American Journal of Agricultural and Biological Sciences

Original Research Paper

Agronomic and Economic Parameter Estimates of Cocoyam as Influenced by Fertilizer and Environment

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Article history
Received: 27-08-2022
Revised: 11-10-2022
Accepted: 12-10-2022

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Abstract: The effects of fertilizer and environment on agronomic traits and economic parameters in cocoyam were assessed at the Njala Agricultural Research Centre experimental site during the 2014/2015 and 2015/2016 cropping seasons. The fertilizer types used were 200 kg ha^{-1} NPK 15-15-15, 2000 kg ha^{-1} Rabbit Manure (RM), and no fertilizer (control). The trial was established in the open field and mango tree forest environments using a randomized complete block design. Findings revealed that fertilizer and environment significantly ($p<0.05$) affected cocoyam leaf area, plant span, plant height, disease severity, cormel and corm yields, dry matter contents in leaf, petiole, corm, cormel and root organs, and economic parameters. Application of 2000 kg ha^{-1} RM (6.75 t ha^{-1}) and 200 kg ha^{-1} NPK (5.65 t ha^{-1}) had significantly ($p<0.05$) highest cormel produced in the forest environment comprising 60% forest cover than those grown in the open field. Fertilizer application and environment significantly ($p\leq0.05$) affected the Partial Factor Productivity (PFP) and Agronomic Efficiency (AE) of cocoyam corm and cormel. The PFP and AE values were higher for cormels and corms produced in the open field and forest environments using 200 kg ha^{-1} NPK 15-15-15 than those obtained using the 2000 kg ha^{-1} RM. The significant influence of fertilizer and environment on traits suggests that increasing yields and maximizing profits require the use of appropriate production environments, fertilizers, and improved farming practices that could be exploited for increased productivity of cocoyam.

Keywords: Agronomic Traits, Economic Traits, Cocoyam, Fertilizer, Environment

Introduction

Cocoyam belongs to the Araceae family and ranks as the third most important root and tuber crop cultivated and consumed in the African continent, after cassava and yam. The crop consists of several genera and species, of which, the two most widely cultivated genera and species in Africa are *Colocasia esculenta* and *Xanthosoma sagittifolium* (Prince *et al*., 2015). The total global production of cocoyam was estimated at 10.54 million tons in 2019 (FAOSTAT, 2021). In Africa, the total production and yield of cocoyam on smallholder production systems were estimated at 7619 t and 4.34 t ha^{-1}, respectively, obtained on 1756 ha (FAOSTAT, 2021). These values are lowest compared to the averages reported for America, Asia and Oceania. In the tropics and subtropics, the average daily consumption of the crop is estimated at 0.5-1.0 kg (Dapaah, 2009; Asante *et al*., 2017). In sub-Saharan Africa, cocoyam leaves are utilized as pig feed (Rodrıguez *et al*., 2006), poultry feed, vegetables, or potherb (Osei and Mintah, 2003). The petioles are more useful as feed for pregnant sows due to their ability to deal with large and wieldy feeds (Rodrıguez *et al*., 2006). Young cocoyam leaves and petioles are rich in calcium, phosphorus, iron, vitamin C, thiamine, riboflavin, and niacin, with about 23% protein based on a dry weight estimate (Ndon *et al*., 2003; Asante *et al*., 2017). The crop is nutritionally superior to cassava and yam, with more readily digested starch and higher protein, mineral, and vitamin contents (Odebunmi *et al*., 2007).

Cocoyam is a shade-tolerant crop that is usually cultivated within stands of plantation trees such as oil palm, coconut, and cocoa (Asante *et al*., 2017). Cocoyam possesses the merit of utilizing low light intensity passing through leaf canopies of tree crops (Asante *et al*., 2017). Cocoyam plants are grown under shade often results in larger and thinner leaf production (Onwueme and Johnston, 2000). The yields of *Xanthosoma sagittifolium* cormels noted in an intercropping of oil palm (*Elaeis guineensis*) with cocoyam during the fifth and sixth years after the establishment of the oil palm were 11.30 t ha^{-1} and 7.5 t ha^{-1} for the shade and open field environments, respectively (Asante *et al*., 2017). The good performance of *X. sagittifolium* in the shade environment suggests its tolerance ability in tree crop shade during the early stages of the establishment (Asante *et al*., 2017).

Despite its importance, there is a lack of knowledge on the influence of fertilizer and the environment on economic parameter estimates (the Partial Factor Productivity (PFP), Agronomic Efficiency (AE), Marginal Returns (MR), Value Cost Ratio (VCR) in cocoyam. Moreover, there is a dearth of knowledge on the severity of disease attacks and other key physiological and agronomic traits of the crop under diverse environments and fertilization. This is partly due to research neglect of cocoyam in many regions of the world including Sierra Leone (Prince *et al*., 2015). The dearth of knowledge also indicates the need to investigate the untapped potential within underutilized crops including cocoyam (Akwee *et al*., 2015).

