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Diversification of maize-based intercropping systems in tropical rainforest agroecosystem of Nigeria: productivity, profitability and soil fertility

Anthony Oyeogbe[2*], Joshua Otoadese[1] and Bryan Ehanire[1]

[1]Department of Agronomy and Environmental Management, Benson Idahosa University, Benin-City, Nigeria.
[2]Department of Grassland and Fodder Science, University of Rostock, Rostock, Germany.

* Corresponding author: aoyeogbe@biu.edu.ng

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Smallholder farmers in Africa are in dire need of resilient maize-based cropping systems that can guarantee food, nutrition, and income security in the face of increasing armyworm infestations, erratic rainfall and drought occurrences. Thus, this study aims to identify adaptive maize-based systems with high productivity, increased profitability, and enhanced soil fertility for the tropical rainforest of Nigeria. We evaluated four maize-based systems, comprising of sole maize; maize/cowpea intercrop; maize/groundnut intercrop; and maize/sweet potato intercrop for higher productivity, profitability, and soil fertility. Results showed that the system productivity of maize/sweet potato intercrop (4.2 t ha^{-1}) was significantly higher (P = 0.05) than those of maize sole (2.6 t ha^{-1}); maize/cowpea (3.5 t ha^{-1}); and maize/groundnut (3.0 t ha^{-1}). Also, maize/sweet potato ($ 1081 ha^{-1}) significantly increased the net income in terms of monetary profits compared to those of maize sole ($ 557 ha^{-1}); maize/cowpea ($ 882 ha^{-1}); and maize/groundnut ($ 699 ha^{-1}). However, the net benefit-cost ratio of maize/sweet potato (2.47) and maize/cowpea (2.35) was similar. The effect of cowpea, when intercropped with maize, significantly increased the total nitrogen (N) content and available phosphorus (P) in soil by about 22% and 6-12%, respectively, compared to those of maize sole, and maize/sweet potato and maize/groundnut. Here, we conclude that the intercropping of maize with sweet potato and/or cowpea in this agroecosystem is an adaptive and resilient system, which is capable of meeting the food, nutrition, and income stability of farmers while maintaining the soil health. Crop diversification through intercropping can contribute to agroecological balance and maintenance of the soil ecosystem services.

1. Introduction

Maize (Zea mays L.) is an important staple crop that is grown under rainfed and irrigated systems in southern and northern Nigeria (Olaniyan & Lucas, 2004). About 80 % of the total maize production is consumed by humans and livestock, while 20 % is utilised for industrial processes such as ethanol and starch production (Onuk *et al.,* 2010). Many farmers in Africa grow maize as a sole crop during the cropping seasons; however, this mono-cropping practice is unsustainable as weather variability such as drought, flood, and pests and disease outbreaks can lead to crop failure and loss of income (FAO, 2014). In recent years, armyworm infestation is devastating millions of hectares of maize farms across Nigeria, Africa, and globally with a significant yield loss of up to 50-60 %. Furthermore, this is threatening the food security of more than 300 million people in Africa, coupled with a significant economic loss of up to $ 4.8 billion from maize production alone (FAO, 2017).

Increase in maize production in Nigeria is due to the expansion in area cultivation rather than an increase in yield (Ogundari *et al.,* 2006). However, crop diversification with the maize-based intercropping system can contribute to increased yield per unit area without increasing the land area while creating a more resilient production system. Also, diversification within cropping systems maximises the use of soil, water, and biological resources, and the benefits of on-farm nutrient cycling and pest and disease control (Kremen & Miles, 2012; Lin, 2011). The diversification of maize-based systems is crucial to improving food, nutrition, and livelihood security while providing insurance against climate uncertainties (Senger *et al.,* 2017). Research has shown that intercropping enhances productivity, profitability, resource use efficiency, and soil fertility by increasing land-use efficiency, improving soil fertility, ensuring economic stability and utilising on-farm available resources (Li *et al.,* 2020; Gong *et al.,* 2020; Altieri *et al.,* 2012).

