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Cotton (*Gossypium hirsirtum* L.) production under an organic crop rotation system and weather vagaries in the humid tropics

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Abstract

Climate change is an established challenge to global agricultural productivity. This two-year study evaluated the effects of five cropping systems on the agronomic performance of cotton in the humid tropics. Field trials were carried out during the late cropping seasons (July–December) of 2019 and 2020 on the Organic Research plot of the Institute of Food Security, Environmental Resources and Agricultural Research, Federal University of Agriculture, Abeokuta, Nigeria. Five cropping systems: continuous cropping without organic fertilizer (CS1), continuous cropping with organic fertilizer (CS2), crop rotation with organic fertilizer (CS3), crop rotation without organic fertilizer (CS4), and conventional cropping (CS5) were evaluated in a randomized complete block design and replicated three times. Sesame and soybeans were the preceding crops. The weather vagaries were described during the cropping seasons. In 2019, cotton plants under CS2, CS3, and CS4 produced significantly ($p < 0.05$) greater number of bolls per plant (24.3, 23.2, and 22.3), seed weight (16.0, 18.9, and 19.3 g), and greater seed yield (631.96, 675.08 and 677.88 kg/ha) than did cotton plants under CS1, respectively. A similar trend was recorded in 2020, except for the number of bolls per plant. Number of rainy days was 53 and 32 in 2019 and 2020, respectively. Prospective cotton growers in the region can adopt cotton production in rotation schemes that involve sesame and soybeans with (CS3) or without (CS4) the application of organic fertilizer and continuous application of organic fertilizer (CS2). A robust near real-time climate information service to aid farmers in their production activities is recommended.

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Introduction

Cotton (*Gossypium* spp.) is the most widely cultivated fibre crop on all continents of the world, except for the Antarctic, and is cultivated in more than 60 countries[1]. Cotton fibre serves as a raw material for textile industries with an annual economic value worth more than USD$600 billion and provides employment opportunities for many people involved in its value chain[2]. According to FAOSTAT[3], as of 2022, the average production and yield of cotton in the world and Africa stood at 69,668,142.85 and 4,716,293.5 metric tonnes and 2,216.80 and 957.9 kg/ha, respectively. Organic cotton accounts for only 1.4% of cotton grown in the world based on the 2020/21 report of the International Cotton Advisory Committee (ICAC)[4]. It has been reported that agricultural practices such as intercropping, crop rotation, the use of compost, and FYM (farmyard manure) have been used instead of agrochemical inputs in organic cotton production[5,6].

Generally, climatic factors (rainfall, number of rainy days, temperature, relative humidity, sunshine hours, light, and wind) affect the growth of cotton because they interact with other environmental factors such as nutrient availability in soil, cultivar, soil moisture, and agronomic practices to affect cotton growth[7,8]. In recent decades, climate change has been reported to affect the phenological phases of cotton[9,10]. Globally, integrated approaches to reduce the losses attributable to climate change are being developed while tackling other traditional challenges to crop production[11,12]. A combination of crop rotation and early warning systems (EWS) were recently recommended as a highly promising archetype for achieving the objectives of the CSA in tropical Africa[13]. The Early Warning System (EWS) is a general agricultural alert system that provides reliable and early information on agricultural impacts induced by climate change[14]. It is a system designed to monitor changes in weather patterns, climate conditions, and environmental factors that can engender agricultural losses[4]. The system is to predict and provide timely alerts about adverse agricultural conditions, such as droughts, floods, or pest outbreaks[15]. To achieve this, it integrates satellite-derived climate data, information from weather stations, and predictive models to help farmers make informed decisions and mitigate risks[16]. Establishing a robust near-real-time climate information service system together with crop rotation practices will enhance the overall stability and productivity of cotton farming in the humid tropics.

Crop rotation has been described as a veritable strategy to achieve one of the principles of agroecology aimed at enhancing the recycling of biomass, optimizing nutrient availability, and balancing nutrient flow[17]. A recent study concluded that cotton demonstrated an increase in yield when planted after soybean due to increased levels of soil N through fixation from the preceding soybean crop or an alteration of soil microbial populations favourable to the succeeding cotton crop[18]. Crop yields have been improved further by introducing longer rotations, such as the addition of a third crop to the rotation, and reported yield increases attributed to greater residue diversity and improvement in soil conditions[19], and alleviation of some of the problems associated with no-till[20]. Unfortunately, the bulk of conventional cotton is produced under a continuous cropping system that often records an increase in the prevalence of soil-borne diseases which is directly linked to the increase of the pathogen abundance[21] and reduction in the abundance of beneficial soil organisms over time[22], which are essential to soil fertility, health, and crop yield. Organic fertilizer application to cotton can help alleviate some of these problems because organically bound nutrients are held more tightly in soil than nutrients obtained from mineral fertilizers; therefore, their chances of losses by volatilization and leaching are far less[23].

This study was therefore carried out to determine the agronomic performance of cotton sown after sowing soybeans and sesame under different cropping systems in an organic crop rotation scheme under prevailing climatic conditions in a humid tropical location.

Materials and methods

Study area

The study was conducted at the Organic Research Plots of the Institute of Food Security, Environmental Resources and Agricultural Research (IFSERAR) of the Federal University of Agriculture, Abeokuta (Nigeria). The farm is located within (7°13'51.17" N and 7°13'53.16" N and longitudes 3°23'49.12" E and 3°23'51.86" E, at an altitude of 131.5 m above sea level). Figure 1 shows a map of the project area.

