Substitutive Effects of Upland Rice and Soybean Plant Populations on the Performance of the Component Crops in Intercropping System

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Abstract. A two–year field experiment was carried out in the 2018-2019 cropping seasons to determine the effect of substitutive plant population on the yield and productivity of component crops in the upland rice/soybean intercropping in the lowland humid region of Umudike, Southeast Nigeria. The treatments comprised three intercrop populations and one sole crop population of upland rice and soybean, which includes sole upland rice (*Oryzae sativa* L.) 100%, sole soybean 100%, Upland rice (*Oryzae sativa* L.) 25% + Soybean 75%, Upland rice (*Oryzae sativa* L.) 50% + Soybean 50% and Upland rice (*Oryzae sativa* L.) 75% + Soybean 25%. The experiment was laid out in randomized complete block design (RCBD) with three replications. The yield data collected were subjected to analysis of variance (ANOVA) using Genstat (2009), which includes grain yield of upland rice, number of panicles per plant, weight of seeds per panicle, weight of seeds per plant, and 1000-seed weight while soybean includes number of seeds per pod, number of seeds per plant, weight of seeds per plant. The treatments that received Rice 75/Soybean 25 produced the highest number of seeds/panicle weight of seeds/plant in 2018, while the correlation result showed a strong and positive association between grain yield of upland rice, number of panicle per plant, weight of seeds per panicle, weight of seeds per plant, and 1000-seed weight. Based on the result of the investigation, Rice 50/Soybean 50 gave the highest total land equivalent ratio (TLER), land equivalent ratio (LER), and % land saved in 2018. However, it was not consistent in 2019.

Keywords: plant population; rice; soybean; treatment; grain.

INTRODUCTION

Rice (*Oryza sativa* L.) is the third most widely grown cereal in the world after wheat and maize, and Its production is said to have improved food security, particularly in rain-fed lowland areas [1]. Upland rice is cultivated on dry land that is not watered throughout its lifetime, and the water source comes from soil moisture derived from rainfall [2]. It is the staple food for about half of the world's population and has contributed mainly to smallholder farmers' economic growth and development. It is the most commonly grown cereal crop in tropical countries like Nigeria, and it has helped solve national issues of low grain production.

Soybean (Glycine max L), which belongs to Leguminoseae and genus Glycine, is an annual crop grown for its oil and protein. It can potentially fix atmospheric nitrogen, meet its own needs, and be a viable and low-cost medium for soil fertility improvement [3].

Inter-cropping can be described as growing two or more crops on the same land during a growing period [4]. The system is more efficient than sole cropping and improves the soil's physical and chemical properties [5]. The main objective of intercropping has been to maximize the use of resources such as space, light and nutrients [6] and improve crop quality, quantity and greater cash returns. One of the critical factors for achieving a triumphant intercropping return is developing appropriate planting density, which depends on the plant species and the particular varieties used [7]. The study was conducted to determine the effect of substitutive plant population on the yield and productivity of component crops in upland rice/soybean intercropping.

METHODS

Two field experiments were established at the research farm of Michael Okpara University of Agriculture, Umudike, located around longitude 07o 33'E and latitude 05o 29' N at an elevation of 122m above sea level in the humid tropical lowland of southeast Nigeria in 2018 and 2019 cropping seasons. The treatments comprised four intercrop populations and one sole crop population of upland rice and soybean. The treatments were as follows:

Sole upland rice (*Oryzae sativa* L.) 100% (20×20 cm – 500,000 plants/ha at two plants/stand);

Sole soybean 100% (20×20 cm – 250,000 plants/ha at one plant/stand);

Upland rice (*Oryzae sativa* L.) 25% (20×20 cm – 125,000 plants/ha at two plants/hill) + Soybean 75% (20×20 cm – 187, 500 plants/ha at one plant/hill),

Upland rice (*Oryzae sativa* L.) 50% (20×20 cm – 250,000 plants/ha at two plants/hill) + Soybean 50% (20×20 cm – 125,000 plants/ha at one plant/hill);

Upland rice (*Oryzae sativa* L.) 75% (20×20 cm – 375,000 plants/ha at two plants/hill) + Soybean 25% (20×20 cm – 62,500 plants/ha at one plant/hill).