The yield and quality traits of cocoyam are threatened by various abiotic and biotic factors. The most important foliar diseases causing economic damage to the yield and quality traits of the crop include cocoyam leaf spot (Bandyopadhyay *et al*., 2011; Zarafi *et al*., 2012), bacterial leaf blight (Singh *et al*., 2012; Opara *et al*., 2013) and Dasheen mosaic virus (DsMV). Bacterial leaf blight was first detected as an important cocoyam foliar disease in Nigeria (Opara *et al*., 2013). The causal agent of this disease is known as *Xanthomonas axonopodis* pv. dieffenbachiae. Dasheen Mosaic Virus (DsMV) first reported from Dasheen (*Colocasia esculenta* (L) Schott) (Zettler *et al*., 1970), is an aphid-transmitted potyvirus, which infects a wide variety of cultivated aroids and ornamental plants worldwide. This disease causes serious damage to the ornamentals such as Caladium, Dieffenbachia, and Zantedeschia and is also present in tropical root crops belonging to the genera Colocasia, Xanthosoma, and Amorphophallus (Brunt *et al*., 1996).

Knowledge of efficient fertilizer use in a production environment is key to increasing crop yields with corresponding economic returns. Efficient fertilizer use refers to the maximum returns per unit of fertilizer applied (Mortvedt *et al*., 1999). The judicious use of appropriate fertilizers is a key factor in the root and tuber crops-based system for sustainable agriculture. The selection of type and amount of fertilizer utilized by smallholder farmers depends on the price, with the least costly fertilizer per kilogram of plant food usually selected over the expensive ones. Moreover, most smallholder cocoyam farmers in Sub-Saharan Africa including Sierra Leone grow the crop with little or no chemical fertilization. These farmers mostly depend on the inherent fertility of the soil and sometimes apply compost or farm yard manure in the planting holes (Lebot, 2009).

Farmers are profit-oriented, with more interest in the net returns than the gross returns. However, the largest net returns may not always be achieved because of the generally high costs of production and other risks associated with farming (Saleem, 1986). Maximization of profitability is dependent upon the reduction of the use of N per unit area and lowering costs per unit crop production through higher yields. This depicts the relevance of the economic analysis for robust decisions and recommendations from agronomic experiments for farmers. The adoption of inefficient nutrient management practices results in low Partial Factor Productivity (PFP) and Agronomic Efficiency (AE). The PFP and AE are useful measures of nutrient use efficiency as they provide an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system (Yadav, 2003). The decline in the PFP for nitrogen is probably due to nutrient imbalance, the decline in indigenous soil nitrogen supply, subsoil compaction, reduced root volume, and increased incidence of pests and diseases (Kareem and Ramasamy, 2000). Accordingly, Cassman *et al.* (1996) opined that increasing partial factor productivity is contingent upon increasing the amount, uptake, and utilization of indigenous nutrients and increasing the efficiency with which applied nutrients are taken up by the crop and utilized to increase yield. The present study provides vital information that contributes to the formulation of guidelines for a cocoyam production environment, disease (bacterial leaf blight, leaf spot, and DsMV), and soil fertility management decisions.

The research questions that prompted the present study included the following: (i) Are the effects of fertilizer and environment on selected agronomic traits in cocoyam (*Xanthosoma sagittifolium* L.) significant? and (ii) are the effects of fertilizer and environment on the economic parameter estimates in cocoyam significant? Thus, the objectives of this study were to: (i) Assess the effects of fertilizer and environment on selected agronomic traits in cocoyam (*X. sagittifolium* L.), and (ii) determine the effects of fertilizer and environment on the economic parameter estimates in cocoyam (*X. sagittifolium* L.) using two different types of fertilizers and contrasting environments.

Materials and Methods

Experimental Sites

The research was done in an open field and forest environment of the Njala Agricultural Research Centre (NARC) trial site, Njala, Southern Sierra Leone, during the May 2014/2015 and 2015/2016 cropping seasons. The geographical positioning system of Njala shows an elevation of 54 m above sea level at 8°06′N latitude and 12°06′W longitude. The climatic attributes of the trial are annual rainfall ranging between 2000 mm and 2900 mm and mean monthly air temperature ranging from 21-28°C during the rainy season. During the months of December, January, and February the average monthly minimum temperatures range from 14-20°C, whereas, the minimum temperature values range from 20-23°C for the remaining months of the year. Moreover, during the rainy season, relative humidity ranges from 95-100% with the sunshine of 6-8 h day^{-1}.

Soil and Rabbit Manure Sample Collections and Analyses

Soil and Rabbit Manure (RM) samples were randomly collected and prepared for analyses using the procedure described by Kroma *et al*. (2016). The collected and processed samples were analyzed using established laboratory techniques (ISRIC/FAO, 2002). The pH was determined on 1:1 soil/RM: Water extracts. The soil organic/RM carbon was determined by titration using the Walkley-Black procedure, while total nitrogen was done according to the Kjeldahl distillation (Kjeldahl, 1883) method. The available Phosphorus (P) was measured using the Bray 1 procedure while potassium (K), calcium (Ca), and Magnesium (Mg) were determined on neutral 1 N ammonium acetate extracts. Exchangeable K and sodium (Na) were read on a Flame Photometer, while exchangeable Ca and Mg were determined by titration. The exchangeable acidity (Al + H) was done by extraction and titration with 1 m KCl and 0.025 m NaOH, respectively. The Cation Exchange Capacity (CEC) was estimated as the summation of exchangeable cations and exchangeable acidity. The chemical compositions of the soil and rabbit manure (Estefan *et al*., 2013; Table 1) reveal that the rabbit manure had the highest nutrient whereas the open field soil had the lowest.

