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Exploring Synergies: The Benefits of Maize - Legume Intercropping Systems in Eastern Uganda

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ABSTRACT

The study was carried out to investigate the agronomic and economic benefits of intercropping maize (Mz) with legumes. The experiment was arranged in RCBD with three replications during 2023 and 2024. The 8 treatments were conventional Mz (75 x 30cm), paired row (PR) Mz (100/50 x 30cm), 3 PR maize + 2 rows of each of groundnuts (Gn), soybeans (Sb) and beans (Bn) plus 3 pure legumes at 40x 10 cm. Results in 2023 and 2024 showed that PR maize + legumes significantly (P>0.05) increased maize plant height in both seasons, but the cobs per plant, 1000 seed weight and maize grain yield were not significant. During 2023, significant reductions were recorded in pods per plant (PP) and filled pods per plant (FPP). Percent filled pods (PFP) increased under Sb and reduced for Bn but was not significant for Gn. In 2024 the PP and FPP reduced for the intercrops while PFP were not significant. Height for the intercrops increased during 2023 and it raised only for Gn and soybeans in 2024. Legume intercrops yields declined during 2023 and 2024. The Partial land equivalent ratio (pLER) of Mz were less than unity during both seasons and Sb similarly recorded a low pLER during 2023 but a high pLER was recorded in 2024. Combined LER (cLER) for Mz and intercrops were significant (P>0.001) for groundnuts during both seasons. Mz/Gn recorded higher MAI & MEY during 2023 while Mz + Bn and Mz + Sb had low values. Mz/Gn produced high TMGYE during 2023 and the other treatments were low. Higher Aggresivity (A) was recorded under Mz/Gn during 2023 and 2024 with low A under Mz/Sb and Mz/Bn in 2024. The results indicate that Mz + Gn had higher synergies amongst the cropping combinations and recommended.

Keywords: Beans, conventional, groundnuts, land equivalent ratio, paired row maize, soybeans

INTRODUCTION

The latest projections by the United Nations suggest that the world's population could grow to around 8.5 billion in 2030 and 9.7 billion in 2050 [1]. The population in Sub-Saharan Africa (SSA) is growing exponentially. The region has to fulfill global food demand by sustainably producing adequate food and nutrition amidst challenges of inappropriate resources. Intercropping is a multiple cropping system that provides opportunity to harness available resources through cultivation of two or more crops planted simultaneously at the same time and in space in a specific row arrangement. [2]; [3]; [4]; [5]; reported intercropping to offer yield benefits over monocropping. Intercropping as an agroecosystem promotes plant diversity within crop fields, which enhances conditions for natural enemy populations [6] & [7]. The system provides the possibility of yield benefit and minimizes crops failure [8]. The principal reasons for smallholder farmers to intercrop are flexibility, low fixed costs for land as a result of a second crop in the same field, risk minimization against total crop failure, soil conservation, improvement of soil fertility, balanced nutrition, efficient taping of solar radiation, high water use efficiency, pests and diseases control [9] & [10]. The systems also improve ecosystem services, including biological control [11]. Another major benefit of intercropping is increased production per unit area compared to sole cropping through the effective use of resources (water, nutrients, and solar energy), reduced weed competitions and stabilized yield [12]. Intercropping cereals with legumes, is thus a food security strategy of subsistence farmers.

Intercropping is an ancient multiple-cropping system that is popular among smallholder farmers in developing countries today, due to its higher land and nutrient use efficiency, better economic returns and lower pest and disease incidence as compared to sole crops [13]. It offers sustainable practices that enhance increased food productivity, resilience to climate variability and reduce environmental impact to meet Sustainable Development Goal (SDG) 2 of Zero hunger. Practices of multiple cropping offer sustainable solutions by promoting practices that increase resilience to climate variability and reduce environmental impact (SDG 13). Traditional monoculture systems often rely heavily on chemical inputs, vulnerable to climatic fluctuations, have low productivity and not resilient to climate change. [5] reported that mono-cropping systems exhibit intra-specific location crop competition above and below ground surface. [14] noted that mono-cropping usually causes serious economic losses due to soil degeneration, decreased crop yield and quality, and increased disease incidence, and pest occurance. The researchers attributed it mainly to changes in soil microbial communities, nutrient availability and allelopathic effects. Numerous scientists; [15]; [2] & [16] expressed success of cereal-legumes (CL) intercropping systems compared to the monocrops. The CL intercropping systems therefore, increase net profits and address the challenges under SDG 1 of ending poverty. [17] recorded high productivity of the maize + legumes intercropping system with yield advantage of 2-63% and LER of 1.02-1.63 indicating efficient utilization of land resource under the CL system. [14] reported that the low- level technologies in mono cropping used by farmers and dry spells being experienced in SSA greatly promote soil degradation and restricts plant development and crop yields.

