American Journal of Plant Sciences, 2025, 16(7), 878-902
https://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Yield, Yield Components and Yield Stability of Component Crops in a Maize-Cowpea Intercrop System in the Sudan Savannah Zone in Ghana

Listowell Aditwin Akologo[1], Harrison Kwame Dapaah[2], Margaret Esi Essifie[2], Julius Yirzagla[3]

[1]Gbewaa College of Education, Pusiga-Bawku, Ghana
[2]Mampong Campus, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Mampong, Ghana
[3]Council for Scientific and Industrial Research - Savanna Agricultural Research Institute (CSIR-SARI), Nyankpala, Ghana
Email: aditwinlisto@gmail.com

How to cite this paper: Akologo, L.A., Dapaah, H.K., Essifie, M.E. and Yirzagla, J. (2025) Yield, Yield Components and Yield Stability of Component Crops in a Maize-Cowpea Intercrop System in the Sudan Savannah Zone in Ghana. *American Journal of Plant Sciences*, **16**, 878-902.
https://doi.org/10.4236/ajps.2025.167060

Received: February 22, 2025
Accepted: July 25, 2025
Published: July 28, 2025

Abstract

A cereal-legume intercrop multi-location research was conducted at the experimental fields of the Council for Scientific and Industrial Research-Savannah Agricultural Research Institute (CSIR-SARI) at Manga, Binduri District and at the Presbyterian Agricultural Station (PAS) at Garu District, from July - October 2021 and repeated in same time and place in 2022. The aim of this research was to examine the influence of intercropping systems on yield, yield components and stability of maize and cowpea in a maize-cowpea intercrop in a multi-location experiment in the Sudan Savannah zone in Ghana. The study was carried out in a 3 × 3 factorial, laid out in a Randomized Complete Block Design (RCBD) with 4 replications. The factors studied were Row arrangements (RA): 1 row maize altenating with 1 row cowpea (1M:1C), 2 rows maize altenating with 2 rows cowpea (2M:2C) and 3 rows maize alternating with 3 rows cowpea (3M:3C) as Factor A. Factor B was the relative times of planting, Simultaneous planting of maize and cowpea (SIM), maize planted 2 weeks before cowpea (M2WBC) and cowpea planted 2 weeks before maize (C2WBM) in addition to Sole maize and sole cowpea crops. The yield and yield components of both maize and cowpea were significantly higher than the sole crops at both locations and seasons. Component crops planted simultaneously (SIM) at 2M:2C produced the largest maize yield of 13.33 t/ha, followed by planting maize 2WBC at 2M:2C (8.27 t/ha), while the least maize yield was reported by 3M:3C + C2WBM (1.40 t/ha). The highest cowpea yield was obtained when cowpea was planted 2WBM at 1M:1C (3.79 t/ha), followed by planting maize and cowpea simultaneously (SIM) at 1M:1C. The lowest cowpea yield was produced by 3M:3C + SIM (0.93 t/ha) at Garu in 2021. Yield stability analysis indicated that 1M:1C + C2WBM and 2M:2C + C2WBM for maize and 2M:2C + M2WBC, 2M:2C + SIM and Sole Cowpea for cowpea had regression coefficient values close to 1 making these systems more stable. It is recommended that farmers interested maize yields could adopt planting the two crops simultaneously at 2M:2C row arrangement for maximum crop yield and those interested in cowpea yields could adopt planting cowpea 2 weeks before maize at 1M:1C to harvest more cowpea.

Keywords

Agro-Ecological, Ecosystem Services, Phenological Development, Component Crops

1. Introduction

Maize (*Zea mays* L.) is a major staple cereal crop that provides energy for millions of the global population, particularly Africa and Asia, where it is a major contributor to global food security [1]. Maize is the major cereal crop grown in Ghana, contributing to about 50% - 60% human and animal feed and thrives. It is high yielding, hence contributes largely to food security in Ghana [2]. Many farmers in the Savannah regions cultivate maize in both subsistence and commercial systems, giving farmers in the area experiences and expertise in managing its cultivation in terms of applying the right agricultural and agronomic practices for increased yield.

Cowpea (*Vigna unguiculata*) is a shade tolerant leguminous crop that is compatible in intercropping systems with cereal crops such as maize (*Zea mays* L.), millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor* L. Moench). its high protein content, cowpea contains essential food nutrients such as fat and oils and hence its consumption is recommended for the reduction of household malnutrition in poorer communities. It is also consumed as a leafy vegetable in many parts of the world. Intercropping can strengthen and stabilize agro-ecosystems under climate change by improving resource use efficiency, enhancing soil water holding capacity and increasing the diversity [1] [3] [4]. Generally, intercropping is one of the modern agricultural techniques that is employed worldwide to increase productivity and improve farmers' livelihood due to increased incomes from sale of produce. According to Manda *et al.* [5] & Wossen *et al.* [6], increased agricultural productivity has long been adopted as a major tool and effective pathways through which farmers are helped to increase their incomes and reduce rural poverty among vulnerable people.

2. Materials and Methods

2.1. Experimental Site

The study was conducted in the Sudan Savannah Ecological Zone in the Upper East Region in Ghana, at CSIR-SARI outstation at Manga and the Presbyterian Agricultural Station (PAS), at Garu. The CSIR-SARI, Manga is an outstation experimental fields of the CSIR-SARI, located at Manga in the Binduri District, while the PAS is a non-governmental research centre owned by the Presbyterian Church of Ghana, located at the Garu District. The studies were carried out at both locations from July - October, 2021 for the first year and July - October, 2022 for the second year. Binduri District is located approximately between latitudes 11˚11'S and 10˚40'N and longitudes 0˚18'W and 0˚6'E in the North-Eastern corner of the Upper East Region. The second location, PAS, Garu District, is located in the North-Eastern part of the Upper East Region between Latitude 10˚ 1˚N and Longitude 0˚ 1˚W.

2.2. Soil Analysis and Climatic Conditions

Initial soil (0 - 30 cm depth) at Garu indicated soil chemical properties of pH 5.7. It contained major nutrients of %N (0.02), P (1.5 mg/kg) and K (22.2 mg/kg). The minor nutrients were Ca^{2+} (0.8 cmol/kg) and Mg^{2+} (0.7 cmol/kg) with %OC (0.5). The loamy sand contained sand (80.2%), clay (9.6%) and silt (10.2%) (**Table 1**). Similarly, initial soil analysis at Manga indicated soil chemical properties of pH 5.6. It also contained major nutrients of %N (0.03), P (1.4 mg/kg) and K (24 mg/kg). The minor nutrients possessed were Ca^{2+} (0.9 cmol/kg) and Mg^{2+} (0.7 cmol/kg) with %OC (0.5). The loamy sand contained sand (83.9%), clay (6.4%) and silt (9.7%) (**Table 1**).

Generally, the initial soil analysis for both Garu and Manga showed the soils were slightly acidic and that the nutrient level were low phosphorus, nitrogen and manganese. However, the initial soil analysis indicated that soil from both locations had medium organic carbon and potassium. Manga has classified the Manga field into the Varempare Series, which are mainly sandy loams associated with hornblende and granites, while the PAS soils belong to the Tafali Series, which is also suitable for the cultivation of legumes, cereals and vegetables. The climate of both locations is characterised by a uni-modal rainy season from May /June to October and a dry harmattan season from November to April. The average amount of rainfall during the period is between 800 - 860 mm per annum. The vegetation is mainly the Sudan Savannah Ecology consisting scattered drought resistant trees, shrubs and grasses which often get burnt during the long dry season. The most common economic trees found within the zone are the dawadawa, baobab, mango and the shea tree. Farming is the predominant occupation of the people in the district with the total farmer population ranging between 80% and 90%.

2.3. Experimental Design and Treatments

The experimental design used for the study was a 3 × 3 factorial arranged in a Randomized Complete Block Design (RCBD) with 4 replicates. The study was conducted at Manga and Garu simultaneously in the 2021 cropping season and repeated in the 2022 cropping season at both locations. The treatments consisted Row arrangements (RA): 1 row maize altenating with 1 row cowpea (1M:1C), 2 rows maize altenating with 2 rows cowpea (2M:2C) and 3 rows maize alternating with 3 rows cowpea (3M:3C) as Factor A, while factor B comprised Simultaneous planting of maize and cowpea (SIM), maize planted 2 weeks before cowpea (M2WBC) and cowpea planted 2 weeks before maize (C2WBM) in addition to Sole maize and sole cowpea crops. Sole maize and sole cowpea crops were added for comparison to bring the total number of treatments to eleven. Maize variety was planted 0.75 m × 0.4 m, while the cowpea variety was planted 0.75 m × 0.2 m. Each plot consisted 4 sets of the intercrops for the 1M:1C and 3 sets of intercrops for the 2M:2C and 3M:3C. The central two sets of the intercrops for 1M:1C and 1 set of intercrops for 2M:2C and 3M:3C served as the harvestable areas for the final yield and yield components assessment. The sole maize and cowpea plots were planted 6 rows per plot. Row length was 5 m long. The central 2 rows of the sole maize and cowpea served as harvestable rows. Improved medium maturing maize variety (Wangdataa) and improved medium maturing cowpea variety (Wangkae), were sourced from Manga, an outstation of SARI.

