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THE INTEGRATED EFFECTS OF FERTILIZER ON SWEET POTATO (*Ipomea Batatas,* Lam.) IN ANDOSOL AND NITISOL SOILS

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ABSTRACT

Sweet potato is a food and nutrition security crop in sub-Saharan Africa with low yields resulting from soil infertility. We examined the effects of nine fertilizer regimes on the growth performance of orange-fleshed (OFSP) and white-fleshed (WFSP) sweet potato varieties in two agro-ecological zones characterized by Andosol and Nitisol soils. The treatments were: NPK20-10-10, NPK6-15-28, rice husk biochar (RHB), fast compost (FC), *Tithonia diversifolia* leaf powder, poultry litter (PL), RHB/NPK20-10-10, FC/NPK20-10-10 and PL/NPK20-10-10. These were compared to a control of no fertilizer. The Andosol and Nitisol soils were acidic with significant differences ($p < 0.05$) in total nitrogen, organic carbon, C/N ratio, phosphorus, potassium, calcium and magnesium. Fertilizer effects were dominant on the adventitious root, total and marketable yields, moderately affecting main stem length and harvest index (HI) with weak effects on branch number, petiole length and leaf area index (LAI). Soil type and sweet potato variety strongly affected main stem length and HI. Variety × fertilizer strongly influenced adventitious root formation, while soil × variety × fertilizer affected total and marketable yields. LAI, primary branch number, dry biomass, total and marketable yields were best for the OFSP in the Andosol, while main stem length, petiole length, adventitious roots and HI were best for the WFSP in the Nitisol. Results of the study showed that FC, PL/NPK20-10-10 and RHB/NPK20-10-10 were the most promising soil fertility amendments to boost sweet potato productivity in the Nitisols and Andosols.

Contribution/Originality: The use of organic fertilizers in sweet potato production is uncommon in the degraded soils of sub-Saharan Africa. This study used the agroecological options; fast compost, biochar and poultry litter to reduced mineral fertilizer dose by 50% leading to efficient sweet potato yields in Andosols and Nitisols.

1. INTRODUCTION

Agricultural production in West and Central Africa faces enormous constraints, as evidenced by low crop yields. These constraints include soil infertility, ecosystem degradation, climate change, pandemics and conflicts. The most prominent constraint responsible for low plant biomass and declining per capita food production in sub-Saharan Africa is soil infertility (Ngome, Becker, Mtei, & Mussgnug, 2011; Pay, Lucy, Dagmar, & Olufunke, 2001; Sanchez, 2002). Soil degradation from deforestation, erosion, overexploitation, inappropriate agricultural practices and climate change results in biodiversity extinction and essential nutrient depletion (Alley & Vanlauwe, 2009). Fertilizer application restores soil fertility, increases plant biomass and can sustain ecosystem services. Fertilizers increased nutrient availability and use efficiency in seed crops like wheat and rice during the Green Revolution (Pingali, 2012).

The use of fertilizers in vegetatively propagated crops like sweet potato (Ipomoea batatas, Lam.), yam (*Dioscorea* spp.) and cassava (*Manihot esculentus Crantz*) is uncommon. Yet, it is necessary to increase yields of such tubers to complement seed crops in order to meet food and nutrition demands for the ever-growing world population. In smallholder-owned production systems of sub-Saharan Africa, the fertilizer application rate is the lowest (8.3 kg/ha) in the world and most often directed to seed crops (Morris, Kelly, Kopicki, & Byerlee, 2007). There is a need to address fertilizer application in vegetatively propagated crops, like sweet potato to out-scale agricultural diversification and respond to food and nutrition insecurity. Sweet potato is an important crop for human and animal nutrition in Cameroon. Recent advances in breeding released the orange-fleshed sweet potato (OFSP) varieties distributed globally to address vitamin A deficiency and food insecurity (Neela & Fanta, 2019). A portion (100 g) of the OFSP can supply the daily needs of vitamin A in children (400 µg RAE (Retinol Activity Equivalents)). The OFSP is also under dissemination as a functional food in some parts of the world (Low et al., 2017).

Although sweet potato can grow in marginal soils, fertilization maximizes yields and improves quality in terms of physicochemical properties (Gichuhi, Kpomblekou-A, & Bovell-Benjamin, 2014). To our knowledge, limited studies have addressed the use of fertilizers to maximize and stabilize OFSP yield in sub-Saharan Africa.

Farmers use inorganic and organic fertilizers to enrich soils with essential elements like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), hydrogen (H), organic carbon (C), sulphur (S), zinc (Zn) and boron (B). Potassium is a limiting element for sweet potato nutrition (Byju & George, 2005; Du, Liu, Yin, Zhao, & Shi, 2021). Thus, potassium-rich fertilizers are suitable for sweet potato productivity (Norman, Pearson, & Searle, 1995). Different types of organic fertilizers exist in smallholder-owned production systems: biochar from crop residues, animal litter, and farmyard compost. However, the nutrient composition of organic manure is low due to the slow decomposition and release of essential nutrients for plant nutrition (Cobo, Barrios, Kass, & Thomas, 2002; Zanasi, Basile, Paoletti, Pugliese, & Rota, 2020). With the advocacy for a sustainable planet gaining prominence, a shift from high-input chemical-intensive farming to low-input ecological agriculture is preferred. Blending inorganic and organic fertilizers can reduce the negative impact of excessive chemicals contaminating soils and plant health, complement shortages from organic manure and increase biomass and yields more sustainably. Combining inorganic and organic fertilizers to meet crop requirements is uncommon in sub-Saharan Africa. This study investigates the effects of organic and inorganic fertilizer blends on the growth and yield performance of vitamin A-rich OFSP in two agro-ecologies of Cameroon, characterized by Andosol and Nitisol soils.

