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Performance of Direct-Seeded Upland Rice-Based Intercropping Systems Under Paired Rows in East-West Orientation

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Abstract

Production potential of rice based intercropping systems with legumes in Uganda is little known. Studies were conducted at Ikulwe Station of the National Agricultural Research Organisation to evaluate upland rice-based intercropping systems under paired-rows in the EW direction. A randomized complete block design with 3 replications was adopted during 2022 and 2023 with 8 pure stand and intercropped treatments. Adjustment from conventional planting to paired rows recorded high rice height and significant 1000 seed weights. In 2022 the 2 pure rice treatments produced significantly more tillers and panicles but legume intercrops reduced numbers of rice tillers and panicles. Intercropping significantly reduced the beans height (48%) and soybean pods (41%) during both years and also reduced the pods filling for beans (66%), groundnuts (36%) and soybeans (18.3%) during 2022. Although paired rice did not influence rice yield during both years, lower mean yield for rice (19.8%), beans (35%), groundnuts (33%) and soybeans (30.5%) were recorded. Lower legume intercrop yields were similarly recorded for beans (70%), groundnuts (73%) and soybeans (62%) during 2023. Partial (p) land equivalent ratios (LER) for intercrops were not significant and less than unity, but the one for rice intercropped with beans increased to more than unity (1.06) during 2023. All combined LER for rice-legumes were more than unity and the pLER of sole crops was 1.0. Rice + beans recorded high area time equivalent ratio during the 2 years while high relative equivalent yield and monetary advantage indices were recorded under rice + soybeans. Rice was more aggressive than other crops and intercropped treatments recorded higher Total Rice Grain yield equivalent (TRGYE) than sole rice. Rice + soybeans (2022) and rice + beans (2023) scored higher TRGY. The findings suggest that farmers can intercrop soybean in rice under paired rows in EW orientation for more benefits.

Keywords: conventional planting, intercrops, legumes, sole rice

1. Introduction

Rice (*Oryza sativa* L.) is a staple food for more than half of the world's population. It is grown in over 100 countries with 90% of the total global production from Asia and consumed by more than half of the world's population (Emerick & Ronald, 2019). It is also one of the three most important cereal crops globally (Banjara et al., 2021). Rice has the potential to improve farmers' incomes and livelihoods, thereby contributing to socio-economic growth of many rural farm households in Uganda (Oryokot et al., 2004), and is an important food security factor (UNRDS, 2008-2018). Rice is now widely grown particularly in the Eastern and Northern regions of Uganda (Kijima et al., 2011). In the past, rice production was mainly limited to irrigation schemes that had been established by the government in the 1960's and 1970's. In 2021, rice paddy production for Uganda was 727,000 Mt from 373,000 Mt (2020), an increase of 95%. The increase was attributed to amongst others; introduction and adoption of improved agronomic practices, development of high yielding, pests, disease and drought tolerant cultivars besides other technologies (Uganda Statistical Abstracts 2021). The introduction of upland rice in the early 2000 has changed the trend as more small scale and a few large-scale farmers take on the relatively new enterprise (UNRDS, 2008-2018). The production of upland rice in Uganda is still to a large extent done by resource poor farmers who hardly use external inputs. Therefore, the yields and consequently incomes from upland rice are still low relative to paddy rice (Defoer et al., 2004). In Uganda, the production of upland rice by small scale farmers has been associated with challenges. Therefore, upland rice has failed to meet the diversified needs of small holder farmers. These conditions necessitate a shift from mono-cropping to intercropping.

The population in Sub-Saharan Africa (SSA) is growing exponentially and the region has to fulfill its obligation of producing adequate food and nutrition. A beautiful approach for increasing productivity and labor utilization per unit area of available land is to intensify land use**.** Intercropping systems with legumes, is a food security strategy of small-holder, resource-poor farmers in SSA. The principal reasons for smallholder farmers to intercrop are flexibility, risk minimization against total crop failure, soil conservation and improvement of soil fertility, weed control and balanced nutrition. In intercropping systems, land equivalent ratio (LER), area time equivalent ratio (ATER), monetary advantage index (MAI), rice equivalent yield (REY), total rice grain yield equivalent (TRGYE) are used to assess the productivity and economic benefits.

Numerous scientists (Li et al., 2023; Santo et al., 2023; Nassary et al., 2020; Mugisa et al., 2020; Xu et al., 2020; Matusso et al., 2014) who have been working with cereal-legume intercropping systems in SSA, expressed its success compared to the monocrops. The system also increases total crop productivity and profitability due to low fixed costs for land as a result of a second crop in the same field and efficiently taps solar radiation, coupled with high water use efficiency, pests and diseases control. Singh et al. (2021) reported LER greater than unity under rice intercropping systems. In monocropping systems, crops get intraspecific competition in their location above and below surface. Seran and Brintha (2010) stated that the seeding rate of each crop under intercropping systems must be adjusted to below its full rate to optimize plant density. If full rates of each crop were planted, neither would yield well because of intense over-crowding and competition. Brintha and Seran (2009) observed that the choice of compatible crops depends on the plant growth habit, land, light, water and fertilizer utilization. Muoneke et al. (2007) recorded high productivity of the intercropping system with yield advantage of 2-63% and LER of 1.02-1.63 indicating efficient utilization of land resource under intercropping system. Mugisa et al. (2020) indicated that intercropping rice with beans, groundnuts and maize led to more yield benefits from the LER with an average of 1.5.

The conventional method of planting rice (30 × 12.5 cm hills) does not permit intercropping because of narrow row spacing and intensive binding of soil by root mass of closely growing rice plants. Consequently, a new pattern of planting rice in wide spaced multi-row strips maintaining normal plant population has been developed. The additive series where the main crop population is adopted using paired rows maintains the plant population, creating space for a legume intercrop, relative to replacement planting which reduces the population of rice through crop substitution. The system not only gives high yield comparable to the conventional planting system, but also facilitates interplanting, management and harvesting of intercrops without damage to the rice (main) crop. Given the significance of intercropping, the present study evaluated the comparative performance of different upland paired row rice-based intercropping systems under additive series by maintaining the main crop population to optimum (100%) and added a legume intercrop (38% of sole crop).