Growth conditions during the experimental period

The rainfall pattern in the study area is bimodal with two peaks in July and September and a dry spell in August termed the '*August break*'. However, the two peaks were recorded in June and October in 2019 and June and September in 2020. During the experimental period, a total rainfall of 693.1 and 493.3 mm were recorded in 2019 and 2020, respectively. The experiment was carried out during the late cropping seasons (July–December) of 2019 and 2020 (Fig. 2). The textural class of the soils under the cropping systems was loamy sand, except for the soil under continuous cropping (CS1) without organic fertilizer which was sandy in both years (Tables 1 & 2). The pH of the soils under the various cropping systems was slightly acidic, especially in 2019 and 2020, all the cropping system soils had slightly alkaline pH values with CS2 and CS4 having the highest values of 7.4. The nitrogen, phosphorus, potassium, and organic carbon contents of the soils across the cropping systems were generally low in both years (Table 1).

Experimental design and treatments

The experiment was performed in a Randomized Complete Block Design (RCBD) and replicated three times. The five cropping systems evaluated were as follows: a. CS1 - Continuous cropping (without organic fertilizer); b. CS2 - Continuous cropping (with organic fertilizer); c. CS3 - Rotation (with organic fertilizer); d. CS4 - Rotation (without organic fertilizer); e. CS5 - Conventional system (60 kg N, 56 kg P_2O_5 and 60 kg K_2O and herbicide application).

The test varieties of the experimental crops were as follows: Cotton - Samcot 11, an erect type, lobed land glanded leaves, slightly conical bolls, a long staple, with a potential yield of seed cotton at 2.5 t/ha, mean fibre length of 26.5–27.5 mm and late maturing variety[24]; soybean - TGx 1448-2E, a medium maturing, pod shattering resistant and high yielding variety[25] and sesame - E-8 variety, a drought-tolerant, good seed quality, with a 1,000-seed weight > 3.0 g and high yield[26]. Sowing was performed on July 10, 2019, and July 24, 2020.

Soil sampling and analysis

Before planting each year, soil samples were collected from the experimental field on a cropping system basis for routine soil analysis to determine the physical and chemical properties of the soil.

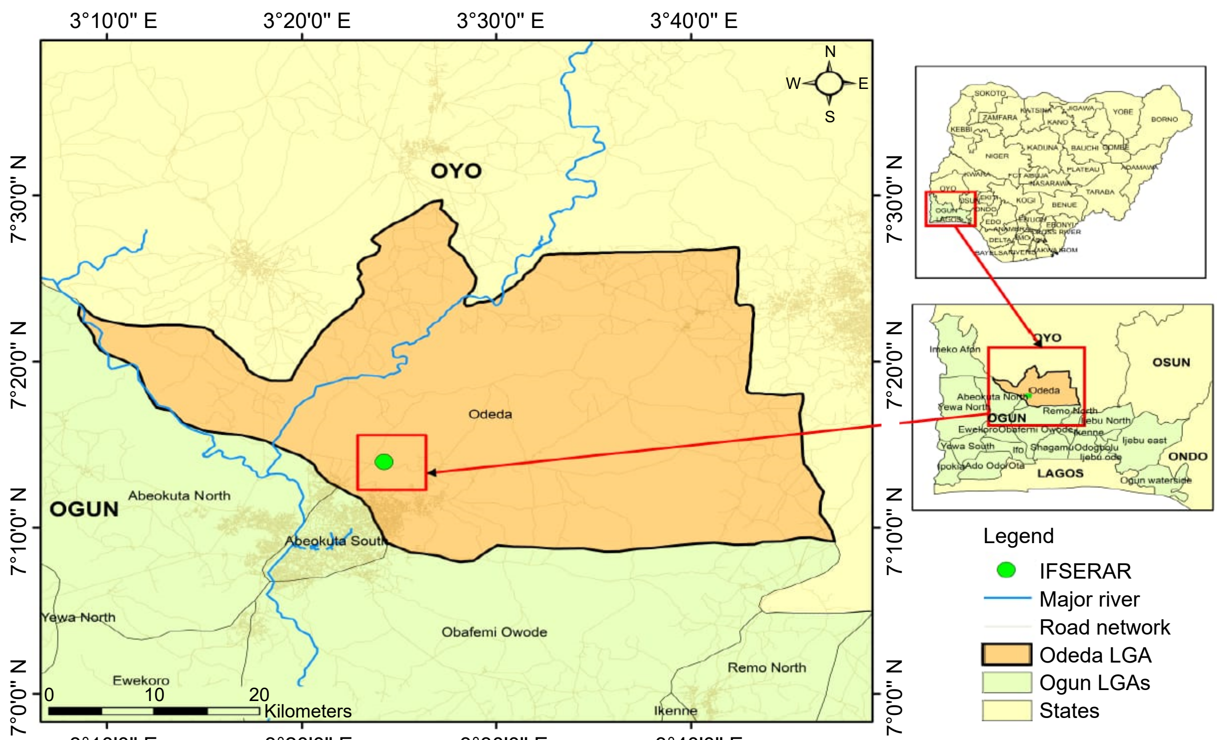

Fig. 1 Map of the experimental plots at the Federal University of Agriculture, Abeokuta, Nigeria.

