weeds were allowed to sprout and when the weeds had attained 4-5 leaves, glyphosate was sprayed at a rate of 4 L/ha as recommended by manufacturer. Planting was done as soon as rain started in the months of April for first season (A) and August for second season (B). Weeds in ripped plots were managed through spot weeding by hand pulling and hand hoeing at least three times during the season. Maksoy 3N and Water efficient maize variety (WEMA) 2115 were used in this trial. WEMA 2115 is drought tolerant and performs well in the Northern Agroecological Zone (NAEZ). Soybean Maksoy 3N performs well in this region. Maize was planted at a spacing of 75 × 30 cm for land prepared by ox plough, and rip lines (Otim et al., 2015). Sole soybean was planted at a spacing of 50 × 10 cm, two rows and one row of soybean were planted between maize row, respectively for each intercropping pattern (Table 2). In Uganda the average application rate of fertilizer is 0.23-1.5 kg/hectare, far below the average rate of 8 kg/hectare in sub-Saharan Africa (UBOS, 2020).

2.3 Grain Yield Measurement

Harvesting of maize and soybean was done manually by hand at physiological maturity. Net plot yield was got by leaving out border rows. The harvested maize and soybean were dried, weighed and moisture content noted. The yield data was corrected to 14% moisture content for both crops.

2.4 Land Equivalence Ratio

Land Equivalent Ratio (LER), defined as the relative land area required as sole crops to produce the same yields as intercropping (Willey, 1979). LER was used to express the yield advantage or disadvantage of intercropping. LER can be written:

$$LER = LA + LB = YA/SA + YB/SB \tag{1}$$

where, LA and LB are the LERs for the individual component crops, YA and YB are the individual crop yields in intercropping, and SA and SB are their yields under sole cropping.

2.5 Leaf Area Index

The LAI, data were collected from ten maize plants randomly selected along a diagonal for each experimental unit/plot leaving out guard rows at the stage of silking/tasseling as described by Bréda (2003) and Watson (1947). Leaf area was measured using the recommended LI-3100 (LI-COR, Lincoln, NE) leaf area meter device (Yan et al., 2019). The LAI (m^2 m^{-2}) was determined by taking into account the number of plants in the unit area.

2.6 Statistical Analysis

ANOVA was used to evaluate the effect of season, tillage, soil cover practices, intercropping and their interaction on maize grain yield. Where the F-test was significant, turkey's test was used to compare means at $P \leq 0.05$, if not stated otherwise.

3. Results

3.1 Effect of Intercropping on Maize Yield

Soil cover practice and season had a significant effect on maize yield (p = 0.000); however, tillage method did not significantly affect maize yield (p = 0.082) (Table 3).

Table 3. Analysis of Variance: Mean maize yield's tillage, soil cover practice, season

Source	DF	Adj SS	Adj SS	F-Value	P-Value
Tillage Method	1	7917654	7917654	3.08	0.082
Soil cover Practice	4	575390277	143847569	55.95	**0.000**
Replication	2	2652863	1326432	0.52	0.598
Season	3	383245902	127748634	49.69	**0.000**
Error	109	280252228	2571121		
Total	119	1249458923			

Note. Effect of tillage method not significant: P > 0.05, Effects of soil cover and season are significant: P < 0.05.

Maize Pure stand with mulch had a significantly higher yield compared to maize without mulch by an increase of 7.5%. However, the yield of intercropped maize with one row of soybean between maize row was similar to that of sole maize without mulch (p > 0.05; Table 4). Maize intercropped with two rows of soybean in between maize row had the lowest maize yield at only 4513 kg/ha (Table 4).

Table 4. Effect of intercropping pattern on yield

Treatments	Maize Yield	Soybean Yield
Mulched maize	6068A	NA
Maize without mulch	5616AB	NA
Maize with 2 rows of soybeans	4513B	582.8B
Maize with 1 row of soybeans	5071AB	476B
Pure soybeans	NA	989.5A

Note. Means that have same letters in the same column are not significantly different, NA (Not applicable).