Planting Material, Treatments, Design, and Trial Management

A popularly grown red cocoyam variety was used as the experimental planting material. Three fertilizer types (200 kg ha^{-1} NPK 15-15-15, 2000 kg ha^{-1} rabbit manure, and 0 kg ha^{-1} control) were used in two contrasting environments (open field and forest/shade). Before planting, the open field and forest environments, the experimental areas were prepared and mounds constructed. The trial consisted of three replications laid out in a Randomized Complete Block Design (RCBD). The rabbit manure was applied in the planting holes created on the crest of the mounds and well incorporated in the soil using a hand trowel a week before planting. The cocoyam materials were planted at 1 m × 1 m spatial arrangement to give a population of 10,000 plants ha^{-1}. In both environments, three critical weeding at one, three, and five Months After Planting (MAP) was done manually using hand.

Data Collection

Fourteen agronomic parameters including growth, disease, yield, and related quality traits were collected in this study. Before the commencement of the growth parameter collection, five plants were randomly selected and tagged in each plot. Data collected included shoot traits ((leaf area (cm^2), plant span (cm), plant height (cm), leaf chlorophyll content); diseases ((Bacterial Leaf Blight (BLB), Cocoyam Leaf Spot (CLS) and dasheen mosaic virus (DsMV)); yield and related traits (fresh yields of corms and cormels, dry matter contents of the leaves, petioles, roots, corms, and cormels). The shoot and disease traits were sampled at 5 MAP. The cocoyam leaf area was determined based on the nondestructive technique by Stoppani *et al.* (2003). The leaf area was estimated based on the procedure described by Agueguia (1993).

LA = 0.75 × L × B, where LA is the leaf area, L is the length and B is the largest width of the leaf. The leaf chlorophyll content was measured on 5 completely opened leaves as described by Markwell *et al*. (1995) using a SPAD-index meter (SPAD-502, Konica Minolta, Osaka, Japan). The diseases were collected using a 1-5 scale where 1 = no visible symptom, 2 = mild, 3 = low, 4 = medium and 5 = high. The dry matter contents in cocoyam leaf, petiole, corm, cormel, and root organs were only collected during the 2015/2016 cropping season and determined using the oven dry method at 8 MAP (AOAC, 1990).

Table 1: Chemical properties of soil (open field and shade) and rabbit manure samples from the trial sites at 0– 20 cm

Soil characteristics	Open field	Shade	Rabbit manure
pH	4.51	6.44	5.57
Carbon (g kg^{-1})	5.73	7.16	38.48
CEC (dS m^{-1})	2.10	16.50	19.60
Nitrogen (g kg^{-1})	0.14	0.17	0.92
Phosphorus (mg kg^{-1})	5.24	6.91	13.48
Sodium (cmol+ kg^{-1})	0.03	0.03	0.14
Potassium (cmol+ kg^{-1})	0.07	0.08	0.31
Calcium (cmol+ kg^{-1})	0.11	0.18	0.42
Magnesium (cmol+ kg^{-1})	0.06	0.09	0.26
Exchangeable Acidity (cmol+ kg^{-1})	5.20	2.00	4.00
Exchangeable Aluminium (cmol+ kg^{-1})	2.00	2.00	1.20

Statistical Analysis

The data collected were analyzed using the analysis of variance of the GENSTAT statistical package and differences between treatment means were compared using the Least Significant Difference (LSD) at a significance level of $\alpha = 0.05$.

The Partial Factor Productivity (the ratio of the grain yield to the applied rate of fertilizer) and Agronomic Efficiency (the ratio of the increase in grain yield over fertilizer-control plots to the applied rate of fertilizer) were determined according to the procedures described by Yadav (2003). The Net Returns (the value of the increased yield produced as a result of N-fertilizers applied, less the cost of N) and Value-Cost Ratio (the ratio between the value of the additional crop yield and the cost of N) were estimated using the procedures described by Saleem (1986); Bhatti (2006). The Marginal Return (the ratio of net return to the cost of N) was determined following the procedure by Yadav (2003).

