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Original article

Productivity of sunflower (*Helianthus annuus* L.) introduced at different dates into sesame-based intercropping system in a humid tropical location

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Abstract

Sustainable resource efficiency is crucial for enhanced productivity of any cropping system. Two field trials were carried out during the late cropping season (July – Nov.) of 2018 and 2019 to determine the grain yield and productivity of sunflower (var. Favorit) introduced into a sesame-based cropping system. Agronomic Efficiency (AE), Partial Factor Productivity (PFP), Production Efficiency (PE), Actual Yield Loss (AYL_{sun}), System Productivity Index (SPI), and Land Use Efficiency (LUE) were used for the cropping systems productivity evaluation. The experiment was laid out in a randomized complete block design using a split-split plot arrangement with sesame varieties (E8 and Cameroun White), organic fertilizer (No fertilizer and organic fertilizer) and sowing dates (C1- sown simultaneously with sesame, C2 - 10 days after sowing, DAS, and C3 - 20 DAS) as the main, sub and sub-sub plots, respectively, and replicated three times. Cropping systems significantly ($P < 0.05$) affected sunflower grain yield and all the productivity indices evaluated in both years. The maximum grain yield of sunflower was recorded when sown simultaneously with sesame variety E8 (1,054.00 and 720.70 kg/ha) and Cameroun White (503.53 and 675.23 kg/ha) in 2018 and 2019, respectively. The productivity of sunflower declined when introduced beyond C2. Based on comparatively high grain yield (702.17 – 1,054.00 kg/ha), PE (7.31 – 10.98 $kg.ha^{-1}$ day^{-1}), positive AYL_{sun} (0.54 – 0.73), and LUE (51.4 – 58.32%) recorded when sunflower was introduced at C1 and C2 into E8, it is concluded that intercropping sunflower with E8 variety is a better option than with Cameroun White.

Keywords: Actual Yield Loss; Agronomic Efficiency; Land Use Efficiency; Partial Factor Productivity; Production Efficiency; System Productivity Index.

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INTRODUCTION

Sunflower (*Helianthus annuus* L.) is an essential oilseed crop and it is the third oilseed produced in the world, the fourth vegetable oil and third oilseed meal among protein feed sources (Pilorge 2020). A total of 58.5 million tonnes of sunflower was produced worldwide by 81 countries from 30.1 million hectares in 2023 with an average yield of 1,942.9 kg/ha (FAOSTAT 2025). According to the latest survey report, sunflower is second (15.4%) to soybeans (62.3%) among oilseeds based on global distribution of organic oilseed land in 2023 (FiBL 2025). The crop is primarily grown for its seed, which contains oil (36–52%) and protein (28–32%), as reported by Rosa et al. (2009). The recent global decline in sunflower productivity in the last decade could be attributed to lower resource use efficiency, extreme climatic conditions, and increased pest infestations and diseases due to imbalanced (N) fertilizer application (Ozer et al. 2004; Nasim et al. 2017; Olowe et al. 2021; Tovar et al. 2021; Rahman et al. 2021; Perveen et al. 2021).

Intercropping systems that involved oilseeds have been beneficial in providing food security, variety of food stuffs, efficient use of resources and sustainable agricultural development in the humid tropics (Olowe and Adeyemo 2009; Olowe and Adebimpe 2009, Adekunle et al. 2014; Somefun et al. 2020). Nutrient Use Efficiency (NUE) indices are often used in agronomy to describe major crop production systems as the managers of such systems strive to meet the growing demand for food, fiber and fuel (Fixen et al. 2015). Though NUE might appear as a simple term, yet it is very complex to implement because it depends on the various N sources that contribute to crop production (inorganic and organic fertilizers, soil organic matter, biological fixation, atmospheric deposition); the interplay between soil N availability, transformation, storage, movement and loss; edaphic conditions; crop genetics; and the impact of management, weather, and climate (Congreves et al. 2021). Furthermore, there is no single literature that contains a comprehensive list of all NUE indices. Highly commendable efforts have been made by Dobermann (2007) and Fixen et al. (2015) to collate various indices and recommend their use. Their efforts have been complemented more recently by Congreves et al. (2021) that compiled various NUE indices and their associated formulae, interpretation, strengths, and limitations. They partitioned the indices into fertilizer-based, plant-based, soil-based, isotope-based, ecology-based and system-based. In our study, we used a mix of indices such as Agronomic Efficiency (AE), Partial Factor Productivity (PFP), Production Efficiency (PE), System Productivity Index (SPI), Actual Yield Loss (AYL), and Land Use Efficiency (LUE) to evaluate sunflower productivity in a sesame-based intercropping system in the tropics under organic system. Sesame was the dominant crop while sunflower was the dominated crop in this study.