Rice, beans, soybeans and groundnuts being C_3 plants are not efficient in utilizing Cabondioxide like C_4 crops. Kaiira et al. (2023) recorded higher rice growth and grain yields in the East-West row orientation. Borger (2020) reported that East-west crops more effectively shade weeds in the inter-row space than NS row crops. The shaded weeds had reduced biomass, reduced seed and weed growth which led to increased crop yield. Increased shading by EW crop reduces the soil surface temperature and evaporation in the inter-row space, leading to increased soil moisture. The increased moisture occasionally increases crop yield where moisture is limited. Little work has been done on rice based intercropping systems in Uganda. This study was conducted with the major objective of determining the production potential of different rice based intercropping systems in Uganda under paired rows in the EW row direction.

2. Materials and Methods

2.1 Study Site

The study on the performance of direct-seeded upland rice-based intercropping systems under paired rows was conducted at the National Agricultural Research Organization (NARO), Ikulwe station in Mayuge District of Uganda during the second rain seasons (September-December) of 2022 and 2023. Ikulwe is located at 00°26′23.2″N 033°28′40.9″E, at 1209 meters above sea level. The rainfall at the site during the cropping season was 652 mm during 2022 and 850.6 mm during 2023 (Table 1). During 2022 the mean cropping season's minimum and maximum temperatures were 19.5 °C and 31 °C against the annual average temperatures of 18.3 °C and 32 °C. The mean minimum and maximum temperatures during 2023 cropping season were 18.4 °C and 30.6 °C, respectively. The properties of the soil classified as luvisol soil were determined before conducting the study and the pH of the soil was on average 5.8 with textural sand (56%), silt (21%) and clay (23%). The amounts of organic matter (3.4%), available nitrogen (0.19%), exchangeable phosphorus (5.06 mg kg^{-1}) and 5.09 mg kg^{-1} exchangeable potassium were the determined averages

2.2 Study Area

2.2.1 Rainfall During 2022 and 2023

The data on rainfall during seasons September-December 2022 and 2023 as measured at Ikulwe Research station is indicated in Table 1. The weekly and monthly total (seasonal) rainfall during 2023 was higher (815.0 mm) than during 2022 (652.0 mm).

Table 1. Rainfall received during 2022 and 2023

Month	Week	2022		2023	
		Weekly total (mm)	Total monthly rainfall (mm)	Weekly total rainfall (mm)	Total monthly rainfall (mm)
September	1	7.3	141.7	97.0	191.7
	2	35.4		39.5	
	3	40.0		54.5	
	4	59.0		0.7	
October	1	86.1	223.0	9.2	125.7
	2	27.1		52.5	
	3	97.9		28.5	
	4	9.6		35.5	
November	1	18.9	155.1	75.5	387.0
	2	3.7		31.9	
	3	28.9		107.2	
	4	103.6		172.4	
December	1	25.8	132.2	46.1	110.6
	2	42.0		50.0	
	3	63.9		7.0	
	4	0.5		7.5	
TOTAL			652.0		815.0

2.2.2 Experimental Design and Treatments

The experimental design was a randomized complete block design with three replications. Each Plot size of 5m x 10m were maintained throughout with a 1m strip between plots. The studies were conducted for two growing seasons of September-December in 2022 and 2023 with 8 treatments each year namely; T_1 = Conventional rice (30 × 12.5 cm), T_2 = Paired row rice (40/20 × 12.5 cm), T_3 = Paired row rice + NAROBEAN 15 (40/20 × 12.5 cm + 1 row beans), T_4 = Paired row rice + 1 row MAKSOY 3 (40/20 × 12.5 cm), T_5 = Paired row rice + 1 row Red beauty ground nuts (40/20 × 12.5 cm), T_6 = Beans (40 × 10 cm), T_7 = Groundnuts (40 × 10 cm), T_8 = Soybeans (40 × 10 cm). The rice seed was directly planted using the drilling method in all treatments. Conventional rice was planted at 30 × 12.5 cm and paired rice was established at 40/20 × 12.5 cm in all treatments with one seed per hill. All intercrops were directly seeded with one seed per hill between the paired rows of rice at a spacing of 112.5 cm inter-row. The pure legumes were established (1 seed) at the time of planting rice. Fertilizers were applied to rice 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 three equal splits at 15 days after emergence (DAE), 30 DAE (tillering stage) and 45 DAE (panicle initiation stage) to rice crop only. No fertilizers were applied to the legume crops.

2.3 Data Collection and Analysis

Ten plants were selected and tagged for biometric data measurements at 21 DAE on plant height, number of tillers, number of leaves, leaf length and width. At panicle initiation stage, plant height was taken from the base of the plant to the base of the flag leaf and the longest and widest parts of the leaves were taken on the tagged plants. Prior to harvest 10 plants per plot were selected randomly (excluding border hills) for collection of data on yield parameters that included; panicles per plant and grains per panicle, 1000 grain weight for rice and pods per plant and plant height for the legumes. At harvest of rice, ground nuts and soy beans (100 DAE) and beans (60 DAE) plants within the net plot (45 m^2) were harvested per plot, dried on a cemented floor and the panicles and pods were carefully threshed/opened, seeds were cleaned and further dried in the Agronomy Field Laboratory to record the data on grain yield. The later was obtained by extrapolating to kg ha^{-1}. Data was analysed using GenStat statistical package (GenStat, 2013) to generate analyses of variance (ANOVA) to compare the yield differences of the different treatments.

2.3.1 Competitive Indices

(1) Land Equivalent Ration (LER)

The LER defined as the relative land area required as a sole crop to produce the same yields as intercrops was calculated using the formula:

$$LER = \sum(Yp_i/Ym_i) \quad (1)$$

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 (Mead & Willey, 1980). When LER > 1 the intercropping favors the growth and yield of the species. In contrast, when LER < 1 there is no intercropping advantage.

(2) The Area Time Equivalent Ratio

The Area Time Equivalent Ratio (ATER) was calculated using the following formula based on the duration to harvest for sole conventional rice (110 days), and intercropped beans (60 days), Groundnuts (90 days) and Soybeans (100 days):

$$ATER = (LERa/LERb) \times (DC/Dt) \quad (2)$$

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 harvest for 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 (Yahuza, 2011).

(3) The Monetary Advantage Index (MAI**)**

The Monetary Advantage Index (MAI) was determined as described by Gosh (2004):

$$MAI = \text{Value of Combined Intercrops} \times (LER - 1)/LER \quad (3)$$

The higher the index value, the more profitable is the cropping system (Dhima et al., 2007).