The conventional method of planting maize (75 x 30 cm) does not permit intercropping because of narrow interrow spacing and results in poor performance of the intercrops. Consequently, a new pattern of planting maize in paired rows with wide spaced multi-row strips maintaining normal plant population has been developed to enhance the resilience of farming systems to climate change. This additive series where the main crop population is adopted using paired rows (100/50 x 30 cm + 2 rows of a legume) maintains the maize plant population (55,000 plants per hectare), creating space for a legume intercrop (38%), relative to replacement system that reduces the population of maize base crop through crop substitution. The paired rows system not only gives high yield comparable to the conventional planting system, but also mitigates droughts, eases management and harvesting of intercrops without damage to the base crop. The performance of CL intercropping systems is basically determined by crop varieties and component crops planting densities, among other factors [9]. Several intercropping studies show that while the yield of an intercrop may be lower than that of one in pure stand, the productivity of land is typically higher for mixtures than for sole crops [18].]Muoneke *et al*.,[19] reported that optimum plant density and choice of suitable varieties are good measures of regulating competition among component crops for a profitable intercropping system. Given the significance of CL cropping systems, the present study evaluated the performance of Bazooka maize inter cropped with beans (NARO bean 6), Soybeans (MakSoy 3N) and Groundnuuts (Red beauty). A field experiment was conducted at the National Agricultural Research Organisation (NARO) -Ikulwe Station during the second rains seasons (September – December) of 2023 and 2024 to investigate the ecological, agronomic and economic benefits of intercropping maize with legumes. The aim was to understand how this practice enhances productivity, sustainability and resilience in agroecosystems with the specific objectives of evaluating the agronomic performance of maize - legume intercropping systems with respect to growth and yield comparison; and also to analyze using competitive indices, the economic viability of the maize-legumes intercropping compared to monocropping systems.

MATERIALS AND METHODS

Study Site

Ikulwe station is located in Mayuge District of Eastern Uganda at 00^0 26’23.2N 0330 28’40.9E, and 1209 meters above sea level. The rainfall at the site during the cropping season was 815.0 mm during 2023 and 638.0 mm during 2024 (Table 1). During 2023 the mean cropping season’s minimum and maximum temperatures were 19.8^{0}C and 30^{0}C against the annual average temperatures of 18.3^{0}C and 32^{0}C. The mean minimum and maximum temperatures during 2024 cropping season were 19.4^{0}C and 30.9^{0}C, respectively. The properties of the luvisol soil were established before conducting the study, and it was established that: the soil pH was 5.7 with textural sand (57%), silt (20%) and clay (23%). The amounts of organic matter (3.6%), available nitrogen (0.20%), exchangeable phosphorus (5.08 mg kg^{-1}) and 5.06 mg kg^{-1} exchangeable potassium were the established averages.

Study Area

Rainfall During 2023 and 2024:

Figure 1 indicates the rainfall received during the cropping seasons of September – December 2023 and 2024 as measured at Ikulwe Research station. The monthly total (seasonal) rainfall during 2023 was higher (815.0 mm) than during 2024 (638.0 mm).

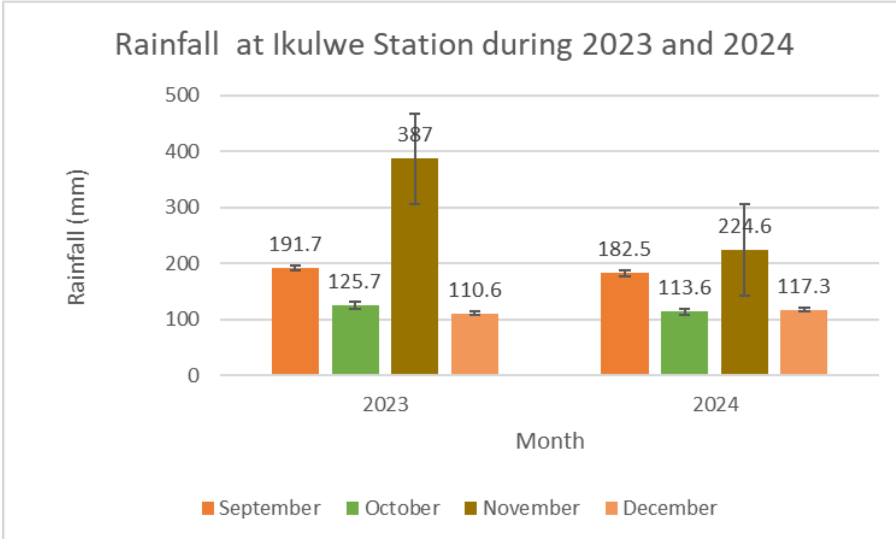

Figure 1: Rainfall during cropping season for 2023 and 2024

Experimental Design and Treatments:

The experimental design was a randomized complete block design (RCBD) with three replications. Each Plot size of 10m x 10m were maintained throughout with a 2m strip between plots. The experiments were conducted during the two growing seasons of September – December in 2023 and 2024 with 8 treatments each year namely; T_1= Conventional maize (75 x 30 cm), T_2 = Paired row maize (100/40 x 30cm), T_3= Paired row maize (100/40x30 cm) + 2 rows NAROBEAN 6 (40x 10 cm), T_4= Paired row maize (100/40 x 30cm) + 2 row MAKSOY 3N (40x 10 cm), T_5= Paired row maize (100/40 x 30cm) + 2 rows Red-beauty ground nuts (40 x10 cm), T_6= NARO bean 6 (40x 10cm), T_7= Red-beauty groundnuts (40x10cm), T_8= Maksoy 6N Soybeans (40x10cm). The maize seeds were planted using a chop and plant method in all treatments with two seeds per hill and all the legumes were planted with one seed per hill between the paired rows of maize at the same time. The pure legumes were also established at the time of planting maize. Fertilizers were applied to maize at 100 kg ha^{-1}, 60 kg ha^{-1}, 40 kg ha^{-1} of NPK in the form of Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MOP), respectively. The entire TSP and MOP were applied as basal at planting and Urea was top dressed in two equal splits at 30 days after emergence (DAE (knee high stage) and 55 DAE (tasselling stage) to maize crop only. No fertilizers were applied to the legumes.

Data Collection, Measurement and Analysis

Growth and Yield Components and Yield Data:

Ten legume plants were selected per treatment and tagged for biometric data measurements at 21 DAE on plant height during peak vegetative stages. At tasselling stage for maize, plant height was taken from the base of the plant to the base of the flag leaf. Prior to harvest 30 plants per plot were randomly selected (excluding border hills) and tagged for collection of data on plant height, cobs per plant and plant height for the legumes. The maturity periods (harvest time) for the crops were recorded. At harvest of maize (120 DAE), ground nuts (90 DAE), soy beans (100 DAE) and beans (60 DAE), the plants within the net plot (90 m2) were harvested per plot, dried on a cemented floor and carefully threshed, cleaned and further dried in the Agronomy Field Laboratory to record the data on grain yield. The later was obtained by extrapolating to Mt ha-1. Data was also collected on number of cobs per plant from 30 plants in the net plot and 1000 seeds weight was determined for the different maize treatments. Data were analysed using GenStat statistical package (GenStat, 2013) to generate analyses of variance (ANOVA) to compare the yield differences of the different treatments.

System Productivity and Economic Returns:

Land Equivalent Ration (LER):

The LER defined as the relative land area required as a sole crop to produce the same yield as under intercrops was calculated using the formula; LER= $\sum (Yp_i/Ym_i)$ Where Y_p is the yield of each crop or variety in the intercrop or polyculture and Ym is the yield of each crop or variety in the single crop or monoculture. LER indicates the efficiency of intercropping, using the environmental resources compared to monocropping [20] (Mead & Willey 1980). When LER > 1 the intercropping favours the growth and yield of the species. In contrast, when LER < 1 there is no intercropping advantage.

Area Time Equivalent Ratio:

The Area time equivalent ratio (ATER) was calculated using the following formula: ATER= (LERa /LERb) x (DC/ Dt), based on the duration to harvest for sole conventional maize (120 days), and intercropped with beans (60 days), Groundnuts (90 days) and Soybeans (100 days); where LERa is land equivalent ratio of base crop, LERb is land equivalent ratio of the intercrop, DC is duration (days) taken by base crop and Dt is days from planting to harvesting of the intercrop. Area time equivalent ratio (ATER) provides more realistic comparison of the yield advantage of intercropping over monocropping in terms of time taken by component crops in the intercropping systems. ATER was calculated using the following formula:

Monetary Advantage Index (MAI):

The monetary advantage index (MAI) was determined as described by [21] Gosh (2004). MAI = value of combined intercrops × (LER−1) / LER. The higher the index value, the more profitable is the cropping system [22] (Dhima *et al.,* 2007).

Maize Equivalent Yield:

The maize equivalent yield (MEY) for 2023 and 2024 were calculated in Kg ha^{-1}, based on current market price in Uganda Shillings (UGX) of P_r (Maize): 1000, P_x (Beans): 3500 UGX, P_x (Soybeans):4000 UGX, and P_x (Groundnuts): 5000 UGX. The MEY was calculated to compare system performance by converting the yield of non-maize crops into equivalent maize yield on a price basis, using the formula: MEY = Yx (Px/Pr)

Where Yx is the yield of non-maize crop (kg Ha^{-1}), Px is the market price of non-maize crops at harvest.

Total Maize Grain Yield Equivalent:

The total maize grain yield equivalent (TMGYE) was calculated for the different intercropping systems by summing the yield on intercropped maize and the MEY under intercropping using the formula; TMGYE = Yr + MEYx. Where Yr is the yield of maize and MEYx is the maize equivalent yield for the intercrop with maize.