2. MATERIALS AND METHODS

2.1. Characteristics of the Experimental Sites

We conducted two field experiments during the cropping season of 2020 in two agro-ecological zones (AEZ) of Cameroon. The first experiment, from March 23 to July 31 was carried out at the Nkolbisson research center in reddish-brown clayey Nitisols. The second experiment, was conducted from July 2 to October 31 at the Njombé multipurpose station of the Institute of Agricultural Research for Development (IRAD) in dark volcanic Andosols.

The periods are the suitable sweet potato production season which are harvested once yearly in these AEZ. Njombé is in the humid forest zone with a monomodal rainfall pattern and is a sweet potato high-yielding ecology (Ngeve & Bouwkamp, 1993). Nkolbisson, is in the humid forest with a bimodal rainfall pattern, per the agro-ecological classification of agricultural production systems in Cameroon by IRAD and is a low-yielding ecological environment. Table 1 summarizes the geographical coordinates, the agro-ecological zones and the major soil types (Ngeve & Bouwkamp, 1993). Also, included in Table 1 is the soil identification of the two sites following the International Union of Soil Sciences Working Group (IUSS WG), World Reference Base for Soil Resources (WRB) classification (IUSS Working Group, 2015) and the meteorological data of the sites during the production period. The soil physicochemical properties for the Tombel facilitated the identification procedure (Billa, Angwafo, & Ngome, 2019). Tombel and Njombe are in the same agro-ecological zone.

Table 1. Brief description of the experimental sites and meteorology during the study period.

Item	Njombé	Nkolbisson
Location (GPS)	Latitude: N 9° 38′ 46.21″ Longitude: E 4° 34′ 51.17″	Latitude: N 3° 51′ 58.06″ Longitude: E 11° 27′ 49.23″
Agroecological zone (AEZ)	Humid forest with monomodal rainfall pattern	Humid forest with bimodal rainfall pattern
Soil*	Dark volcanic Andosol	Reddish-brown clayey Nitisol
Soil Group$^{\Psi}$	Dystric Vitric Andosols (humic)	Haplic/Rhodic Humic Nitisols
Altitude (meters above sea level)	80	750
Average annual rainfall (mm/year)	2250	545
Average daily rainfall (mm/day)	0–94	0–21
Minimum daily temperature (℃)	22–23	19–23
Average daily temperature (℃)	25–26	21–26
Maximum daily temperature (℃)	29–31	23–30
Minimum daily relative humidity (%)	61–73	72–76
Maximum daily relative humidity (%)	99.68–99.97	78–94

Source: * Ngeve and Bouwkamp (1993) $^{\Psi}$ (IUSS Working Group, 2015; Nguemezi, Tematio, Yemefack, Tsozue, & Silatsa, 2020).

2.2. Soil Sampling

The soil samples were collected with an auger at a depth of 0–20 cm (topsoil) before land preparation in ten different locations in a zigzag pattern. The samples were shade-dried, homogeneously bulked and 250 g enveloped for laboratory characterization.

2.3. Preparation of the Fertilizer Regimes

2.3.1. Fast Compost (FC)

To prepare the fast compost (FC), banana, plantain, sweet potato, cocoyam, cassava peelings, ripe banana, papaya, mango, pineapple skin, and discarded whole fruits were used. To these components was added farmyard waste gathered after clearing the experimental plot, cornhusk, corncobs, topsoil from under a mango tree, topsoil from a dustbin pit, and running tap water. The components decomposed for eight weeks, the fine dark compost with earthworms was packaged in bags, and a sub-sample was reserved for laboratory characterization.

2.3.2. Rice Husk Biochar (RHB)

The RHB was prepared by incomplete combustion in an Elsar barrel, designed to foster carbonization (Billa et al., 2019). After ten cycles of pyrolysis (feedstock of 5 kg, carbonized for 48 min at 450 °C per cycle), the produced biochar was bulked and a sub-sample (250 g) was enveloped for laboratory analysis.

2.3.3. Poultry Litter (PL)

Poultry litter was collected from a commercial poultry (*Gallus gallus domesticus*) firm, packed in bags and shade dried for 48 hours. After eliminating foreign matter, the litter was homogenized and 250 g reserved in labelled envelopes for laboratory analysis. The rest of the manure was stored in the shade until needed.

2.3.4. Tithonia Diversifolia Leaf Powder

Fresh leaves of wild sunflower plants were harvested from the bush, air-dried for two weeks with continuous mixing and crutched to powder. A subsample of 250 g was put in labelled envelopes for laboratory analysis and the rest packaged in plastic bags until needed.

2.3.5. Inorganic Fertilizers

The NPK20-10-10 and NPK6-15-28 mineral fertilizers were purchased and stored at ambient temperature until needed.