(4) Rice Equivalent Yield

The Rice Equivalent Yield (REY) for 2022 and 2023 were calculated in kg ha^{-1}, based on current market price in Uganda Shillings (UGX) of P_r (Rice): 3000, P_x (Beans): 3500 UGX, P_x (Soybeans): 4000 UGX, and P_x (Groundnuts): 6000UGX. The REY was calculated to compare system performance by converting the yield of non-rice crops into equivalent rice yield on a price basis, using the formula:

$$REY = Yx(Px/Pr) \quad (4)$$

where, Yx is the yield of non-rice crop (kg ha^{-1}), Px is the market price of non-rice crops at harvest.

(5) Total Rice Grain Yield Equivalent

The total rice grain yield equivalent (TRGYE) was calculated for the different intercropping systems by summing the yield on intercropped rice and the REY under intercropping using the formula:

$$TRGYE = Yr + REYx \quad (5)$$

where, Yx is the yield of rice and REYx is the rice equivalent yield for the intercrop with rice.

(6) 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 (McGilchrist, 1965). An aggressivity value of zero indicates that component crops are equally competitive.

Aggressivity (A) is expressed as:

$$A = LERa \times Pbi; \ A = LERb \times Pbi \quad (6)$$

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:

$$Ai = Yi / Yb \times Pri - Yii / Yi \times Pr \quad (7)$$

where, Yi is the yield of rice under intercropping, Yb is the yield of the sole rice and Pr is the sown proportion of rice 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.

3. Results

3.1 Plant Height, Tiller and Panicles for Rice During 2022 and 2023

The data on plant height, number of tillers and panicles per plant for 2022 and 2023 is indicated in Table 2. Pairing of rice rows had no influence on the rice plant height, number of tillers and panicles during both years. Higher plant height was however recorded under conventional and sole paired rice than under rice intercropped with beans and groundnuts during both seasons. Significantly ($P \leq 0.05$) higher tillers (6 tillers) and panicles (32-35 panicles) per m^{-2} were recorded under the two sole rice treatments, relative to other treatments during 2022. Introduction of legume intercrops in rice, resulted in lower numbers of tillers (5 tillers) per plant and panicles (22-25 panicles) per unit area in 2022. Intercropping soybeans in rice during 2023, significantly ($P = 0.005$) enhanced the height (106.2 cm) of rice during 2023. The number of tillers and panicles per plant were not influenced by intercropping systems during the year.

Table 2. Plant height, number of tiller and panicles for Rice during 2022 and 2023

Treatment	2022			2023		
	Plant height (cm)	Tillers per plant	Panicles per M^{-2}	Plant height (cm)	Tillers per plant	Panicles per plant
Conventional rice	63.0	6.0a	34.5a	92.2b	7.65	7.45
Paired row rice	64.9	6.1a	31.7a	92.8b	8.63	7.73
Paired rice + Beans	60.5	5.0b	24.7b	85.6b	7.47	6.91
Paired rice + Groundnuts	58.6	4.6b	24.0b	80.4b	7.97	7.83
Paired rice + Soybeans	58.9	5.0b	22.3b	106.2a	8.93	8.52
P-value	NS	<0.001	<0.001	0.005	NS	NS
LSD (P ≤ 0.05)	10.9	0.4	3.4	12.63	1.47	1.65
CV (%)	8.5	4.4	6.1	6.7	8.7	10.3

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

3.2 Plant Height and Pods per Plant for Legumes During 2022

Table 3 shows the data on height for beans, groundnuts and soybeans during 2022. There was significant ($P = 0.04$) reduction in the height of beans (48%) and number of soybeans pods per plant (41%) when intercropped in rice. Introduction of groundnuts and soybeans in rice did not influence the height of the legume intercrops. The number of beans and groundnuts pods per plant were not affected by intercropping.

Table 3. Plant height and pods per plant for legumes during 2022

Treatment	Plant height (cm)			Pods per plant		
	Beans	Groundnuts	Soybeans	Beans	Groundnuts	Soybeans
Pure Beans	31.0a			10.3		
Beans in paired rice	20.9b			11.0		
Sole groundnuts		27.5			18.5	
Groundnuts in paired rice		29.3			17.4	
Pure Soybeans			68.5			32.4a
Soybeans in paired rice			78.2			23.0b
P-value	0.04	NS	NS	NS	NS	0.007
LSD (P ≤ 0.05)	9.90	3.46	15.0	2.64	5.9	5.19
CV (%)	17.1	5.50	9.0	10.6	14.7	8.30

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

3.3 Plant Height and Pods per Plant for Legumes During 2023

The results on plant height and pods per plant for the pure and legumes intercropped in paired rice are given in Table 4. Introduction of beans as intercrops in rice significantly (P = 0.05) reduced legume height (25.4%) during 2023. The height of groundnuts and soybeans during 2023 besides the pods for beans, groundnuts and soybeans were not significant.

Table 4. Plant height and pods per plant for legumes during 2023

Treatment	Plant height (cm)			Pods per plant		
	Beans	Groundnuts	Soybeans	Beans	Groundnuts	Soybeans
Pure beans	42.0a			8.4		
Beans in paired rice	31.3b			9.6		
Pure groundnuts		49.3			14.6	
Groundnuts in paired rice		54.4			15.1	
Pure Soybeans			92.5			44.2
Soybeans in paired rice			89.8			55.0
P-value	0.05	NS	NS	NS	NS	NS
LSD (P ≤ 0.05)	9.2	16.0	31.5	2.3	4.0	21.7
CV (%)	15.4	18.6	15.2	11.5	11.8	19.3

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

3.4 Percent Pods Filled for Legumes Intercropped in Rice During 2022 and 2023

The percent pod filled for beans, groundnuts and soybeans during 2022 and 2023 are indicated in Table 5. Intercropping beans, groundnuts and soybeans in rice significantly (P = 0.03) reduced the filling of the pods by 66%, 36% and 18.3 % respectively during 2022. The percent filling of beans pods similarly reduced (34.1%) due to intercropping of the beans during 2023. Intercropping groundnuts and soybeans in rice however, did not affect the percent pods filled during the same year.