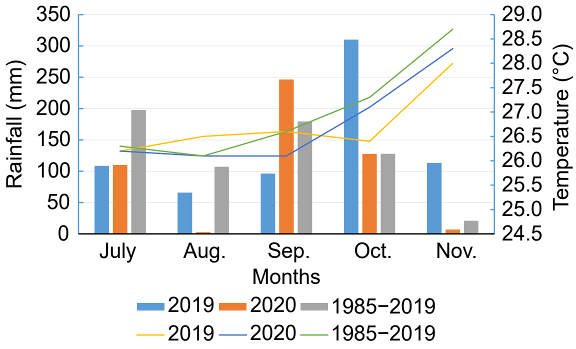

Fig. 2 Monthly rainfall distribution and mean temperature during the experimental periods (July–November 2019 and 2020) and the long-term (1985–2019) at the Federal University of Agriculture Abeokuta, Nigeria.

Table 1. Pre-cropping physical and chemical properties of the soil in 2019.

Soil composition	Continuous cropping (−OF) (CS1)	Continuous cropping (+OF) (CS2)	Rotation (+OF) (CS3)	Rotation (−OF) (CS4)	Conventional (CS5)
Mechanical composition (g/kg)					
Clay	65	85	85	85	65
Silt	35	45	45	25	65
Sand	900	870	870	890	870
Textural classification	Sand	Loamy sand	Loamy sand	Loamy sand	Loamy sand
pH	6.6	6.9	6.5	6.9	6.8
Total N (g/kg)	0.97	0.94	0.77	0.84	0.59
OC (g/kg)	9.5	5.4	10.4	8.4	13.4
P (mg/kg)	2.56	4.87	23.59	3.01	3.64
Exchangeable cation (cmol/kg)					
K	0.12	0.06	0.08	0.09	0.12
Ca	3.89	2.89	2.99	3.39	4.59
Mg	1.74	1.48	1.63	1.96	1.81
Na	0.49	0.34	0.39	0.30	0.59
Micronutrient (mg/kg)					
Mn	264	280	356	288	299
Fe	12	12	12	10	14
Zn	51	54	51	52	51

OC: organic carbon.

Crop husbandry

Each year, the experimental field was ploughed twice at two-week intervals and subsequently harrowed one week later. The crops were sown in their respective plots using the following row spacings: soybean - 60 cm × 5 cm, sesame - 60 cm × 5 cm, and cotton - 90 cm × 40 cm. Weeding was performed at 3, 6, and 9 weeks after sowing (WAS). Five plants (cotton) were randomly selected and tagged at 5 WAS from the net plot for plant height and yield attribute measurements on a plot basis. The experiment was carried out under rain-fed conditions. The organic fertilizer used was Aleshinloye Grade B (an abattoir-based fertilizer) which was applied at 3 WAS using the side dressing method at the rate equivalent to the recommended nitrogen level (60 kg N/ha) while the inorganic fertilizer was applied to the conventional system at 3 WAS at the rate of (60 kg N, 56 kg P_2O_5, and 60 kg K_2O). The organic fertilizer contained 10.96 g/kg N, 0.01 g/kg P, and 6.30 g/kg K in 2019 and 12.30 g/kg N, 3.37 g/kg P, and 2.01 g/kg K in 2020. In 2018 and 2019, soybean and sesame were planted as preceding crops for cotton grown in 2019 and 2020, respectively.

Data collection

The rainfall distribution, monthly mean temperature, sunshine hours, and relative humidity were used as proxies for weather variations. Five plants (cotton) were randomly selected and tagged at 5 WAS from the net plot for plant height and yield attribute measurements on a plot basis. Data were collected on the following parameters: plant height (cm) at harvest was measured as height from the soil surface to the apex of the plant, which was measured with a metre rule; number of sympodia branches (primary) as the total number of the fruiting branches which was carried out by visual counting; number of monopodia branches (secondary) as the total number of the vegetative branches which was done by visual counting; total number of branches by counting the number of branches per plant and the mean average determined; number of bolls per plant (NBOLLS) by counting the number of bolls for each tagged plant at harvest and the average determined; weight (g) of seed cotton per plant (SCWT) was weighed after the bolls were detached from the cotton plant and they contained both the seeds and the lint; number of seeds per open boll (NSEED), weight (g) of seeds (SEEDWT) the seeds were weighed after the seeds have been detached from the lint from the tagged plants; weight (g) of lint (WTLINT) per plant this was weighed after the lint has been detached from the seed, and cotton seed yield (kg/ha) was computed from seed cotton yield per plot and converted to a unit area. Weighing of all the samples was carried out using a sensitive scale (ATOM A – 120 with maximum capacity of 10 kg).

Table 2. Pre-cropping physical and chemical properties of the experimental site in 2020.