Maize is suitable and adaptable for the intercropping system due to its wide inter-row spacing and erect growth habit, which allows for complementary benefits for the intercrops. Intercrops with different light distribution intensity and root systems can utilise resources more efficiently (Gong *et al.,* 2020; Prasad & Brook, 2005). The combined yields and profits from intercropping systems often exceed those of monocultures; thus, it is popular among farmers (Javanmard *et al.,* 2009). For example, maize intercropped with cowpea, soybean, potato, and groundnut showed a significant yield advantage compared to sole cropping in tropical agroecosystems (Begum *et al.,* 2016; Mucheru-Muna *et al.,* 2010; Chinaka & Obiefuna, 2000). Maize, when intercropped, is less susceptible to pests, diseases and weed infestations (Bilalis *et al.,* 2010). More importantly, the inclusion of legumes in intercropping systems plays an essential role in soil fertility restoration through biological nitrogen fixation (Sanginga, 2003; van Kessel *et al.,* 2000).

However, research on adaptive maize-based intercropping systems that are resilient to the changing climate is lacking. Thus, there is an urgent need for the identification of diversified cropping systems due to the devastating effects of army-worm invasion on maize yields. This study focuses on the productivity, profitability and soil fertility of maize-based intercropping systems in the rainforest of Nigeria. We hypothesis that intercropping of maize with either of cowpea, groundnut, and sweet potato would increase productivity, profitability, and soil fertility compared to maize sole cropping.

2. Materials and Methods

2.1. Site description and experimental design

The field experiment was conducted during the 2017-2018 rainy season in tropical rainforest in Nigeria. The soil is slightly acidic pH (4.4) and is classified as ultisol according to USDA soil taxonomy. Within 0-15 cm soil depth, the total nitrogen, available phosphorus and potassium, and organic carbon were 0.07 g kg^{-1}, 6.8 mg kg^{-1}, 0.2 mg kg^{-1}, 1.1%, respectively. The rainfall amount, average temperature and relative humidity recorded during the growing season were 1764 mm, 28 °C and 68 %, respectively. The field experiment layout was randomised design replicated four times with four treatments, namely: maize sole cropping, maize/cowpea, maize/groundnut, and maize/sweet potato intercropping. The experimental field was ploughed, and seeds of maize were sown manually at a spacing of 0.75 m × 0.25 m, while the intercrops of cowpea and groundnut were adjusted at 0.75 m × 0.15 m, and sweet potato at 0.75 m × 0.4 m.

2.2. Crop management practices

The seed rates for maize, groundnut (Arachis hypogea), and cowpea (Vigna unguiculata) were 20, 60, and 25 kg ha^{-1}, respectively, and sweet potato vine cuttings with 4-5 nodes of 30 cm long. Seeds of maize and groundnut and vines of sweet potato (Ipomea batata) were sown on the same day (May 20, 2018), while cowpea was sown 40 days after (June 30, 2018). Compound fertiliser of NPK (15:15:15) at the rate of 40:20:20 kg NPK ha^{-1} was applied, with half dose at sowing and the remaining half as top dressing 30 days after sowing. A pre-emergent herbicide (atrazine; 2 kg a.i ha^{-1}) was applied a day after maize sowing to reduce weed growth, and this was followed by manual weeding with a hand-hoe on day 30, 60, and 90. Economic yields of respective crops were harvested manually at the physiological maturity stage (i.e. cowpea pods: 70

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days, maize cobs: 98 days, groundnut pods: 101 days, and sweet potato tubers: 126 days).