Aggressivity:

Aggressivity value (A) is an index that determines the competitive ability of a crop when grown in association with another crop. It measures how much the relative yield of one crop component is greater than that of another [23] (McGilchrist 1965). An aggressivity value of zero indicates that component crops are equally competitive. Aggressivity (A) is expressed as LERa x Pbi or LERb x Pbi, where Pbi is the proportion of base crop in mixture with intercrop and Pi is the proportion of the intercrop in mixture. If Ab or Ai = 0, both crops are equally competitive. When Ab is positive then the base crop species is dominant and when it is negative then the intercrop is the dominating species. It may thus be put as Ai = Yi /Yb × Pri - Yii / Yi × Pr; where Yi is the yield of maize under intercropping, Yb is the yield of the sole maize and Pri is the sown proportion of maize in mixture. Yii is the yield of the legume intercrop, Yi is the yield of the sole intercrop and Pr is the sown proportion of the legume intercrop.

RESULTS

Plant Height, Cobs Per Plant, 1000 Seed Weight and Yield of Maize During 2023 and 2024

The data on plant height and grain yield for maize during 2023 and 2024 is presented in Table 1.

Table 1: Maize plant height and grain yield during 2023 and 2024 at Ikulwe station

	2023		2024	
Treatment	**Plant height (cm)**	**Yield (Kg ha^{-1})**	**Plant height (cm)**	**Yield (Mt ha^{-1})**
Sole maize conventional	236.7b	7.82	244.7b	7.68
Paired maize	245.6a	7.78	252.3a	7.76
Paired maize + groundnuts	250.7a	7.47	252.3a	7.33
Paired maize +soybeans	245.0a	7.50	247.7a	7.36
Paired maize + beans	270.3a	7.40	251.3a	7.32
P-value	0.05	NS	0.04	NS
LSD (P≤0.05)	32.1	1.06	6.07	0.55
CV (%)	6.7	8.5	3.5	6.3

Note: Values with different letters in a column are significantly different at P≤ .05, NS: Not Significant

Changing of maize rows from the conventional orientation (50/100x30cm) to pure paired row maize or paired maize intercropped with legumes significantly (P>0.05) increased maize plant height from 236.7 cm to 245-270 cm in 2023 and from 244.7 cm to 247.7 - 252.3 cm in 2024 seasons. The maize grain yield was however, not influenced by paired maize rows or by legume inter crops. The data collected on number of cobs per maize plant from the net plot and 1000 seed weight were not significant amongst the treatments.

Total Pods, Filled Pods, Percent Filled Pods, Plant Height and Yield for Groundnuts, Soybeans and Beans During 2023 at Ikulwe Station

The data on total number of pods, filled pods, percent pods filled, plant height and yield for groundnuts, soybeans and beans during 2023 is presented in Table 2. There was significant (P≤0.05) reduction in total pods per plant by 54%, 84% and 31% for groundnuts, soybeans and beans when introduced as intercrops in paired maize. The filled pods per plant similarly declined by 58%, 73% and 61% for groundnuts, soybeans and beans respectively. Groundnuts in paired maize did not influence the percent filled pods (PFP) but significantly (P>0.05) increased the PFP for soybeans by 78% as reduced (P>0.05) under beans intercrop by 43.7%. The plant height of intercropped ground nuts, soybeans and beans significantly (P>0.05) increased by 12%, 23% and 12% respectively due to introduction of the legume inter crops in paired maize. The yields reduced by 26%, 80% and 58% respectively for groundnuts, soybeans and beans (38% pure stand population) when introduced in paired maize

Table 2: Pods, plant height and yield of groundnuts, soybeans and beans inter cropped at Ikulwe station during 2023

Treatment	Pods plant $^{-1}$	Filled pods plant^{-1}	Percent filled pods	Plant height (cm)	Yield (Mt ha^{-1})
Groundnuts in paired maize	16.07b	11.67b	72.62	53.61a	1.70b
Pure groundnuts	34.57a	27.87a	80.62	47.70b	2.56a
P-value	< 0.001	< 0.001	NS	0.005	0.001
LSD (P≤0.05)	3.50	2.9	15.2	3.49	0.39
CV (%)	5.1	6.5	8.3	3.0	7.6
Soybean in paired maize	9.80b	7.83b	80.0a	122.0a	0.33b
Pure soybeans	63.00a	28.60a	45.0b	99.0b	1.68a
P value	0.004	< 0.001	0.04	0.02	<.001
LSD (P≤0.05)	8.90	4.80	22.4	16.50	1.08
CV (%)	7.0	15.7	18.7	4.0	8.3
Beans in paired maize	4.80b	1.24b	25.80b	41.90a	0.36b
Pure beans	7.00a	3.21a	45.85a	37.50b	0.85a
P-value	0.14	0.05	0.04	0.03	0.02
LSD (P≤0.05)	3.30	1.90	19.2	13.26	0.46
CV (%)	25.1	37.9	16.5	14.7	16.8

Note: Values with different letters in a column are significantly different at P≤ .05, NS: Not Significant

Total Pods, Filled Pods, Percent Filled Pods, Plant Height and Yield for Groundnuts, Soybeans and Beans During 2024 at Ikulwe Station

The data on total number of pods, filled pods, percent filled pods, plant height and yield for groundnuts, soybeans and beans during 2024 is presented in Table 3. Total pods, filled pods per plant and grain yield significantly (P>0.05) reduced with introduction of groundnuts, soybeans and beans inter crops in paired maize. The groundnuts, soybeans and beans pods per plant reduced by 48%, 32% and 59% respectively as the filled pods per plant declined by 49%, 25% and 43% respectively and the percent filled pods were not significant for all the treatments. Introduction of the legume inter crops which occupied 38% of the pure crop acreage in paired maize significantly (P≤0.05) increased the plant height of ground nuts (28%) and soybeans (31%) inter crops but the height for beans crop was not significant. Lower yields recorded for the legumes that were only 38% of the pure crops were 39%, 39% and 28% of the pure crops (100%) yield.