The experiment was laid out in a randomized complete block design (RCBD) with three replications. Each experimental plot measured 2×2m (4 m^2) with an intra-block spacing of 0.5m and inter-block spacing of 1 m. Crop varieties used were Upland rice (FARO 58) and Soybean (TGX 47). The yield parameters measured for upland rice include weight of seeds per panicle, weight of seeds per plant, 1000-seed weight and grain yield.

Data collected for soybeans include the number of seeds per pod, the number of seeds per plant, the weight of seeds per plant, and the grain yield. The growth and yield data collected were subjected to analysis of variance (ANOVA) using Genstat [8]. Treatment means were compared for statistical significance using Fisher's least significant difference (F-LSD) at 0.05 probability level, according to [9].

Land Equivalent Ratio (LER). It was used to determine the intercropping advantage of the system and calculated as follows:

$$LER = \frac{\text{yield of component A in mixture}}{\text{yield of component A in pure stand}} + \frac{\text{yield of component B in mixture}}{\text{yield of component B in pure stand}}$$

If LER is calculated to be 1.0, it indicates the exact yield as expected. LER less than 1.0 shows a yield advantage [10, 11]. According to [4], LER can assess yield performances in replacement and additive models.

Area Time Equivalent Ratio (ATER) is calculated as follows:

ATER = [(Ryc x tc) + (Ryp x tp)]/T,

where Ryc, Rpy = relative yield of species of c or p, which equals yield of intercrop per hectare divided by yield of sole crop per hectare; t – duration (days, weeks or months) for species c or p; T – duration (days, weeks or months) for intercrop system [12, 13].

Land Equivalent Coefficient (LEC). LEC is the product of intercrop and equivalent ratios [14] calculated as follows:

LEC = L1 x L2 x… y1 / Y1 x y2 / Y2

where L1, L2 – represents partial LER of the component crops in the intercrop; y1, y2 – represents the yield of the component crops in the association; Y1, Y2 …represents their corresponding optimum sole crop yield for the total land area occupied by both or all associated crops.

The LEC indicates that the mixtures' productivity depends on enhancing the performance of the less favoured species, such that the more equitable the contribution of component crops is, the more productive the system will be.

The percentage of land saved was calculated using the following formula:

*% of land saved = (Area under mono-crop – Area under intercrop) / Area under mono-crop * 100.*

RESULTS AND DISCUSSION

The total annual rainfall for the 2018-2019 cropping seasons was 2028.6 mm and 3075.0 mm, respectively (Table 1). The rainfall was bimodal and peaked in April and September 2018 and July and September 2019, but it was highest in September 2019 compared to other months. April to October experienced high and stable rainy days in 2018 and 2019. The temperature was relatively high throughout 2018 and 2019. The mean monthly max temperature was 32.9 °C and 31.7 °C, respectively, in 2018 and 2019. Relative humidity was highest in 2018 compared to 2019.

Table 1 – Agro meteorological data of the experimental sites for 2018 and 2019

Month	Rainfall Amount (mm)	Maximum air temperature, °C	Relative humidity, % (0900 Hrs)	Rainfall Amount (mm)	Maximum air temperature, °C	Relative Humidity, % (0900Hrs)
	2018			2019		
January	0.0	34.1	78	38.9	35	65
February	80.1	34.5	81	80.9	34	69
March	9.6	34.4	87	65.7	34	84
April	337.5	32.5	88	137.1	36	79
May	246.6	32.6	87	355.7	32	77
June	326.6	30.9	87	523.4	29	76
July	237	29.6	84	554.1	28	90
August	173.3	30.4	80	206.6	30	89
September	334.7	30.1	85	635.0	27	88
October	238.9	40.8	78	367.3	31	78
November	44.3	30.7	81	107.2	32	70
December	0.0	34.5	87	0.0	32	47
Total	2028.6	395.1	1003	3075.0	380	912

Yield and Yield Components of Upland Rice. Crop ratio showed a significant difference (P<0.05) in number of seeds per plant, weight of seeds per plant, and grain yield of rice in 2018. In 2019, the number of seeds per plant and grain yield produced a significant difference (Table 2). However, among the significant treatments, Rice 75/Soybean 25 consistently produced the highest number of seeds/panicle, weight of seed/plants, and grain yield in 2018, although the trend was not the same in 2019.