2.3. Assessment of crop growth and yields

Plant height (cm) of maize in the different cropping systems were measured at harvest, including the yields components such as the number of maize cobs per grain and 1000 seeds weight. The system productivity in terms of the equivalent yield of maize was derived by converting the yields of the individual intercrop(s) based on the grain yield of maize and the market price using the formula (Begum *et al.,* 2016; Bandyopadhyay, 1984).

$$\text{System productivity (t ha}^{-1}\text{)} = \text{Maize grain yield} + \frac{\text{intercrop(s) yield} \times \text{price of intercrop(s)}}{\text{price of maize grain}}$$

2.4. Economic analysis of the cropping systems

The cost of cultivation in Naira (₦)/US dollar ($) per hectare for the cropping systems was computed from the fixed and variable costs incurred during the growing season(s). Gross return was derived from the economic yields of the respective cropping systems based on the local market price, while the net return was derived by deducting the cost of cultivation from the gross return. The net benefit-cost is the ratio of gross returns to the cost of cultivation, which describes the profit advantage of the individual cropping systems for the farmer.

2.5. Evaluation of soil nutrients/fertility

Soils from the different cropping systems were analysed for total N, available N, P, and organic carbon (OC). The soil samples collected from 0-15 cm depth were air-dried, crushed, and sieved through a 2 mm mesh for total N, available N and P, and 0.5 mm for OC. Total N (g kg^{-1}) in soil was analysed using the Kjeldahl digestion method, while soil available P and K (mg kg^{-1}) were estimated by Bray P and flame photometer methods, respectively. The soil organic carbon (%) was estimated using the wet oxidation method.

2.6. Statistical analysis

Collected data were subjected to analysis of variance (ANOVA) for the randomised complete block design using the SAS package 9.1. Only the datasets with complete treatments were analysed. Where treatment effects were significant at $P \leq 0.05$, least significant difference (LSD) tests were used to compare the means of each treatment combination.

3. Results

3.1. Growth, yields and system productivity

The growth (heights) of maize remained the same for the different cropping systems (Table 1), whereas the number of maize cobs and grain weights was significantly different ($P \leq 0.05$). Maize yields from the diversified systems were significantly different (Table 2). The grain yield of maize sole cropping system (2.60 t ha^{-1}) was significantly higher than those of maize/cowpea (2.26 t ha^{-1}), maize/groundnut (2.22 t ha^{-1}), and maize/sweet potato (2.39 t ha^{-1}). The yields of the intercrops are as follows: sweet potato tuber yield (2.34 t ha^{-1}); cowpea pod (1.01 t ha^{-1}); and groundnut pod (0.85 t ha^{-1}). The system productivity in terms of maize equivalent yield was significantly higher in the maize/sweet potato (4.19 t ha^{-1}) compared to those of cowpea (3.50 t ha^{-1}), groundnut (3.00 t ha^{-1}), and the sole cropping (2.60) (Fig. 1).

3.2. Economics and profitability

Economics of the diversified cropping systems were significantly different ($P \leq 0.05$). The cost of cultivation decreased significantly in the maize sole cropping than those of the intercrops, whereas the gross revenue and net profits under the intercropping systems increased significantly compared to that of sole cropping (Table 3). Within the intercropping systems, the income generated from maize/sweet potato was significantly higher than those of maize/cowpea and maize/groundnut. However, the benefit-cost ratio was comparable between the intercropping systems but significantly higher than that of maize sole cropping.

3.3. Soil nutrients/fertility

Soil nutrients availability was significantly different ($P \leq 0.05$) among the diversified cropping systems (Table 4). The total N and available P in soil were slightly higher under maize/cowpea compared to those of maize sole, maize/sweet potato, maize/groundnut. In contrast, the available K and organic carbon remained the same.

Table 1. Yield components of the different cropping systems

Cropping systems	Plant height at harvest (cm)	Number of grains cob^{-1}	1000-grain weight (g)
Maize sole	194.00a	321.10a	179.52a
Maize/cowpea	191.30a	298.25bc	164.70b
Maize/groundnut	189.70a	288.58c	163.55b
Maize/sweet potato	191.00a	304.99b	173.12ab
LSD (0.05)	ns	13.25	10.19

Means with a different letter in the same column under respective cropping systems are significantly different based on LSD ($P \leq 0.05$).