Table 3: Pods, plant height and yield of groundnuts, soybeans and beans inter cropped at Ikulwe station during 2024

Treatment	Pods plant $^{-1}$	Filled pods plant^{-1}	Percent filled pods	Plant height (cm)	Yield (Mt ha^{-1})
Groundnuts in paired maize	16.07b	10.50b	75.60	54.0a	0.07b
Pure groundnuts	33.0a	21.33a	64.60	42.0b	0.18a
P-value	0.01	0.007	NS	0.06	0.003

LSD (P≤0.05)	13.13	6.20	15.40	10.82	0.09
CV (%)	16.5	11.10	18.60	6.40	5.60
Soybean in paired maize	10.4b	6.27b	60.30	116.0a	0.50b
Pure soybeans	33.0a	25.00a	75.70	88.7b	1.27a
P value	0.06	0.001	NS	0.001	0.05
LSD (P≤0.05)	15.66	4.36	17.5	5.68	0.65
CV (%)	20.1	12.0	12.3	1.50	24.0
Beans in paired maize	4.33b	1.18b	27.3	41.7	0.30b
Pure beans	7.33a	2.83a	38.6	39.3	1.08a
P-value	0.016	0.03	NS	NS	0.03
LSD (P≤0.05)	2.07	1.31	12.4	12.9	0.62
CV (%)	15.0	28.7	18.2	14.1	26.5

Note; Values with different letters in a column are significantly different at P≤ .05, NS: Not Significant

System Productivity and Economic Returns

Land Equivalent Ratios during 2023 and 2024:

The data on land equivalent ratios (LER) for maize and legume intercrops during 2023 and 2024 is indicated in Table 4. Introduction of legume intercrops in maize during 2023 and 2024 had no effect on the partial land equivalent ratio (pLER) of maize. The pLER of maize intercropped with beans, groundnuts and soybeans were all less than unity and ranged between 0.90 and 0.94. The pLER of groundnuts reduced to a significantly P>0.05) low value of 0.7 during 2023 and 0.39 in 2024. The value similarly declined significantly P>0.05) to 0.42 (2023) and 0.28 (2024) for beans. Soybean recorded a lower pLER of 0.2 during 2023 and a higher pLER of 0.40 during 2024. The combined LER (cLER) for maize and the 3 legume intercrops differed significantly ((P≤0.001) with high scores for groundnuts during 2023 (1.58) and 2024 (1.31). Sole conventional maize recorded a LER/cLER of 1.0.

Table 4: Land equivalent ratio as influenced by intercropping during 2023 and 2024

	2023			**2024**		
Treatment	**pLER maize**	**pLER legumes**	**LER/cLER**	**pLER maize**	**pLER legumes**	**LER/cLER**
Sole maize conventional	-	-	1.0b	-	-	1.00c
Paired maize/groundnuts	0.92	0.66a	1.58a	0.91	0.39a	1.31a
Paired maize/soybeans	0.90	0.20c	1.10b	0.94	0.40a	1.34a
Paired maize/beans	0.94	0.42b	1.36a	0.90	0.28b	1.18b
P-value	NS	<0.001	<0.001	NS	<0.001	<0.001
LSD (P≤0.05)	0.07	0.06	0.14	0.07	0.04	0.12
CV (%)	3.9	7.3	4.2	4.0	6.2	4.1

Note. Values with different letters in a column are significantly different at P ≤ 0.05. LER: Land equivalent ratio, pLER: Partial land equivalent ratio, cLER: Combined land equivalent ratio.

Area Time Equivalent Ratio During 2023 and 2024:

The Area time equivalent ratio (ATER) data for 2023 and 2024 is indicated in Table 5. The results indicated high ATER for maize + beans (4.5 & 6.4) for 2023 and 2024 than under the other intercropping combinations (1.85 - 3.10) during the 2 years.

Monetary Advantage Index During 2023 and 2024:

The monetary advantage index (MAI) values for 2023 and 2024 are indicated in Table 5. The higher the index value, the more profitable is the cropping system [22] (Dhima *et al.* 2007).

Maize + groundnuts recorded significantly (P>0.05) high MAI (0.68) during 2023 than other treatments. A high MAI (0.18) was observed under maize + beans during 2024. Generally low MAI were recorded under the maize + soybeans intercropping combination.