Table 2 – Effect of substitutive plant populations of upland rice and soybean on yield and yield components of upland rice in 2018 and 2019 cropping seasons

Treatment	2018					2019				
	Number of panicles per plant	Number of seeds per panicles	Number of seeds per plant	Weight of seeds per plant	Grain yield (t/ha)	Number of panicles per plant	Number of seeds per panicles	Number of seeds per plant	Weight of seeds per plant	Grain yield (t/ha)
Sole upland rice (100 %)	5.88	118.30	687.00	13.50	1.31	4.84	113.20	585.00	4.26	1.53
Upland rice (25%) + Soybean (75 %)	5.07	126.70	611.00	14.40	1.44	4.97	117.90	600.00	4.50	1.40
Upland rice (50 %) + Soybean (50 %)	7.15	105.70	758.00	20.90	2.09	6.60	126.10	835.00	3.63	2.46
Upland rice (75 %) + Soybean (25%)	7.23	129.30	941.00	24.900	2.48	5.63	130.70	726.00	4.59	2.06
LSD(0.05)	Ns	ns	297.90	7.83	0.710	1.64	ns	198.30	ns	0.62

Upland Rice Correlation (Table 3) indicated a strong, significant and positive correlation association between the grain yield of upland rice and the number of panicles/plant, weight of seeds/panicle, number of seed per plant, the weight of seeds per plant and 1000- seed weight. Still, it exhibited an enormously significant but negative correlation association with the number of leaves per plant eight weeks after planting. The variables exhibited different degrees of association amongst themselves.

Table 3 – Combined Pearson's linear correlation matrix across two cropping seasons (2018 and 2019) between different agronomic attributes of upland rice as influenced by substitutive plant populations of rice and soybean in intercrop

Rice	Grain yield, t/ha	Number of panicle / plant	Number of seeds / panicles	Weight of seeds per panicle, g	Length of panicle, cm	Number of seeds / plant	Weight of seeds/ plant, g	1000-seed weight, g	Plant height (cm)	Number of leaves / plant	Number of tillers / plant	Leaf area index
Plant characters									(8 WAP)			
Grain yield (t/ha)	1.00											
Number of panicles/plant	0.73**	1.00										
Number of seeds/panicles	0.11	-0.11	1.00									
Weight of seeds/panicle	0.60**	0.11	0.62**	1.00								
Length of panicle (cm)	0.12	-0.01	0.10	0.43*	1.00							
Number of seeds/ plant	0.77**	0.90**	0.28	0.37	0.1	1.00						
Weight of seeds/ plant	0.93**	0.79**	0.29	0.67**	0.3	0.90**	1.00					
1000-seed weight (g)	0.46*	0.07	0.22	0.70**	0.32	0.14	0.46*	1.00				
Plant height 8wap	-0.17	-0.42*	0.18	0.12	0.27	-0.29	-0.20	0.22	1.00			
Number of leaves 8WAP	-0.52**	-0.46*	-0.23	-0.43*	-0.17	-0.49*	-0.59**	-0.17	0.22	1.00		
Number of tillers 8WAP	-0.31	0.01	-0.01	-0.36	-0.11	-0.03	-0.19	-0.38	-0.21	0.19	1.00	
Leaf area index 8WAP	-0.27	-0.46*	0.08	0.06	0.15	-0.38	-0.34	0.07	0.52**	0.52**	-0.42*	1.00

Notes: WAP – Weeks after planting; *, ** – correlation not significant or significant at 0.05 and 0.01% level of probability (2-tailed), respectively.