2.4. Crop Management and Cultural Practices

The experimental field at both locations were ploughed with a tractor and an animal drawn mould board plough used in ridging. Ridges formed measured 0.75 m apart. Planting of maize and cowpea were done with hoes. The crops were planted 3 seeds per hill and later thinned to two plants per hill when plants were established. The sole maize and cowpea were planted when component crops were planted simultaneously. Manual weeding was done regularly till component crops were harvested. Basal application of NPK was applied to the maize crop at the rate of 68 kg N, 38 kg P_2O_5 and 38 K_2O at 14 DAP and top-dressed with urea at 65.2 $kg \cdot ha^{-1}$ at 50 DAP.

Inoxacarb (30 g/l) and Acetamiprid (16 g/l), a systemic insecticide against armyworm and a wide spectrum of pests on maize and vegetables was used. The Viper 46 EC (0.4 L/Acre), equivalent to 40 ml/15 L of water and (Inoxacarb, 30 g/l and Acetamiprid, 16 g/l) were sprayed. The spraying was carried out on both maize and cowpea plots. Generally, high farm hygiene was maintained to ensure maximum productivity. Alternate host plants around the trials were cleared regularly.

3. Results and Discussion

3.1. Yield and Yield Components of Maize

The analysis of yield and yield components indicated that number of maize plants harvested, cob length, number of maize cobs harvested, harvest index, total grain yield per hectare (t/ha) indicated significant differences at ($P < 0.05$). However, thousand seed weight did not register any significant differences at ($P < 0.05$).

There were high significant effects for RA, RTP and Year on the number of maize plants harvested across both locations and seasons. The number of plants harvested registered high significant interactions for RA × RTP and RA × Year for

Garu and only RTP × Year for Manga. The study showed that maize planted 2 weeks before cowpea and maize planted simultaneously with cowpea produced the highest number of plants harvested per plot than maize plated 2 weeks after cowpea during the study period. Good environmental conditions, available soil nutrients coupled with less competition for growth factors enhanced high maize growth and maize yield (**Table 1**). According to Uhart and Andrade [7], unfavourable environmental conditions can affect the phenology and growth variables of maize leading to a reduced total maize yield.

Table 1. Number of maize plants harvested as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Cropping systems		Number of plants harvested per plot					
		Garu			Manga		
Row arrangement (RA)	Relative times of planting (RTP)	2021	2022	Mean	2021	2022	Mean
1M:1C†	M2WBC#	48	39	44	44	31	38
	SIM	45	39	42	45	31	38
	C2WBM	38	38	38	31	23	27
2M:2C	M2WBC	47	38	43	46	39	43
	SIM	48	46	47	37	34	36
	C2WBM	38	45	42	26	28	27
3M:3C	M2WBC	71	64	68	63	56	60
	SIM	66	65	66	67	54	61
	C2WBM	53	65	59	24	31	28
Mean		50	49		43	36	
Sole maize		42	45	44	42	35	
RA		HSD = 5.18 p < 0.0001			HSD = 5.13		p = 0.0001
RTP		HSD = 5.18		p < 0.0001	HSD = 5.13		p = 0.0078
Year		HSD = 3.51		p < 0.0001	HSD = 3.48		p < 0.0001
<u>Interactions</u>							
RA × RTP		HSD = 3.17		p = 0.0040	HSD = NS		p = 0.3455
RA × Y		HSD = NS		p = 0.1510	HSD = NS		p = 0.1076
RTP × Y		HSD = 1.75		p = 0.0060	HSD = 1.91		p = 0.0005
RA × RTP × Y		HSD = NS		p = 0.0549	HSD = NS		p = 0.1958

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

There were significant effects of RA on cob length at Manga, while Year indicated significant effect on cob length at Garu. However, there were no significant interactions for RA, RTP and Year on the length of maize cobs for both locations and seasons. Generally, maize cob length ranged from 9cm to 15.3cm for both seasons and locations. Maize plants arranged 3M:3C produced the longest cobs among the row arrangements at Garu in 2021 and 2022 (**Table 2**). Cob length is an important yield component. Row arrangement and year registered significant differences when the length of maize cobs were harvested and measured. Generally, maize cob length registered up to 15.3 cm for both seasons and locations. Cob length was largely influenced by more absorptance from Maize plants arranged 3M:3C and the favourable rainfall received at Garu throughout the experimental period. The number of cobs harvested per plot was significantly influenced by the intercropping systems because sole maize had less number of plants with cobs for harvesting than some intercrops. This was contrary to findings by Gabatshele *et al.* [8].

Maize planted simultaneously and maize planted 2 weeks before cowpea had more harvest index than maize planted 2 weeks after cowpea. The higher harvest index obtained by Maize planted simultaneously and maize planted 2 weeks before cowpea was due to early growth of maize that established and accumulated a lot of biological mass before the maize planted when cowpea was already 2 weeks old. Harvest index measures how effective the accumulated resources in the plant are partitioned into the harvested maize grain yield [9].

Table 2. Cob length of Maize as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Cropping systems		Cob length (cm)					
		Garu			Manga		
Row arrangement (RA)	Relative times of planting (RTP)	2021	2022	Mean	2021	2022	Mean
1M:1C†	M2WBC#	13.2	13.7	13.5	9.0	12.8	10.9
	SIM	13.5	13.7	13.6	12.8	12.8	12.8
	C2WBM	12.9	12.8	12.9	11.0	13.5	12.3
2M:2C	M2WBC	13.4	14.2	13.8	12.0	13.3	12.7
	SIM	12.5	14.2	13.4	12.0	14.0	13.0
	C2WBM	11.8	13.6	12.7	11.3	13.0	12.2
3M:3C	M2WBC	13.6	14.4	14.4	11.8	14.0	12.9
	SIM	14.4	15.3	14.9	12.5	13.8	13.2
	C2WBM	13.1	14.3	13.7	10.8	14.0	12.4
Mean		13.2	14.0		11.5	13.5	
Sole maize		13.3	15.1	14.2	11.3	14.3	12.8
RA		HSD = NS	p = 0.4292		HSD = 0.746	p = 0.0030	
RTP		HSD = NS	p = 0.0963		HSD = NS	p = 0.4574	

Continued

Year	HSD = 0.86.	p = 0.0003	HSD = 0.505	p = 0.0315
Interactions				
RA × RTP	HSD = NS	p = 0.3638	HSD = NS	p = 0.8934
RA × Y	HSD = NS	p = 0.3563	HSD = NS	p = 0.8323
RTP × Y	HSD = NS	p = 0.3563	HSD = NS	p = 0.4106
RA × RTP × Y	HSD = NS	p = 0.7023	HSD = NS	p = 0.5356

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

Thousand seed weight of maize did not show any significant differences for RA and Year, but differed significantly among RTP at Garu. Similarly, significant interactions occurred only between RTP and Year at Manga. In the first season, 3M:3C + SIM produced the largest thousand seed weight (288.4 g) in 2021, while 3M:3C + M2WBC recorded the largest weight (332.7 g) in 2022 at Garu. Similarly, 3M:3C + C2WBM produced the lowest thousand seed weight (166.4 g) in 2021, while the 3M:3C + M2WBM recorded the lowest seed weight (266.9 g) in 2022 at Garu (**Table 3**).

3.1.1. Total Grain Yield

There were significant effects and interactions of RA, RTP and Year on total grain yield of maize for both locations and seasons. Maize planted 2 weeks before cowpea and maize planted simultaneously produced the highest grain yield than yields from maize planted 2 weeks after cowpea for the two seasons and experimental sites. The intercrop plots generally produced maize yields that were higher than the sole crops indicating higher crop productivity and efficient land use cropping system. The average total yield per hectare of 8.18 t/ha for Garu and 5.52 t/ha for Manga is far above the average maize in the Sudan ecological zone of 3.5 t/ha. The dominant performance of maize for both locations and seasons were maize planted 2 weeks before cowpea and maize planted simultaneously. This was due to early establishment, high tasseling, silking and other growth parameters obtained that gave them competitive advantage over the late crops. There was also effective use of growth resources to promote phenological and vegetative growth and finally yield and yield components of component crops. Similarly, planting maize 2 weeks before cowpea gave the maize a head starts before the late crop (**Table 4**).