Results

Effect of Environment and Fertilizer Treatment on Cocoyam Shoot and Disease Severity Traits

The effects of environment and fertilizer treatment on shoot and disease traits of cocoyam are presented in Table 2. Generally, both environment and fertilizer treatments significantly affected ($p<0.05$) cocoyam leaf area production, plant height, and disease traits (bacterial leaf blight severity, cocoyam leaf spot severity, and dasheen mosaic virus severity), whereas leaf chlorophyll content and plant span had a non-significant environmental effect. Forested plots amended with 2000 kg ha^{-1} rabbit manure exhibited the largest leaf area (2138 cm^2), followed by those amended with 200 kg ha^{-1} NPK in the forest (1875 cm^2) and open field (1854 cm^2), whereas the non-amended plots in the open field environment exhibited the smallest leaf area of 1330 cm^2. In both environments, fertilizer-amended plots produced taller plants than the non-fertilized plots. The tallest plants (165.9 cm) were exhibited by plots amended with 200 kg ha^{-1} NPK, whereas the non-amended plots in the open field environment had the shortest plants with 89.5 cm. The highest leaf chlorophyll content was exhibited by plots amended with 2000 kg ha^{-1} rabbit manure in the open field environment, whereas the non-amended plots in the forest environment exhibited the lowest value of 52.0 (Table 2).

Generally, the disease severity scores ranged from mild to low. Both the environment and fertilizer treatments significantly ($p\leq0.05$) affected the disease severity of cocoyam sampled at 6 MAP. Cocoyam grown in the open field environment had higher severity scores for bacterial leaf blight, cocoyam leaf spot, and dasheen mosaic virus than those established in the forest environment (Table 2). The non-amended (0 kg ha^{-1}) plot in the open field environment had the highest bacterial leaf blight severity score of 2.5 (low), whereas application at 2000 kg ha^{-1} rabbit manure had the lowest score of 1.2 (mild). The cocoyam leaf spot attack was mild in both environment and fertilizer treatments. The attack of dasheen mosaic virus was low in plots amended with 200 kg ha^{-1} NPK (2.5) in the open field environment, whereas plots amended with 2000 kg ha^{-1} rabbit manure in the forest environment had the lowest value of 1.2 and was among plots with mild infection of the disease. These findings suggest that deforestation promote conditions for the rise and spread of pathogen that might affect the yield and quality of crops.

Effect of Environment and Fertilizer Treatment on Dry Matter Contents of Shoot and Tuber Traits of Cocoyam

The dry matter contents in cocoyam leaf, petiole, corm, cormel, and root organs were significantly ($p\leq0.05$) affected by the environment, fertilizer treatment, and interaction (Table 3). The forest environment produced higher leaf dry matter content compared to their corresponding open field environment. Application at 2000 kg ha^{-1} rabbit manure had the highest value of 27.33%, whereas the non-amended control plot had the lowest value of 14.67% leaf dry matter content in the forest and open field environments, respectively. The dry matter contents in cocoyam petiole, corm, cormel, and root organs were higher in the open field environment compared to their corresponding forest environment. Application at 2000 kg ha^{-1} rabbit manure had the highest value of 12.67%, whereas the 200 kg ha^{-1} NPK amended plots had the lowest value of 10.00% petiole dry matter content in the forest environment. The dry matter contents in cocoyam corm were higher than in the fertilizer-amended plots. At the 0 kg ha^{-1} application, the highest value of 49.33% corm dry matter content was produced compared to plots amended with 2000 kg ha^{-1} rabbit manure which had the lowest value of 23.00%. Application at 2000 kg ha^{-1} rabbit manure and 0 kg ha^{-1} exhibited the highest value of 48.00% cormel dry matter content in the open field, whereas the 200 kg ha^{-1} NPK amended plots had the lowest value of 38.00% cormel dry matter content in the forest environment. The dry matter contents in cocoyam roots were highest at 30.00% in the open environment amended with 200 kg ha^{-1} NPK, whereas, the lowest value of 15.33% was obtained in the forest environment amended with 2000 kg ha^{-1} rabbit manure. Do not use abbreviations in the title or headings unless they are unavoidable.

Effect of Environment and Fertilizer on Yield and Economic Parameter Estimates of Cocoyam

The effects of environment and fertilizer treatment on cormel and corm yields and economic parameter estimates of cocoyam are presented in Tables 4 and 5. The environment significantly affected ($p \leq 0.05$) cocoyam cormel production, whereas fertilizer treatments significantly affected ($p \leq 0.05$) cocoyam corm yield. The mean cocoyam cormel yield in the forest environment (6202 kg ha^{-1}) was significantly ($p \leq 0.05$) higher than their corresponding open field environment (3316 kg ha^{-1}). Conversely, the mean cocoyam corm yield in the open field environment (9711 kg ha^{-1}) was significantly ($p \leq 0.05$) higher than their corresponding forest environment (9574 kg ha^{-1}). Plots amended with 200 kg ha^{-1} NPK (10680 kg ha^{-1}) and 2000 kg ha^{-1} rabbit manure (9861 kg ha^{-1}) had the highest corn yields compared to the remaining treatments. Similarly, plots amended with 200 kg ha^{-1} NPK (5325 kg ha^{-1}) and 2000 kg ha^{-1} rabbit manure (5310 kg ha^{-1}) had the highest cormel yields compared to the remaining treatments. The environment and fertilizer effects on partial factor productivity and agronomic efficiency indicated that the mean values of these parameters were significantly affected ($p \leq 0.05$) by fertilizer, whereas net return, value cost ratio, and marginal return were affected by the environment (Table 4). Maximum partial factor productivity (52.1 kg corms kg-^{1} N), agronomic efficiency (13.2 kg corns kg^{-1} N and 8.0 kg cormels kg^{-1} N), value cost ratio (3.7) and marginal return (SLL 2.7 SLL^{-1} spent on N) were obtained in plots of cocoyam amended with 200 kg ha^{-1} NPK 15-15-15 in the open field environment (NPK_{E1}). However, the maximum partial factor productivity value of 25.5 kg cormels kg^{-1} N was obtained in plots of cocoyam amended with 200 kg ha^{-1} NPK 15-15-15 in the forest environment (NPK_{E2}).