According to Mortvedt et al. (2003) adequate soil fertility is one of the requirements for profitable sunflower production and N is the most yield limiting nutrient for its production. The rule of the thumb is if a unit of fertilizer does not increase the yield enough to pay for its cost, its application will not be economical and will not return profit even after a constant increase in the yield (Singh 2004). Therefore, the application of essential plant nutrients in optimum quantity and right proportion, through correct method and time of application, is very crucial to increased and sustained crop production (Cisse and Amar 2000). Research results have demonstrated increased productivity of sunflower through the application of different single and compound fertilizers (Nassim et al. 2012a; 2012b; Akpojotor et al. 2019) and organic fertilizers (Rasool et al. 2013; Oshundiya et al. 2014; Alipatra et al. 2019; Olowe et al. 2021). The optimum rates of the major nutrients especially nitrogen vary across different ecological zones. It has been reported that appropriate integration of synthetic fertilizers, organic manures and residues is essential for sustaining moderate to high crop yields through the improvement of soil organic matter and fertility (Faisul-ur-Rasool et al. 2013). However, most studies conducted in the humid tropics on sunflower, neither quantified its resource use efficiency of sunflower nor demonstrated the effectiveness of organic fertilizers in tropical soils. There is a dearth of research works on productivity of sunflower in mixtures under an organic production system in the tropics using indices such as AE, PE, PFP, AYL, LUE, and SPI. More recently, the competitiveness and profitability of sunflower intercropped with peanut (Ouda et al. 2018, NUE of some mineral fertilizers in sunflower in Mexico (Delgado Martinez et al. 2018) and Brazil (Coelho et al. 2022), sesame–groundnut mixtures in Egypt (Abou-Kerisha et al. 2008), and different crops in India (Kumari et al. 2019) were reported in literature. However, such research reports are very limited in tropical Africa. The hypothesis of the study was based on the assumption that sunflower will perform the same way irrespective of the time it is introduced into sesame. Therefore, the objective of our study was to determine the productivity of sunflower introduced into in a sesame-based cropping system at varying dates under organic production system.

MATERIALS AND METHODS

Growth conditions

The two year study was carried out during the late cropping seasons (June-November) of 2018 and 2019 on the Organic Research plot of the Institute of Food Security, Environmental Resources and Agricultural Research, of the Federal University of Agriculture, Abeokuta, Nigeria (7º 13′ 51.17″ N and 7º 13′ 53.16″ N and longitudes 3º 23′ 49.12″ E and 3º 23′ 51.86″ E, on altitude 131.5m above sea level). In order to describe the growth conditions experienced during the period of experimentation, data on rainfall distribution, temperature, sunshine hours, and relative humidity were collected from the University weather station. The traditional bimodal rainfall distribution with two peaks in July and September that is peculiar to this location, as shown in the long-term distribution was only observed in 2018 (Table 1). Total rainfall distribution in 2018 (864.1 mm) and 2019 (693.5 mm) was within the recommended rainfall range recommended as adequate for sunflower (500-750mm) by Weiss (2000). The total rainfall distribution in both years compared well with the long-term mean (660.7mm). In both years, temperature was not limiting during the period of experimentation and was within the recommended range of 21^{o} – 35^{o}C for sunflower (Putnam et al., 1990). The weather data were further partitioned into rainfall distribution, number of rainy days, and total sunshine hour duration on a sowing date basis (Table 2). These parameters decreased in magnitude as sowing was delayed in both years. On average, the soil of the experimental sites was loamy sand in texture with average values of 6.1 pH, 2.04% organic matter, 0.063 g/kg N, 4.74 mg/kg available P, 0.065 mol/kg exchangeable K, 4.5% clay, 5.8% silt and 89.7% sand.

Table 1: Rainfall distribution (mm), mean monthly temperature (T^{o}C) and relative humidity (RH %) during growth period of sesame and sunflower in 2018 and 2019, long-term (1984 - 2017)

Weeks	Months									
	July		August		September		October		November	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
I	91.6	13.0	0.0	20.3	94.6	33.4	76.6	79.0	9.0	71.9
II	12.0	8.0	9.0	26.5	47.9	19.7	31.9	117.1	27.0	32.0
III	76.2	59.2	69.4	8.3	66.9	15.5	14.4	49.1	0.0	8.4
IV	43.1	28.5	83.4	10.7	60.6	28.3	50.5	64.6	0.0	0.0
TR (mm)	222.9	108.5	161.8	65.8	270.0	96.9	173.4	310.0	36.0	112.3
LTMR (mm)	195.6		108.9		177.9		121.6		18.2	
Mean (T^{o}C)	25.3	26.2	25.8	26.5	26.5	26.6	27.3	26.4	28.3	27.9
RH (%)	80.3	79.7	77.2	76.2	74.8	81.1	73.3	84.0	68.7	82.4

SOURCE: Department of Water Resources and Agro-meteorology, Federal University of Agriculture, Abeokuta, TR – total rainfall, LTMR – Long-term mean rainfall (1984-2017)

Table 2: Rainfall distribution, number of rainy days and total daily sunshine duration across three planting dates of sesame and sunflower in 2018 and 2019

Sowing date	2018			2019		
	Rainfall (mm)	Number of rainy days	Daily sunshine duration (hr)	Rainfall (mm)	Number of rainy days	Daily sunshine duration (hr)
C1	672.7	48	383.3	684.3	42	430.2
C2	613.5	45	371.4	641.2	39	402.2
C3	585.0	41	344.0	641.2	39	384.4

Notes: C1- Simultaneous sowing of sesame with sunflower on July 24 (2018) and July 18 (2019), C2 - 10 days after sowing sesame (DAS) on August 3 (2018) and July 28 (2019), C3- 20 DAS on August 13 (2018) and August 7 (2019)

Planting materials

Sunflower variety ‘Favorit’ with potential yield of 2.5-3.0 tons per hectare, oil content 40-41%, protein content 30-31%, maturity 123-125 days, 1000-seed weight 115g and height 215 cm (Dobrudza Agricultural Institute 2019) was sown into two early maturing and high yielding varieties of sesame (E-8 and Cameroun White) which are both drought tolerant, with good seed quality, 1000-seed weight > 3.0g and high-yielding (Olowe et al. 2003; Olowe 2004).