Maize yield also significantly differed over seasons (Table 5) with higher maize yield in 2020A (6900 kg/ha) compared to 2019B (2122 kg/ha). Generally, maize yield obtained from season B was significantly lower than those obtained from season A (Table 5). Weather conditions were responsible for the different yield performance across seasons. Rainfall amount and number of rainy days were significantly different across seasons (Figure 1). For example, rainfall amount was highest in September 2020B at 384 mm with 21 rainy days, whereas in the same month of 2019B rainfall amount was the lowest at 22.6 mm with 17 rainy days. In the first rains of 2020A, the month of May had the highest rainfall amount at 221 mm and 23 rainy days, compared to season 2021A where rainfall amount was highest in the month of April with 140 mm and 15 rainy days. In 2020B despite high amount of rainfall compared to other seasons maize yield was moderately low probably due to the reduced number of rainy days (Figure 1). Therefore, the number of rainy days per month was very crucial in determining maize yield.

Table 5. Yield variation during the seasons

Season	2019B	2020A	2020B	2021A
Maize mean yield (kg/ha)	2122C	6900A	3257BC	4735B
Soybean yield (kg/ha)	205B	397AB	474A	563A

Note. Means that have same letters in the same row are not significantly different.

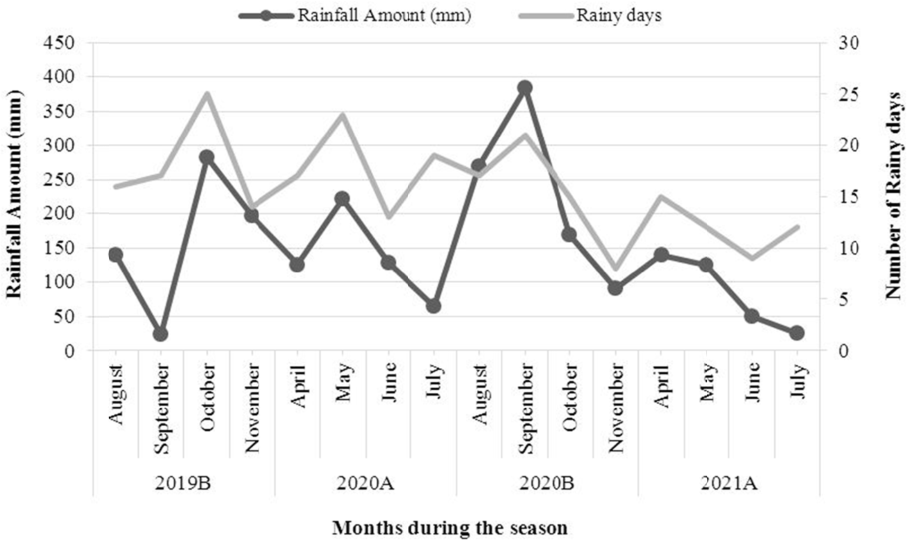

Figure 1. Rainfall amount and rainy days' distribution in the four seasons. *Note*. Rainfall amount and number of rainy days were significantly different within season

3.2 Effect of Intercropping on Soybean Yield

Soybean yield obtained from pure stand was significantly higher than those obtained from both the one and two-row intercropping patterns by an average of 46%. Soybean yield obtained from the intercrops were not significantly different (Table 4). Soybean crop yield was more negatively affected by intercropping compared to maize crop.

Soybean yield also significantly differed over seasons (Table 5). High soybean yield performance was observed in 2021A (563 kg/ha) and low performance in 2019B (205 kg/ha). Generally, soybean performance increased along 2019A, 2020A, 2020B and 2021A season. Tillage method did not significantly affect soybean yield ($P = 0.365$), whereas soil cover practice and season highly influenced soybean yield at ($p = 0.000$).