Table 2: Impacts of environment and fertilizer on growth (leaf area, plant span, plant height,) and disease severity (bacterial leaf blight, cocoyam leaf spot, and dasheen mosaic virus) of cocoyam

Treatment	Leaf area (cm^2)	Plant span (cm)	Plant height (cm)	SPAD chlorophyll meter reading of leaf	Bacterial leaf blight severity score	Cocoyam leaf spot severity score	Dasheen mosaic virus severity score
Environment							
Open field	1612.0^{b}	184.3^{a}	126.0^{b}	54.27^{a}	2.2^{a}	1.9^{a}	2.2^{a}
Forest	1813.0^{a}	197.2^{a}	153.0^{a}	52.40^{a}	1.5^{b}	1.5^{b}	1.4^{b}
Fertilizer							
C_{E1}	1330.0^{b}	159.8^{c}	89.5^{c}	52.98^{b}	2.5^{a}	2.0^{a}	2.3^{a}
C_{E2}	1427.0^{b}	181.5^{b}	144.0^{ab}	52.00^{b}	1.3^{c}	1.2^{c}	1.3^{c}
NPK_{E1}	1854.0^{ab}	173.5^{bc}	130.7^{b}	53.43^{ab}	2.3^{a}	2.2^{a}	2.5^{a}
NPK_{E2}	1875.0^{ab}	187.6^{b}	165.9^{a}	53.03^{ab}	2.0^{b}	2.2^{a}	1.8^{b}
RM_{E1}	1653.0^{b}	219.7^{a}	157.8^{ab}	56.41^{a}	1.8^{b}	1.7^{b}	1.7^{b}
RM_{E2}	2138.0^{a}	222.5^{a}	149.1^{ab}	52.18^{b}	1.2^{c}	1.2^{c}	1.2^{c}
LSD_{E}	353.0	21.2	14.97	2.84	0.31	0.27	0.30
LSD_{F}	432.4	26.0	18.34	3.48	0.38	0.33	0.37
LSD_{EF}	611.5	36.8	25.93	4.92	0.54	0.47	0.52

Six fertilizer treatment combinations (C_{E1} and C_{E2} = control plots with 0 kg ha^{-1} or no fertilizer applied in the open field and forest environments, respectively; NPK_{E1} and NPK_{E2} = 200 kg ha^{-1} NPK 15-15-15 in both environments; RM_{E1} and RM_{E2} = 2000 kg ha^{-1} rabbit manure in both environments)

Table 3: Effect of environment and fertilizer on leaf dry matter content, petiole dry matter content, corm dry matter content, cormel dry matter content, and root dry matter content of cocoyam genotype

Treatment	Leaf dry matter content (%)	Petiole dry matter content (%)	Corm dry matter content (%)	Cormel dry matter content (%)	Root dry matter content (%)
Environment					
Open field	16.7^{b}	12.2^{a}	39.6^{a}	46.4^{a}	27.3^{a}
Forest	24.7^{a}	10.9^{b}	26.8^{b}	38.4^{b}	18.7^{b}
Fertilizer					
C_{E1}	18.7^{d}	11.3^{b}	42.9^{a}	44.0^{a}	19.7^{c}
C_{E2}	17.3^{d}	12.7^{a}	35.1^{b}	44.0^{a}	29.0a
NPK_{E1}	22.7^{b}	11.3^{b}	27.6^{c}	39.3^{c}	25.7^{ab}
NPK_{E2}	21.3^{bc}	10.7^{b}	35.1^{b}	42.0^{b}	19.7^{c}
RM_{E1}	20.7^{c}	12.0^{a}	28.9^{c}	44.0^{a}	23.7^{b}
RM_{E2}	23.3^{a}	11.3^{b}	29.4^{c}	41.3^{b}	20.3^{bc}
LSD_{E}	0.70	0.70	2.50	0.70	2.10
LSD_{F}	1.20	1.20	4.40	1.20	3.60
LSD_{EF}	1.15	1.09	1.72	1.08	3.37

Six fertilizer treatment combinations (C_{E1} and C_{E2} = control plots with 0 kg ha^{-1} or no fertilizer applied in the open field and forest environments, respectively; NPK_{E1} and NPK_{E2} = 200 kg ha^{-1} NPK 15-15-15 in both environments; RM_{E1} and RM_{E2} = 2000 kg ha^{-1} rabbit manure in both environments)

Table 4: Effect of environment and fertilizer on the economic parameter estimates of cocoyam genotype