Table 5. Percent pod filled for legumes intercropped in rice during 2022 and 2023

Treatment	Percent pods filled					
	2022			2023		
	Beans	Groundnuts	Soybeans	Beans	Groundnuts	Soybeans
Pure beans	82.7a			85.6a		
Beans in paired rice	49.7b			56.4b		
Pure groundnuts		66.5a			72.8	
Groundnuts in in paired rice		49.0b			53.1	
Pure soybeans			91.7a			66.7
Soybeans in paired rice			74.7b			62.0
P-value	0.03	0.03	0.03	0.05	NS	NS
LSD (P ≤ 0.05)	29.6	11.4	16.39	26.2	25.3	16.3
CV (%)	14.4	7.0	9.2	15.3	17.7	11.6

Note. Values with different letters in a column are significantly different at P ≤ .05.

3.5 1000-Grain Weight

There were significant differences in 1000 grain weight among the treatments. The conventional and paired sole rice produced significantly (P ≤ 0.05) higher average 1000 grain weight (20.22 g) than the intercropped treatments, which were at par (18-19 g) during the 2 years.

3.6 Yield of Rice and Legumes Intercropped at Ikulwe Station During 2022 and 2023

The data on yield of rice and legumes during 2022 is indicated in Table 6. Pairing of rice rows had no influence on the rice grain yield (4.0-4.3 kg ha^{-1}) during 2022 and 2023 (5.0-5.7 Mt ha^{-1}). The yield for the 2 pure rice treatments during 2022 was however, significantly (P ≤ 0.05) higher than under other intercropping combinations (3.2-3.6 Mt ha^{-1}) that were at par during 2022. Introduction of beans intercrop that occupied 38% of the acreage of sole rice in 2022 reduced the beans grain yield by 35% from 0.73 Mt to 0.54 Mt ha^{-1} and the groundnuts yield similarly significantly ($P \leq 0.05$), declined by 33% from 2.33 Mt to 1.56 Mt ha^{-1} as soybeans yield dropped from 3.70 to 2.57 Mt ha^{-1} by 30.5%.During 2023 the yield of rice was not significant amongst treatments. Pairing of rice rows in EW row orientation however, increased the rice grain yield numerically from 4.9 Mt to 5.73 Mt ha^{-1} (17%). Rice intercropped with beans recorded high yield (5.18 Mt ha^{-1}) compared to rice with other legume intercrops (4.0-4.5 Mt ha^{-1}). Significantly, ($P \leq 0.05$) higher legume grain yields were obtained from sole beans (1.10 Mt ha^{-1}), groundnuts (0.3 Mt ha^{-1}) and soybeans (1.3 Mt ha^{-1}) relative to intercropped legumes. The yield for beans, groundnuts and soybeans reduced by 71%, 73% and 62% respectively due to intercropping during 2023. Generally, the rice yields were higher in 2023 than in 2022 and the legume yields reduced in 2023 compared to 2022.

Table 6. Yield of rice and legumes intercropped at Ikulwe station during 2022 and 2023

Treatment	2022				2023			
	Rice yield (Mt ha^{-1})	Legumes grain yield (Mt ha^{-1})			Rice yield (Mt ha^{-1})	Legumes grain yield (Mt ha^{-1})		
		Beans	Groundnuts	Soybeans		Beans	Groundnuts	Soybeans
Conventional rice	4.27a				4.90			
Paired rice	4.08a				5.73			
Paired rice + Beans	3.60b	0.54b			5.18	0.32b		
Paired rice + G/nuts	3.22b		1.56b		4.50		0.08b	
Paired rice + S/beans	3.23b			2.57b	4.07			0.50b
Pure Beans		0.73a				1.10a		
Pure Groundnuts			2.33a				0.30a	
Pure Soybeans				3.70a				1.30a
P-value	0.001	0.02	0.001	<.001	NS	0.02	0.002	0.05
LSD (P ≤ 0.05)	0.45	0.14	0.27	0.25	2.04	0.53	0.08	0.78
CV (%)	6.8	9.80	6.20	3.60	23	29.3	4.1	26

Note. Values with different letters in a column are significantly different at P ≤ .05. G/nuts: Groundnuts; S/beans: Soybeans; Mt ha^{-1}: Metric tons per hectare.

3.7 Height, Tillers and Yield of Pure and Intercropped Rice During 2022 and 2023

The pooled data for 2022 and 2023 on rice height, number of tillers and yield are presented in Table 7. The parameters; height, tillers and yield of pure and intercropped rice were not influenced by both the pairing of rice rows and intercropping rice with the different legumes during 2022 and 2023.

Table 7. Height, tillers and yield of pure and intercropped rice at Ikulwe station during 2022 and 2023

	Height (cm)	Tillers	Yield (Mt ha^{-1})
Conventional rice (2022)	77.6	6.83	4.59
Paired rice (2022)	78.8	7.37	4.91
Paired rice + Beans (2022)	73.0	6.23	4.39
Paired rice + G/nuts (2022)	69.5	6.29	3.86
Paired rice + S/beans (2022)	82.5	6.96	3.65
Conventional rice (2023)	79.5	7.25	4.44
Paired rice (2023)	80.5	7.75	5,05
Paired rice + Beans (2023)	75.0	7.23	4.49
Paired rice + G/nuts (2023)	72.2	7.40	4.16
Paired rice + S/beans (2023)	79.0	7.30	3.85
P-value	NS	NS	NS
LSD (P ≤ 0.05)	46.58	4.54	1.94
CV (%)	27.20	28.9	20.1

Note. Values with different letters in a column are significantly different at P ≤ .05.

3.8 Height, Pods, Percent Filled Pods and Yield of Pure and Intercropped Legumes Under Pooled Data for 2022 and 2023

The data pooled for 2022 an 2023 on height, pods per plant, percent filled pods and grain yield of pure and intercropped legumes during 2022 and 2023 are indicated in Table 8. The height of beans was not influenced by intercropping during 2022 and 2023. The number of pods, percent filled pods and bean yield however, significantly (p = 0.001) differed with higher values under pure beans during 2023. The groundnuts height, percent filled pods and yield were significant during 2022 and 2023 and groundnuts intercropped in rice registered significantly (P < 0.001) higher height (55.45 cm) during 2023 than other treatments. Pure groundnuts had higher percent filled pods (73.15%) during 2023 than other treatments. The highest groundnuts yield (in pod) was under pure groundnuts (3.4 Mt ha^{-1}) during 2022 and lower (0.09 Mt ha^{-1}) yield was under intercropped groundnuts during 2023. The height of soybean was high (92.5 cm) under the pure stand during 2023 relative to other treatments and lower (64.3 cm) for soybean intercrops in rice during the same year. Pure soy bean produced higher grain yield (3.8 Mt ha^{-1}) during 2022 followed by intercropped soybean during the same year compared to other treatments.