The higher maize grain yield obtained from the study in both locations and years could also be attributed to adequate and stable distribution of rainfall during the vegetative, tasseling, silking and grain filling stages of the maize plant because these are the growth stages that require adequate water for vigorous plant growth and efficient grain filling as reported by Abdul-Rahman *et al.* [10]. Maize yields obtained suggest that the overall productivity of the intercrop system was superior to the sole crop. Earlier studies confirm these findings [11]-[15] (**Table 4**).

Furthermore, previous studies support this result as was stated that intercropped maize is usually characterized by a deeply proliferated root system with a larger mass of fine roots that could support better access to soil nutrients, which made maize more competitive than cowpea that was largely over shadowed underneath [16] (**Table 4**).

Nonetheless, other studies have stated lower yields for cereal-legume intercrops compared yields from sole crops [17] [18]. The yield obtained from this research suggest that intercropping is a climate smart agriculture innovation that is required in this era of climate change and food insecurity. The study produced yields that were largely varied in both seasons and experimental sites. Intercropping studies have revealed that such variations are normal due to the various treatment combinations. The combinations of intercrops across and other systems are less predictable and sometimes lead to yield losses [19], because yield is strongly tied to competition between intercrops [20] (**Table 4**).

Table 3. Thousand seed weight of maize as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Cropping systems		1000 seed weight (g)					
		Garu			Manga		
Row arrangement (RA)	Relative times of planting (RTP)	2021	2022	Mean	2021	2022	Mean
1M:1C†	M2WBC#	209.6	313.3	261.5	295.6	325.6	310.6
	SIM	272.0	317.3	294.7	297.8	325.3	311.6
	C2WBM	246.6	267.1	256.9	227.2	263.5	245.4
2M:2C	M2WBC	284.9	311.5	298.2	238.8	312.5	275.7
	SIM	239.4	299.7	269.6	338.6	321.0	329.8
	C2WBM	201.7	246.7	224.2	249.3	254.4	251.9
3M:3C	M2WBC	279.5	332.7	306.1	263.2	299.0	281.1
	SIM	288.4	322.3	305.4	248.0	309.1	278.6
	C2WBM	166.4	266.9	216.7	209.9	313.8	261.9
Mean		243.2	286.4		263.2	302.7	
Sole maize		293.6	330.2	311.9	297.5	306.6	302.1
RA		HSD = NS	p = 0.5501		HSD = NS	p = 0.3710	
RTP		HSD = 27.38	p = 0.0012		HSD = NS	p = 0.3572	
Year		HSD = NS	p = 0.1495		HSD = NS	p = 0.3173	
Interactions							
RA × RTP		HSD = NS	p = 0.5791		HSD = NS	p = 0.4120	
RA × Y		HSD = NS	p = 0.4541		HSD = NS	p = 0.3728	
RTP × Y		HSD = NS	p = 0.8143		HSD = 804.1	p = 0.03789	
RA × RTP × Y		HSD = NS	p = 0.6305		HSD = NS	p = 0.4066	

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

3.1.2. Harvest Index (HI)

Harvest index recorded significant differences for RTP and Year and differed significantly for RA, RTP and Year at Manga. There were also significant interaction effects for RTP and Year, and RA and Year at Manga. The highest Harvest index for maize was registered by 3M:3C + SIM at Garu, while the highest Harvest index for Manga came from 2M:2C + SIM. Harvest index recorded at Garu were higher than harvest recorded at Manga. Sole maize recorded Harvest index of maize ranging from 0.45 - 0.71 across both seasons and locations. Maize planted simultaneously and maize planted 2weeks before cowpea had more Harvest index than maize planted 2 weeks after cowpea (Table 5).

Table 4. Total Grain Yield of Maize as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Cropping systems		Total Maize Grain Yield (t/ha)					
		Garu			Manga		
Row arrangement (RA)	Relative times of planting (RTP)	2021	2022	Mean	2021	2022	Mean
1M:1C†	M2WBC#	8.02	6.63	7.32	5.60	6.60	6.10
	SIM	8.82	8.93	8.88	6.80	5.27	6.03
	C2WBM	5.07	6.60	5.83	2.67	3.67	3.17
2M:2C	M2WBC	6.87	8.93	7.90	6.40	8.27	7.33
	SIM	7.67	13.33	10.50	7.40	6.33	6.87
	C2WBM	5.07	6.67	5.87	2.87	4.87	3.87
3M:3C	M2WBC	5.77	7.90	6.83	5.70	6.70	6.20
	SIM	6.37	8.22	7.30	3.64	4.53	4.09
	C2WBM	3.60	6.35	4.97	1.40	3.47	2.43
Mean		6.36	8.18		4.72	5.52	
Sole maize		7.27	12.80	10.04	6.67	7.33	7.00
RA		HSD = 1264.3	p = 0.0021		HSD = 1375.8	p = 0.0026	
RTP		HSD = 0.5836	p < 0.0001		HSD = 1375.8	p < 0. 0001	
Year		HSD = 858.49	p = 0.0003		HSD = 934.18	p < 0. 0001	
Interactions							
RA × RTP		HSD = NS	p = 0.6344		HSD = NS	p = 0.3326	
RA × Y		HSD = NS	p = 0.4680		HSD = NS	p = 0.7535	
RTP × Y		HSD = NS	p = 0.4766		HSD = 162.7	p = 0.0035	
RA × RTP × Y		HSD = NS	p = 0.6729		HSD = NS	p = 0.4403	

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

Table 5. Harvest Index (HI) of Maize as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Cropping systems		Harvest Index (HI)					
		Garu			Manga		
Row arrangement (RA)	Relative times of planting (RTP)	2021	2022	Mean	2021	2022	Mean
1M:1C†	M2WBC#	0.64	0.59	0.62	0.47	0.34	0.41
	SIM	0.62	0.69	0.66	0.43	0.41	0.42
	C2WBM	0.51	0.62	0.56	0.38	0.35	0.37
2M:2C	M2WBC	0.56	0.67	0.62	0.43	0.47	0.45
	SIM	0.61	0.68	0.65	0.41	0.52	0.46
	C2WBM	0.51	0.55	0.53	0.41	0.38	0.39
3M:3C	M2WBC	0.66	0.76	0.71	0.31	0.47	0.39
	SIM	0.70	0.78	0.74	0.45	0.36	0.42
	C2WBM	0.50	0.73	0.61	0.40	0.38	0.39
Mean		0.54	0.67		0.41	0.41	
Sole maize		0.62	0.71	0.67	0.36	0.53	0.45
RA		HSD = NS	p = 0.7985		HSD = 0.0598	p = 0.0069	
RTP		HSD = 0.07	p = 0.0187		HSD = 0.0598	p = 0.0141	
Year		HSD = 0.49	p < 0.0001		HSD = 0.0406	p < 0.0001	
Interactions							
RA × RTP		HSD = NS	p = 0.5082		HSD = NS	p = 0.0900	
RA × Y		HSD = NS	p = 0.2921		HSD = 0.0224	p = 0.0036	
RTP × Y		HSD = 0.029	p = 0.0126		HSD = NS	p = 0.07019	
RA × RTP × Y		HSD = NS	p = 0.5537		HSD = NS	p = 0.7220	

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

3.1.3. Yield Components of Cowpea

The component crops for the study are maize and cowpea. The yield and yield components data include number of pods per plant, number of seed per pod, hundred seed weight, HI and Total Cowpea Grain Yield (t/ha). The performance of the variables was significantly influenced by row arrangement and relative times of planting at various levels during the experiment. The research showed a high performance of cowpea planted 2 weeks before and after maize than those planted simultaneously with maize. The reason could be that cowpea planted simultaneously suffered negative competition at the podding stage, hence its inability to effectively mobilise and utilise growth factors to produce more pods.