Treatment	Corm yield (kg ha^{-1})	Cormel yield (kg ha^{-1})	Partial factor productivity (kg corm kg^{-1} N)	Partial factor productivity (kg cormel kg^{-1} N)	Increase in corm yield over control (kg ha^{-1})	Increase in cormel yield over control (kg ha^{-1})	Agronomic efficiency (kg corm kg^{-1} N)	Agronomic efficiency (kg cormel kg^{-1} N)
Environment								
Open field	9711.0a	3316.0b	29.0a	10.4a	1614.0a	927.0a	6.8a	3.8a
Forest	9574.0a	6202.0a	25.8a	15.8a	2600.0a	2235.0a	6.7a	4.9a
Fertilizer								
NPK$_{E1}$	10680.0a	5325.0a	52.1a	22.1a	3145.0a	2147.0a	13.2a	8.0a
NPK$_{E2}$	9424.0b	4208.0a	48.4a	25.5a	1889.0ab	1030.0a	12.0a	7.9a
RM$_{E1}$	8604.0b	4193.0a	2.7b	4.1b	1069.0b	1015.0a	0.2b	0.7b
RM$_{E2}$	9861.0b	5310.0a	6.5b	0.7b	2325.0ab	2132.0a	1.5b	0.9b
LSD$_{E}$	1260.2	1989.0	4.6	6.3	1365.3	1347.8	6.2	4.1
LSD$_{F}$	1782.2	2812.9	6.4	8.8	1930.8	1906.1	8.7	5.7

Six fertilizer treatment combinations (C$_{E1}$ and C$_{E2}$ = control plots with 0 kg ha^{-1} or no fertilizer applied in open field and forest environments, respectively were utilized for determination of the economic parameters; NPK$_{E1}$ and NPK$_{E2}$ = 200 kg ha^{-1} NPK 15-15-15 utilized per environment; RM$_{E1}$ and RM$_{E2}$ = 2000 kg ha^{-1} rabbit manure in both environments), 1 USD = SLL 13,000

Table 5: Effect of environment and fertilizer on the corm and cormel yield values and related economic parameter estimates of cocoyam genotype

Treatment	Corm yield Values (SLL ha^{-1})	Cormel yield values (SLL ha^{-1})	Increase in gross revenue over control (SLL ha^{-1})	Gross revenue (SLL ha^{-1})	Cost value (SLL ha^{-1})	Net return (SLL ha^{-1})	Value-cost ratio (SLL ha^{-1})	Marginal return (SLL ha^{-1})
Environment								
Open field	95744351^{a}	62023333^{a}	120217685^{b}	157767685^{a}	37550000	82667685^{a}	3.2^{a}	2.2^{a}
Forest	97105476^{a}	33158809^{b}	927142856^{a}	130264286^{b}	37550000	55164286^{b}	2.5^{a}	1.5^{a}
Fertilizer								
NPK$_{E1}$	93560833^{ab}	56513333^{ab}	116124167^{a}	150074167^{ab}	33950000	82174167^{a}	3.7^{a}	2.7^{a}
NPK$_{E2}$	107485476^{a}	38821905^{b}	112357381^{a}	146307381^{ab}	33950000	78407381^{a}	3.1^{ab}	2.1^{a}
RM$_{E1}$	97927870^{ab}	67533333^{a}	124311204^{a}	165461204^{a}	41150000	83161204^{a}	2.7^{abc}	1.7^{a}
RM$_{E2}$	86725476^{b}	27495714^{bc}	73071191^{b}	114221190^{b}	41150000	31921191^{b}	2.1^{bc}	1.1^{ab}
LSD$_{E}$	12601732.7	18668205	27306327	27306327	N^{a}	27306327	0.71	0.71
LSD$_{F}$	17821541.3	26400828	38616977	38616977	N^{a}	38616977	1.01	1.01

Six fertilizer treatment combinations (C$_{E1}$ and C$_{E2}$ = control plots with 0 kg ha^{-1} or no fertilizer applied in open field and forest environments, respectively were utilized for determination of the economic parameters; NPK$_{E1}$ and NPK$_{E2}$ = 200 kg ha^{-1} NPK 15-15-15 utilized per environment; RM$_{E1}$ and RM$_{E2}$ = 2000 kg ha^{-1} rabbit manure in both environments), 1 USD = SLL 13,000