Experimental treatments and design

The three-factor experiment was laid out in a randomized complete block design (RCBD) in a split-split plot arrangement and replicated three times. The three factors evaluated were: sesame varieties (E8 and Cameroun White), organic fertilizer (No fertilizer and Organic fertilizer) and sunflower staggered sowing date (C1- simultaneous sowing of sunflower with sesame, C2 – introducing sunflower 10 days after sowing of sesame, and C3 – introducing sunflower 20 days after sowing of sesame, and were allocated to the main plot, sub plot and sub-sub plot, respectively.

Crop husbandry

The experimental fields were cleared, ploughed twice and harrowed once before marking out the plots. During the first and second trials, simultaneous sowing of sesame and sunflower seeds was done on July 24, 2018 and July 18, 2019, respectively, while the remaining sunflower seeds were sown at an interval of ten days (August 4 and August 14, 2018 and July 28 and August 8, 2019) in both years. Sowing was done at a spacing of 60 cm × 30 cm for sunflower between the inter rows of sesame. Each gross experimental plot was 4 m × 3 m (12 m^2), withwalk way of 0.5 m between plots and 1 m between replicates. The application of organic fertilizer used (Organo-farm), was in quantities equivalent to the recommended nitrogen rates (60 kg N/ha) at three weeks after sowing (WAS). The nutrient composition of fertilizer is shown in Table 3. Weeding was done at 3 and 6 WAS. There were sole plots of the three test varieties with and without organic fertilizer application for the purpose of mixture productivity. The experiment was conducted under rain-fed conditions, and no disease incidence was recorded during the experimental period in both years.

Table 3: Nutrient composition of Organo-farm organic fertilizer in 2018 and 2019

Parameters	2018	2019
ph	7.94	9.10
OC, %	13.16	20.12
OM, %	22.7	34.74
TN, %	1.50	1.09
P, %	0.017	0.001
Na, %	0.25	0.12
K, %	0.120	0.63
Ca, %	4.50	4.40
Mg, %	0.75	0.535
Mn, %	0.31	0.050
Fe, %	0.40	0.60
Cu, %	0.0010	0.005
Zn, %	0.040	0.017

Data collection

The parameters below were determined to quantify the productivity of sunflower in the study:

a. Partial factor productivity (PFP) (Cassmen et al. 1996).

It is an integrative index that quantifies total economic output related to utilization of all nutrient resources applied to the production system.

$$PFP\ (kg\ kg^{-1}) = \frac{\text{Grain yield of fertilized sunflower (kg)}}{\text{Amount of fertilizer applied (kg)}}$$

b. Agronomic efficiency (Cassmen et al. 1996)

Agronomic efficiency [N-AE [kg (kg N) −1] is defined as the increase in economic yield of sunflower per unit of fertilizer N applied. It is an indicator of the plant's capacity to increase grain yield in response to applied N. This was calculated using the following equation:

$$AE\ (kg\ kg^{-1}) = \frac{{}^{Y}OF - {}^{Y}NF}{F}$$

where: Y_{OF} – grain yield of fertilized sunflower (kg/ha)
Y_{NF} – grain yield of unfertilized sunflower (kg/ha)
F – amount of fertilizer applied (kg)

c. Production efficiency (PE) (Kumari et al., 2019)

This index reflects the per day productivity of a component crop in the cropping system under a specific treatment imposed.

$$PE\ (kg/day) = \frac{\text{GY of sunflower (kg/ha)}}{\text{Duration of sunflower plant (days)}}$$

d. Land Use Efficiency (Kumari et al.,2019)

Land Use Efficiency was calculated by taking the total field duration of the sesame and sunflower divided by 365 days and expressed in percentage.

$$LUE\ (\%) = \frac{\text{Total field duration of sesame and sunflower}}{\text{365 days}} \times 100$$

e. Actual Yield loss (AYL) of sunflower (Banik 2000)

It represents the relative decrease of yield of sunflower per sowing proportion in intercropping with sesame compared to the sole yield of sunflower.

It was calculated thus:

$$[(Y_{sun.ses}/Z_{sun.ses})/(Y_{sun}/Z_{sun-})] - 1$$

where Y_{sun} is sole crop yield of sunflower, $Y_{sun.ses}$ is the intercrop yield of sunflower, $Z_{sun.ses}$ is the proportion of sunflower in the intercrop, Z_{sun} is sunflower in sole plot.

Positive AYL indicates advantage an intercropping; negative AYL indicates disadvantage in intercropping system.

f. System Productivity Index (SPI) (Odo 1991).

It standardizes the yield of the dominated crop (sunflower) in terms of the dominant crop (sesame).
It was calculated thus:

$$SPI = [(Y_{ses}/Y_{sun}) \times Y_{sun.ses}] + Y_{ses.sun}$$

where: Y_{ses} is yield of sole sesame, Y_{sun} is yield sole sunflower, $Y_{sun.ses}$ is yield of sunflower in intercrop and $Y_{ses.sun}$ is yield of sesame in intercrop

Data Analysis

All data collected were subjected to analysis of variance (ANOVA) using the GENSTAT 12th edition Series, and significant (P<0.05; F-test) treatment means were separated using the least significant difference method at 5% probability level.