2.4. Characterization of the Soil, Compost, Biochar and Poultry Litter

The International Institute of Tropical Agriculture's (IITA) analytical laboratory service in Yaounde, Cameroon, characterized the soil, RHB, FC, PL and *Tithonia diversifolia* samples. The physicochemical properties analyzed were: pH, total nitrogen (N), organic carbon (C), available phosphorus (P), exchangeable potassium (K), calcium (Ca) and magnesium (Mg). The air-dried samples were ground to pass through a 2 mm sieve and sub-samples for organic C and N were further ground to pass through a 0.5 mm sieve. The pH was measured in a sample to water suspension ratio of 1:2.5 (w/v), using a digital electronic pH meter (Eutech Instruments Pte Ltd, PC 700, Waltham Massachusetts, USA). Organic C was determined by spectrophotometry following heated digestion in chromic acid (Heanes, 1984). The total nitrogen was determined from a wet acid digest (Buondonno, Rashad, & Coppola, 1995) and quantified by colorimetry (Anderson & Ingram, 1993). The macronutrients (Ca, K, Mg and P) were extracted using the Mehlich-III procedure (Mehlich & Mehlich, 1984). The exchangeable base cations (Ca^{2+}, Mg^{2+}, and K^+) were extracted in ammonium acetate and nitric acid while P was extracted with acetic acid and ammonium fluoride. The exchangeable K^+ was determined by flame atomic absorption spectrophotometry while Mg^{2+} and Ca^{2+} were determined by atomic absorption spectrophotometry (Anderson & Ingram, 1993). Available P was quantified using the molybdate blue procedure (Murphy & Riley, 1962).

2.5. Land Preparation, Experimental Setup and Monitoring

The experimental plot at the Njombé multipurpose station had been previously used for tomato trials and fallowed for five years while the site at the Nkolbisson center had been used for rice trials and fallowed for two years. The plot was cleared manually and all the wild plant biomass was swept and used to make the compost. The land preparation was done by manual ploughing, forming ridges of 0.5 × 2 × 4 m in depth, width and length. A completely randomized block design of 2 × 10 factorial in triplicates, with ten fertilizer amendments, split by sweet potato variety (two) was adopted for this experiment. There were 60 ridges separated by 1 m between units, covering 8 × 4 m for the three replicates per fertilizer regime. The two sweet potato varieties were a widely cultivated white-skin white-fleshed local variety (WFSP) used as the control and a vitamin A-rich purple-skin orange-fleshed variety (OFSP). The OFSP, referred to as NASPOT 9 O (VITA) is an early maturing variety that can potentially contribute to the management of vitamin A deficiency. Fresh sweet potato vines harvested and planted within 24 hours with 0.5 m spacing between lines and within rows. The long vines were reduced to 30 cm to give 5–6 nodes and planted at 45° with 3–4 nodes into the soil to optimize establishment. The ten treatments categorized into four groups were: (1) the control (no fertilizer), (2) mineral fertilizers (NPK20-10-10 and NPK6-15-28), (3) organic manure (rice husk biochar (RHB), fast compost (FC), *Tithonia diversifolia* leaf powder and poultry litter (PL)) and (4) blends of RHB/NPK20-10-10, FC/NPK20-10-10 and PL/NPK20-10-10. NPK20-10-10 is the most used fertilizer in the study zone and NPK6-15-28 is the compound formulation with a high proportion of potassium, an essential element for sweet potato growth (Byju & George, 2005; Du et al., 2021). At four weeks after planting (WaP) and following first weeding, NPK20-10-10 and NPK6-15-28 were incorporated into the soil at 200 kg/ha, organic at 6 t/ ha and the blends at half the initial rates (i.e., 100 kg/ha inorganic and 3 t/ ha organic fertilizers). The second (8 WaP) application rates were 100 kg/ha, 3 t/ha and 50 kg/ha + 1.5 t/ha for the inorganic, organic and blended amendments. The plot was freed of weeds manually at monthly intervals until harvest at 16 WaP.

2.6. Determination of Growth and Harvest Index Components

2.6.1. Leaf Area Index (LAI), Petiole Length, Main Stem Length and Branch Number

We used the LAI-2200 plant canopy analyser (LI-COR Inc., Lincoln, Nebraska) to measure LAI of each of the plots. This non-destructive method captures incoming light above and below the canopy to estimate LAI as the ratio of the single sided leaf area to the soil area. Petiole length for 10 mature leaves was measured from the point of attachment on the primary vine to the point of insertion of the leaf blade. The length of the main vine was measured for 10 plants per plot from the ground level to the tip using a string and a 500 cm meter rule. From the same 10 plants, the primary branch number was recorded.

2.6.2. Total and Marketable Yield

After harvest, the total number of storage roots from each demarcated area (2×3 m^2) were recorded. The storage roots were classified into small, medium and large on fresh weight basis as follows: small <100 g, 100 g < medium < 200 g and large > 200 g (Hartemink, 2003). In each category, the total weight was recorded and total yield calculated for each treatment per hectare using Equation 1.

$$\text{Yield } (t/ha) = \frac{\text{Total storage root weight}}{6\ \text{m}^2} \text{ x } \frac{10{,}000\ \text{m}^2}{1000} \qquad (1)$$

In the same way, the weight of medium plus big storage roots was used to calculate the marketable yield of each treatment per hectare.