Total Maize Grain Yield Equivalent During 2023 and 2024

Table 5: Indices and equivalent ratios for maize intercropped with groundnuts, soybeans and beans during 2023 and 2024

Cropping system	Growing season	Yield (Mt Ha^{-1})		ATER		MAI		MEY		TMGYE (Mt ha^{-1})		Aggressivity	
		Maize	Legume									Maize + Legume	
Maize pure	-2023	7.82	-	-		-		-		7.82	-		
	-2024	7.68	-	-		-		-		-	7.68		
Beans pure	-2023		0.85										
	-2024		1.08										
Groundnuts pure	-2023		2.56										
	-2024		0.18										
Soybeans pure	-2023		1.65										
	-2024		1.27										
Maize + Beans	-2023	7.4	0.36	4.5a	-	0.28b	-	1.26b	-	8.66b	-	0.52b	-
	-2024	7.32	0.3	-	6.4a	-	0.18a	-	1.05b	-	8.37b	-	0.45b
Maize + G/nuts	-2023	7.47	1.7	1.85b	-	0.68a	-	5.95a	-	13.42a	-	0.60a	-
	-2024	7.33	0.07	-	3.1b	-	0.01b	-	0.25c		7.58c	-	0.50a
Maize + Soybeans	-2023	7.5	0.33	2.40a	-	0.15c	-	1.16c	-	8.66b	-	0.42c	-
	-2024	7.36	0.5	-	2.8b	-	0.01b	-	1.75a	-	9.11a	--	0.51a
P-value				< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	0 .001
LSD ($P \leq 0.05$)				0.25	0.32	0.09	0.02	0.03	0.03	0.04	0.52	0.05	0.03
CV (%)				10,0	4.6	8.7	18.1	11.7	15	0’2	3.1	5.4	3.3

Values with different letters in a column are significantly different at P<0.05

Mt Ha^{-1} = metric tons per hectare, ATER = Area time equivalent ratio, MAI = monetary advantage index, MEY= maize equivalent yield, TMGYE = Total maize grain yield equivalent.

All the intercropping treatments resulted in substantially higher total maize grain yield equivalent (TMGYE) than sole crop of maize during 2023 and 2024 (Table 5). The highest TMGYE of 13.42 Mt Ha^{-1} during 2023 was recorded under maize + groundnut followed by maize + beans and maize soybeans intercropping systems that were t par (8,66 Mt Ha^{-1}). During 2024 maize + soybeans recorded high TMGYE (9.11 Mt Ha^{-1}) followed by maize + beans (8.37) and low under maize + groundnuts (7.58 Mt Ha^{-1})

Aggressivity during 2023 and 2024:

The aggressivity (A) of the different maize/ legume intercropping systems during 2023 and 2024 is shown in Table 5. Higher levels of A were observed under maize + groundnuts during 2023 (0.60) and 2024 (0.50). During the 2023 season, a lower A (0.42) was realized under maize + soybeans, and maize + beans similarly produced lower A (0.45) in 2024.

DISCUSSION

Plant Height, Cobs Per Plant, 1000 Seed Weight and Yield of Maize During 2023 and 2024

The increased (P>0.05) maize height in 2023 (4-14%) and during 2024 (1-3%) due to changes from conventional to paired rows could be ascribed to etiolation of maize due to competition for solar radiation under the closely spaced paired rows of maize (50 cm) and between the base crop (maize) and legume intercrops. In an attempt to offset the competition the for light, the intercropped maize plants grew taller than sole maize plants. The results are similar to results observed by [16]. Conversely, [24] found that sole maize was higher than the intercropped maize plants probably because the groundnuts plants were aggressive enough to out compete the maize plants for available growth resources like soil moisture, nutrients, light and space. In both seasons of the trial, row arrangement and introducing intercrops had no significant (P>0.05) effects on number of cobs per plant and 1000 seed weight. This implies that there was little inter-specific competition between the component crops for available resources. The results of this study are in line with those of [25]. The non-significant yield for conventional, pure paired rows and paired row maize with legume intercrops could have resulted from similarity in efficient absorption of above and below ground resources for growth and development under the maize row arrangements. The results are supported by [26] who reported similar maize grain yield and biomass for the conventional and double rows system. [27] reported higher maize output under intercropping with Groundnut variety SAMNUT 24. Talukdar *et al,.*[28], similarly reported higher growth, yield parameters and yield of maize (5.54 Mt ha-1) under maize + soybeans than maize + french bean system. Paired rows behave like border rows and thus absorb optimum resources like conventional maize. The higher yield attributes in border rows reported by the researchers were attributed to higher nutrient supply, favorable micro climatic conditions and higher crop growth. [29] reported paired rows (2:2) ratio of maize and soybeans as superior to other treatments in respect to growth, yield attributes and grain yield. Higher gross returns, net returns, LER (1.80) and B:C ratio (3.04) were observed under the crop combination.