RESULTS AND DISCUSSION

Grain yield of sunflower

Cropping system significantly ($P < 0.05$) affected the grain yield of sunflower in both years with the sunflower sown simultaneously with sesame variety E8, and the sole sunflower recording the highest grain yield values of 1,054.00 and 774.97 kg/ha in 2018 and 2019, respectively (Table 4). On average, grain yield of sunflower recorded when introduced to sesame variety E8 on the same day or 10 days after sowing sesame was superior to the yield values of sunflower when introduced to sesame Cameroun White variety in both years. However, all the yield values recorded at these two dates, especially when introduced into E8 sesame variety and in sole plots were lower than African (1,018.2 kg/ha) and world (1,942.9 kg/ha) according to FAOSTAT (2025). Only the grain yield (1,054.00 kg/ha) recorded in 2018 when sunflower was sown on the same day with sesame E8 variety recorded comparable grain yield to the African average (1,018.2 kg/ha). Delayed introduction of sunflower into sesame beyond 10 days after sowing depressed grain yield, especially when intercropped with E8 variety. Sesame and sunflower have different growth habits even though they both grow slowly after emergence in the first month. Rapid growth starts in sunflower after the formation of the head, capitulum and continues for the next 3 – 4 weeks before it diminishes at the peak of anthesis. Whereas, for sesame rapid growth starts from the stage of bud formation and lasts longer till ripening of the first capsule (Ustimenko-Bakumovsky 1980). Consequently, sesame can utilize the growth resources longer than sunflower.

Table 4: Grain yield, Agronomic Efficiency (AE) and Partial Factor Productivity (PFP) of sunflower intercropped with sesame in 2018 and 2019

Cropping system	Sunflower grain yield Kg/ha		AE kg/ha		PFP kg/ha	
	2018	2019	2018	2019	2018	2019
SoleSUNNF	829.93	774.97	-	-	22.44	16.76
V1OFC1	1054.00	720.70	7.39	1.64	17.66	12.01
V1OFC2	961.83	702.17	6.16	1.39	16.03	11.70
V1OFC3	833.27	506.60	6.81	0.54	13.89	8.44
V2O FC1	503.53	675.23	-0.06	2.13	8.39	11.25
V2OFC2	458.43	511.10	1.46	-0.23	7.64	8.52
V2OFC3	447.87	566.77	1.46	1.88	7.46	9.44
Lsd 5%	152.148	124.115	2.415	0.665	3.894	1.939

AE – Agronomic Efficiency, PFP – Partial Factor Productivity, NF – No fertilizer, OF – Organic fertilizer, V1 – E8, V2 – Cameroun White, C1- sown simultaneously with sesame, C2 - 10 days after sowing, DAS, and C3 - 20 DAS, SUN – Sunflower, LSD – Least significant difference

Agronomic efficiency of sunflower in mixtures

Agronomic efficiency is a measure of nutrient use efficiency because it quantifies the output of the crop relative to the nutrients applied (Yadav 2003). In this study, agronomic efficiency of sunflowers that received organic fertilizer in mixtures with two sesame varieties is shown in Table 4. There was significant ($P < 0.05$) effect in agronomic efficiency of sunflower in mixtures. Sowing of sesame varieties E8 and Cameroun White on the same day with sunflower (C1) enhanced AE of sunflower in 2018 and 2019. The magnitude of AE has been reported to be a function of the interactions between biotic and abiotic factors, type of nutrient source applied and the metabolic activities within the plant that aid absorption of the nutrients (Souza et al. 2018). More importantly, sunflower utilizes nitrogen in achene formation (Schwerz et al. 2016) and this was evident in the achene yield values recorded when sunflower was sown on the same day with sesame, especially the E8 variety in both years. The negative values recorded for AE when sunflower was sown on the same day with sesame variety Cameroun White in 2018 and 10 days later in 2019 could be attributed to the microclimatic differentiation and complementary resource utilization in those mixtures that made the sunflower in the mixture to produce grain yield slightly higher than the grain yield of the sole sunflower (He et al. 2011; Yu et al. 2015).

Partial Factor Productivity (PFP) of sunflower

The PFP sunflower was significantly ($P < 0.05$) affected by cropping system in both years (Table 4). The PFP of sunflower introduced into E8 variety of sesame was consistently higher than the values of PFP of sunflower introduced into Cameroun White sesame across the sowing dates in both years. The decrease in PFP as the introduction of sunflower into sesame was delayed could partly be attributed to the shading effect of the taller sesame plants in the mixtures and the interspecific competition for growth resources by the two crops (Somefun et al. 2020). Furthermore, sunflower take more water and nutrients at post anthesis period (>50 Days After Sowing) when interspecific completion between the mixtures is rather intense (Coelho et al. 2022). Furthermore, decrease in PFP had also been attributed to nutrient imbalance, decline in indigenous soil N supply, sub soil compaction, reduced root volume and increased pests and diseases infestation in mostly sole cropping (Karim and Ramasamy 2000). However, increase in PFP of crops have been attributed to proper crop management practices such as appropriate nutrient application, and conversion of solar radiation to the economic yield (Yadav 2003; Panwar et al. 2019). We observed both increase and decrease in PFP of sunflower in this study.