3.3 Land Equivalence Ratio (LER)

Land equivalence ratio (LER) of all the two intercropping patterns were above one. This implies intercropping has an advantage over sole maize stand (Table 6). Total LER between the two intercropping patterns were not significantly different. The LER for maize yield were not significantly different between the two intercropping patterns. However, LER for soybean yield was significantly different between the two intercropping patterns with two-row soybean intercrop having higher value (Table 6).

Table 6. Effect of intercropping pattern on LER

Treatments	Maize LER	Soybean LER	Total LER
Mulched maize	NA	NA	NA
Maize without mulch	NA	NA	NA
Maize with 2 rows of soybeans	0.71A	0.63A	1.34A
Maize with 1 row of soybeans	0.78A	0.47B	1.27A
Pure soybeans	NA	NA	NA

Note. Means that have same letters in the same column are not significantly different, NA (Not applicable).

3.4 Effect of Intercropping on Key Maize Crop Parameters

Results indicated that there was no significant difference among the different soil cover practices on the following maize crop parameters: plant height, 100 grain weight, ear height and field weight (Table 7). The number of plants per plot, number of ears per plot, leaf area index (LI) differed significantly (Table 7).

Table 7. Effect of intercropping on maize 100 grain weight, plant height, ear height, No. of ears/plot and plants/plot

Treatments	100 grain weight	Plant height	Ear height	No. of Ears/plot	No. of plants per plot	LAI	Field Weight (kg/ha)	Maize Yield (kg/ha)
SC1	9.4A	194.7A	89.52A	67.75A	67A	2.27A	11.69A	6068A
SC2	8.7A	188.3A	89.39A	70.42A	67.92A	2.1AB	11.08A	5616AB
SC3	8.2A	184.4A	88.57A	54.67B	52.79B	2.35A	9.26A	4513B
SC4	7.2A	186.4A	87.82A	61.50AB	56.67B	1.63B	10.70A	5071AB
SC5	NA	NA		NA	NA	NA	NA	NA

Note. Means that have same letters in the same column are not significantly different. SC 1 = Mulched Maize, SC2 = Control no mulch, SC3 = Two rows of soybean in between one row of maize, SC4 = One row of soybean in between one row of maize, SC5 = Sole soybean), NA = not applicable.

The number of plants per plot was not significantly different among the two sole maize treatments (Mulched and unmulched). Also, it was not significantly different among the two intercropping patterns (One row and two rows of soybean in between the maize rows). However, it was significantly different between sole stand and intercropping patterns by an average of 17.5%.

The number of ears per plot was not significantly different among the two sole maize treatments (Mulched and unmulched). Also, it was not significantly different among the two intercropping patterns (One row and two rows of soybean in between the maize rows). However, it was significantly different between sole stand and intercropping patterns by an average of 15.8%.

The leaf area index was significantly different among the treatments, intercropped maize with two rows of soybean in between maize row had the highest LAI at 2.35, followed by mulched maize at LAI of 2.27, then pure stand of maize without mulch at LAI of 2.1 and one row of soybean in between maize row at 1.63 (Table 6).

4. Discussion

4.1 Effect of Intercropping on Maize Yield

Maize grain yield was highest in the mulched sole maize due to the advantages that mulching offers such as control of weeds, maintaining an ideal soil temperature, aeration and moisture for normal maize growth. This trend was also observed in several studies (Dzvene et al., 2022; Nyirenda & Balaka, 2021; Uwah, 2011; Yin et al., 2019). In the study done by Nyirenda and Balaka (2021), the maize yield doubled due to the effect of mulching compared to unmulched maize. The intercropped maize with one row of soybean between maize row presented a higher yield than sole maize without mulching because soybean as a live crop mulch-controlled weeds in maize by impeding weed growth and reducing their ability to take away soil nutrients. The effect of interaction between intercropping and minimum tillage was such that intercropping improved maize yield in minimum tillage practices (Figure 2). The increase in grain yield of maize could result from maize-legume association due to symbiotic nitrogen fixation by legumes and absorption of nitrogen to the associated maize plants (Kheroar & Patra, 2013). Also, soybean improves growth and grain yield of maize with better utilization of nutrients (Saudy et al., 2021; Zhang et al., 2021, 2023). Hence, soybean could be used as an agroecological method to manage weeds in maize cultivation.