Total Pods, Filled Pods, Percent Filled Pods, Plant Height and Yield for Groundnuts, Soybeans and Beans During 2023

The significant (P≤0.05) reductions in total pods per plant by 54%, 84% and 31% following the introduction in paired maize of groundnuts, soybeans and beans intercrops may be attributed to reduced deposition of assimilates into the legume plants due to reduced nutrient uptake following increased interspecific and intraspecific competition between crops. The filled pods similarly declined by 58%, 73% and 61.4% for groundnuts, soybeans and beans respectively due to possible similar reasons. Percent pods filled for groundnuts intercrops in paired maize was not significant(P≤0.05) but increased for soybeans (78%) and reduced under beans (43.7%). The high percent pods filled for soybeans (78%) and reduced values for beans (43.7%) may be attributed to the higher depositions in the lower number of pods as sink organs for soybeans and high number of pods for beans intercrops relative to sole beans. Source organs (photosynthetically active part) provide a net uptake of resources whilst sink organs have a net drawback of resources. Only what is available can be consumed for growth and maintenance and how much is produced by plants also depends on demand. Yield reduced for groundnuts (26%), soybeans (80%) and beans (58%) intercrops in maize that were 38% of pure stand population. This may be attributed to the high percent reductions in the pods per plant for groundnuts (53%), soybeans (84%) and beans (31%), coupled with the reduced plant population for the legume crops of 38% of the pure stand. Therefore, there was a higher reduction in yield for soybean, followed by groundnuts and least for beans due to intercropping. Intercropping treatments resulted into significantly (P≤0.05) increased ground nuts, soybeans and beans plant height by 12%, 23% and 12% respectively. This could have resulted from longer internodes in an effort to reach incident solar radiation under partial light conditions to the intercrops, that were in competition with the base maize crop.

System Productivity and Economic Returns

Land Equivalent Ratios during 2023 and 2024:

Legume intercrops in maize had no effect on the pLER of maize but the pLER of maize intercropped with beans, groundnuts and soybeans reduced to less than unity during 2023 and 2024. The pLER of groundnuts, soybeans and beans similarly reduced significantly (0.001) to during 2023 and 2024. Values of pLER that were less than 1 imply that the intercropping had lower yield potential and performed less efficiently than monoculture system. More land must be used for thr intercrop in order to match the productivity of the monoculture, This may be associated with yield reduction. The results may be attributed to lower utilization of available land, nutrients or other resources due to resource competition as would be under a pure crop and is a sign of resource competition or incompatibility between the crops with reduced economic returns. All the cLER were greater than 1 and increased with introduction of groundnuts (1.58) followed by beans (1.36) during 2023. This implied a 58% and 36% higher efficiency for the cropping systems respectively. In 2024, groundnuts and soybeans registered high cLER than beans. Generally, all the cLER designated higher productivity for maize intercropping with the legumes than monocropping. The high land use efficiency may be ascribed to complementary relationships between the crops where they utilize different resources (like light, water or nutrients) in ways such as plant height, depth of roots, nitrogen fixation etc. that improves soil health, and maximize overall productivity. Higher cLER can lead to better economic returns for farmers from multiple crops on the same land, leading to higher total yields and potentially higher profits The cLER of more than 1 also promotes ecological sustainability by reducing the need for synthetic inputs, maintaining biodiversity, and enhancing soil fertility. The results are in line with the range reported by Agugi *et al.,* (2024) who recorded the high cLER (1.3) when maize was intercropped with Groundnut variety, SAMNUT 23. Anyoni *et al.*, [30] similarly recorded cLER of above 1.2 for both maize+ soybeans intercropping patterns. [31] also noted that maize-soybean intercropping system showed better productivity (LER = 1.73) and economic viability than the kidney bean and groundnut systems at both sites. High LER with a yield advantage of 14-32% was similarly reported by [32] for maize + soybeans intercropping system. Li *et al.*, [2] recorded higher LER for intercropping than monocroping systems. [33] reported that maize + peanut gave the highest mean LER (1.81) followed by maize + Cowpea (1.74) and maize + soybean (1.59) all sown in the ratio of 2:1. Mogiso & Nazib [34] obtained high LER (1.52 &1.62) and MAI from 1:1 maize-common bean intercropping. The yield advantage obtained due to intercropping was attributed to a better use of resources by crops grown in combinations, as compared to sole stands. [35] and [36] indicated that cereal-legume interropping resulted in higher productivity than sole cropping under limited moisture conditions because of increased water use efficiency.

Area Time Equivalent Ratio During 2023 and 2024:

High ATER were recorded for maize+ beans during 2023 (4.5) and 2024 (6.4) than under the other intercropping combinations (1.9-3.1). The results imply that maize + beans intercropping system utilized both land and time 5 to 6 times better than monocropping systems. The maize + soybeans and maize + groundnuts similarly, utilised the land and time 2 -3 times better than monocropping systems. Since all the ATER were more than 1, this indicated that intercropping was more efficient than monocropping. The intercropping systems also produced a higher yield per unit area and time compared tomonoculture, demonstrating a yield advantage from intercropping. [37] reported ATER of 1,57 for cocoyam + cowpeas intercropping system. The results thus showed that more land and/ or time was used effectively in the intercropping systems with synergy. The maize + beans intercropping system with higher ATER enhances higher productivity and sustainability per unit area and time than the other systems or monocropping.