Table 8. Height, pods per plant, percent filled pods and grain yield of pure rice and legumes intercropped in rice at Ikulwe station during 2022 and 2023

	Height (cm)	Pods per plant	Percent filled pods	Yield (Mt ha^{-1})
Pure beans (2022)	20.9	8.55b	83.60a	0.76b
Pure beans (2023)	36.6	10.0a	57.60b	1.15a
Beans intercrops in rice (2022)	35.6	11.65a	49.95c	0.55c
Beans intercrops in rice (2023)	44.3	10.5a	56.80b	0.30c
P-value	NS	0.001	0.001	0.001
LSD (P ≤ 0.05)	25.43	2.47	3.55	0.17
CV (%)	13.4	63	2.9	6.6
Pure grounndnuts (2022)	28.5c	19.05	67.15b	2.34a
Pure groundnuts (2023)	49.75b	15.30	73.15a	0.33c
Groundnuts intercrops in rice (2022)	29.28c	17.95	49.60d	1.52b
Groundnuts intercrops in rice (2023)	55.45a	17.05	51.65c	0.09d
P-value	<0.001	NS	<0.001	<0.001
LSD (P ≤ 0.05)	3.97	3.67	1.99	0.08
CV (%)	2.4	7.6	1.2	2.7
Pure Soybeans(2022)	69.30c	33.50	92.50	3.80a
Pure Soybeans (2023)	92.50a	44.20	67.30	1.30c
Soybeans intercrops in rice (2022)	78.20b	23.00	74.70	2.57b
Soybeans intercrops in rice (2023)	64.30d	55.75	67.30	1.50c
P-value	0.02	NS	NS	0.008
LSD (P ≤ 0.05)	4.40	16.5	16.5	0.22
CV (%)	3.0	2.7	2.40	2.0

Note. Values with different letters in a column are significantly different at P ≤ .05.

3.9 Competitive Indices

3.9.1 Land Equivalent Ratios During 2022

The data on land equivalent ratios (LER) for rice and legume intercrops during 2022 is indicated in Table 9. Introduction of legume intercrops in rice during 2022 had no effect on the partial land equivalent ratio (LER) of rice. The partial LER (pLER) of rice intercropped with beans, groundnuts and soybeans were 0.77, 0.75 and 0.74 respectively. The pLER of legumes reduced to a significantly (0.001) higher value of 0.71 under beans but significantly reduced to 0.68 and 0.65 for groundnuts and soybeans respectively. The combined LER (cLER)for rice and the 3 legume intercrops were similar (1.4-1.5) but significantly (P < 0.01) differed from the pLER (1.0) of sole conventional rice.

3.9.2 Land Equivalent Ratios During 2023

The results on LER for rice and legume intercrops during 2023 are indicated in Table 9. The pLER for rice intercropped with beans increased to more than unity (1.06) during 2023 whereas, significantly lower pLERs were recorded for rice intercropped with groundnuts (0.92) and soybeans (0.83). The results further indicated numerically lower non-significant pLER for intercropped beans (0.29), groundnuts (0.26) and soybeans (0.38). The cLER recorded for rice/beans (1.35), with similar but lower cLER for rice/groundnuts (1.18) and rice/soybeans (1.21) were more than the LER (1.0) for sole rice. Generally, the pLER for rice were lower during 2022 than 2023 and conversely higher pLER were recorded for legume intercrops during 2022 than under 2023. The results indicated higher cLER (1.39-1.48) during 2022B than in 2023 (1.18-1.35).

3.9.3 Area Time Equivalent Ratio

The Area time equivalent ratio (ATER) data is indicated in Table 10. The results indicated high ATER for rice + beans (1.98 and 6.70) than under other intercropping combinations (1.33-1.43) during the 2 years. During 2023 the ATER significantly (P < 0.05) reduced (2.5) under rice + soybeans.

Table 9. Land equivalent ratio as influenced by intercropping

Treatment	2022			2023		
	pLER rice	pLER legumes	LER/cLER	pLER rice	pLER legumes	LER/cLER
Sole rice conventional	-	-	1.0b	-	-	1.00b
Paired rice/beans	0.77	0.71a	1.48a	1.06a	0.29	1.35a
Paired rice/Groundnuts	0.75	0.68b	1.43a	0.92b	0.26	1.18b
Paired rice/soybeans	0.74	0.65b	1.39a	0.83b	0.38	1.21b
P-value	NS	0.001	<0.001	<0.001	NS	<0.001
LSD (P ≤ 0.05)	0.14	0.11	0.14	0.05	0.06	0.09
CV (%)	6.7	5.4	5.60	4.6	7.0	4.3

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.

3.9.4 Monetary Advantage Index

The monetary advantage index (MAI) was determined as Value of Combined Intercrops × (LER − 1)/LER and indicated in Table 10. The higher the index value, the more profitable is the cropping system (Dhima et al., 2007). Rice + soybeans recorded numerically high MAI (1.03) during 2022 than other treatments. The results however indicated that it was as equally profitable as the other intercropping combinations. During 2023 the rice + beans cropping system recorded high MAI (1.03) followed by rice + soybeans (0.93) and MAI was least under rice + groundnuts (0.70). The 3 indices were statistically at par.

Table 10. Indices and equivalent ratios for rice intercropped with beans, groundnuts and soybeans during 2022 and 2023

Cropping system	Growing season	Yield (Mt ha^{-1})		ATER		MAI		REY		TRGYE (Mt ha^{-1})		Aggressivity	
		Rice	Legume	Rice	Legume	Rice	Legume	Rice	Legume	Rice	Legume	Rice	Legume
Rice Sole	(2022)	4.27	-	-		-		-		4.27b	-		
	(2023)	4.90	-	-		-		-		-	4.90b		
Sole Beans	(2022)		0.73										
	(2023)		1.10										
Sole G/nuts	(2022)		2.33										
	(2023)		0.30										
Sole soybeans	(2022)		3.70										
	(2023)		1.30										
Rice + Beans	(2022)	3.60	0.54	1.98a	-	1.34	-	0.85b	-	4.45b	-	0.24	-
	(2023)	5.18	0.32	-	6.7a	-	1.03	-	1.43a	-	6.44a	-	0.15
Rice + G/nuts	(2022)	3.22	1.56	1.39b	-	1.48	-	4.70a	-	7.90a	-	0.23	-
	(2023)	4.50	0.08	-	4.3b	-	0.70	-	0.70b		5.20b	-	0.13
Rice + Soybeans	(2022)	3.23	2.57	1.33b	-	1.63	-	5.10a	-	8.33a	-	0.25	-
	(2023)	4.07	0.50	-	2.5c	-	0.93	-	1.64a	-	5.71b	-	0.13
P-value				<0.001	<0.001	NS	NS	<0.001	<0.001	<0.001	0.002	NS	NS
LSD (P ≤ 0.05)				0.32	0.55	0.3	0.56	0.56	0.31	0.37	0.56	0.03	0.07
CV (%)				9.1	5.8	8.8	24.7	6.2	10.8	5.2	4.6	5.7	13.1

Note. 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; REY: rice equivalent yield; TRGYE: Total rice grain yield equivalent.