Soybean yield. Crop ratio showed a significant difference (P<0.05) in the parameters evaluated (weight of pods per plant and weight of seeds per plant) of soybeans in both cropping seasons (Table 4). 50% +50% soybean produced consistently the highest number of pods per plant and weight of seeds per plant in the 2018 and 2019 cropping seasons.

The combined (2018 and 2019) Pearson's correlation analysis (Table 5) indicated a powerful, significant, and positive correlation association between soybean grain yield, number of pods/plant, and 1000-seed weight. Still, they showed a negative and significant correlation between grain yield and the number of branches eight weeks after planting, and the variables exhibited varying degrees of association among themselves.

Furthermore, the regression between the land equivalent ratio and net return (N:K).

Table 4 – Effect of substitutive plant populations of upland rice and soybean on yield and yield components of soybean in 2018 and 2019 cropping seasons

Treatment	2018					2019				
	Number of pods per plant	Number of seeds per plant	Weight of pods per plant	Weight of seeds per plant	Grain yield (t/ha)	Number of pods per plant	Number of seeds per plant	Weight of pods per plant	Weight of seeds per plant	Grain yield (t/ha)
Sole Soybean 100%	62.59	116.70	10.43	8.58	2.76	58.90	108.70	10.37	7.15	2.46
25% Rice + 75% Soybean	63.14	121.30	12.81	10.56	1.87	58.30	131.70	12.37	9.61	1.98
50% Rice + 50% Soybean	61.62	121.30	15.99	12.35	2.24	64.40	126.20	17.85	13.35	2.40
75% Rice + 25% Soybean	60.55	126.40	13.97	11.58	2.39	63.20	127.00	14.22	10.68	2.14
LSD(0.05)	ns	ns	3.812	3.214	ns	ns	18.520	6.315	5.479	ns

Table 5 – Combined Pearson's linear correlation matrix across two cropping seasons (2018 and 2019) between different agronomic attributes of soybean as influenced by substitutive plant populations of rice and soybean in intercrop

Soybean	Grain yield (t/ha)	Number of pods/ Plant	Weight of Pods/ Plant	Weight of seeds / Plant	Number of seeds/ plant	100-Seed Weight(g)	Plant height 8WAP	Number of leaves 8WAP	Number of branches 8WAP
Grain yield (t/ha)	1.00								
Number of pods/ Plant	0.54**	1.00							
Weight of Pods/Plant	0.44*	0.56**	1.00						
Weight of seeds/Plant	0.47*	0.55**	0.92**	1.00					
Number of seeds/Plant	0.37	0.37	0.36	0.45*	1.00				
100-Seed weight (g)	0.61**	0.52**	0.69**	0.81**	0.64**	1.00			
Plant height 8WAP	-0.09	-0.33	-0.60**	-0.67**	-0.52**	-0.49*	1.00		
Number of leaves 8WAP	0.07	-0.26	-0.52**	-0.62**	-0.03	-.030	.0.90**	1.00	
Number of branches 8WAP	-0.46*	-0.14	0.00	-0.04	-0.35	-0.25	-0.04	-0.18	1.00

Notes: *, ** – Correlation is significant 2-tailed), respectively.

Table 6 – Substitution effect of plant populations of upland rice and soybean on land equivalent ratio, area x time equivalent ratio, land equivalent coefficient, % land saved and intercrop susceptibility index of component crops in 2018 and 2019 cropping seasons

	Land equivalent ratio (LER)			Area x-time equivalent ratio (ATER)	Land equivalent coefficient (LEC)	% land saved	Intercrop susceptibility index (ISI)	
	Partial		Total					
	Rice	Soybean					Rice	Soybean
2018								
Sole rice 100	1	1	1	-	-	-	-	-
Sole soybean 100	1	1	1	-	-	-	-	-
Rice 25 /soybean 75	0.58	0.68	1.26	1.11	0.39	20.52	0.42	0.32
Rice 50 /soybean 50	0.84	0.81	1.65	1.44	0.68	39.55	0.16	0.19