Soil composition	Continuous cropping (−OF) (CS1)	Continuous cropping (+OF) (CS2)	Rotation (+OF) (CS3)	Rotation (−OF) (CS4)	Conventional (CS5)
Mechanical composition (g/kg)					
Clay	37.8	1.00	16.1	19.0	18.0
Silt	40.5	149.8	100	151.1	163.5
Sand	958.5	833.7	879.3	834.3	798.7
Textural classification	Sand	Loamy sand	Loamy sand	Loamy sand	Loamy sand
pH	7.3	7.4	7.3	7.4	7.2
Total N (g/kg)	0.82	0.53	0.87	0.81	0.92
OC (g/kg)	9.6	6.2	10.2	9.4	10.6
P (mg/kg)	35.68	45.42	37.51	61.86	40.55
Exchangeable cation (cmol/kg)					
K	0.34	0.36	0.69	0.41	0.36
Ca	0.98	1.52	2.29	1.68	1.51
Mg	1.04	1.08	1.79	1.21	1.13
Na	0.17	0.18	0.29	0.18	0.18
Micronutrient (mg/kg)					
Mn	4.29	4.68	7.35	4.52	4.20
Fe	9.10	10.22	10.70	7.35	8.00
Zn	5.61	7.23	9.69	7.28	6.81

OC: organic carbon.

Statistical analysis

All data collected were subjected to analysis of variance (ANOVA) to test the significance of the cropping system effects using the MSTATC package[27]. When the cropping system effects were significant ($p < 0.05$), the means were separated using the least significant difference (LSD) method at the 5% probability level.

Results and discussion

Weather parameters

The agronomic performance of crops, especially under rain-fed conditions, is largely affected by prevailing weather conditions and water is the major limiting growth resource[28]. The rainfall distribution was more favourable in 2019 (693.1 mm) than in 2020

(493.3 mm) as shown in Table 3. The mean long-term (35 years) average of 632.8 m only compared favourably with the 2019 rainfall and the recommended water requirement of 700–1,300 mm for good cotton crops[29]. The number of rainy days recorded in 2019 and 2020 late cropping seasons were 53 and 32 d, respectively (Table 3). Water has been reported to be critical to cotton seed and lint yield[30]. Moisture is most critical for cotton from the square (flower bud) stage to the first bloom and first boll opening stages. During this critical period, cotton vegetation growth is rapid, and the number of potential fruiting sites is high[29]. In our study, the critical period occurred approximately 45 d after sowing (DAS), and the cotton plants were able to escape the prolonged dry spell of August 2020, since sowing was done on July 24, 2020. The beginning of the critical period coincided with a wetter September (246.3 mm) in 2020 compared with 96.3 mm in 2019. Similarly, the mean monthly temperature ranges of 26.2–26.5 °C, in 2019 and 25.7–28.3 °C, in 2020 compared well with the recommended temperature range of 15–32 °C[7]. At higher temperatures, cotton plants are likely to experience inhibited photosynthesis[31] and at temperatures above 32 °C, boll growth decreases significantly and boll shedding can set in[32]. However, these high-temperature conditions were not experienced during flowering and boll formation in our study. Sunshine hours have been reported as an effective climatic factor during and preceding and succeeding periods of boll production[33]. In our study, sunshine hours recorded in 2019 (13.6 h) and 2020 (17.7 h) during the late cropping seasons were not limiting (Table 3). Figure 3 illustrates the coefficient of variation (CV) of rainfall patterns during Nigeria's primary growing season (June–September) for the last 30 years. Most states in Nigeria experienced CV beyond 10%, meaning there are uncertainties in the rainfall patterns. The decade 1991–2000 was remarkably volatile, with almost the entire country exhibiting CV in the range of 11% to 20% as indicated in the map. A higher CV indicates more erratic rainfall, while a lower CV reflects a more stable and consistent rainfall pattern within a given period. A location with a CV of 10% suggests that erratic rainfall occurs once every 10 years, and a CV of 20% implies that extremities and uncertainties in rainfall are experienced two out of every five years.

These rainfall uncertainties are particularly noticeable in the South-western region, during the 2001 to 2010 period and in the North-west and North-east regions during 2011 to 2020, where the CV exceeded 20%. The average number of wet and dry days per year for all Agro-Ecological Zones in Nigeria during the last three decades revealed that the Arid/Sahel (AS) and Semi-Arid (SA) zones in the north recorded significantly fewer wet days compared to dry days, making them suitable for growing short-duration crops like millet, cowpea, and sorghum. Conversely, the Humid Forest (HF) and derived Savanna (DS) zones in the south (which describes the ecology of our project site), have slightly more wet days than dry. This derived savanna region has consistently stable rainy days ranging from 127.5 to 129.1 d over the last four decades compared to other AEZs (Table 4). The derived Savannah zone should therefore be ideal for producing fibre crops like cotton.

The connection between adopting a crop rotation system involving sesame and soybean with organic fertilizer and establishing a near-real-time climate information service lies in enhancing the resilience and productivity of cotton production under changing weather conditions. Cotton grows best in rich soils and under optimum weather conditions. Access to virgin land in tropical Africa is a challenge, hence there is the need to effectively manage the land used for continuous production. Since crop rotation and organic fertilizer application improve soil health and reduce pest and disease pressures, it is logical to adopt the system for sustainable productivity. Meanwhile, the farmers also require clear guidance in the timing of farming operations, fertilizer application, and harvesting dates. Thus, allowing them to adapt more effectively to weather variability and reduce potential crop losses. A robust climate information service is required to provide timely information that can guide farmers decisions.

Table 3. Some weather parameters during the late cropping season (July–November) in 2019 and 2020.