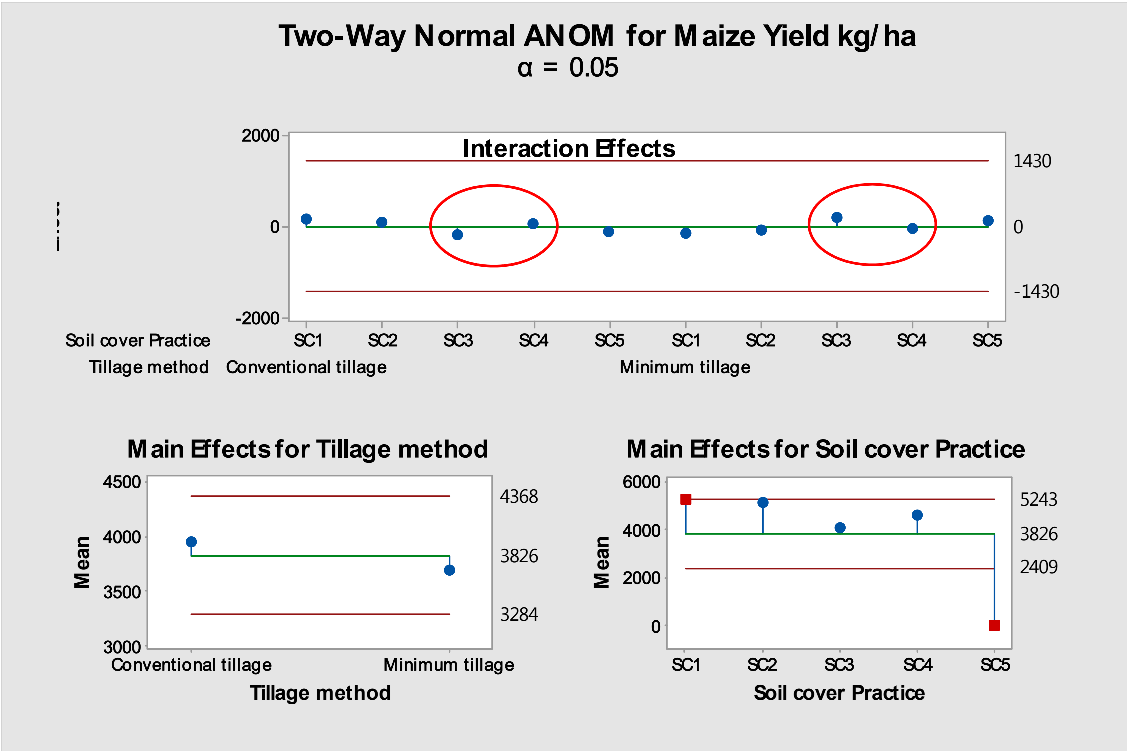

Figure 2. Interaction effects of tillage and soil cover practice on maize yield.

Note. Soil cover practice (SC) 1 = Mulched Maize, SC2 = Control no mulch, SC3 = Two rows of soybean in between one row of maize, SC4 = One row of soybean in between one row of maize, SC5 = Sole soybean). Circled in red, are the positive effects of minimum tillage-intercropping interaction.

4.2 Effect of Intercropping on Soybean Yield

Soybean crop was much affected by intercropping than the maize crop. This is probably due to the effect of shading by the maize crop making it yield much less than the sole crop by 46%. Similar trends were observed by Li et al. (2021), Muoneke et al. (2007) and Rahman et al. (2017). The result obtained from this study is in line with other studies where maize was found to have a competitive advantage over soybean by utilizing available resources more effectively (Connolly et al., 2001; Raza et al., 2021; Yu et al., 2023).