2.6.3. Harvest Index (HI)

Biomass accumulation was evaluated at harvest. On a demarcated surface of 2×3 m^2, plants were carefully pulled out and the storage roots, adventitious roots, stems, petioles and leaves separated and the fresh weight noted differently. The stems were cut to an average of 4 cm and each of the components dried in a fan-assisted firewood oven at 80 ℃ to constant weight and the mass recorded. The above ground biomass consisted of stems, leaves and petioles while the underground biomass consisted of storage roots and adventitious roots. As such, the harvest index was the ratio of underground biomass to the above ground biomass on dry weight basis.

2.7. Statistical Analysis

Data analysis was performed in JMP® version 8 (SAS Institute Inc., Cary, NC.) with the growth and harvest index components as the response variables and soil and fertilizer types as the fixed or X factors. Least square means were used to generate bar charts for LAI and HI and the differences between the soils and sweet potatoes were determined using the Student's t-test for each pair. The differences in growth and HI index components across the fertilizer regimes were determined following the Tukey honestly significant difference (HSD) test for all pairs.

3. RESULTS

3.1. Physicochemical Properties of Soils, Poultry Litter, Tithonia Diversifolia, Rice Husk Biochar and Fast Compost

The soil and fertilizer regimes showed a high level of significant variation in total N, organic C, C/N, available P, K^+, Mg^{2+}, $Ca^{2+}$and pH (Table 2). Both the Andosols and the Nitisols were acidic with respective pH of 5.75 and 5.47 with no significant difference at $p < 0.05$ level of significance between the soils. Poultry litter (6.54) and fast compost (4.60) were acidic, while rice husk biochar (7.90) and *Tithonia diversifolia* (9.23) were alkaline and significantly different ($p < 0.05$). Total N was 0.25 % in Andosol and significantly different ($p < 0.05$) from the 1.03 % in Nitisol soil. Total N was significantly highest (Prob > F, < 0.0001) in *Tithonia diversifolia* (5.24 %) followed by PL (3.01 %), RHB (0.35 %) and FC (0.33%). Organic C was 2.37 % in the Andosol, significantly different from 2.15 % in Nitisol soils. For the manures, the highest level of organic C occurred in *Tithonia diversifolia* (42.35 %), followed by PL (32.21 %) and significantly (F ratio 2380505, Prob>F < 0.0001) lowest in RHB (7.22 %) and the FC (3.35 %). C/N, an important physiological indicator of growth and tuberization in roots and tubers (Zheng et al., 2018) showed a moderate level of significant variation (F ratio 5442.49, Prob>F < 0.0001) between the soils and the organic amendments. C/N was lowest in the Nitisol (2.15) than the Andosol soil (6.69). RHB (20.44) had the highest C/N, followed by PL (10.69), FC (10.20) and *Tithonia diversifolia* (8.09). Soil available P varied significantly between the Andosol (18.29 %) and the Nitisol (10.13). For the manures, P significantly varied (F ratio 3797472.00, $p < 0.0001$) from 39.68 % in FC to 0.07 % in RHB.

Table 2. Chemical characteristics of biochar, compost, poultry manure, and wild sunflower leaves used as organic fertilizer against the control (soil).

Item	Total N	Organic C	C:N ratio	P	K^+	Ca^{2+}	Mg^{2+}	pH
	%			%	Cmol (+)/kg			
Soil								
Andosol soil	0.25 ± 0.01^{f}	2.37 ± 0.01^{e}	9.69 ± 0.22^{d}	18.29 ± 0.01^{b}	1.74 ± 0.00^{d}	2.51 ± 0.10^{b}	0.88 ± 0.01^{b}	5.75 ± 0.06^{d}
Nitisol soil	1.03 ± 0.01^{c}	2.15 ± 0.04^{f}	2.10 ± 0.02^{f}	10.13 ± 0.03^{c}	1.03 ± 0.01^{e}	5.30 ± 0.01^{a}	1.19 ± 0.02^{a}	5.47 ± 0.05^{d}
Organic manure								
Rice husk biochar	0.35 ± 0.00^{d}	7.22 ± 0.01^{c}	20.44 ± 0.04^{a}	0.07 ± 0.00^{f}	0.67 ± 0.01^{f}	0.03 ± 0.00^{d}	0.01 ± 0.00^{d}	7.90 ± 0.03^{b}
Fast compost	0.33 ± 0.00^{e}	3.35 ± 0.01^{d}	10.20 ± 0.13^{c}	39.68 ± 0.01^{a}	2.87 ± 0.06^{b}	0.13 ± 0.01^{cd}	0.03 ± 0.00^{d}	4.60 ± 0.25^{e}
Poultry litter	3.01 ± 0.00^{b}	32.21 ± 0.01^{b}	10.69 ± 0.01^{b}	1.22 ± 0.01^{d}	2.72 ± 0.01^{c}	0.17 ± 0.01^{c}	0.08 ± 0.00^{c}	6.54 ± 0.02^{c}
Tithonia diversifolia	5.24 ± 0.01^{a}	42.35 ± 0.02^{a}	8.09 ± 0.01^{e}	0.68 ± 0.00^{e}	5.71 ± 0.01^{a}	0.12 ± 0.01^{cd}	0.09 ± 0.00^{c}	9.23 ± 0.61^{a}
F Ratio	368803.2	2380505	5442.49	3797472	16529.21	8029.99	10401.54	120
Prob > F	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*

Note: Mean±SD in a column connected by the different superscripts letter(s) a, b, c, d, e and f are significantly different following Tukey HSD test. *indicates that the variation in the chemical composition of the soil and organic manure is significantly different.