Parameters	July		Aug		Sept		Oct		Nov		Total		Long term rainfall
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	35 years
Mean temperature (°C)	26.2	25.7	26.5	26.2	26.6	26.1	26.4	27.1	27.9	28.3	141.2	133.4	–
Total rainfall (mm)	108.7	109.5	65.8	2.9	96.3	246.31	310	127.6	112.3	7.0	693.1	493.3	632.8
Number of rainy days	11	8	8	1	10	11	19	11	5	1	53	32	–
Relative humidity (%)	87.4	82.5	83.4	80.0	85.7	79.0	84.0	71.8	86.9	69.1	427.4	382.4	–
Sunshine (h)	2.2	2.3	2.5	3.2	2.0	2.9	1.7	3.8	5.2	5.5	13.6	17.7	–

Source: Department of Agro Meteorology and Water Management, Federal University of Agriculture, Abeokuta, Nigeria.

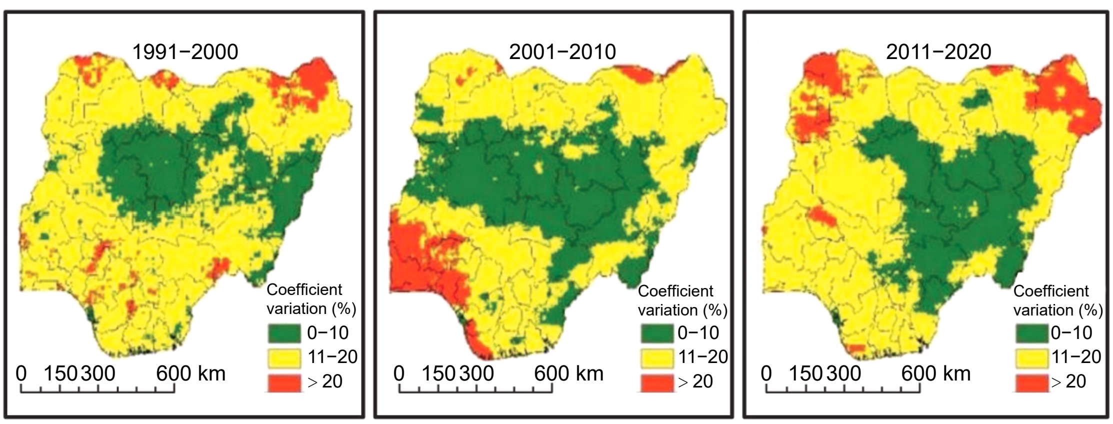

Fig. 3 The coefficient of variation of rainfall during the growing season in Nigeria for three decades.

Table 4. Mean annual rainy days (MAnRD) and Mean annual dry days (MAnDD) in the agroecological zones (AEZs) from 1991 to 2020.

AEZs	1991−2000		2001−2010		2011−2020	
	MAnRD	MAnDD	MAnRD	MAnDD	MAnRD	MAnDD
AS	56.2	309.1	56.9	308.3	58.6	306.7
SA	83.1	282.2	84.3	280.9	84.9	280.4
NGS	107.1	258.2	106.9	258.3	107.8	257.5
SGS	115.1	250.2	114.1	251.1	115.2	250.1
HA	184	181.3	177.7	187.5	181.6	183.7
MA	138.4	226.9	135.8	229.4	139.5	225.8
DS	127.5	237.8	127.8	237.4	129.1	236.2
HF	161	204.3	162.3	202.9	167.4	197.9

AS: Arid/Sahel; SA: Semi-Arid; NGS: Northern Guinea Savanna; SGS: Southern Guinea Savanna; HA: High Altitude; MA: Mid Altitude; DS: Derived Savanna; HF: Humid Forest; MAnDD: Mean Annual Dry Days; MAnRD: Mean Annual Rainy Days.

Cotton agronomic traits and seed cotton yield

Cotton plants tend to experience inhibited photosynthesis[33], boll growth decreases significantly, and boll shedding at high temperatures above 32 °C[34]. However, these high-temperature conditions in our study did not affect flowering or boll formation. Similarly, sunshine hours affect boll production[31]. In our study, sunshine hours recorded in 2019 (13.6 h) and 2020 (17.7 h) during the late cropping seasons were not limiting (Table 3).

At maturity in 2020, cotton plants under CS2, CS3, and CS5 were significantly taller than those from CS1 and CS4 (Table 5). This finding is similar to that of Kumbhar et al.[35], Rochester et al.[36], and Ndor et al.[37] that the plant height of cotton plants is related to nitrogen application. In both years, all the cotton plants grown under CS2, CS3, CS5, or CS4 produced more sympodia branches than the cotton under CS1. A similar trend was reported for cotton grown in legume rotation with nitrogen application[35]. The number of bolls per plant increased in response to the application of fertilizer (CS2, CS3, and CS5) and crop rotation (CS4) in 2019. Apparently, the applied fertilizers and nutrients from the preceding soybean in 2018 enhanced the production of fruiting bolls by the plants. Earlier reports have shown an increased number of bolls per plant following the application of nitrogen fertilizer and the incorporation of preceding legume crops[38] and cotton sown after soybean in a soybean, corn, and cotton rotation[18]. Similarly, Ndor et al.[37] reported a linear increase in the number of bolls per plant as the nitrogen application rate increased from 30 to 90 kg in the southern Guinea savannah in Nigeria.