3.9.5 Rice Equivalent Yield

The rice equivalent yield (REY) for 2022 and 2023 are presented in Table 8. Soybean intercrop recorded significantly ($P < 0.001$) high REY in 2022 (5.1Mt ha^{-1}) and in 2023 (1.64 Mt ha^{-1}) than other intercrops. Groundnuts intercrop similarly recorded high REY in 2022 (4.70 Mt ha^{-1}) and in 2023, rice + beans scored similarly high REY (1.43 Mt ha^{-1}).

3.9.6 Total Rice Grain Yield Equivalent

All the intercropping treatments resulted in substantially higher total rice grain yield equivalent (TRGYE) than sole crop of rice during 2022 and 2023 (Table 8). The highest TRGYE of 8.33 and 7.90 Mt ha^{-1} were recorded under rice + soybeans, followed by rice + groundnuts intercropping systems during 2022B, while rice + beans intercropping systems produced higher TRGYE (6.44 Mt ha^{-1}) during 2023 compared to other cropping systems. Low TRGYE were recorded under rice intercropped with groundnuts (5.20) and soybeans (5.71) during 2023B. The total rice grain yield from sole rice was 4.3Mt and 4.9 Mt ha^{-1} for 2022 and 2023, respectively.

3.9.7 Aggressivity

The aggressivity of the different rice/legume intercropping systems during 2022 and 2023 is shown in Table 7. During 2022 the aggressivity of the intercropping systems ranged between 0.23-0.25. In 2023 the aggressivity was 0.13-0.15.

4. Discussion

4.1 Plant Height, Tiller and Panicles for Rice During 2022 and 2023

The change in spatial arrangement from conventional (30 × 12.5 cm) rice to paired rows (20/40 × 12.5 cm) recorded similar plant height, number of tillers and panicles during 2022 and 2023. The parameters; height, tillers and yield of pure and intercropped rice were similarly not influenced by both the pairing of rice rows and intercropping rice with the different legumes under pooled data for 2022 and 2023. This may be probably attributed to similar growth conditions under the 2 treatments. There was low plant height recorded under rice intercropped with beans and groundnuts relative to sole paired and conventional rice during both seasons. This could be attributed to higher competition for below and above ground surface resources like solar radiation, water and nutrients under the intercropping systems. Sole paired rice and conventional rice recorded significantly, higher numbers of tillers and panicles per m^{-2}, relative to intercropped rice during 2022. The results may be attributed to lower but similar intraspecific competition for solar radiation and other resources. Matusso et al. (2013) similarly reported similar maize grain yield and biomass for the conventional and double rows system. The rice plant height increased under intercropping with soybeans in 2023 relative to sole rice crop. This may be related to more efficient absorption of solar radiation under competition between rice and the phenotypically tall soybean crop planted in the East-West row direction. Kaiira et al. (2023) reported that rice being a C_3 plant produced higher rice growth and grain yields in the EW row direction due to reduced weeds, more efficient in utilizing Cabondioxide and solar radiation. Similar observations were earlier made by Borger (2020). The similar number of tillers per plant and panicles per square meter under the sole and intercropping systems during 2023 could have resulted similar assimilation from the same interception of below and above soil surface resources for growth and development with reduced intraspecific crop competition, due to the high rainfall (851 mm) in 2023.

4.2 Plant Height and Pods per Plant for Legumes During 2022 and 2023

Reduction occurred in height of beans crop (48%) for 2022 and in 2023 (25.4%) and in the number of intercropped soybean pods per plant (41%). Pooled data for 2022 and 2023 also indicated significant reductions in the number of pods for legume intercrops. This could have resulted from lower deposition of assimilates into the legume plants due to reduced photosynthesis following increased interspecific competition between the main crop and intercrops. The similar crop height for pure and intercropped groundnuts during 2022 and 2023, besides height of pure and intercropped soybeans in 2022 and beans (2023) and similar number of groundnuts pods per plant for single and intercropped treatments may be related to possible identical interception of above and below ground resources for the sole legume and legume intercrops under paired row architecture.The taller soybean under pure stand during 2023 could have resulted from the inncreased photosynthetic activities during the year with increased rainfall (Section 2.2.1).

4.3 Percent Pods Filled for Legumes Intercropped in Rice During 2022 and 2023

Significant reduction in the percent filled pods occurred due to intercropping rice with beans (66%), groundnuts (36%) and soybeans (18.3%) during 2022, This could be attributed to reduced deposition of assimilates into the sinks of the legumes, arising from the lower interception of solar radiations by beans and groundnuts which are shorter relative to rice. The relatively taller soybeans in contrast to beans and groundnuts scored numerically higher percent filled pods during 2022.This could be possibly because soybean crop being a C_3 plant, equally competed with rice (C_3), trapped and assimilated solar radiation for photosynthesis and subsequently deposited dry matter into the sinks. Terrestrial C_3 plants increase in productivity due to high but non-saturating photosynthetically active solar radiation; when water, temperature and nutrients are not limiting. There was higher percent pod filling for pure relative to intercropped beans during 2023. This may similarly be attributed to higher dry matter saturation in the sinks of pure stand beans as the legume intercrop could have been deprived of incident solar radiation by the taller rice plants (Tables 2 and 3). An increase in percent pod filling for sole soybeans was recorded in 2022, relative to 2023. This possibly resulted from the lower number of soybeans sink organs recorded in 2022 than 2023. Source organs 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. A source (photosynthetically active part) is not always a source and a sink (area of active growth and storage) is not always a sink. During 2022 the photosynthetically active parts of soybeans could have acted as source sreducing the potential for pod filling while in 2023 with higher rainfall, the pods (sinks) could have also worked as sources for the vigorously growing crops (Table 2). Kato (1989) reported that the rate of filling in rice correlates positively with the traits related to grain size and negatively with those related to grain number. The high numbers of pods recorded during 2023 may be associated with increased total soluble sugars due to increased nutrient uptake following the higher rainfall received during the year. The lower rainfall received during 2022 and possibly higher temperatures and solar radiation could have contributed to the lower number of pods per soybean plant. Liu et al. (2011) reported that reduction of total soluble sugar concentration was directly responsible for lower pod number in soybeans under shading conditions.