Exchangeable K+ marked a significant difference between the Andosol (1.74 cmol(+)/kg) and the Nitisol (1.03 cmol(+)/kg) soils. For the manures, K+ followed the trend RHB > PL > FC > *Tithonia diversifolia* with the highest content of 5.71 cmol(+)/kg. The Ca2+ varied significantly between the two soils, with the Nitisol having the highest value of 5.30 cmol(+)/kg.

Ca2+ was highest in the soils compared to the organic amendments in which PL (0.17 cmol(+)/kg) emerged best. Mg2+ like Ca2+ expressed a similar trend in the soils, marking the highest content in Nitisol soil (1.19 cmol(+)/kg). For the organic amendments, Tithonia diversifolia (0.09 cmol(+)/kg) had the highest Mg2+.

3.2. Growth Performance and Harvest Index Components of the OFSP and WFSP Varieties in the Andosol and Nitisol Soils

Figure 1 illustrates the LAI of the OFSP and WFSP cultivated in the Andosol and Nitisol soils using different fertilizer regimes. LAI of the OFSP was highest in the RHB/NPK20-10-10 blend in the Andosol (5.42), and scored least in the control. For the WFSP, LAI in the Andosol soil varied from 2.63 (control) to 6.75 (FC) with clear marked differences between the FC and *Tithonia diversifolia* (4.83), NPK6-15-28 (4.96), NPK20-10-10 (3.43), RHB (3.08), control and the three organic/NPK20-10-10 blends. In the Nitisol soil, the LAI of the OFSP followed a similar pattern as in the Andosol with the highest score in the RHB/NPK20-10-10 blend (5.04) and the lowest in the control (2.83). For the WFSP in the Nitisol, LAI also scored best in FC/NPK20-10-10 followed by *Tithonia diversifolia* and least in the control.

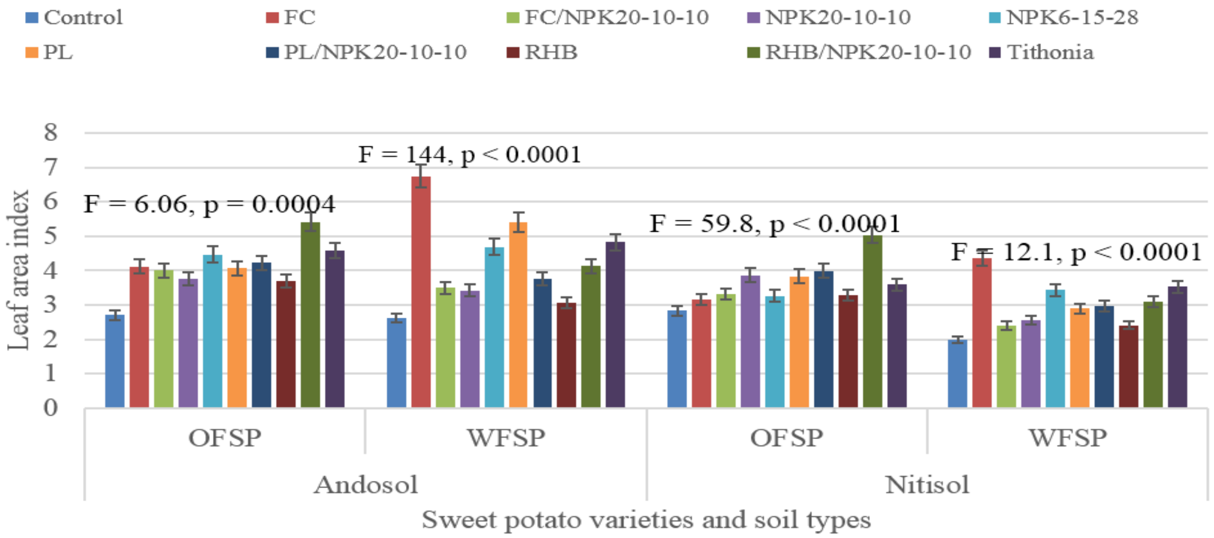

Figure 1. Bar charts of the LSmeans for LAI of OFSP and WFSP on Andosol and Nitisol soils of Cameroon under different fertilizer regimes.

The HI of the OFSP and WFSP cultivated in the Andosol and Nitisol soils using different nutrient sources is shown in Figure 2. For the OFSP in the Andosol soil, HI marked significant variation (F = 254, p < 0.0001) across the amendments. Like the control (0.19), fertilizer regimes with low HI (< 0.50) were the FC, *Tithonia diversifolia*, NPK20-10-10, RHB, PL/NPK201-10-10, FC/NPK20-10-10 and NPK6-15-28 (0.47). Only PL (0.70) and RHB/NPK20-10-10 (0.83) expressed HI > 0.5 for the OFSP. In the Nitisol soil, low HI (< 0.50) occurred in the control plot, *Tithonia diversifolia*, NPK20-10-10, NPK6-15-28 and FC. For the WFSP, HI marked weak variation between the fertilizer regimes in the Andosol (F = 22.1, p < 0.0001) and the Nitisol (F = 15.3, p < 0.0001) soils. The highest HI with no marked variations occurred in FC, RHB, PL, FC/NPK20-10-10, PL/NPK20-10-10 and NPK6-15-28. In the Nitisol soil, HI was highest on the FC. There were no wide differences in HI between the FC, *Tithonia diversifolia*, NPK6-15-28, RHB/NPK20-10-10 and the control plot.