Production Efficiency of sunflower

The PE of sunflower was significantly (*P < 0.05*) influenced by the cropping systems (Table 5). The sunflower on the sole fertilized plots recorded significantly (*P < 0.05*) higher PE (15.13 kg ha^{-1} day^{-1} in 2018 and 10.70 kg ha^{-1} day^{-1} in 2019) than sunflower under all the mixtures of both varieties in both years. Delaying introduction of sunflower into sesame based cropping system with or without fertilizer application beyond 10 days resulted in significant PE with sesame variety E8 in both years. Decrease in PE can be attributed to interspecific competition between the component crops as they both advanced in growth and development and to a large extent on the management practices adopted in the system (Yadav 2003; Panwar et al. 2019).

Table 5: Sunflower Grain Yield, Production Efficiency (PE), System Productivity Index (SPI), Actual Yield Loss of sunflower (AYL_{sun}), and Land Use Efficiency (LUE) in 2018 and 2019

Insert Table 5

Cropping system	Sunflower Grain yield (kg/ha)		PE (kg.ha^{-1} day^{-1})		SPI		AYL_{sun}		LUE (%)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
SoleSUNNF	829.93	774.97	9.32	8.24	-	-	-	-	-	-
SoleSUNOF	1346.23	1005.53	15.13	10.70	-	-	-	-	-	-
V1NFC1	610.60	622.43	6.36	6.48	474.9	1,130.0	0.62	0.74	52.5	57.02
V1NFC2	592.07	618.93	6.23	6.45	523.8	1,013.5	0.58	0.77	53.0	56.75
V1NFC3	424.60	474.27	4.57	4.84	450.6	996.5	0.13	0.35	52,2	56.76
V1OFC1	1054.00	720.70	10.98	7.67	938.0	980.9	0.73	0.58	52.1	56.71
V1OFC2	961.83	702.17	10.34	7.31	838.7	1,052.7	0.57	0.54	51.4	58.32
V1OFC3	833.27	506.60	9.06	5.17	837/0	1,051.3	0.37	0.11	50.9	58.40
V2NFC1	507.13	547.30	5.28	5.82	370.8	834.3	0.34	0.56	52.8	57.16
V2NFC2	371.17	524.67	3.95	5.46	357.2	844.9	-0.01	0.47	52.7	58.32
V2NFC3	423.50	454.27	4.55	4.45	377.0	751.7	0.13	0.54	52.8	58.40
V2O FC1	503.53	675.23	5.36	7.03	575.4	1,783.8	-0.17	0.02	53.3	56.74
V2OFC2	458.43	511.10	4.93	5.22	562.9	1.703.9	-0.24	0.11	51.7	58.02
V2OFC3	447.87	566.77	4.87	5.78	529.0	1.813.0	-0.26	0.14	50.9	58.99
Lsd 5%	152.148	124.115	1.489	0.752	3.93	0.71	0.014	0.046	0.99	1.928

PE – Production efficiency, SPI – System Productivity Index, AYLsun – Actual Yield Loss of sunflower, LUE – Land Use Efficiency

NF – No fertilizer, OF – Organic fertilizer, V1 – E8, V2 – Cameroun White, C1- sown simultaneously with sesame, C2 - 10 days

after sowing, DAS, and C3 - 20 DAS, SUN – Sunflower, LSD – Least significant differenceSystem Productivity Index (SPI)

The SPI was calculated in order to standardize the yield of sunflower in terms of sesame yield, and also to identify the cropping systems that utilized the growth resources most effectively and still maintained a stable yield output as described by Osen (2010). The results showed that organic fertilizer application significantly ($P < 0.05$) enhanced SPI across the sowing dates when sunflower was introduced into both sesame varieties in both years, except for E8 without fertilizer application in 2019 (Table 5). The comparatively high SPI values recorded when organic fertilizer was applied to the cropping systems indicate relative stable productivity in our study, Similar trends have been reported in other mixtures that involved annual arable crops such as wheat/faba bean in Ethiopia (Agegnehu et al. (2008), sorghum/cowpea in Nigeria (Osen 2010), sesame/turmeric in Bangladesh (Islam et al. 2016) and sunflower/peanut in Egypt (Quda et al. 2018).

Actual Yield loss of sunflower (AYL_{sun})

The AYL_{sun} was significantly (P <0.05) affected by cropping system in both years (Table 5). This index provides information that gives an insight into the proportionate yield loss or gain by its sign and value (Dhima et al. 2007) and, inter and intraspecific competitions of each component in an intercropping system (Saeidi et al. 2019). The positive AYL_{sun} recorded when sunflower was intercropped with sesame E8 variety in both years with or without fertilizer application suggest a yield advantage for sunflower intercropped with E8. However, negative values recorded for sunflower introduced 10 DAS without fertilizer application and at the three dates with fertilizer application in 2018 suggest interspecific competition between the component crops for the basic growth resources below those cropping systems. When AYL is positive for a mixture, it indicates compatibility of the component crops in the system and this ability declined as sunflower introduction was delayed. Positive and negative AYL had also been reported for mixtures involving groundnut/sesame in Egypt (Abou-Kersha et al. 2008), sunflower/peanut in Egypt (Ouda et al. 2018), safflower/faba bean in Iran (Saeidi et al. 2019).