Table 2. Economic and biological yields of the cropping systems

Cropping systems	Maize yields		Intercrop yields	
	Grain	Straw	Pod/tuber	Straw
	(t ha^{-1})			
Maize sole	2.60a	2.19a	-	-
Maize/cowpea	2.26c	1.81b	1.01b	1.09a
Maize/groundnut	2.22c	1.80b	0.85b	1.05a
Maize/sweet potato	2.39b	2.05ab	2.34a	0.98a
LSD (0.05)	0.32	0.39	1.51	ns

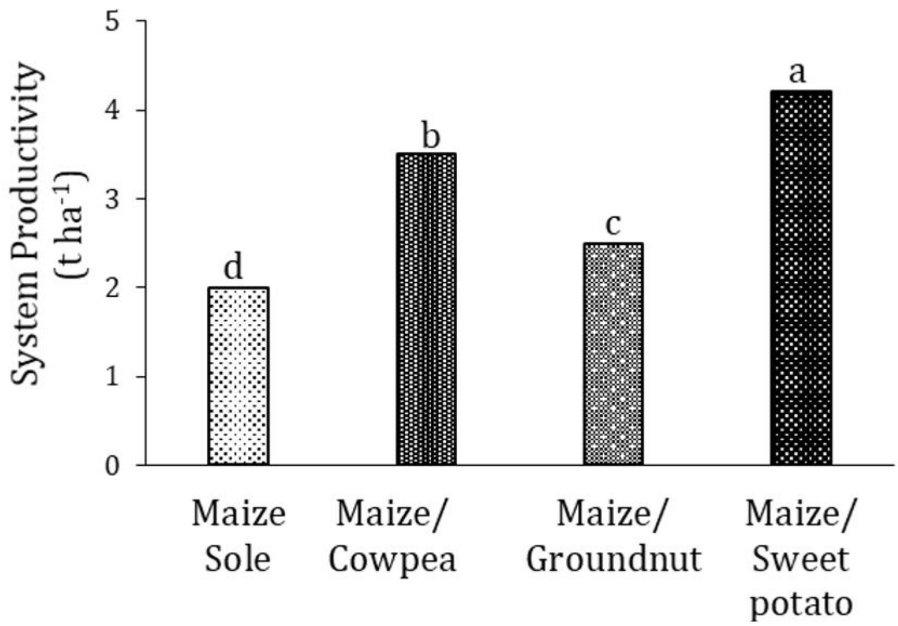

Figure 1. System productivity of the diversified cropping systems. Bars with a different letter under respective cropping system is significantly different based on LSD ($P \leq 0.05$).

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Table 3. Economics of the cropping systems

Cropping systems	Cost of cultivation	Gross returns	Net returns	Benefit:cost
	₦ ha^{-1} ($*)			
Maize sole	170940 (570)	338000 (1127)	167060 (557)	1.98
Maize/cowpea	190940 (636)	455400 (1518)	264460 (882)	2.39
Maize/groundnut	180940 (603)	390600 (1302)	209600 (699)	2.16
Maize/sweet potato	220400 (735)	544700 (1816)	324300 (1081)	2.47

Market price (₦ kg^{-1}): cowpea (₦160 kg^{-1}); groundnut (₦ 120 kg^{-1}); sweet potato (₦ 150 kg^{-1}). *(1 USD = ₦ 300).

Table 4. Soil nutrients availability in the diversified cropping systems

Cropping systems	N (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	OC (%)
Maize sole	0.07b	7.01b	0.15a	1.06a
Maize/cowpea	0.09a	7.46a	0.15a	1.09a
Maize/groundnut	0.07b	6.92b	0.15a	1.05a
Maize/sweet potato	0.07b	6.60c	0.14a	1.02a
LSD (0.05)	0.002	0.003	ns	ns

Means with a different letter in the same column under respective cropping system is significantly different based on LSD ($P \leq 0.05$).