At Garu, 3M:3C + M2WBC registered the highest number of pods per plant (40) in 2021, but cowpea planted simultaneously with maize produced the least number of pods (19), which was statistically different. The cowpea planted before maize had a head start while the cowpea after maize was influenced by ecosystem services from already established component crop. The simultaneous cowpea could have been overshadowed by the vigorous growing maize. However, Gabatshele *et al.* [8] reported a contrary finding where there were no significant differences for number of pods per plant of cowpea between sole cowpea crop and intercrop as occurred in this study. The prevailing soil conditions could have also contributed to the differences registered. Pod number produced by cowpea depends on a number of factors particularly field and climatic conditions. The greatest number of pods were produced was 43 at Garu in the 2022 cropping season more than the sole crop. The environmental conditions and agro-ecosystem services provided by the intercrop system generally enhanced cowpea yield and yield components. According to Thorat and Gadewar [21], environmental factors and treatment combinations can influence cowpea yield. Therefore, the yield differentials between the years could be attributed to the varied rainfall recorded during the experiment. In both seasons, the first year recorded more rainfall succeeding year. The number of pods per plant registered a positive correlation with number of seeds per pod and leaf area index at Garu (**Table 6**).

Number of seeds per pod of cowpea did not record any significant differences for Row arrangement just like the number of pods per plant, but relative times of planting recoded significant difference for year. Generally, the number seeds per pod of cowpea ranged from 8 - 13 as the highest and lowest number seeds per pod of cowpea. The number of seeds per pod of cowpea significantly varied from 2021 and 2022, indicating that the various locations had distinct environmental conditions that influenced plant growth and subsequent performance on yield and yield components. According to Thorat and Gadewar [21], the number of seeds per pod is influenced by the pod length and size in most situations as well as prevailing environmental conditions. The number of seed per pod also recorded a strong correlation with total grain yield at Garu (**Table 7**).

Hundred seed weight per plot recoded significant difference for Year only. The lack of significance means the intercrop system recorded significant interactions for year and relative times of planting due to the varied climatic conditions recorded at the various experimental sites within the data sampling period. The hundred seed weight significantly varied from 2021 and 2022 heterogeneous environment where the cropping was carried out. A maize-cowpea study reported that there were no significant differences in 100 seed weight of cowpea, conforming to this maize-cowpea multi-location study. Cowpea planted simultaneously with maize produced the highest (21.9 g) hundred seed weight per plot of cowpea than those planted before and after maize and sole cowpea due to benefits of ecological system services from two crops growing with less competition. Ecological intensification with complementary intercrops that occupy different spatial niches have the potential to achieve higher combined productivity than monocultures [22]. Again, biodiversity ensures that more species perform a higher number of vital ecosystem services, and if one component of a diverse ecosystem in diverse cropping systems [23] (**Table 8**).

Harvest index (HI) indicates a progressive measure for selection of varieties largely because high harvest index indicates the quality and yield potential of such variety. Harvest index per plot of cowpea registered significant differences for row arrangement, relative times of planting and Year. The highest performance for harvest index was produced by cowpea planted 2 weeks before maize, which was higher than cowpea planted 2weeks after maize, simultaneously and sole cowpea respectively. The 3M:3C + C2WBM produced the largest harvest index of 0.64 at Manga in 2022. The vigorous growth recorded by cowpea planted 2 weeks before maize were largely due to the head start of cowpea because it was planted first and effective partitioning of assimilates or photosynthates. This conforms to findings by Himmelstein *et al.* [20]. According to Himmelstein *et al.* [20], harvest index measures how efficiently biomass is partitioned into the economic product of component crops. The early planting of cowpea also made it very competitive and effective in biomass production and dry matter accumulation [20] (**Table 10**).

There were high significant effects of row arrangement, relative times of planting and year but no significant interactions on total grain yield of cowpea during the data collection period. The treatment that dominated in the cowpea yield is row arrangement cowpea planted 2 weeks before maize, followed by cowpea planted simultaneously which was significantly higher than cowpea planted 2 weeks after maize. Cowpea planted before maize and cowpea planted simultaneously with maize tend to start growth early, spread it leaves wide and attract more radiation for high photosynthates or assimilate production, hence effective phenological and vegetative growth and consequently higher yields. Cowpea planted 2 weeks before maize produced the highest cowpea grain yield of 3.22 t/ha at Garu, less than cowpea grain yield of 3.79 t/ha obtained at Manga. These results were due to the different environmental conditions experienced at both experimental sites. The early cowpea also had head start for cowpea planted 2WBM, allowing component crops to effectively use the available growth resources. The yields of the intercrop cowpea were higher than the sole cowpea because of interaction effect of component crops which the sole cowpea did not experience. These findings contradicted Several previous studies that reported lower intercrops yields for cereal–legume trials [17] [18]. According to Atis *et al.* [24], competition among component crops for growth factors such as light, available water and nutrients, and root space is among the crucial factors that determines the variations in their productivity levels. Himmelstein *et al.* [20] also stated that crop yield is strongly tied to competition between intercrops. This means the competitiveness is negative, crop yield would reduce, but a minimal competition may not affect crop yield (**Table 9**).

Table 6. Number of pods per plant of cowpea as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Cropping systems		Number of pods per plant					
		Garu			Manga		
Row arrangement (RA)	Relative times of planting (RTP)	2021	2022	Mean	2021	2022	Mean
1M: 1C†	M2WBC#	34	33	34	12	26	19
	SIM	26	19	23	8	20	14
	C2WBM	39	43	41	16	27	22
2M: 2C	M2WBC	36	33	35	14	27	21
	SIM	29	23	26	10	18	14
	C2WBM	32	32	32	15	26	21
3M: 3C	M2WBC	40	31	36	16	29	23
	SIM	19	19	19	9	27	18
	C2WBM	38	31	35	17	35	26
Mean		33	29		13	26	
Sole Cowpea		33	29	31	14	27	21
RA		HSD = NS	p = 0.8955		HSD = NS	p = 0.4924	
RTP		HSD = 4.154	p < 0.0001		HSD = 4.70	p < 0. 0001	
Year		HSD = 2.821	p < 0.0001		HSD = 3.11	p = 0.0480	
Interactions							
RA × RTP		HSD = NS	p = 0.1063		HSD = NS	p = 0.4733	
RA × Y		HSD = NS	p = 0.6947		HSD = 1.75	p = 0.0153	
RTP × Y		HSD = NS	p = 0.2047		HSD = NS	p = 0.1299	
RA × RTP × Y		HSD=NS	p=0.4878		HSD = NS	p = 0.3960	

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

Table 7. Number seeds per pod of cowpea as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Cropping systems		Number of seeds per pod					
		Garu			Manga		
Row arrangement (RA)	Relative times of planting (RTP)	2021	2022	Mean	2021	2022	Mean
1M:1C†	M2WBC#	12	11	12	11	11	11
	SIM	10	10	10	11	12	12
	C2WBM	13	11	12	10	12	11

Continued

2M:2C	M2WBC	11	11	11	10	9	10
	SIM	10	11	11	10	11	11
	C2WBM	11	12	12	11	11	11
3M:3C	M2WBC	11	10	11	11	10	11
	SIM	8	12	10	10	11	11
	C2WBM	10	11	11	10	10	10
Mean		11	11		11	12	
Sole cowpea		12	10	11	10	11	11
RA		HSD = 1.03	p = 0.0149		HSD = NS	p = 0.5065	
RTP		HSD = 1.03	p = 0.0078		HSD = 1.12	p = 0.0137	
Year		HSD = NS	p = 0.2379		HSD = NS	p = 0.7162	
Interactions							
RA × RTP		HSD = NS	p = 0.9782		HSD = NS	p = 0.5248	
RA × Y		HSD = NS	p = 0.3460		HSD = NS	p = 0.3217	
RTP × Y		HSD = 0.421	p = 0.0141		HSD = NS	p = 0.8478	
RA × RTP × Y		HSD = NS	p = 0.5743		HSD = NS	p = 0.5117	

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

Table 8. Hundred seed weight as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Cropping systems		Hundred seed weight per plot (g)					
		Garu			Manga		
Row arrangement (RA)	Relative times of planting (RTP)	2021	2022	Mean	2021	2022	Mean
1M:1C†	M2WBC#	20.1	21.6	20.9	20.2	17.8	19.0
	SIM	19.2	20.2	19.7	18.8	17.6	18.2
	C2WBM	20.3	20.4	20.4	19.4	19.6	19.5
2M:2C	M2WBC	19.5	19.2	19.4	20.7	16.7	18.7
	SIM	19.3	19.9	19.6	21.9	17.6	19.8
	C2WBM	20.7	19.2	20.0	18.5	19.4	19.0
3M:3C	M2WBC	19.9	19.9	19.9	19.0	16.9	18.0
	SIM	19.3	21.3	20.3	17.3	17.8	17.6
	C2WBM	20.6	18.9	19.8	18.3	17.7	18.0
Mean		19.9	20.1		19.3	17.9	
Sole Cowpea		19.4	19.5	19.5	17.2	19.3	18.3
RA		HSD = NS	p = 0.4816		HSD = NS	p = 0.1218	
RTP		HSD = NS	p = 0.7649		HSD = NS	p = 0.5358	