4.4 1000-Grain Weight

The 1000 grain weight differed significantly among the treatments with higher values under the conventional and paired sole rice. The increased 1000 grain weight under sole rice treatments may be attributed to higher nutrient uptake and increased absorption of solar incident radiation for photosynthesis. The two attributes were reported by Fageria et al. (2013) to positively enhance yield parameters including 1000 grains weight.

4.5 Yield of Rice and Legumes Intercropped at Ikulwe Station During 2022B and 2023

Adjustment of the row arrangement from conventional (30 × 12.5 cm) to paired rows (40/20 × 12.5 cm) did not significantly affect the rice grain yield during 2022 and 2023 but the yield under conventional (30 × 12.5 cm) and paired rice (40/20 × 12.5 cm) increased during 2023. The result may possibly be attributed to the higher tillers and more panicles (Section 3.1) and increased 1000 grain weight (Section 4.4) recorded. The positive change in yield parameters could have resulted from similar but higher uptake of soil nutrients and incident solar radiation under the pure crop treatments relative to intercropped rice. Fageria et al. (2013) disclosed that the 1000 grain weight increased (9%) at higher K nutrient level compared to lower levels. Hasegawa (2003) similarly, reported positive correlation between 1000 grain weight and grain yield of rice. Pairing of rice rows has been reported to imitate guard rows architecture and benefits from properties such as optimization of light absorption for photosynthesis. Mak (2021) reported that border treatment had significant and positive influence on yield components and yield of rice. Rezazadeh et al. (2018) also attributed the border effects to advantageous environmental factors like higher solar energy and air circulation. Earlier reports by Wang et al. (2013) indicated that plants in border rows produced higher rice tillers and spikelet per panicle than in central plots and nutrient uptake was reported to be higher in border compared to centre rows. The higher yield attributes in border rows reported by the researchers were attributed to higher nutrient supply, favorable microclimatic conditions and higher crop growth. Nagashima and Hikosaka (2011) in their studies recorded higher numbers of rice panicles per hill, spikelet per panicle, length of panicles, earlier flowering and filled grains per rice panicle in border rows than inner rows. The late flowering of central rows was similarly attributed to poor light interception and growth due to mutual shading as compared to conditions under border rows. The observations could have resulted from pairing of rice rows, a condition that imitated guard rows. Boarder rows get higher deposition of assimilates into the sinks and this contributes to higher yields. The results also support the innovation of paired rows adopted in the current study since the rice grain yield did not decline due to row adjustment.

During 2022 introduction of beans, groundnuts and soybeans intercrops caused a reduction in legume population to 38%, of pure stands and reduced the beans, groundnuts and soybeans grain yield by 26%, 33% and 31% respectively. The results indicated increased grain yield considering the reduced legume population to 38% due to paired rows. The yield gain may be attributed to benefits from intercropping legumes with rice in the EW row direction. Rice and the legume intercrops are all C_3 plants which increase in productivity in EW row direction, due to high but non-saturating photosynthetically active solar radiation; when water, temperature and nutrients are not limiting.

Pairing of rice rows increased (17%) the rice grain yield during 2023. The yield increase may be attributed to the higher number of tillers, more panicles and increased 1000 grain weight recorded under the paired rows (Section 3.1). Higher rice yield was obtained under intercropping with beans relative to the other intercrops. Base crop yields positively correlate with harvest intervals between the base and intercrops. The increased rice yields could be attributed to physiological and nutritional benefits that the rice gained when the early maturing beans were harvested relative late harvested groundnuts and soybeans. The significantly higher legume grain yield obtained from sole beans, groundnuts and soybeans relative to intercropped legumes resulted from the lower plant density for the latter that constituted only 38% of the sole crop population. Higher rice yields were in 2023 than in 2022 under EW row direction and the legume yields reduced in 2023 compared to 2022. This could have resulted from the higher rainfall (815 mm) recorded during the year relative to the drought season of 2022 with lower (652 mm) rainfall. Rice is a C_3 plant that uses the C_3 pathway in the dark reaction of photosynthesis and use the Calvin cycle. Rice requires more water than other plants and yields are higher with increased rainfall.

4.6 Competitive Indices

4.6.1 Land Equivalent Ratios During 2022 and 2023

The 3 legume intercrops had no effect on the partial land equivalent ratio (pLER) of rice during 2022. This indicated that the intercrops equally exerted inter-specific interference to the rice crop. During 2022, there was a drop in pLER for rice intercropped with beans, groundnuts and soybeans and for legumes intercropped in rice to less than unity (1.0). This implied that the inter-specific competition exhibited was stronger than intra-specific interactions under monocropping ecosystems. The pLER for rice intercropped with beans increased to more than unity (1.06) during 2023B. The results designated benefits for rice from intercropping possibly arising from positive and beneficial inter-specific interactions since the legume intercrop matured much earlier. This yield advantage could be attributed to more efficient utilization of light, water and nutrients during the growing season considering that the legumes are much shorter than the rice. Willey and Osiru (1972) emphasized the difference in growth cycles since they enable more efficient water and nutrient utilization during the growth period. The LER of 1.06, indicated that the area planted with rice would need 6% greater land area than land planted with rice + beans for the two to produce the combined yield. Xu et al. (2020) reported an average LER for rice/soybean intercropping as 1.32±0.02, indicating a substantial land sparing potential of intercropping over sole crops Similar combined LER of more than 1.0 were recorded under rice-legume intercrops, which significantly differed from the pLER (1.0) of sole conventional rice. This may be attributed to lower inter-specific (rice-legume) interference relative to the rice intra-specific (rice-rice) competition. The results implied that rice-legume intercropping systems favored the growth and yield of the species. Li et al. (2023) reported that intercropping performs well in producing a diverse set of crop products and performs almost similar to the most productive component sole crop to produce raw products, while improving crop resilience, enhancing ecosystem services, and improving nutrient use efficiency. Mugisha et al. (2020) indicated that the 3 intercropping systems namely; rice-beans, rice-groundnuts and rice-maize led to more yield benefits based on the average LER of 1.5 obtained. Nassary et al. (2020) reported advantages of land utilization of intercrops over monocultures that yielded a total LER of 1.58, whereas the average PLER of individual beans was 1.53. Yu et al. (2019) similarly observed LERs > 1.0 under rice-legume intercropping and indicated that the potential negative effects of intercropping on the use efficiency of labor and other resources were more than offset by its higher land-use efficiency compared with monocropping. Martin (2018) revealed that when the same land area was managed in monoculture, intercrops produced 38% more gross energy (mean relative land output of 1.38) and 33% more gross incomes (mean relative land output of 1.33) on average, whilst using 23% less land (mean land equivalent ratio of 1.30). Amanullah et al. (2016) reported that intercropping of common bean under compost treated plots had higher LER when grown as T2 (1.14) and T4 (1.07) as compared with sole cropping (1.0). Oroka and Omoregie (2007) reported LER at all levels of nitrogen and plant densities to be range between 1.79 to 2.30 for a rice-cowpea mixture.