In our study, CS3 and CS4 increased the seed cotton weight per plant in both years (Table 6). This could be attributed to the significant role played by nitrogen in enhancing the photosynthetic activity of the plants and the partitioning of photosynthates from the leaves to the seeds of cotton plants grown on CS2, CS3, and CS4. The slow release of nutrients by the organic fertilizer and crop residues incorporated into the soil could have contributed to the observed trend as suggested by Pettigrew et al.[18], Kumbhar et al.[35], and Olowe & Adejuyigbe[17]. The weight of the seeds per plant of cotton followed a trend similar to that of the seed cotton weight. Nitrogen is crucial to cotton seed yield[38−40] and the cropping systems that received organic fertilizer application significantly enhanced cotton seed yield relative to the CS1 and CS5 in both years. During the wetter year (2019), the seed cotton yield of cotton plants under CS2, CS3, and CS4 ranged between 631.9 and 677.8 kg/ha (Table 6). However, in 2020, the yield under similar cropping systems ranged between 541.8 and 784.8 kg/ha. These values are slightly lower than the Nigerian average of 842.8 kg/ha and less than the African average of 1,044 kg/ha and the global average of 2,137 kg/ha according to FAOSTAT[3]. The markedly high world seed cotton yield could be attributed to the inclusion of the yield of genetically modified organism (GMO) cotton (e.g. Bt cotton). A

Table 5. Effects of cropping system on plant height (cm) at maturity, number of synpodia, monopodia, and total branches of plant, and bolls per plant in 2019 and 2020.

Cropping system	2019					2020				
	PHTMAT (cm)	NSYPB per plant	NMONB	NTBR	NBOLLS	PHTMAT (cm)	NSYPB per plant	NMONB	NTBR	NBOLLS
CS1	86.1^{a}	11.4^{c}	1.1^{a}	12.5^{c}	13.6^{c}	54.8^{c}	12.6^{c}	0.4^{a}	13.0^{a}	9.1^{c}
CS2	109.6^{a}	14.7^{ab}	1.0^{a}	15.8^{b}	24.3^{a}	79.6^{ab}	15.7^{ab}	0.7^{a}	16.4^{a}	11.7^{bc}
CS3	109.1^{a}	14.3^{b}	1.5^{a}	15.8^{b}	24.2^{a}	85.9^{a}	15.6^{ab}	1.3^{a}	16.9^{a}	17.6^{a}
CS4	105.3^{a}	14.0^{b}	1.5^{a}	15.5^{b}	22.3^{ab}	67.0^{bc}	14.7^{b}	0.6^{a}	15.3^{a}	9.8^{c}
CS5	113.1^{a}	16.9^{a}	2.3^{a}	19.2^{a}	21.2^{b}	87.0^{a}	17.0^{a}	1.5^{a}	18.6^{a}	13.5^{b}
LSD 5%	ns	2.28	ns	2.26	2.26	16.90	1.98	ns	ns	2.90

CS1 - Continuous cropping (without organic fertilizer), CS2 - Continuous cropping (with organic fertilizer), CS3 - Rotation (with organic fertilizer), CS4 - Rotation (without organic fertilizer) and CS5 - Conventional system (60 kg N, 56 kg P_2O_5 and 60 kg K_2O, and herbicide), ns: not significant, LSD: least significant difference, PHTMAT: Plant height at maturity, NSYPB: Number of synpodia branches, NMONB: number of monopodia branches, NTBR: number of total branches, NBOLLS: Number of bolls. Means followed by the same alphabeths are not significantly different from each other based on the leaset significance difference test at 5% probability level.

Table 6. Effects of cropping system on seed cotton weight (g), weight of seeds (g), weight of lint (g), and seed cotton yield (kg/ha) in 2019 and 2020.

Cropping system	2019				2020			
	SCWT	WTSEEDS	WTLINT	SCYD	SCWT	WTSEEDS	WTLINT	SCYD
CS1	7.3^{a}	5.3^{b}	2.0^{a}	204.96^{b}	8.6^{b}	6.3^{c}	2.5^{c}	230.44^{c}
CS2	22.5^{a}	16.0^{a}	6.4^{a}	631.95^{a}	19.3^{a}	12.1^{b}	6.4^{b}	541.80^{b}
CS3	24.1^{a}	18.9^{a}	5.1^{a}	675.08^{a}	25.7^{a}	18.1^{a}	8.2^{ab}	692.16^{ab}
CS4	24.2^{a}	19.3^{a}	4.8^{a}	677.88^{a}	28.0^{a}	20.1^{a}	9.3^{a}	784.56^{a}
CS5	11.3^{a}	5.8^{b}	5.5^{a}	318.40^{b}	9.7^{b}	5.8^{c}	3.2^{c}	272.72^{c}
LSD 5%	4.35	3.75	ns	122.048	7.90	4.06	2.55	207.380

CS1 - Continuous cropping (without organic fertilizer), CS2 - Continuous cropping (with Organic fertilizer), CS3 - Rotation (with Organic fertilizer), CS4 - Rotation (without organic fertilizer) and CS5 - Conventional system (60 kg N, 56 kg P2O5 and 60 kg K2O, and herbicide), ns: not significant, LSD: least significant difference, SCWT: Seed cotton weight, WTSEEDS: Weight of seeds, WTLINT: Weight of lint, SCYD: Seed cotton yield. Means followed by the same alphabeths are not significantly different from each other based on the leaset significance difference test at 5% probability level.

seed yield of 3,395 kg/ha of Bt cotton was reported following the use of drip irrigation combined with bio-fertigation of a liquid formulation[11].