Continued

Year		HSD = NS	p = 0.4389	HSD = 0.746	p < 0.0001
Interactions					
RA × RTP		HSD = NS	p = 0.8354	HSD = NS	p = 0.1749
RA × Y		HSD = NS	p = 0.4089	HSD = NS	p = 0.4732
RTP × Y		HSD = 0.829	p = 0.0439	HSD = 0.411	p = 0.0168
RA × RTP × Y		HSD = NS	p = 0.7946	HSD = NS	p = 0.9513

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

Table 9. Total Grain yield of cowpea as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Cropping systems		Cowpea Grain Yield (t/ha)					
		Garu			Manga		
Row arrangement (RA)	Relative times of planting (RTP)	2021	2022	Mean	2021	2022	Mean
1M:1C†	M2WBC#	1.91	2.15	2.03	1.98	3.46	2.72
	SIM	2.26	1.72	1.99	1.96	3.59	2.78
	C2WBM	2.52	3.22	2.86	2.64	3.79	3.22
2M:2C	M2WBC	1.70	2.21	1.96	1.86	2.82	2.34
	SIM	1.19	1.51	1.35	1.37	2.21	1.79
	C2WBM	2.52	2.29	2.41	2.25	2.71	2.48
3M:3C	M2WBC	1.27	1.42	1.35	1.25	1.90	1.58
	SIM	0.93	1.22	1.08	1.07	1.63	1.35
	C2WBM	1.49	1.36	1.43	1.56	2.17	1.87
Mean		1.56	1.90		1.97	3.00	
Sole Cowpea		1.56	1.59	1.97	2.17	2.84	2.51
RA		HSD = 482.4	p = 0.0001		HSD = 486.54	p < 0.0001	
RTP		HSD = 482.4	p = 0.0031		HSD = 486.54	p = 0.0131	
Year		HSD = NS	p = 0.9263		HSD = 330.37	p < 0.0001	
Interactions							
RA × RTP		HSD = NS	p = 0.5426		HSD = NS	p = 0.5322	
RA × Y		HSD = NS	p = 0.9690		HSD = NS	p = 0.1659	
RTP × Y		HSD = NS	p = 0.9724		HSD = NS	p = 0.6445	
RA × RTP × Y		HSD = NS	p = 0.9111		HSD = NS	p = 0.5565	

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

3.1.4. Harvest Index of Cowpea

There were no significant effects for RA on the harvest index (HI) of cowpea at Garu, but registered significant effect on HI at Manga. However, RTP and Yeah significantly affected HI at both Garu and Manga in the two seasons. The RTP and Year indicated significant interaction effect on HI at Garu, with 3M:3C + SIM producing the highest HI at Manga in 2022, while 3M:3C + SIM gave the lowest HI at Garu in 2021 (Table 10).

Generally, Manga recorded the highest HI in 2021 which was significantly higher than HI recorded at Garu in 2021 and 2022, and at Manga in 2022 (Table 9). The highest performance for harvest index was produced by cowpea planted 2weeks before maize, which was higher than cowpea planted 2weeks after maize and then cowpea planted simultaneously and the sole cowpea respectively throughout the data sampling period (Table 10).

Table 10. Harvest index per plot of cowpea as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Cropping systems		Harvest index (HI)					
		Garu			Manga		
Row arrangement (RA)	Relative times of planting (RTP)	2021	2022	Mean	2021	2022	Mean
1M:1C†	M2WBC#	0.45	0.45	0.45	0.40	0.55	0.48
	SIM	0.19	0.38	0.24	0.41	0.55	0.48
	C2WBM	0.31	0.47	0.39	0.48	0.56	0.52
2M:2C	M2WBC	0.37	0.47	0.42	0.40	0.42	0.41
	SIM	0.19	0.28	0.23	0.37	0.44	0.40
	C2WBM	0.32	0.41	0.37	0.37	0.55	0.46
3M:3C	M2WBC	0.47	0.45	0.46	0.45	0.62	0.53
	SIM	0.11	0.38	0.25	0.39	0.51	0.47
	C2WBM	0.47	0.50	0.48	0.48	0.64	0.56
Mean		0.31	0.42		0.42	0.54	
Sole maize		0.28	0.40	0.34	0.40	0.40	0.40
RA		HSD = NS	p = 0.4371		HSD = 0.076	p = 0.0245	
RTP		HSD = 0.087	p < 0.0001		HSD = 0.076	p = 0.0102	
Year		HSD = 0.059	p = 0.0002		HSD = 0.052	p < 0.0001	
<u>Interactions</u>							
RA × RTP		HSD = NS	p = 0.7609		HSD = NS	p = 0.8354	
RA × Y		HSD = NS	p = 0.7775		HSD = NS	p = 0.6481	
RTP × Y		HSD = 0.032	p = 0.0021		HSD = NS	p = 0.4337	
RA × RTP × Y		HSD = NS	p = 0.5707		HSD = NS	p = 0.5188	

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

3.2. Stability of Component Crops

3.2.1. Maize Yield Stability

The mean yield of maize was estimated for yield stability using the yield data collected on maize and analysed according to Eberhert and Russel [25], Finlay and Wilkinson [26] and Francis Kannenberg [27]. Eberhert and Russell [25] estimate yield stability using the regression coefficient value of b = 1, or close to 1, less values for Error mean square (δ^2d) and the yield above the average mean yield (**Table 11**).

The estimates of yield stability parameters for maize grain yield for 10 treatments indicated two treatments having regression coefficients close to 1. The 1M:1C + C2WBM and 2M:2C + C2WBM had their regression coefficient values close to 1 indicating that those treatments were stable. However, 3M:3C + SIM, 3M:3C + C2WBM and Sole Maize recorded regression values that were higher than b value of 1 indicating that those treatments were unstable. Also, 1M:1C + M2WBC, 1M:1C + SIM, 2M:2C + M2WBC and 3M:3C + M2WBC also recorded b values of less than 1 and are therefore considered not to be stable. All the treatments were also compared with the average mean performance of grain yield. Comparatively, 1M:1CM2WBC, 1M:1CSIM, 2M:2C + SIM and Sole Maize recorded high values for Error mean square (δ^2d), while 1M:1C + C2WBM**,** 2M:2C + M2WBC**,** 2M:2C + C2WBM**,** 3M:3C + M2WBC**,** 3M:3C + SIM and 3M:3CC2WBM registered low values for Error mean square (δ^2d) (**Table 11**). Therefore, the stable treatments are 1M:1C + C2WBM and 2M:2C + C2WBM [25].

Yield stability was also estimated using the Finlay and Wilkinson [26] approach. This approach uses mean yield and regression coefficient value to determine the most stable treatments or crop varieties for adoption. This stability measure uses average mean yield with regression value b close to 1. From the results, values of b close to 1 with consistent mean yield were 1M:1C + C2WBM (1.04) and 2M:2C + C2WBM (0.91). The performance of these treatments meet the criteria proffered by Finlay and Wilkinson [26]. They were therefore considered very stable treatments. Mean yield values for 2M:2C + SIM, 3M:3C + SIM, 3M:3C + C2WBM and Sole Maize were higher than the overall grand mean but had high regression value of b. Also, 3M:3C + SIM and 3M:3C + C2WBM registered less mean yield compared with the overall grand mean and higher b values and are therefore not stable, according to Finlay and Wilkinson [26] (**Table 11** & **Figure 1**).

The third approach adopted to determine the yield stability was the Francis and Kannenberg method [27]. This approach measures the mean yields and their coefficients of variation relative to the grand mean and the average coefficient of variation (CV) calculated. For the grain yield of maize, the procedure identified 2M:2C + M2WBC, 3M:3C + M2WBC and Sole Maize as most desirable with higher than average yield and smaller than average CV (**Table 11** & **Figure 1**). Treatments 3M:3C + C2WBM were identified within the group with low yield below the grand mean with large variation higher than the average CV. Only 1M:1C + C2WBM, 2M:2C + C2WBM and 3M:3C + SIM were located within the group with low yield based on the overall grand mean with small variations which is also based on mean CV. For the last group, with low yield and large variation was recorded by 3M:3C + C2WBM. Estimated according to Francis and Kannenberg [27] (**Figure 1**).