4.6.2 Area Time Equivalent Ratio During 2022 and 2023

Rice + beans intercropping systems recorded higher ATER during the 2 years than other intercropping combinations. This indicated the advantages of intercropping beans in rice over sole cropping in terms of variation of time taken by the other component crops. The higher ATER may be attributed to the high yield advantage (pLLER) observed under the treatment perhaps arising from positive and beneficial inter-specific interactions of the earlier maturing beans intercrop. This yield advantage arises from more efficient utilization of light, water and nutrients during the growing season as reported by Willey and Osiru (1972). The lower ATER under rice + groundnuts and rice soybeans during the 2 years is possibly associated with the lower yield advantage expressed by pLLER and cLLER during 2022 and 2023 respectively.

4.6.3 Monetary Advantage Index

Numerically higher MAI was observed under the rice + soybeans intercropping system. Much as the MAI was at par with other intercropping systems, intercropping rice with either soybeans or beans proved superior to rice + groundnuts intercropping systems. Dhima et al. (2007) reported that the higher the MAI, the more profitable is the cropping system.

4.6.4 Rice Equivalent Yield

Significantly high REY was recorded under rice + soybeans intercropping system relative to other cropping systems during 2022 and in 2023. This may be attributed to the high relative soybean yield (2.57 Mt ha^{-1} and 0.5 Mt ha^{-1}) recorded under soybeans intercropped in rice, relative to the lower yield for intercropped groundnuts (0.08 and 1.56 Mt ha^{-1}) and beans (0.54 and 0.32 Mt ha^{-1}) during the 2 years. The higher market price per kilogram for soybeans (4,000 UGX) possibly contributed to the REY. The high REY for rice + groundnuts (2022) and rice + beans (2023) are similarly associated with the high crop yield under the treatments and high market price (6,000 UGX per kg) of groundnuts.

4.6.5 Total Rice Grain Yield Equivalent

Significantly high TRGYE values were recorded under rice based intercropping systems relative to sole crop rice during 2022 and 2023 with higher TRGYE under rice + soybeans and rice + groundnuts intercropping systems during 2022 besides rice + beans during 2023. This may be associated with the relatively high soybeans yield (2.57 Mt ha^{-1}) and good harvest of groundnuts (1.56 Mt ha^{-1}) during 2022B besides the high cereal grain yield (5.18 Mt ha^{-1}) when rice was intercropped with beans during 2023. The rice yield gain in 2023 may be attributed to benefits from intercropping the early maturing beans with rice in the EW row direction with rice. Rice and the beans are all C_3 plants which increase in productivity in EW row direction, due to high photosynthetically active solar radiation, water, temperature and nutrients (Kaiira et al., 2023). The increased rice yields could be attributed to physiological and nutritional gains by rice following the harvest of early maturing beans relative to late maturing groundnuts and soybeans. The high harvest of groundnuts and soybeans during 2022 may be associated with the conducive ecological conditions experienced then with 652mm rainfall of compared to the higher (815 mm) during 2023. Ahamad et al. (2007) reported the highest TRGYE (6.45 t ha^{-1}) under rice + forage maize intercropping system followed by rice + cowpea (5.08 t ha^{-1}) and Rice + Sesbania (4.92 t ha^{-1}) against the minimum (4.02 t ha^{-1})

for monocrop rice clearly indicating yield advantages of intercropping over monocropping of rice. Increase in TRGYE as a result of intercropping was also reported by Rana et al. (2013).

4.6.6 Aggressivity

The aggressivity of the different rice/legume intercropping systems during 2022 and 2023 is shown in Table 7. The aggressivity were not significantly different. The data indicated that rice was more aggressive than the three legume intercrops since the difference between the aggressivity of rice (Ab) as a base crop and legumes intercrops (Ai) were all positive. The higher aggressivity values recorded during 2022 than in 2023 implied existence of higher relative yield difference between one crop component and another in 2022 than during 2023.

5. Conclusion

Adjustment from the conventional (30 × 12.5 cm) to paired rows of rice (40/20 × 12.5 cm) to enable the introduction of one row of the legume intercrop between the paired rows of rice, proved beneficial for the rice based intercropping systems. The change in row arrangement did not affect the rice yield for the main crop and allowed the introduction and benefits of a legume crop. Whereas, there was some reduction in rice yield (19.8%) under intercropped treatments and yield reductions under beans (35%), groundnuts (33%) and soybeans (30.5%) in paired rice relative to sole crops, the total productivity of the intercropping systems increased. The Combined Land Equivalent Ratios, Monetary Advantage Indices and Total Rice Grain Yield Equivalent were higher under rice-beans and rice + soybeans intercropping systems indicating more benefits from intercropping than sole crops. Rice + soybeans intercropping under paired row arrangement performed better amongst the intercropping treatments and therefore hereby recommended for farmers in Uganda. The cropping systems increased total crop grain yields per unit area of available land and it is a food security strategy for small-holder, resource-poor farmers, flexible and minimizes risks against total crop failure as 2 crops are planted and harvested in the cropping cycle.

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