Conclusions

Compared with the continuous cropping system without fertilizer (CS1), the crop rotation system plus organic fertilizer application (CS3), crop rotation without organic fertilizer application (CS4), and continuous cropping with organic fertilizer application (CS2) increased the number of bolls per plant (24.3, 23.2, and 22.3), seed weight (16.0, 18.9, and 19.3 g) and greater seed yield (631.96, 675.08, and 677.88 kg/ha) than did cotton plants under CS1, respectively in 2019. A similar trend was recorded in 2020, except for the number of bolls per plant. With respect to climate variability, drought scenarios were recorded in the derived savanna region (study area) in both years with wet days ranging from 127.5 to 129.1 d over the last three decades. The late cropping seasons of 2019 and 2020 recorded 53 and 32 rainy days, respectively. It is therefore, recommended that cotton can be cultivated in rotation schemes involving soybean and sesame with (CS3) or without (CS4) the application of organic fertilizer and under continuous cropping with organic fertilizer application (CS2) for enhanced food security and soil sustainability in the forest–savanna transition zone of Nigeria. The cultivation of crops such as cotton on a commercial scale in this agroecological zone will require a robust near real-time climate information service to guide prospective farmers on when to grow cotton.

Author contributions

The authors confirm contribution to the paper as follows: study conceptualization: Olowe VIO; methodology, and supervision: Ijaodola OE, Olowe VIO; data curation: Ijaodola OE, Olowe VIO, Adejuyigbe CO; data analysis: Ijaodola OE, Oyedepo JA; formal analysis: Olowe VIO, Adejuyigbe CO; field experiment: Ijaodola OE; Enikuomehin OA; investigation: Odedina JN; draft manuscript preparation: Olowe VIO, Oyedepo JA; manuscript reviewing and editing: Olowe VIO, Enikuomehin OA, Adejuyigbe CO, Odedina JN. All authors reviewed the results and approved the final version of the manuscript.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conflict of interest

The authors declare that they have no conflict of interest.

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References

1. Connolly-Boutin L, Smit B. 2016. Climate change, food security, and livelihoods in sub-Saharan Africa. *Regional Environmental Change* 16:385−99
2. Malinga LN. 2021. *The importance and economic status of cotton production*. Academic letters. South African Sugarcane Research Institute, South Africa. Article 2314. doi: 10.20935/AL2317
3. Food and Agriculture Organization (FAOSTAT). 2024. *Corporate statistical database*. www.fao.org/faostat/en/#data/QC/visualize. (Accessed 26 July 2024)
4. Willer H, Schlatter B, Trávníček J. (eds) 2023. *The World of Organic Agriculture. Statistics and Emerging Trends 2023*. Research Institute of Organic Agriculture (FiBL), Frick, and IFOAM – Organics International, Bonn. Online Version 2 of February 23, 2023. www.organic-world.net/yearbook/yearbook-2023.html
5. Altenbuchner C, Vogel S, Larcher M. 2018. Social, economic and environmental impacts of organic cotton production on the livelihood of smallholder farmers in Odisha, India. *Renewable Agriculture and Food Systems* 33(4):373−85
6. Critchley W, Siegert K, Chapman C, Finket M. 1991. *Water harvesting: a manual for the design and construction of water harvesting schemes for plant production*. Food and Agriculture Organization of the United Nations (FAO), Rome. 15 pp
7. Delate K, Heller B, Shade J. 2021. Organic cotton production may alleviate the environmental impacts of intensive conventional cotton production. *Renewable Agriculture and Food Systems* 36(4):405−12
8. Dakhore KK, Kadam YE. 2018. Effect of weather parameters on crop growth, development and yield of kharif cotton varieties under extended sowing times. *International Journal of Current Microbiology and Applied Sciences* 7(12):3411−18
9. Dhavare SU, Khobragade AM, Kadam YE, Gaikwad JL. 2018. Correlation studies of weather parameters on cotton (*Gossypium* spp.) cultivers under varied weather condition. *Journal of Agriculture Research and Technology* 43(2):371−77
10. Wang HL, Gan YT, Wang RY, Niu JY, Zhao H, et al. 2008. Phenological trends in winter wheat and spring cotton in response to climate changes in northwest China. *Agricultural and Forest Meteorology* 148:1242−51
11. Jayakumar M, Surendran U, Manickasundaram P. 2014. Drip fertigation effects on yield, nutrient uptake and soil fertility of Bt Cotton in semi arid tropics. *International Journal of Plant Production* 8(3):375−90
12. Shah KK, Modi B, Pandey HP, Subedi A, Aryal G, et al. 2021. Diversified crop rotation: an approach for sustainable agriculture production. *Advances in Agriculture* 2021:8924087
13. Olowe VIO, Oyedepo JA. 2022. Crop rotation and use of early warning systems (EWS) in climate smart Organic Agriculture. *Proc. ISOFAR International Scientific Workshops at the 2nd International Organic Expo, Goesan, South Korea, 2022*. pp. 208−11
14. Adedeji O, Olusola A, James G, Shaba HA, Orimoloye IR, et al. 2020. Early warning systems development for agricultural drought assessment in Nigeria. *Environmental Monitoring and Assessment* 192:798
15. Nakalembe C, Becker-Reshef I, Bonifacio R, Hu G, Humber ML, et al. 2021. A review of satellite-based global agricultural monitoring systems available for Africa. *Global Food Security* 29:100543
16. Sharafi L, Zarafshani K, Keshavarz M, Azadi H, Van Passel S. 2021. Farmers' decision to use drought early warning system in developing countries. *Science of The Total Environment* 758:142761
17. Olowe VIO, Adejuyigbe C. 2020. Agronomic performance of soybean (*Glycine max* (L.) Merrill) and sunflower (*Helianthus annuus* L.) under crop rotation in the humid tropics. *Advances in Ecological and Environmental Research* 5(3):87−99