Monetary Advantage Index During 2023 and 2024:

Maize + groundnuts recorded significantly (P>0.05) high MAI (0.68) during 2023 than other treatments. A high MAI (0.18) was observed under maize + beans during 2024. Generally low MAI were recorded under the maize + soybeans intercropping combination. The results indicated that maize + groundnuts had higher economic benefits/ profitability and better resource use (eg N fixation) than growing the 2 crops separately during 2023. The high MAI may be related to the higher yields associated with high rainfall during 2023. The positive MAI signaled that intercropping systems have capacity to increase incomes and sustainability. Cropping systems with high MAI also had better risk management characteristics. The higher the index value, the more profitable is the cropping system. The results of the current study are supported by [38] who observed better yield advantages, MAI and economic returns under intercropping of maize with Faba beans than other intercropping system as justified by the higher LER and MAI. [39] in a related study recorded higher yield and economic returns from intercropped French beans than soybeans. Mekuanint (2020) reported maize - soybean combinations as more advantageous in terms of yield and monetary advantage for smallholder farmers. [22] who used an additive intercropping system of soybeans at 50% planting density and showed a yield advantage of 23.71% over sole cropped maize.

Maize Equivalent Yield during 2023 and 2024:

Significantly (P>0.05) high MEY (5.95Mt Ha^{-1}) was recorded in 2023 under groundnuts intercrop. The increased MEY may be attributed to the high relative groundnuts yield (1.70 Mt Ha^{-1}) recorded when planted as an intercrop in maize during 2023. The high yield could have resulted from the higher amount of rainfall received in 2023. Similarly, a significantly (P>0.05) high MEY (1.75 Mt Ha^{-1}) was also observed under soybeans intercrop during 2024 due to the high grain yield (0.5 Mt Ha^{-1}). Regardless of the ratio in which Maize + peanut was planted [33] reported high mean MAI and Mean Yield Index (MYI) with a greater biological relationship and effective competition for maize + peanut and recommended the crop combination. The studies above support the observed high MEY under groundnuts and soybeans intercrops.

Total Maize Grain Yield Equivalent During 2023 and 2024:

Higher TMGYE (13.42 Mt Ha^{-1}) was under maize + groundnut during 2023 followed by the maize + soybeans and maize/beans intercropping systems that were at par (8,66 Mt Ha^{-1}). During 2024 maize + soybeans recorded high TMGYE. All the treatments resulted in substantially higher total maize grain yield equivalent (TMGYE) than sole crop of maize during 2023 and 2024. Increase in TRGYE as a result of intercropping rice with the three legume crops under this study were also reported by [15].

Aggressivity during 2023 and 2024:

Maize + groundnuts recorded high levels of aggressivity (A) during 2023 and 2024. Low A values were under maize + soybeans and maize + beans in 2023 and 2024. The higher aggressivity recorded for Maize + groundnuts implied existence of higher relative yield difference between one crop component and another. Maize out competed the legume in the mixture, thereby increasing overall quality, while the legume is seen as beneficial for improving the quality of the cropping system by fixing nitrogen in the soil and enhancing soil health. To optimize the benefits of maize-legume mixture, careful consideration of planting ratios and spacing is crucial to ensure both crops can access sufficient resources. The findings of the current study are supported by [33] who reported that ntercropping legumes with maize appeared to be more aggressive than sole planting of maize or legumes.

CONCLUSION

The results of this study demonstrated that change from Conventional to PR maize + legumes significantly increased maize plant height but the number of cobs per plant, 1000 seed weight and maize grain yield were not significant. Mz intercropped with 38% of sole-cropped legume varieties resulted in significant reductions in PP for the latter during 2023. The PFP increased under Sb and reduced for Bn but was not significant for Gns due to intecropping. During 2024 the PP and FPP reduced for all the intercrops, while PFP were not significant. Height for all the intercrops increased significantly during 2023 and in 2024 for Gn and Sb but was not significant for Bn. The yield of legumes and pLER reduced for all intercrops during 2023 and in 2024. The cLER were significant during 2023 and 2024 and Gn recorded high MAI during 2023 than the other intercrops. Gn intercrop similarly recorded high MEY in 2023 and a high MEY was observed under Sb intercrop during 2024. Low MEY values were however recorded under beans during both years. Mz/Gn produced high TMGYE during 2023 compared to the other treatments though during 2024 Mz/Sb scored high TMGYE. High A was recorded under Mz/Gn during 2023 and 2024 and since Mz + Gn had higher synergies amongst the cropping combination it is hereby concluded based on the current investigations that Mz + Gn is the most appropriate maize based intercropping system in Eastern Uganda.

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Competing Interests

Authors have declared that no competing interests exist.

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