Land Use Efficiency (LUE)

Land Use Efficiency was significantly ($P < 0.05$) affected by cropping system in both years (Table 5). The values ranged between 50.9 to 53.3% in 2018 and 56.71 to 58.99% in 2019, respectively. The values recorded in 2019 were higher than the values in 2018 because rain was higher in November 2019 (112.3 mm) than 2018 (36.0 mm) which resulted in prolonged gestation period of sunflower and sesame in the cropping systems (Table 1). The values recorded in our study in both years compared well with the results (59–62%) reported in maize/soybean mixtures in India by Kumari et al. (2019).

CONCLUSIONS

Generally, the results indicate that the cropping system significantly affected the grain yield and the productivity indices evaluated for sunflower introduced into a sesame-based cropping system at three sowing dates. The introduction of sunflower into sesame variety E8 latest 10 DAS demonstrated high productivity based on the relatively high values of grain yield (702.17 – 1,054 kg/ha), PE (7.31 – 10.98 $kg.ha^{-1}$ day^{-1}), SPI (838.7 – 1,052.7), AYL_{sun} (0.54 – 0.73), and LUE (51.4 – 58.32%) in both years when organic fertilizer was applied. Mixtures of sunflower with the sesame variety Cameroun White also performed well based on PE (4.93 – 7.03 $kg.ha^{-1}$ day^{-1}), SPI (562.9 – 1,783.8), and LUE (51.7 – 58.02%) when sunflower was introduced latest 10 DAS with organic fertilizer application. Overall, intercropping sunflower with sesame variety E8 can be a better intercropping system than with Cameroun White under organic production system in humid tropical location.

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REFERENCES

Abou-Kerisha, M.A., Gadallah, R.A., and Mohamdain, E.E.A. (2008). Response of groundnut to intercropping with some sesame varieties under deferent plant density. Arab Universities Journal of Agricultural Sciences 16: 359-375.

Adekunle, Y.A., Olowe V.I., Olasantan, F.O, Okeleye, K.A, Adetiloye, P.O., and Odedina, J.N. (2014). Mixture Productivity of cassava-based cropping system and food security under humid tropical condition. Food and Energy Security 3:43-60.

Agegnehu, G., Ghizaw, A., and Sinebo, W. (2008). Yield potential and land-use efficiency of wheat and faba bean mixed intercropping. Agronomy for Sustainable Development 28: 257-263.

Akpojotor, E., Olowe, V.I.O., Adejuyigbe, C., and Adigbo, S.O. (2019). Appropriate Nitrogen and Phosphorus Fertilizer Regime for Sunflower (*Helianthus annuus* L.) In the Humid Tropics Helia 42:111-125 https://doi.org/10.1515/helia- 2018-0016.

Alipatra, A., Banerjee, H., Bhattacharyya, K., Bandopadhyay, P., and Ray, K. (2019). Yield and quality of hybrid sunflower (*Helianthus annuus* L.) as affected by irrigation and fertilization. Indian Journal of Agricultural Sciences, 89: 1419-1424.

Banik, P., Sasmal, T., Ghosal, P.K., and Bagchi, D.K. (2000). Evaluation of Mustard (*Brassica compestris* var. Toria) and Legume Intercropping under 1M:1S and 2:1 Row-Replacement Series Systems. Journal of Agronomy and Crop Science 185: 9-14. https://doi.org/10.1046/j.1439-037X.2000.00388.x

Cassmen, K.U., Gines, G.C., Dizon, M.A., Samson, M.I., and Alcantace, M. (1996). Nitrogen Use Efficiency in tropical low land rice system – contribution from indigenous and applied nitrogen. Field Crop Research 47:1 – 12.

Cisse, L., and Amar, B. (2000). January. The importance of phosphatic fertilizer for increased crop production in developing countries. In Proceedings of the AFA 6th International Annual Conference (Vol. 31). Casablanca, Morocco: World Phosphate Institute.

Coêlho, E.D.S., Souza, A.R.E.D., Lins, H.A., Santos, M.G.D., Freitas Souza, M.D., Tartaglia, F.D.L., de Oliveira, A.K.S., Lopes, W.D.A.R., Silveira, L.M., Mendonça, V. and Barros Júnior, A.P. (2022). Efficiency of nitrogen use in sunflower. Plants 11(18), p.2390.

Congreves, KA., Otchere, O., Ferland, D., Farzadfar, S., Williams, S., and Arcand, M.M. (2021). Nitrogen Use Efficiency Definitions of Today and Tomorrow. Frontier of Plant Science 12:637108. doi:10.3389/fpls.2021.637108

Delgado Martínez, R., Poot Poot, W.A., Castro Nava, S., Segura Martínez, M.T.D.J. and Moreno Ortega, M.E. (2018). Yield and agronomic efficiency of sunflower in response to nitrogen fertilizer application and sowing season. Revista Caatinga, 31: 871-881.

Dhima, K.V., Lithourgidis, A.S., Vasilakoglou, I. B., and Dordas, C.A. (2007). Competition indices of common vetch and cereal intercrops in two seeding ratio. Field Crops Research, 100: 249-256.