18. Pettigrew WT, Bruns HA, Reddy KN. 2016. Growth and agronomic performance of cotton when grown in rotation with soybean. *Journal of Cotton Science* 20:299−308
19. Bowles TM, Mooshammer M, Socolar Y, Calderón F, Cavigelli MA, et al. 2020. Long-term evidence shows that crop-rotation diversification increases agricultural resilience to adverse growing conditions in North America. *One Earth* 2:284−93
20. Ashworth AJ, Allen FL, Saxton AM, Tyler DD. 2016. Long-term cotton yield impacts from cropping rotations and biocovers under no-tillage. *Journal of Cotton Science* 20:95−102
21. Xi H, Shen J, Qu Z, Yang D, Liu S, et al. 2019. Effects of long-term cotton continuous cropping on soil microbiome. *Scientific Reports* 9:18297
22. Wang X, Zhang J, Xia S, Qin H, Feng C, et al. 2020. Effects of combined nitrogenous based inorganic fertilizers and two forms of organic fertilizers on plant phenotypic characteristics and soil bacterial community structure within a cotton field environment. *Polish Journal of Environmental Studies* 29(6):4397−408
23. Jacoby R, Peukert M, Succurro A, Koprivova A, Kopriva S. 2017. The role of soil microorganisms in plant mineral nutrition—current knowledge and future directions. *Frontiers in Plant Science* 8:1617
24. Institute for Agricultural Research (IAR). 2015. Recommended Cotton production practices in Nigeria by the Fibre Research Programme. Ahmadu bello University, Zaria, Nigeria. 8 pp
25. Asafo-Adeji B, Adekunle AA. 2001. *Characteristics of some released IITA soybean varieties and promising advanced breeding lines*. IITA Publication, Nigeria. 10 pp
26. Olowe VIO, Adeosun JA, Musa AA, 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* 5:119−27
27. Freed R, Einmensmith SP, Guetz S, Reicosky D, Smail VW, et al. 1989. *User's guide to MSTATC, an analysis of agronomic research experiments*. Michigan State University, East Lansing, MI
28. Gerik TJ, Faver KL, Thaxton PM, El-Zik KM. 1996. Late season water stress in cotton: I. plant growth, water use, and yield. *Crop Science* 36:914−21
29. Bauer P, Faircloth W, Rowland D, Ritchie G. 2012. Water-sensitivity of cotton growth stages. In *Cotton Irrigation Management for Humid Regions*, eds Perry C, Barnes E. Cary: Cotton Incorporated. pp. 17−20
30. Huang J, Ji F. 2015. Effects of climate change on phenological trends and seed cotton yields in oasis of arid regions. *International Journal of Biometeorology* 59:877−88
31. Schrader SM, Wise RR, Wacholtz WF, Ort DR, Sharkey TD. 2004. Thylakoid membrane responses to moderately high leaf temperature in Pima cotton. *Plant, Cell & Environment* 27:725−35
32. International Cotton Advisory Committee (ICAC). 2007. *Global warming and cotton production: Part 1*. DC, US: ICAC Press Release. https://staging.icac.org/cotton_info/publications/press/2007/pr_june_07.pdf
33. Sawan ZM. 2017. Cotton production and climatic factors: studying the nature of its relationship by different statistical methods. *Cogent Biology* 3:1292882
34. Huang J. 2016. Different sowing dates affected cotton yield and yield components. *International Journal of Plant Production* 10:63−83
35. Kumbhar AM, Buriro UA, Junejo S, Oad FC, Jamro GH, et al. 2008. Impact of different nitrogen levels on cotton growth, yield and N-uptake planted in legume rotation. *Pakistan Journal of Botany* 40(2):767−78
36. Rochester IJ, Peoples MB, Hulugalle NR, Gault R, Constable GA. 2017. Using legumes to enhance nitrogen fertility and improve soil condition in cotton cropping systems. *Field Crops Research* 70(1):27−41
37. Ndor E, Agbede OO, Dauda SN. 2010. Growth and yield response of cotton (*Gossypium* spp.) to varying levels of nitrogen and phosphorus fertilization in Southern Guinea Savanna Zone, Nigeria. *Production Agriculture and Technology* 6(2):119−25
38. Prakash R, Prasad M. 2000. Effect of nitrogen, chlormequat chloride and farmyard manure applied to cotton (*Gossypium hirsutum*) and their residual effect on succeeding wheat (*Triticum aestivum*) crop. *Indian Journal of Agronomy* 45(2):263−68
39. Pettigrew WT, Adamczyk JJ Jr. 2006. Nitrogen fertility and planting date effects on lint yield and Cry1Ac (Bt) endotoxin production. *Agronomy Journal* 98:691−97
40. Omadewu LI, Iren OB, Eneji AE. 2019. Yield of cotton cultivars as influenced by nitrogen rates and plant density in Yalingo, Nigeria. *World Scientific News* 127(3):106−22