Table 3. Overall performance of growth and harvest index components per soil type, sweet potato varieties and fertilizer regimes.

Treatments	Branch number	Main stem length (cm)	LAI	Petiole length (cm)	Adventitious Roots (Kg)	HI	Dry Biomass (Kg)	Total Yield (t/ha)	Marketable Yield (t/ha)
Soil									
Andosol	5.28 ± 1.38^{a}	146.00 ± 54.25^{a}	4.16 ± 1.06^{a}	28.47 ± 3.43^{b}	0.07 ± 0.05^{b}	0.35 ± 0.17^{a}	2.45 ± 0.64^{a}	16.13 ± 3.57^{a}	12.44 ± 3.09^{a}
Nitisol	4.73 ± 1.36^{b}	163.15 ± 58.49^{a}	3.30 ± 0.71^{b}	30.09 ± 3.30^{a}	0.09 ± 0.05^{a}	0.39 ± 0.10^{a}	1.85 ± 0.34^{b}	13.61 ± 3.27^{b}	8.81 ± 2.12^{b}
Sweet potato variety									
OFSP	5.74 ± 1.40^{a}	103.39 ± 11.24^{b}	3.86 ± 0.74^{a}	27.51 ± 3.56^{b}	0.09 ± 0.05^{a}	0.45 ± 0.15^{a}	2.34 ± 0.63^{a}	18.81 ± 7.02^{a}	14.14 ± 6.43^{a}
WFSP	4.26 ± 0.91^{b}	205.76 ± 32.53^{a}	3.59 ± 1.20^{a}	31.05 ± 2.22^{a}	0.07 ± 0.05^{a}	0.28 ± 0.06^{b}	1.95 ± 0.51^{b}	10.93 ± 2.22^{b}	7.10 ± 1.86^{b}
Fertilizer regime									
No fertilizer	2.64 ± 0.45^{c}	193.84 ± 95.25^{a}	2.54 ± 0.34^{d}	27.28 ± 1.75^{bc}	0.13 ± 0.04^{ab}	0.23 ± 0.07^{c}	2.01 ± 0.69^{a}	6.81 ± 1.51^{c}	4.26 ± 2.11^{d}
RHB	5.28 ± 1.42^{ab}	140.47 ± 36.16^{a}	3.12 ± 0.48^{cd}	28.80 ± 2.67^{abc}	0.07 ± 0.05^{cd}	0.38 ± 0.10^{abc}	1.83 ± 0.74^{a}	14.36 ± 3.32^{ab}	10.06 ± 2.35^{abcd}
FC	4.69 ± 1.22^{b}	135.47 ± 43.53^{a}	4.59 ± 1.40^{a}	28.16 ± 3.93^{abc}	0.16 ± 0.05^{a}	0.38 ± 0.08^{abc}	2.19 ± 0.67^{a}	13.64 ± 3.66^{abc}	9.62 ± 3.76^{abcd}
PL	5.65 ± 0.87^{ab}	164.34 ± 52.37^{a}	4.06 ± 1.09^{abc}	29.41 ± 1.66^{abc}	0.04 ± 0.01^{d}	0.45 ± 0.18^{ab}	1.91 ± 0.36^{a}	16.18 ± 4.26^{ab}	11.44 ± 4.70^{abc}
Tithonia	4.35 ± 0.35^{b}	141.43 ± 58.65^{a}	4.14 ± 0.77^{abc}	26.38 ± 6.86^{c}	0.08 ± 0.04^{cd}	0.29 ± 0.06^{bc}	2.21 ± 0.55^{a}	11.09 ± 1.65^{bc}	7.49 ± 2.45^{cd}
NPK20-10-10	5.64 ± 0.74^{ab}	160.63 ± 46.95^{a}	3.41 ± 0.64^{bcd}	$31.\ 68\pm1.64^{a}$	0.05 ± 0.01^{cd}	0.29 ± 0.05^{bc}	2.40 ± 0.44^{a}	13.84 ± 3.16^{abc}	9.39 ± 4.62^{bcd}
NPK6-15-28	4.65 ± 0.42^{b}	163.05 ± 61.14^{a}	3.97 ± 0.89^{abc}	28.67 ± 3.92^{abc}	0.08 ± 0.02^{cd}	0.39 ± 0.09^{abc}	1.89 ± 0.29^{a}	14.33 ± 2.00^{ab}	9.54 ± 2.58^{bcd}
RHB/NPK20-10-10	6.24 ± 1.15^{a}	143.23 ± 48.34^{a}	4.42 ± 0.95^{ab}	32.00 ± 0.74^{a}	0.09 ± 0.04^{bc}	0.48 ± 0.25^{a}	2.50 ± 0.31^{a}	20.74 ± 8.19^{a}	15.20 ± 7.21^{ab}
FC/NPK20-10-10	5.36 ± 1.52^{ab}	143.70 ± 44.70^{a}	3.31 ± 0.62^{cd}	29.64 ± 0.97^{ab}	0.06 ± 0.05^{cd}	0.39 ± 0.12^{abc}	2.06 ± 0.77^{a}	17.44 ± 7.85^{ab}	12.98 ± 7.06^{abc}
PL/NPK20-10-10	5.53 ± 1.47^{ab}	159.59 ± 56.55^{a}	3.74 ± 0.51^{abc}	30.79 ± 1.00^{ab}	0.04 ± 0.01^{d}	0.38 ± 0.10^{abc}	2.48 ± 0.70^{a}	20.31 ± 10.05^{a}	16.23 ± 8.39^{a}

Note: Mean±SD in a column connected by the different superscripts letter a, b, c and d are significantly different at $p < 0.05$ level of significance following each pair, Student's t test (soil and sweet potato) and all pairs, Tukey HSD test (Fertilizer regime).