Table 11. Stability analysis of maize as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Treatments	Mean yield across environments	Regression Coefficient (b)	MSE (δ^2)	CV
1M:1C M2WBC	6.71	0.21	1.31417	17.08
SIM	7.46	0.76	2.38576	20.72
C2WBM	4.50	1.04	0.20393	10.03
2M:2C M2WBC	7.62	0.55	0.92057	12.59
SIM	8.68	1.80	2.3692	17.73
C2WBM	4.87	0.91	0.44963	13.77
3M:3C M2WBC	6.52	0.54	0.47164	10.54
SIM	5.69	1.24	0.28068	9.34
C2WBM	3.71	1.23	0.32550	15.39
Sole Maize	8.53	1.69	1.23167	13.02

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

3.2.2. Yield Stability of Cowpea

The yield stability of cowpea parameters was determined according to three stability analysis models by Eberhart and Russel [25], Finlay and Wilkinson [26] and Francis and Kannenberg [27]. The estimates of yield stability variables for cowpea grain yield for 10 treatments showed that 2M:2CM2WBC, 2M:2CSIM and Sole Cowpea registered regression coefficient values close to 1 making those treatments stable. However, 1M:1CM2WBC, 1M:1CSIM and 1M:1CC2WBM recorded regression values that were higher than b value of 1, indicating that those treatments were unstable. Again, the 2M:2CC2WBM, 3M:3CM2WBC, 3M:3CSIM and 3M:3CC2WBM also recorded the b values of less than 1 and were therefore considered not stable treatments. All the treatments were also compared with the average mean performance of grain yield. Apart from 1M:1CSIM, 1M:1CC2WBM and Sole Cowpea, all other treatments registered low values for Error mean square (δ^2d). Therefore, the stable treatments were 2M:2CM2WBC and 2M:2CSIM. The stability measure makes use of regression coefficient value b = 1, or close to 1, less values for Error mean square (δ^2d) and the yield above the average mean yield. This yield stability of cowpea yields was determined using the Eberhart and Russell model [25] (**Table 12**).

Furthermore, the yield stability was also determined using the Finlay and Wilkinson [26] approach. This approach uses mean yield and regression coefficient values to determine the most stable treatments or varieties for adoption. This stability measure uses average mean yield with regression value b close to 1.

From stability analysis presentation, values of b close to 1 with consistent mean yield were 2M:2CM2WBC (1.03), 2M:2CSIM (0.92) and Sole Cowpea (1.13). These were described under the Finlay and Wilkinson [26] approach and were therefore considered more stable treatments. Mean yield values for 2M:2CSIM, 1M:1CM2WBC, 1M:1CSIM and 1M:1CC2WBM were higher than the overall grand mean but also had high regression value of b. Also, Sole Cowpea had less mean yield compared with the overall grand mean and higher b values making them unstable (Table 12).

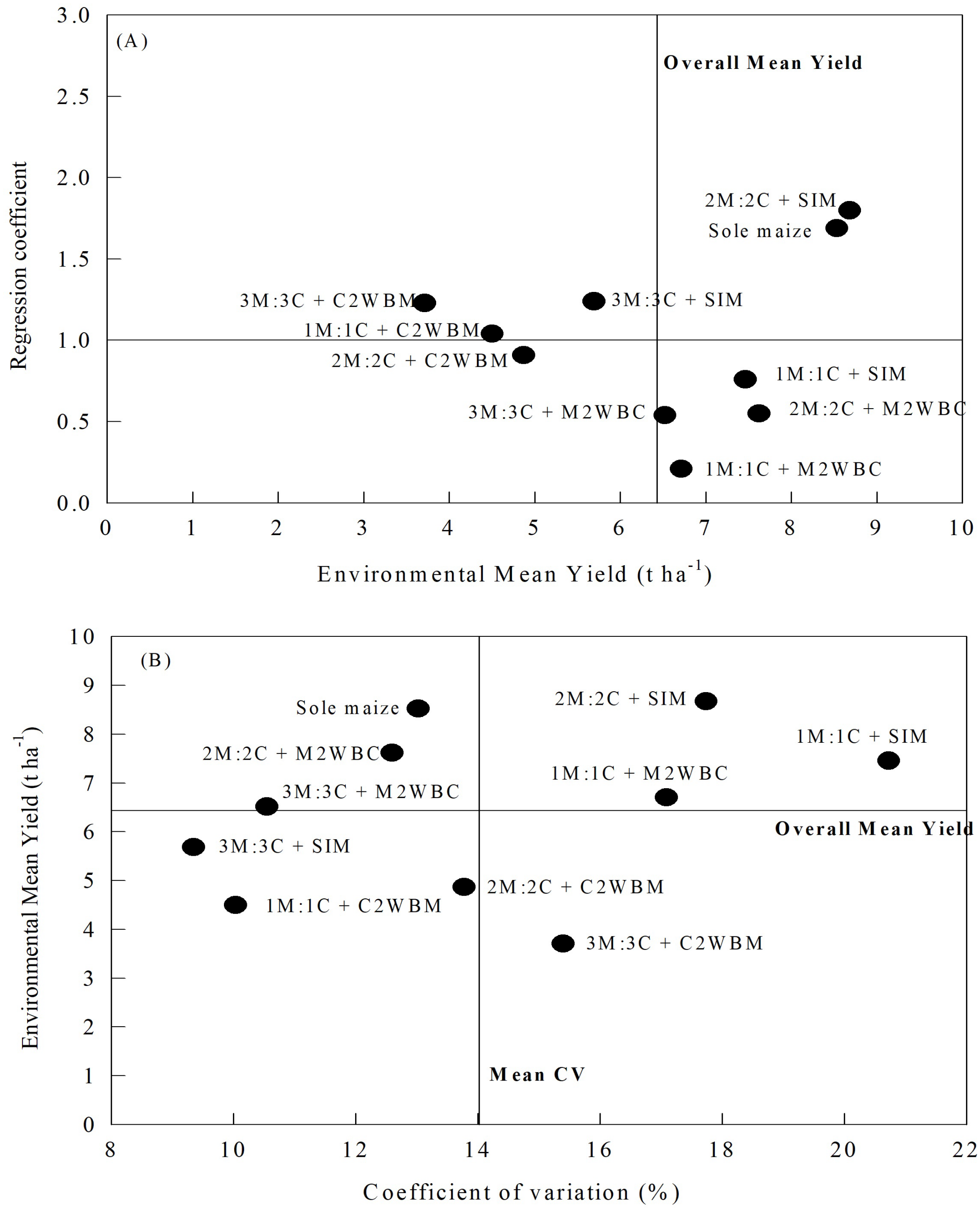

Figure 1. Yield stability of maize in a maize + cowpea intercrop at Garu and Manga during the 2021 and 2022 growing seasons according to (A) Finlay and Wilkinson [26] and (B) Francis and Kannenberg [27].

Additionally, another approach adopted to determine the yield stability analysis was the Francis and Kannenberg [27] approach. This approach measures the mean yields and their coefficients of variation relative to the grand mean and average coefficient of variation (CV). For the grain yield of cowpea, the procedure identified 1M:1CM2WBC and 2M:2CC2WBM as most desirable with higher than average yield and smaller than average CV (**Table 12**). The Sole Cowpea placed into a group with low yield below the grand mean with large variation higher than the average CV. Only 2M:2CSIM, 3M:3CSIM and 3M:3CC2WBM were identified with low yield based on the overall grand mean with small variations which is also based on mean CV. For the last group, with low yield and large variation was recorded by Sole Cowpea. This was estimated according to Francis and Kannenberg [27] (**Figure 1**).

Table 12. Stability analysis of cowpea as affected by row arrangement and relative times of planting at Garu and Manga in 2021 and 2022.

Treatments	Mean yield across environments	Regression Coefficient (b)	MSE (δ^2)	CV
1M:1C M2WBC	2.38	1.60	0.00152	1.64
CSIM	2.38	1.69	0.15377	16.46
C2WBM	3.04	1.16	0.09463	10.12
2M:2C M2WBC	2.15	1.03	0.03767	9.04
SIM	1.57	0.96	0.00876	5.96
C2WBM	2.44	0.36	0.01838	6.90
3M:3C M2WBC	1.46	0.65	0.00430	4.49
SIM	1.28	0.64	0.01029	8.37
C2WBM	1.51	0.75	0.01937	8.46
Sole Cowpea	1.78	1.13	0.11515	16.68

† 1M:1C = 1 row maize alternating with 1 row cowpea; 2M:2C = 2 rows maize alternating with 2 rows cowpea; 3M:3C = 3 rows maize alternating with 3 rows cowpea; # M2WBC = Maize planted 2 weeks before cowpea; C2WBM = Cowpea planted 2 weeks before maize.