The minimum mean values of partial factor productivity (2.7 kg corms kg^{-1} N and 0.7 kg cormels kg^{-1} N) and agronomic efficiency (0.2 kg corms kg^{-1} N and 0.7 kg cormels kg^{-1} N), were found in plots amended with 2000 kg ha^{-1} rabbit manure in the open field environment (RM$_{E1}$), whereas lowest values of net return (SLL 31921190.5 ha^{-1}), value cost ratio (2.1) and marginal return (SLL 1.1 SLL^{-1} spent on N) were found in plots applied with 2000 kg ha^{-1} rabbit manure in the forest environment (RM$_{E2}$). Application at 200 kg ha^{-1} NPK 15-15-15 exhibited higher partial factor productivity values of 22.1 and 25.5 kg cormel kg^{-1} N and agronomic efficiency values of 8.0 and 7.9 kg cormel kg^{-1} N, in the open field and forest environments, respectively, than the 2000 kg ha^{-1} rabbit manure amendment, which had the lowest values of 4.1 and 0.7 kg cormel kg^{-1} N partial factor productivity and 0.7 and 0.9 kg cormel kg^{-1} N agronomic efficiency, respectively, in the open field and forest environments. Similarly, application at 200 kg ha^{-1} NPK had higher corm partial factor productivity values of 52.1 and 48.4 kg corm kg^{-1} N and agronomic efficiency values of 13.2 and 12.0 kg corm kg^{-1} N, in the open field and forest environments, respectively, than the 2000 kg ha^{-1} rabbit manure amendment, which had the lowest values of 4.1 and 0.7 kg corm kg^{-1} N partial factor productivity and 0.2 and 1.5 kg corm kg^{-1} N agronomic efficiency values, respectively.

Discussion

Authors and Affiliations

The findings of the current study revealed the influence of shade, fertilizer, and the interaction between the two factors on growth, pest and disease severity, and yield of cocoyam as well as economic parameters. The leaf area of cocoyam is significantly influenced by shade, fertilizer, and interactions (Baker, 2008). In the present study, the cocoyam leaf area and plant span of plants under a forest environment with about 65% forest cover were larger compared to those established in the open field with full exposure to light intensity. These findings are consistent with the view of Asante *et al*. (2017) who reported that cocoyam plants grew under shade and accumulated higher nutrients and dry matter that culminate into longer petioles and larger leaves, leaf area, and plant span of the plants. The larger leaves and longer petioles merits of shade or forest-grown cocoyam plants cause them to occupy most of the available area, consequently culminating in a greater light interception and a higher rate of carbon assimilation (Baker, 2008). Assessment of the key growth traits including leaf area, plant span, and plant height is in concurrence with Asante *et al*. (2017), who obtained maximum leaf area at six MAP. Beyond six MAP, a redirection of photo-assimilates from leaves to the corm and cormels occurs.

The translocation of photo-assimilates and dry matter content from the foliage to the underground organs occurs during the third growth phase that begins at 7 MAP of cocoyam (Asante *et al*., 2017). Cultivation of cocoyam under a completely closed canopy with no or very little sunlight intensity for photosynthesis drastically contributes to cormel yield reduction (Asante *et al*., 2017). The suggestion of growing cocoyam in sparsely forested mango tree environments rather than the closed canopy environments as in closely spaced tree plantations is consistent with the report by Asante *et al*. (2017) that cocoyam (*X. sagittifolium*) tolerates tree crop shade during the early stages of establishment. In this study, cocoyam plants established in rabbit-amended plots in the open field with full exposure to sunlight produced larger leaf areas than the non-fertilized plot. This was partly due to the ability of organic matter in improving the water-holding capacity of the soil, thereby contributing to enhancing the crop nutrient uptake. Findings agree with the view of Baker (2008) who opined that water-use efficiency, stomatal conductance, and transpiration are higher in plants grown in the open field environment. Findings on leaf chlorophyll content of plants indicate its efficiency in manufacturing plants food needed for sustainable plant growth and subsequent development. The variation in the treatments sampled six months after planting could be explained by seasonal or environmental variation and biotic stresses such as infection by cocoyam diseases. These results are partly supported by earlier reports that the quantity of chlorophyll in plants depends on edaphic and climatic factors including interspecific variation among coexisting species (Li *et al*., 2018), light (Dai *et al*., 2009), soil fertility or fertilization (Zhang *et al*., 2021), water stress (Demirel *et al*., 2010), salt stress (Yıldırım *et al*., 2008), air pollution (Elkoca, 2003), sampling regime during vegetation growth (Zavoruev and Zavorueva, 2002), plant species and position of leaves (Gond *et al*., 1999). Moreover, the amount of chlorophyll in the leaf determines its rate of absorbance of available light needed for photosynthesis (Kamble *et al*., 2015).

The highest leaf dry matter content of 27.33% produced in cocoyam plants established in the forest environment implies the adaptability of the crop in a shaded environment. This agrees with early reports that cocoyam and taro are well adapted to forest growing conditions and the leaves of taro are notably larger and thinner than those established in a fully exposed sunlight environment (Pouliot *et al*., 2012; Onwueme and Johnston, 2000). Cocoyam being a C3 plant is well adapted to a shaded environment compared to other root and tuber crops. Shade-adapted plants usually have a low light compensation point, which makes them photosynthetically efficient in a forest environment, but exhibit less efficiency when exposed to higher light intensities (Valladares *et al*., 2016). It is also probable that water stress, nutrient availability, and high temperatures may hinder photosynthesis outside the crop canopy, resulting in the photoinhibition of cocoyam plants (Lott *et al*., 2009). These limitations could be minimized or removed by varying the fertilization and irrigation schemes in the new tree/crop interaction study. The variation in dry matter contents of the leaves is indicative of the variance in leaf area and plant span development in the two environments studied. These findings concur with Asante *et al*. (2017) who found that cocoyam grew under 50-70% shade exhibited more foliage dry matter and plant nutrients than sun-grown cocoyam plants. The higher dry matter content in cocoyam petioles in the open field environment is in agreement with Asante *et al*. (2017), who found higher dry matter content in petioles of cocoyam plants grown in sparsely shaded plots.