3.3. Overall Response of Growth and Harvest Index Components to Soils, Sweet Potato Varieties and Fertilizer Regime

Pooled data for all the fertilizer regimes comparing the growth performance and harvest index components for the soil types (Andosol vs. Nitisol) and the sweet potato varieties (OFSP vs. WFSP) are summarized in Table 3.

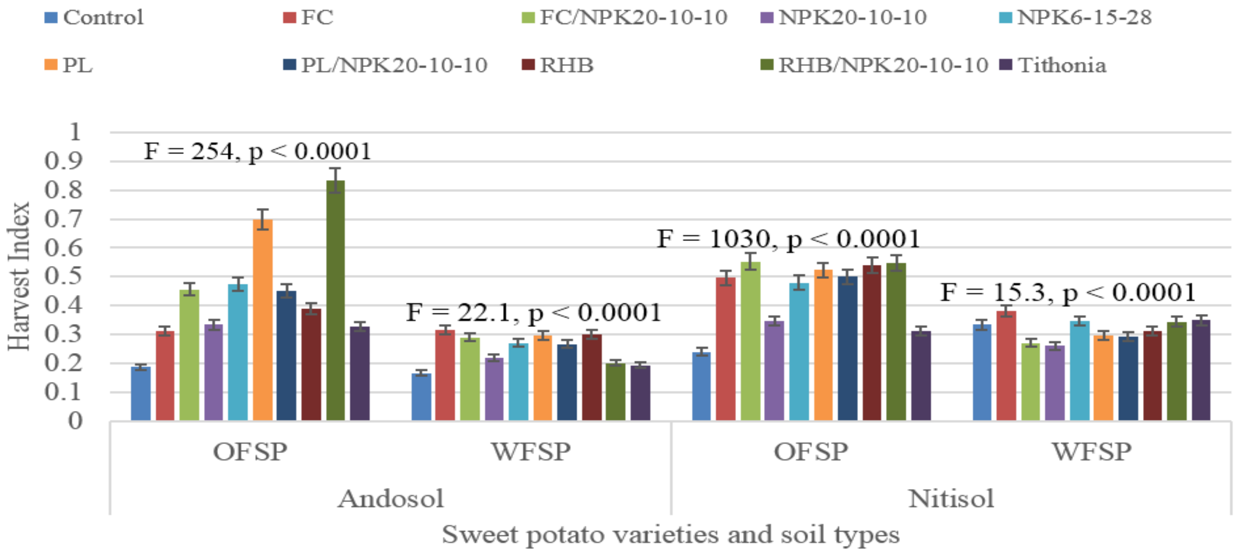

Figure 2. Bar chats of the LSmeans for harvest index of OFSP and WFSP on Andosol and Nitisol soils of Cameroon under different fertilizer regimes.

Branching, LAI, dry biomass, total and marketable yields showed high levels of significant differences in the Andosol while petiole length and the development of adventitious roots varied significantly in the Nitisol soil. However, main stem length and HI showed no statistically significant differences between the soil types. Total and marketable yields were respectively 16 t/ha and 12 t/ha for the Andosol and 14 t/ha and 9 t/ha for the Nitisol. Between the two sweet potato varieties, branching, dry biomass, HI, total and marketable yields showed high levels of significant variation for the OFSP whereas main stem length and petiole length varied significantly in the WFSP. LAI and adventitious root development did not vary significantly between the OFSP and WFSP varieties. Taken together, the total yield of the OFSP was 19 t/ha compared to 11 t/ha for the WFSP. These total yields respectively gave corresponding marketable yields of 14 t/ha and 7 t/ha for the OFSP and WFSP varieties. As such, irrespective of fertilizer regime, the Andosol soil and OFSP produced more marketable storage roots than the Nitisol and WFSP.