4.3 Land Equivalence Ratio (LER)

Maize with soybean intercrops resulted into a better output from the same size of land expressed as LER when compared with their sole crops. A LER above 1.00 has also been reported with maize-soybean intercropping (Aydın et al., 2021, 2021; Liu et al., 2018; Santo et al., 2023; Wei et al., 2022). Lower values of LER for soybean (Table 3) may be attributed to shading (Li et al., 2021; Muoneke et al., 2007; Rahman et al., 2017). They reported that light is the most important factor determining LER of maize and soybean intercropping and LER declines when legume becomes severely shaded. Furthermore, the higher productivity of the intercrop system compared to the sole crop may have resulted from complementary and efficient use of growth resources by the component crops (Matusso et al., 2013).

4.4 Effect of Intercropping on Key Maize Crop Growth Parameters

4.4.1 Leaf Area Index

Sole mulched maize, sole maize and intercropped maize row with two rows of soybean in between indicated the highest LAI that were significantly different from intercropped treatment with one row of soybean in between maize row. The intercropped treatments recorded on average lower values of LAI than sole crops. LAI is a measure for the total area of leaves per unit ground area and directly related to the amount of light that can be intercepted by plants (Addo-Quaye et al., 2011; Trimble, 2020). It is an important variable used to predict photosynthetic primary production, evapotranspiration and as a reference tool for crop growth. However, the lower LAI in the intercrops were insignificant to affect maize yield because the soybean density was still within the lower range that does not affect the maize growth.

Maize plant height, 100 grain weight, ear height and maize field weight were not significantly affected by intercropping. This is similar to studies done by Li et al. (2020, 2023) for maize-legume intercropping systems. The number of plants per plot, number of ears and grain yield were significantly affected by intercropping. Numerous studies done in China, Africa, Europe, Middle East (Alla et al., 2015; Huang et al., 2019; Salama et al., 2022; Toalma, 2006) reported that intercropping significantly affected the number of ears per plot. The maize-soybean intercropping patterns had significant effect on number of plants per plot, number of ears and grain yields during the four seasons. The LER of the two intercropping patterns were not significantly different. However, the maize yield, number of ears per plot and number of maize plants per plot of one row of soybean between one row of maize at 75 cm maize rows was significantly different from two rows of soybean in between one row of maize spaced at 90 cm. The sole maize with mulch observed a significant high yield at 8% increment compared to the conventional sole maize without mulch. Also, sole mulched maize and sole maize without mulch observed a significant maize grain yield with an average increase of 28% and 18% respectively, in comparison to intercrops. Sole soybean presented an increased yield of an average of 46% compared to the intercrops. This observation implies that maize has a competitive advantage over soybean in intercropping and should be adopted if the main crop for the farmers is maize.

5. Conclusion and Recommendation

The high LER above 1.2 for both intercropping partterns was due to better utilization of sunlight, soil nutrients because of a better LAI that averaged 2.0 for the intercrops and the symbiotic relationship between the crops. These combined factors enhanced maize yield performance as the main crop. The intercropping pattern of one row of soybean in between maize row spaced at 75 × 30 cm delivered better output in conservation farming. This intercropping pattern maximizes on available resources to produce similar results than the other intercropping parttern tested in this study. The practice of minimum tillage should also be adopted because it enhances the positive effects of soil cover (intercropping). Maize crop generally performed better during first season as compared to second season. We recommend farmers to utilize the first rains as the main maize production season.

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Authors Contributions

Otim Godfrey Anyoni did the study design and drafting of manuscript, Dr. Obia Alfred and Associate Prof Tumwebaze Susan were responsible for revising study design and manuscript, Ekwangu Joseph and Dr. Mudde Barnabas contributed to manuscript revision.

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