The higher dry matter contents in cocoyam corms and cormels from open field plots with full exposure to sunlight relative to their corresponding treatments in the forest environment imply that conditions favoring shoot organ growth and development of cocoyam may not necessarily translate into underground organ development (Du Thanh *et al*., 2014). These findings concurred with Asante *et al*. (2017), who investigated the effect of shade and level of fertilizer application on nutrient uptake and dry matter partitioning in cocoyam (*Xanthosoma sagittifolium* L.) and found that dry matter content in the cocoyam corms and cormels was significantly higher in plants grown under full exposure of sunlight than those grown under shade at the same rates of fertilizer amendments. The implications of these findings relate to the main focus of cultivating the cocoyam crop since both the leaves and cormels are consumed by various end-users.

Results on the yield and economic parameter estimates indicate that efficient utilization of fertilization for cocoyam production is important for increasing cocoyam corm and cormel yields and maximizing economic returns. The higher cormel yields in the mango tree forest environment relative to the open field environment could be attributed partly to the inherent higher soil fertility of the forest environment that supported both above and underground organ development and the shade tolerance ability of the crop. These findings are consistent with the 11.30 t ha^{-1} and 7.5 t ha^{-1} of *Xanthosoma sagittifolium* cormels obtained in an intercropping study of oil palm (*Elaeis guineensis*) with cocoyam assessed during the fifth and sixth years of establishment of the oil palm under shade and open field environments, respectively. In the present study, the good performance of cocoyam plants under the mango tree canopy implies that cocoyam plants are shade tolerant. This proposition supports the view that the good performance of *X. sagittifolium* under the canopy shade suggests that the cocoyam species tolerate tree crop shade during growth and development (Asante *et al*., 2017).

Inorganic fertilizer application in both open field and forest environments produced higher partial factor productivity and agronomic efficiency of cormels and corms than the organic amended plots. This variation is possibly attributable to the difference in the amount of nitrogen and other key nutrients in the fertilizers and N availability, which necessitate site-specific recommendations for improved and profitable nutrient management. These findings concur with Ahmad and Mahdi (2018) who suggested the relevance of site-specific recommendations for crops due to differential responses to various nutrient inputs across growing environments. Sanchez (2019) also opined that a good understanding of concepts of ideal soil fertility level and response to nutrient management provides practical guidelines for improving nutrient management under the increasing climate variability conditions of smallholder farmers. The increased growth traits (leaf area, plant span, and plant height) may have facilitated light interception resulting in a remarkable increase in corm yield amended with fertilizers and maximum benefits in terms of partial factor productivity and agronomic efficiency. These findings are consistent with Shah *et al*. (2008), who opined that improvement in leaf area index, crop growth rate, and light interception remarkably contribute to an increase in yield and related component traits of maize leading to maximum benefits in partial factor productivity and agronomic efficiency.

The application of a unit fertilizer (organic or inorganic) was economical since the value of the increase in the corm and cormel yields due to the quantity of fertilizer added is greater than the cost of fertilizer used. Findings agree with the view that if the application of a unit of fertilizer does not lead to a corresponding increase in economic yield that buffers the cost of production, this fertilizer application rate is uneconomical and unprofitable (Singh *et al*., 2012). Results are also consistent with Mariga *et al*. (2000); Gehl *et al*. (2005), who opined that the efficient utilization of nitrogen for maize production is important for grain yield enhancement, maximization of economic returns, and minimization of nitrate leaching to ground water. In the present study, treatments with a value-cost ratio of 2 depict a 100% return on the money invested in fertilizer input. This supports the view of Bhatti (2006) who noted that smallholder producers with low technology and limited capital should target a fertilizer rate exhibiting a VCR greater than 2.

Conclusion

This study demonstrates that increasing yields and maximizing profits require adequate use of production environment, fertilizers, and improved farming practices by farmers. Findings established a significant influence of fertilizer and environment on selected agronomic traits and economic parameter estimates in cocoyam that could be exploited for increased productivity of the crop in open-field monocropping and or tree crop intercropping systems with cocoyam.

Acknowledgment

The technical support of students of Njala University (NU), Sierra Leone, and Njala Agricultural Research Centre (NARC), Njala is duly acknowledged.

Funding Information

The financial support by the government of Sierra Leone is duly acknowledged.

Author's Contributions

Prince Emmanuel Norman and Yvonne Sylvia Gloria Ethel Norman: Conceived the experiment, performed the data analysis, and drafted the manuscript.

Jenneh Fatima Bebeley: Interpretation and discussion of results. All authors contributed to writing the article, and read and approved its submission.

Ethics

This article contains primary data and is a research paper. The corresponding author confirms that the other authors read and approved the manuscript and that no ethical issues were involved. Thus, the authors declare that they have no conflict of interest.

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