Yield stability of cowpea in a maize + cowpea intercrop at Garu and Manga was determined using the Finlay and Wilkinson [27] approach. This approach uses mean yield and regression coefficient value to determine the most stable treatments for adoption by stakeholders particularly researchers and farmers. This stability measure uses average mean yield with regression value b close to 1. From stability analysis presentation, values of b close to 1 mean yield were sole cowpea, 2M:2C + M2WBC, 2M:2CSIM, and 1M:1C + C2WBM. These were described under the Finlay and Wilkinson [26] approach and are therefore considered stable. Mean yield values for 1M:1C + M2WBC, 1M:1C + SIM and 1M:1C + C2WBM were higher than the overall grand mean but also had high regression value of b. Also, Sole Cowpea had less mean yield compared with the overall grand mean and higher b values making them unstable (**Figure 2(A)**).

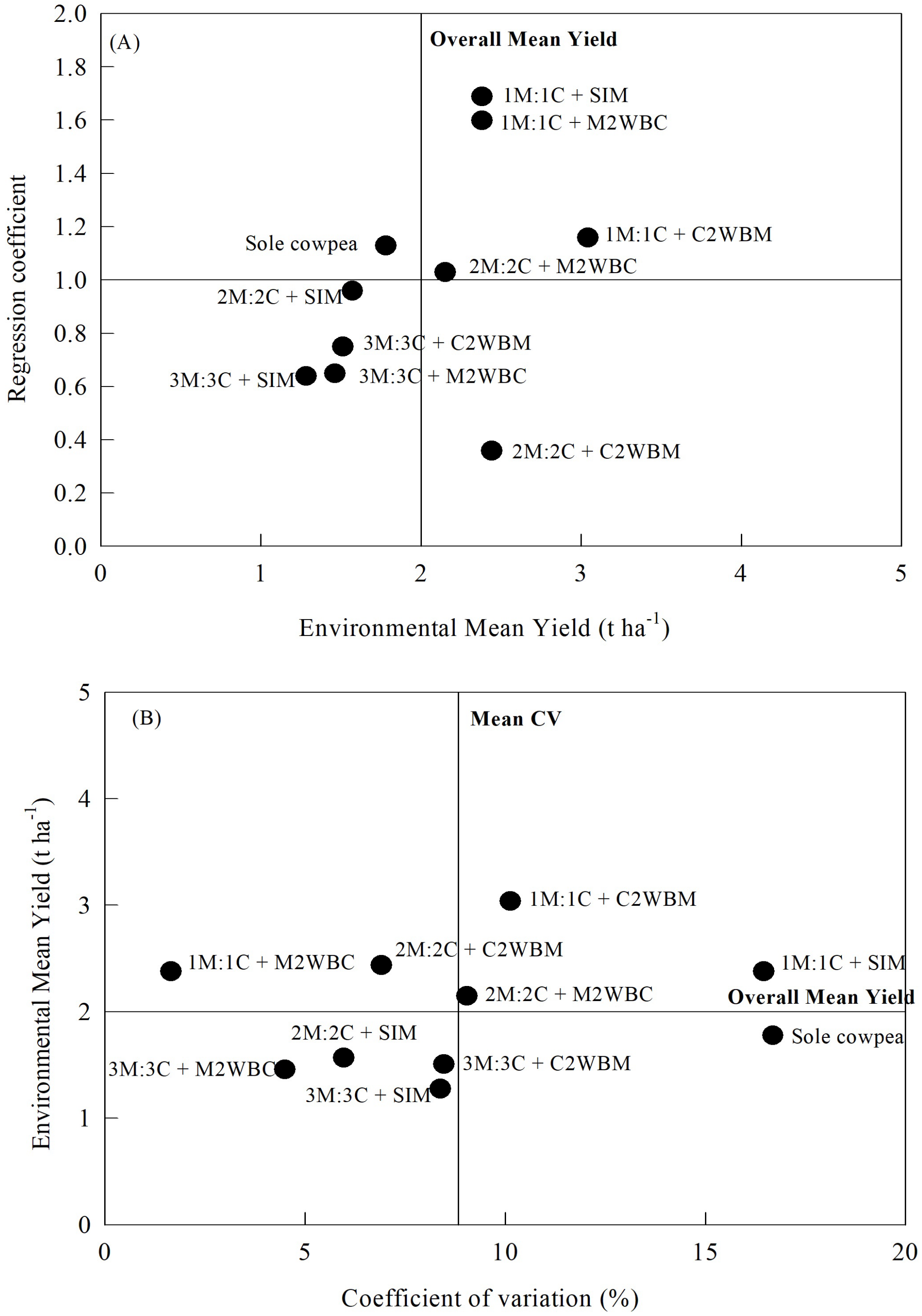

Figure 2. Yield stability of cowpea in a maize + cowpea intercrop at Garu and Manga during the 2021 and 2022 growing seasons according to (A) Finlay and Wilkinson [26] and (B) Francis and Kannenberg [27].

Another approach adopted to determine the yield stability analysis was the Francis and Kannenberg [27] approach. This approach measures the mean yields and their coefficients of variation relative to the grand mean and average

CV. For the grain yield of cowpea, the procedure identified 1M:1CM2WBC and 2M:2CC2WBM as most desirable with higher than average yield and smaller than average CV (**Figure 2(B)**). The Sole Cowpea placed into a group with low yield below the grand mean with large variation higher than the average CV (**Figure 2(B)**). Only 2M:2CSIM, 3M:3CSIM and 3M:3CC2WBM were identified with low yield based on the overall grand mean with small variations which is also based on mean CV (**Figure 2(B)**). For the last group, with low yield and large variation was recorded by Sole Cowpea (**Figure 2(B)**).

4. Conclusions

The intercropping systems largely enhanced growth and development of the component crops compared with the sole crops. Generally, planting maize 2 weeks before cowpea or simultaneously with cowpea enhanced the growth and development of the maize component crop. The 1M:1C and 2M:2C row arrangements also enhanced the growth and development of the maize component crop. The growth and development of the cowpea component crop were enhanced when cowpea was planted 2 weeks before maize and at row arrangements of 2M:2C and 3M:3C.

Planting maize and cowpea simultaneously (SIM) at 2M:2C produced the largest maize yield, followed by planting maize 2WBC at 2M:2C. The least maize yield was produced by 3M:3C + C2WBM. The highest cowpea yield was obtained when cowpea was planted 2WBM at 1M:1C followed by planting maize and cowpea simultaneously (SIM) at 1M:1C.

Land equivalent ratios for the intercrops indicated more efficient use of land resources by the intercropping systems over the sole crops with the 1M:1C + M2WBC, 1M:1C + SIM, 1M:1C + C2WBM and 2M:2C + M2WBC having the highest LERs across both locations. Yield stability analysis indicated that 1M:1C + C2WBM and 2M:2C + C2WBM for maize and 2M:2C + M2WBC, 2M:2C + SIM and Sole Cowpea for cowpea had regression coefficient values close to 1 making these systems more stable. The productivity and yield stability analysis indicated that most of the cropping systems were stable for adoption as a climate smart agricultural innovation, for sustainable, resilient and increased crop yield to promote food security.

All the intercrop systems were also economically profitable than the sole crops, with the 2M:2C + M2WBC and 2M:2C + SIM producing the highest benefit-cost ratios (BCR) at both Garu and Manga.

Recommendations for Adoption

The study revealed that, even in a climate constraint ecology like the Sudan Savannah, with effective row arrangements and the adoption of various relative times of planting, an intercrop system can provide adequate yield to reduce poverty and boost food security.

It is therefore recommended that farmers with high priority for the maize crop or priority for more maize yield should adopt planting 2 rows maize alternating with 2 rows cowpea and planting the two crops simultaneously (*i.e.* 2M:2C + SIM) for maximum yield and high economic returns. However, farmers with priority for the cowpea component crop or priority for more cowpea yield should adopt a spatial arrangement of 1 row maize alternating with 1 row cowpea and planting cowpea 2 weeks before maize (*i.e.* 1M:1C + C2WBM) to maximize yield and high economic returns.

Conflicts of Interest

All Authors have given their consent for this paper to published. There are therefore no conflict of interest issues.