	Land equivalent ratio (LER)			Area x-time equivalent ratio (ATER)	Land equivalent coefficient (LEC)	% land saved	Intercrop susceptibility index (ISI)	
	Partial		Total					
	Rice	Soybean					Rice	Soybean
Rice 75 /soybean 25	0.53	0.87	1.39	1.26	0.46	28.27	0.47	0.13
2019								
Sole rice 100	1	1	1	-	-	-	-	-
Sole soybean 100	1	1	1	-	-	-	-	-
Rice 25 /soybean 75	0.57	0.80	1.37	1.23	0.46	27.22	0.43	0.20
Rice 50 /soybean 50	0.62	0.98	1.60	1.44	0.61	37.40	0.38	0.02
Rice 75 /soybean 25	0.84	0.87	1.71	1.50	0.73	41.57	0.16	0.13

Notes: 1) partial LER for upland rice and soybean was obtained by dividing each intercrop yield by its corresponding sole crop yield; 2) total LER was the sum of the partial LERs from upland rice and soybeans in the intercropping system; 3) no measurements were taken from the corresponding plots because the representative component crop (upland rice or soybean) was not planted in that plot (sole crop); 4) upland rice and soybean sold at the prevailing farm gate prices (N·kg-1) of N250·kg-1 and N140·kg-1·Mt-1, respectively; 5) Net return (NR) was the difference between TGMR and variable Total production costs (TCP) of upland rice and soybean in the systems, while BCR is the ratio of NR and TCP.

Productivity indices and economic returns. The crop ratio LER of the intercrop combination was above (1), indicating a higher intercropping productivity than the individual sole crop (Table 6). With the highest yield advantage, LER was obtained from Rice 50/soybean 50 in 2018, while in 2019, Rice 75/soybean 25 gave the highest LER. Rice 50/soybean50 produced the highest ATER of 1.50, while Rice 75/soybean 25 produced the highest ATER of 1.50 in the 2019 cropping season.LEC (0.68) was higher in Rice 50/soybean 50 in 2018, while LEC (0.73) was higher in Rice 75/ soybean 25 in 2019. In 2018 (39.55%), land was saved in Rice 50/Soybean 50 treatment, while in 2019 (41.5%) Land was saved in Rice 75 / Soybean 25 treatment.

The yield result showed that crop ratio affected rice and soybean yield components. The treatment with a crop ratio of Rece 75/Soybean 25 gave the highest grain yield of rice in 2018, which could be attributed to the complementarity of the component crops. The findings corroborate [15], who reported an increase in the yield parameters of the component crop with an increasing crop ratio. The Pearson correlation analysis in the study aligns with [16], who reported that the increase in the number of pods per plant, pod per plant, weight of seed per plant, and one thousand seed weight positively increased grain yield. The regression analysis aligns [17-21] with those who reported higher productivity, complementary resources use, low cost of production, increased grain yield, economic returns, a better benefit-cost ratio, and increased net return. The LER values greater than one indicated that intercropping resulted in a higher yield advantage than sole crop. This agrees with Li et al. [22], who reported that the optimal crop ratio for rice/soybean intercropping can vary depending on specific conditions. The Rice 75/Soybean 25 crop ratio could be more productive in other environments, such as those with lower rainfall or more fertile soils [23]. The highest LEC obtained from Rice 75/Soybean 25 suggests that despite having a higher proportion of rice, the system exhibited a greater land use efficiency in 2019 than in 2018. The variability observed in ATER could be attributed to differences in rice–soybean ratios. It suggests that Rice 50/Soybean 50 crop ratios might have benefited rice and soybean intercrop.

Conversely, despite its high rate proportion, Rice 75/Soybean 25 treatment might have been managed with strategic crop proportion [24]. The observed increase in % of land saved from 2018 to 2019 can be attributed to a shift in intercropping ratio from Rice 50/Soybean 50 to Rice 75/Soybean 25, demonstrating the intercropping system's adaptability. The higher proportion in the Rice 75/Soybean 25 treatment may have allowed for more efficient utilization of resources, leading to more significant land savings.

CONCLUSIONS

The substitutive upland rice/soybean plant population studies showed that intercropping Rice 50/Soybean 50 gave the highest total land equivalent ratio, land equivalent coefficient and percent land saved compared to other treatments.

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