4. Discussion

Higher grain yields achieved in the maize sole cropping than those of the intercrops is a function of the growth resources (e.g. space, light, nutrients, moisture) available to maize sowed as sole cropping than when intercropped with cowpea, groundnut, and sweet potato. Moreover, the increase in maize yields when intercropped with sweet potato could be attributed to complementary effect in terms of compatibility with light, space, nutrients and water use efficiencies than those of cowpea and groundnut. Competition for growth resources is a major tradeoff in intercropping systems, and hence, selecting crops that differ in photosynthetic activity, growth habit, duration, and nutrients demand are a prerequisite for higher productivity (Gong *et al.,* 2020). Similar to our study, Begum et al. (2016) and Chinaka and Obiefuna, (2000) reported that the system productivity of maize/sweet potato intercrops often exceeds that of sole crops due to synergism that favours the growth and yields of both crops. In a maize/sweet potato intercropping system, Begum et al. (2016) and Ifenkwe and Odurukwe (1990) showed that potato yield is always higher when maize sowing is delayed (30-45 days) than when both crops are sowed simultaneously. This observation is a result of maize canopy shading, which can intercept the availability of light, and consequently negatively affect the productivity of the intercrops. Thus, fine-tuning the planting dates of the intercrops can reduce the competition for growth resources, and hence increase productivity.

Increase in the cost of cultivation of the maize/sweet potato than those of maize/cowpea and maize/groundnut is due to the expenses incurred from additional agronomic management practices for the sweet potato. The yields of sweet potato positively

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affected the income generated than those of cowpea and groundnut. A good indicator of a cropping system is the actual profit obtained, which represents the suitability of a cropping system. Mucheru-Muna et al. (2010) showed that the gross returns from maize/potato, maize/cowpea and maize/groundnut increased significantly than that of maize sole cropping. Thus, the higher net returns from the maize/sweet potato are reflective of the increased productivity of both crops under intercropping systems compared to those of cowpea and groundnut. Interestingly, the benefit-cost ratio of the diversified cropping systems was greater than one, which shows that they were profitable.

Increased availability of N and P under the maize/cowpea system is a function of biological N fixation by cowpea. Legumes supply N, which can contribute to soil fertility improvement in diversified cropping systems (Sanginga, 2003; van Kessel *et al.,* 2000). For instance, cowpea and groundnut can supply about 80 to 350 kg N ha^{-1} through biological N fixation process (Mobasser *et al.,* 2014). Moreover, P availability increased when cowpea was intercropped with maize compared to maize without cowpea (Pypers *et al.,* 2007). Thus, the inclusion of legumes in cropping systems diversification offers a safety net for yield stability through enhanced soil fertility, particularly in the sub-optimal condition of poor-resource smallholder farms across Africa (Sanginga, 2003). Therefore, the choice of cropping systems that can withstand climatic uncertainties and contribute to soil health should become a prerequisite for sustainable diversification of cropping systems (Wang *et al.,* 2010).

5. Conclusion

Crop diversification through intercropping can contribute to yield stability, food security, and income security under the changing climatic conditions. Maize/sweet potato intercrop resulted in higher productivity and profitability, which is reflective of the synergism of both crops in utilising resources (space, light, water and nutrients) more efficiently than those of cowpea and groundnut intercrops. Moreover, increased soil availability of N and P under maize/cowpea and the comparable net benefit-cost with maize/sweet potato demonstrate the positive effects of legumes in the cropping system diversification. The inclusion of a nutrient-enriching crop such as cowpea can contribute to soil fertility improvement while ensuring ecological balance. More importantly, diversification of maize-based systems through intercropping is a sustainable and adaptive approach for food, nutrition, and income security. Therefore, the development of adaptive intercropping systems tailored to farm typologies could contribute to sustainable intensification of crop production from resource-poor smallholder farmers across Africa.

Conflict of interest

The authors declare no conflict of interest. Besides, the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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