References

[1] Gomes, A.M.F., Draper, D., Nhantumbo, N., Massinga, R., Ramalho, J.C., Marques, I., *et al.* (2021) Diversity of Cowpea [*Vigna unguiculata* (L.) Walp] Landraces in Mozambique: New Opportunities for Crop Improvement and Future Breeding Programs. *Agronomy*, **11**, Article No. 991. https://doi.org/10.3390/agronomy11050991

[2] Badu-Apraku, B., Fakorede, M.A.B., Oyekunle, M., Yallou, G.C., Obeng-Antwi, K., Haruna, A., *et al.* (2015) Gains in Grain Yield of Early Maize Cultivars Developed during Three Breeding Eras under Multiple Environments. *Crop Science*, **55**, 527-539. https://doi.org/10.2135/cropsci2013.11.0783

[3] Ozor, N. and Cynthia, N. (2011) Difficulties in Adaptation to Climate Change by Farmers in Enugu State, Nigeria. *Journal of Agricultural Extension*, **14**, 106-122. https://doi.org/10.4314/jae.v14i2.64127

[4] Huss, C.P., Holmes, K.D. and Blubaugh, C.K. (2022) Benefits and Risks of Inter-Cropping for Crop Resilience and Pest Management. *Journal of Economic Entomology*, **115**, 1350-1362.

[5] Manda, J., Alene, A.D., Tufa, A.H., Abdoulaye, T., Wossen, T., Chikoye, D., *et al.* (2019) The Poverty Impacts of Improved Cowpea Varieties in Nigeria: A Counterfactual Analysis. *World Development*, **122**, 261-271. https://doi.org/10.1016/j.worlddev.2019.05.027

[6] Wossen, T., Abdoulaye, T., Alene, A., Nguimkeu, P., Feleke, S., Rabbi, I.Y., *et al.* (2018) Estimating the Productivity Impacts of Technology Adoption in the Presence of Misclassification. *American Journal of Agricultural Economics*, **101**, 1-16. https://doi.org/10.1093/ajae/aay017

[7] Uhart, S.A. and Andrade, F.H. (1995) Nitrogen and Carbon Accumulation and Remobilization during Grain Filling in Maize under Different Source/Sink Ratios. *Crop Science*, **35**, 183-190. https://doi.org/10.2135/cropsci1995.0011183x003500010034x

[8] Gabatshele, M., Legwaila, T., Marokane, K. and Mojeremane, W. (2012) Effects of Intercropping on the Performance of Maize and Cowpeas in Botswana. *International Journal of Agriculture and Forestry*, **2**, 307-310. https://doi.org/10.5923/j.ijaf.20120206.07

[9] Selvaraj, C.I. and Nagarajan, P. (2011) Interrelationship and Path-Coefficient Studies for Qualitative Traits, Grain Yield and Other Yield Attributes among Maize (*Zea mays* L.). *International Journal of Plant Breeding and Genetics*, **5**, 209-223.

[10] Abdul Rahman, N., Larbi, A., Kotu, B., Asante, M.O., Akakpo, D.B., Mellon-Bedi, S., *et al.* (2021) Maize-Legume Strip Cropping Effect on Productivity, Income, and In-

come Risk of Farmers in Northern Ghana. *Agronomy Journal*, **113**, 1574-1585. https://doi.org/10.1002/agj2.20536

[11] Dapaah, H.K., Asafu-Agyei, J.N., Ennin, S.A. and Yamoah, C. (2003) Yield Stability of Cassava, Maize, Soya Bean and Cowpea Intercrops. *The Journal of Agricultural Science*, **140**, 73-82. https://doi.org/10.1017/s0021859602002770

[12] Dapaah, H.K.D., Enin, S., Asafu-Agyei, J.N. and Achirinah, V.M. (2007) Improving Productivity and Household Incomes of Resource Poor Farmers: The Case of Cassava-Cowpea Intercrop. In: Kapinga, R., Kingamkono, R., Msabaha, M, Ndunguru, J., Lemaga, B. and Tusiime, G., Eds., *Tropical Root and Tuber Crops*: *Opportunities for Poverty Alleviation and Sustainable Livelihoods in Developing Countries*, The Journal of Agricultural Science, 218-226.

[13] Ennin, S.A. and Dapaah, H.K. (2009) Legumes in Sustainable Maize and Cassava Cropping Systems in Ghana. *Agricultural and Food Science Journal of Ghana*, **7**, 519-540. https://doi.org/10.4314/afsjg.v7i1.43032

[14] Addo-Quaye, A.A., Darkwa, A.A. and Ocloo, G.K. (2011) Growth Analysis of Component Crops in a Maize-Soybean Intercropping System as Affected by Time of Planting and Spatial Arrangement. *Journal of Agricultural and Biological Science*, **6**, 34-44.

[15] Ogola, J.B.O., Mathews, C. and Magongwa, S.M. (2013) The Productivity of Cassava-Legume Intercropping System in a Dry Environment in Nelspruit, South Africa. *African Crop Science Conference Proceedings*, **11**, 61.

[16] Zhang, G., Zhang, C., Yang, Z. and Dong, S. (2013) Root Distribution and N Acquisition in an Alfalfa and Corn Intercropping System. *Journal of Agricultural Science*, **5**, 128-142. https://doi.org/10.5539/jas.v5n9p128

[17] Salama, H.S.A. and Abdel-Moneim, M.H. (2021) Maximizing Land Use Efficiency and Productivity of Soybean and Fodder Maize Intercrops through Manipulating Sowing Schedule and Maize Harvest Regime. *Agronomy*, **11**, Article No. 863. https://doi.org/10.3390/agronomy11050863

[18] Bacchi, M., Monti, M., Calvi, A., Lo Presti, E., Pellicanò, A. and Preiti, G. (2021) Forage Potential of Cereal/Legume Intercrops: Agronomic Performances, Yield, Quality Forage and LER in Two Harvesting Times in a Mediterranean Environment. *Agronomy*, **11**, Article No. 121. https://doi.org/10.3390/agronomy11010121

[19] Morugán-Coronado, A., Linares, C., Gómez-López, M.D., Faz, Á. and Zornoza, R. (2020) The Impact of Intercropping, Tillage and Fertilizer Type on Soil and Crop Yield in Fruit Orchards under Mediterranean Conditions: A Meta-Analysis of Field Studies. *Agricultural Systems*, **178**, Article ID: 102736. https://doi.org/10.1016/j.agsy.2019.102736

[20] Himmelstein, J., Ares, A., Gallagher, D. and Myers, J. (2016) A Meta-Analysis of Intercropping in Africa: Impacts on Crop Yield, Farmer Income, and Integrated Pest Management Effects. *International Journal of Agricultural Sustainability*, **15**, 1-10. https://doi.org/10.1080/14735903.2016.1242332

[21] Thorat, A. and Gadewar, D.R. (2013) Variability and Correlation Studies in Cowpea (*Vigna unguiculata*). *International Journal for Environmental Rehabilitation and Conservation*, **4**, 44.

[22] Li, C., Hoffland, E., Kuyper, T.W., Yu, Y., Zhang, C., Li, H., *et al.* (2020) Syndromes of Production in Intercropping Impact Yield Gains. *Nature Plants*, **6**, 653-660. https://doi.org/10.1038/s41477-020-0680-9

[23] Lin, B.B. (2011) Resilience in Agriculture through Crop Diversification: Adaptive Management for Environmental Change. *BioScience*, **61**, 183-193.

https://doi.org/10.1525/bio.2011.61.3.4

[24] Atis, I., Konuskan, O., Duru, M., Gozubenli, H. and Yilmaz, S. (2012) Effect of Harvesting Time on Yield, Composition and Forage Quality of Some Forage Sorghum Cultivars. *International Journal of Agriculture and Biology*, **14**, 879-886.

[25] Eberhart, S.A. and Russell, W.A. (1966) Stability Analysis in Plant Breeding. *Plant Breeding*, **101**, 1-23.

[26] Finlay, K.W. and Wilkinson, G.N. (1963) The Analysis of Adaptation in a Plant-Breeding Programme. *Australian Journal of Agricultural Research*, **14**, 742-754. https://doi.org/10.1071/ar9630742

[27] Francis, T.R. and Kannenberg, L.W. (1978) Yield Stability Studies in Short-Season Maize. I. A Descriptive Method for Grouping Genotypes. *Canadian Journal of Plant Science*, **58**, 1029-1034. https://doi.org/10.4141/cjps78-157