Dobermann, A. (2007). Nutrient use efficiency—measurement and management. In: Krauss, A., Isherwood, K., Heffer, P. (Eds.), *Fertilizer Best Management Practices: General Principles, Strategy for Their Adoption and Voluntary Initiatives Versus Regulations*. International Fertilizer Industry Association, Paris, France, pp. 1–28. Online @ https://www.fertilizer.org//images/Library_Downloads/2007_IFA_FBMP%20Workshop_Brussels.pdf

Faisul-ur-Rasool, H., Jahangir, B., Ali, I.A., and Mubarak, T. (2013). Nutritional yield and economic responses of sunflower (*Helianthus annuus* L.) to integrated levels of nitrogen, sulphur and farmyard manure. The Journal of Agricultural Sciences 8: 17–27.

FAO (Food and Agriculture Organisation of the United Nations). (2025). Sunflower yield (hectogram per hectare) for all countries. www.fao.org/faostat/en/#search/Sunflower checked 28/6/2025

FiBL survey (2025). Based on information from the private sector, certifiers, and governments.

Online at https://statistics.fibl.org/visualisation.html In: Willer, Helga Jan Trávníček and Bernhard Schlatter (Eds.) (2025): The World of Organic Agriculture. Statistics and Emerging Trends 2025. Research Institute of Organic Agriculture FiBL, Frick, and IFOAM – Organics International, Bonn.

Fixen, P., Brentrup, F., Bruulsema, T., Garcia, F., Norton, R., and Zingore, S. (2015). "Nutrient/fertilizer use efficiency: measurement, current situation and trends," in Managing Water and Fertilizer for Sustainable Agricultural Intensification, eds P. Drechsel, P. Heffer, H. Magen, R. Mikkelsen, and D. Wichelns (Paris: IFA), 8–38.

Ghosh, P.K. (2004). Growth, Yield, Competition and Economics of Groundnut/Cereal Fodder Intercropping Systems in the Semi-Arid Tropics of India. Field Crops Research, 88: 217-237. https://doi.org/10.1016/j.fcr.2004.01.015

He, H., Yang, L., Fan, L., Zhao, L., Wu, H., Yang, J., and Li, C. (2011). The effect of intercropping of maize and soybean on microclimate. In *International Conference on Computer and Computing Technologies in Agriculture* (pp. 257-263). Berlin, Heidelberg: Springer Berlin Heidelberg.

Karim, A.A., and Ramasamy, C. (2000). Expanding Frontiers of Agriculture: Contemporary Issues; Kalyani Publishers: Ludhiana, India

Kumari, C. P., Sridevi, S., and Goverdhan, M. (2019). Enhancement of productivity and profitability of small farmers through Bio intensive complimentary cropping systems. International Journal of Chemical Studies 7: 334-338.

Mortvedt, J.J., Johnson, D.L. and Croissant, R.L. (2003). Fertilizing sunflowers. Colorado State Comperative Extension Fact sheet No. 543. Soil and Crop Sciences 3/96.

Nasim, W., Ahmad, A., Hammad, H.M., Chaudhary, H.J., and Munis, M.F. (2012a). Effect of nitrogen on growth and yield of sunflower under semi-arid conditions of Pakistan. Pakistan Journal of Botany 44: 639–648.

Nasim, W., Ahmad, A., Bano, A., Olatinwo, R., Usman, M., Khaliq, T., Wajid, A., Hammad, H.M., Mubeen, M., and Hussain, M. (2012b). Effect of nitrogen on yield and oil quality of sunflower (*Helianthus annuus* L.) hybrid under sub-humid conditions of Pakistan. American Journal of Plant Science 3: 243–251.

Nasim, W., Ahmad, A., Ahmad, S., Nadeem, M., Masood, N., Shahid, M., and Fahad, S. (2017). Response of sunflower hybrids to nitrogen application grown under different agro-environments. Journal of Plant Nutrition 40: 82–92. https://doi.org/10.1080/01904167.2016.1201492

Odo, P.E. (1991). Evaluating Short and Tall Sorghum Varieties in Mixtures with Cowpea in Sudan Savanna of Nigeria: LER, Grain Yield and System Productivity Index. Experimental Agriculture, 27, 435-441. https://doi.org/10.1017/S0014479700019426

Olowe, V.I.O., Adeosun, J.O., Musa, A.A., and Ajayi, E. (2003). Characterization of some accessions of sesame (*Sesamum indicum* L.) in a forest-savanna transition location of Nigeria. Journal of Sustainable Agriculture and Environment 5:119-127.

Olowe, V.I.O. (2004). Production potential for sesame (*Sesamum indicum* L.) in the forest savanna transition zone of south west Nigeria. MUARIK Research Bulletin 7: 20–29.

Olowe, V.I.O., Fadeyi, J., Odueme, P.U., Aderonmu, D., and Otaiku, O. (2021). Foliar Fertilization of organic sunflower, enhanced yield components and seed yield in the humid tropics. Helia 74: 73-80 https://doi.org.1515/helia-2020-0010

Olowe, V.I.O., and Adeyemo, A.Y. (2009). Enhanced crop productivity and compatibility through intercropping of sesame and sunflower varieties. Annals of Applied Biology Journal 155: 285-291.

Olowe, V.I.O., and Adebimpe, O.A. (2009). Intercropping Sunflower with Edible Soybeans Enhances Total Crop Productivity. Biological Agriculture & Horticulture 26:265-377.

Oseni, T.O. (2010). Evaluation of sorghum-cowpea intercrop productivity in savanna agro-ecology using competition indices. Journal of Agricultural Science *2*(3), 229.

Oshundiya, F.O., Olowe, V.I.O., Sowemimo, F.A., and Odedina, J.N. (2014). Seed yield and quality of sunflower (*Helianthus annuus* L.) as influenced by staggered sowing and organic fertilizer application in the humid tropics. Helia 37: 237–255.

Ouda, S.A., Hefny, Y.A., Abdel-Wahab, T.I., and Abdel-Wahab, S. I. (2018). Competitiveness and profitability of intercropping sunflower with peanut under different irrigation water levels and potassium fertilizer rates. Agricultural Sciences, 9: 1007-1031.

Ozer, H., Polat, T., and Ozturk, E. (2004). Response of irrigated sunfower (*Helianthus annuus* L.) hybrids to nitrogen fertilization: growth, yield and yield components. Plant Soil Environ 50:205–211

Panwar, A. S., Shamim, M., Babu, S., Ravishankar, N., Prusty, A. K., Alam, N. M., Singh, D. K., Bindhu, J. S., Kaur, J., Dashora, L. N., Pasha, M. D. L., Chaterjee, S., Sanjay, M. T., and Desai, L. J. (2019). Enhancement in Productivity, Nutrients Use Efficiency, and Economics of Rice-Wheat Cropping Systems in India through Farmer's Participatory Approach. *Sustainability*, *11*(1), 122. https://doi.org/10.3390/su11010122

Perveen, S., Ahmad, S., Skalicky, M., Hussain, I., Rahman, M.H.U., Ghafar, A., Bashir, M.M.S., Batool, M., Brestic, M., Fahad, S., Hassan, M., Sabagh, A.E. (2021). Assessing the potential of polymer coated urea and sulphur fertilization on growth, physiology, yield, oil contents and nitrogen use efficiency of sunflower crop under arid environment. Agronomy 11(269):1–12. https://doi.org/10.3390/agronomy11020269

Pilorgé, E. (2020). Sunflower in the global vegetable oil system: situation, specificities and perspectives. Oilseeds and Fats, crops and Lipids Journal, *27*, 34.

Putnam, D.H., Oplinger, E.S., Hicks, D.R., Durgan, B.R., Noetzel, D.M., Meronuck, R.A., Doll, J.D., and Schulte, E.E. (1990). Sunflower: alternative field crops manual. Purdue University, West Lafayette, IN, USA. Available at: http:///www.hort.purdue.edu/newcrop/afcm/sunflower.html [Verified 40 15 June 2025]

Rahman, M.H., Ahmad, I., Wang, D., Fahad, S., Afzal, M., Ghaffar, A., Saddique, Q., Khan, M.A., Saud, S., Hassan, S., and Fahad, M. (2021). Influence of semi-arid environment on radiation use efficiency and other growth attributes of lentil crop. Environmental Science and Pollution Research *28*: 13697-13711.

Rasool, F. U., Hassan, B., Jahangir, I.A., Ali, T., and Mubarak, T. (2013). Nutritional yield and economic responses of sunflower (*Helianthus annuus* L.) to integrated levels of nitrogen, sulphur and farmyard manure. The Journal of Agricultural Science 8: 17–27.

Rosa, P.M., Antoniassi, R., Freitas, S.C., Bizzo, H.R., Zanotto, D.L., Oliveira, M.F., and Castiglioni, V. B.R. (2009). Chemical composition of Brazilian sunflower varieties. Helia 32: 145–156.

Saeidi, M., Yaghoub, R. A., E.I., Amini, R., Taghizadeh, A., Pasban-Eslam, B., and Saralan, A.R. (2019). Competition indices of safflower and faba bean intercrops as affected by fertilizers. Notulae Scientia Biologicae, 11: 130-137.

Schwerz, F., Caron, B.O., Elli, E.F., De Oliveira, D.M., Monteiro, G.C., and De Souza, V.Q. (2016). Avaliação do efeito de doses e fontes de nitrogênio sobre variáveis morfológicas, interceptação de radiação e produtividade do girassol. Revista Ceres 63: 380–386.

Singh, S.S. (2004). Soil fertility and nutrient management. 2nd Edition, Kalyani Publishers, New Delhi, India.

Somefun, O. T., Olowe, V. I. O, Adigbo, S. O. and Olasanta, F. O. (2020). Mixture productivity of sesame (*Sesamum indicum* L.) intercropped with sunflower (*Helianthus annuus* L.) in the humid tropics: effects of sunflower introduction date and organic fertilizer. Crop and Pasture Science 71: 1020-1028 https://doi.org/10.1071/CP20330

Souza, Á.H.C.D., Rezende, R., Lorenzoni, M.Z., SERON, C.D.C. and Santos, F.A.S. (2018). Agronomic efficiency and growth of eggplant crop under different potassium and nitrogen doses. Revista Caatinga, 31: 737-747.

Ustimenko-Bakumovsky G.V. (1980). Sesame. In *Plant growing in the tropics and subtropics*, pp. 272–279. Moscow: Mir Publishers.

Weiss E. A. (2000). 'Oilseed crops.' 2nd edn. (Blackwell Science: Oxford, UK)

Yadav, R.L. (2003). Assessing on-farm efficiency and economics of fertilizers N, P and K in rice-wheat system of India. Field Crops Res. 81: 39–51.

Yu, Y., Stomph, T. J., Makowski, D., and van Der Werf, W. (2015). Temporal niche differentiation increases the land equivalent ratio of annual intercrops: a meta-analysis. Field Crops Research 184: 133-144.