With the sweet potato varieties and soil groups taken together, the highest branching was registered in the RHB/NPK20-10-10 (6.24) comparable to branching in PL, NPK20-10-10, PL/NPK20-10-10, FC/NPk20-10-10 and RHB. The lowest number of branches occurred on the no fertilizer plot and was significantly ($p < 0.05$, Tukey HSD test) different from branch number on the plots amended with *Tithonia diversifolia* powder and NPK6-15-28. Main stem length and dry biomass did not vary across the fertilizer regimes. For petiole length, the highest elongation occurred on the NPK20-10-10 and RHB/NPK20-10-10 plots and the lowest in the no fertilizer and *Tithonia diversifolia* powder plots. The adventitious roots occurred most on the plots amended with FC (0.16 kg) and no fertilizer (0.13 kg) and significantly different from the lowest values in PL/NPK20-10-10 (0.04 kg), NPK20-10-10 (0.05 Kg) and FC/NPK20-10-10 (0.06 kg). Harvest index within the fertilizer regimes significantly varied from 0.23 on the no fertilizer (comparable to *Tithonia diversifolia* powder and NPK20-10-10 as the lowest scoring) to 0.48 on the RHB/NPK20-10-10 (comparable to PL, FC/NPK20-10-10, NPK6-15-28, PL/NPK20-10-10, FC and RHB as the highest scoring). As for yield performance, plots amended with PL/NPK20-10-10, RHB/NPK20-10-10, FC/NPK20-10-10 and PL respectively expressed highest total and marketable yields of 20.32 and 16.23 t/ha, 20.74 and 15.20 t/ha, 17.44 and 12.98 t/ha and 16.18 and 11.44 t/ha. The lowest total and marketable yields occurred on the no fertilizer plot and the plot amended with *Tithonia, diversifolia* powder.

Table 4. Interactive effects of soil type, sweet potato variety and fertilizer regime on growth and harvest index parameters.

Source	Branch number	Main stem length (cm)	Petiole length (cm)	LAI	Adventitious roots (Kg)	Dry Biomass (Kg)	HI	Total Yield (T/ha)	Marketable yield (T/ha)
Soil (S)	*	***	**	**	**	**	**	***	***
Sweet potato (SP)	**	***	**	*	**	*	***	***	***
Fertilizer (F)	*	**	*	*	***	*	**	***	***
S × SP	ns	*	ns	*	*	*	*	*	**
S × F	ns	*	*	*	*	*	*	*	*
SP × F	*	**	**	*	***	**	**	**	**
S × SP × F	ns	*	*	*	*	*	*	*	*

Note: ns = non-significant, * = weakly significant, ** = moderately significant, *** = strongly significant.

3.4. Interactive Effects of Soil, Sweet Potato Variety and Fertilizer on Growth and Harvest Index Components

The effects of soil (environment), sweet potato variety (genotype) and fertilizer on the growth harvest index components are shown in Table 4.

The soil, fertilizer and the interaction between sweet potato genotype and fertilizer exerted weak effects on branch formation. Soil type and sweet potato genotype strongly influenced main stem elongation while fertilizer and the sweet potato × fertilizer interaction expressed moderate effects on main stem length. The effect of soil × sweet potato, soil × fertilizer and soil × sweet potato × fertilizer on main stem length was weak. Soil type, sweet potato genotype, the interaction between sweet potato genotype and fertilizer moderately influenced petiole length. fertilizer, soil × fertilizer and soil × fertilizer × sweet potato genotype had a weak effect on petiole length. The soil × sweet potato interaction did not affect petiole length. fertilizer and the sweet potato genotype × fertilizer interaction strongly influenced adventitious roots, while soil and sweet potato genotype moderately affected adventitious roots. Although adventitious roots were significantly higher in the Nitisol compared to the Andosol, there was no significant difference ($p < 0.05$, student t-test) between the OFSP and WFSP. The soil type expressed a moderate effect while sweet potato genotype, fertilizer and the resulting interactions weakly influenced aboveground biomass. HI was strongly affected by sweet potato variety, while fertilizer, soil type, and sweet potato variety × fertilizer exerted moderate effects on HI. Sweet potato genotype and fertilizer regime strongly influenced total yield whereas, sweet potato × fertilizer had a moderate effect on total yield. The interaction result is a suggestion that yield response was varietal and fertilizer dependent and non-synergistic when combined with soil type, as evidenced in the weak interactive effect of soil × sweet potato, soil × fertilizer and soil × sweet potato × fertilizer on total yield. Soil type, variety and fertilizer exerted strong effects on marketable yield. Although soil, variety and fertilizer had strong effects on marketable yield individually, soil × variety and variety × fertilizer exerted moderate effects while soil × fertilizer and soil × variety × fertilizer had weak effects on marketable yield.

4. DISCUSSIONS

4.1. Physicochemical Properties of Soils, Poultry Litter, Tithonia Diversifolia, Rice Husk Biochar and Fast Compost

Sweet potato is vegetatively propagated from vines and can tolerate acidic and alkaline soils, with optimal growth and yield found at the pH range of 5.6-–6.6 (Stathers et al., 2018). Optimal pH for root and top growth is a function of the sweet potato variety. Tsai and Chang (2020) and Asadi et al. (2021) also reported alkaline pH values for RHB. Alkaline biochars are desirable in acidic soils as they enhance carbon sequestration (Lehmann, 2007) and improve abundance and the community structure of microorganisms (Gul, Whalen, Thomas, Sachdeva, & Deng, 2015). The total N in *Tithonia diversifolia* (5.24 %) was greater than the 3.9% reported by Cobo et al. (2002) in Colombia and in RHB (0.35 %) was less than the 0.49 % reported by Billa et al. (2019) and the 0.9 % by Hossain et al. (2020). This might be due to differences in the quantity of the introduced feedstock, peak temperature, residence time in peak temperature and the tempering duration, which favoured nitrogen dihydroxylation and volatilization (Avornyo, Manu, Laird, & Thompson, 2021). Total N is a limiting factor for sweet potato growth and yield, directly involved in the amino acid synthesis, total starch synthesis and photosynthesis (Duan, Zhang, Xie, Wang, & Zhang, 2019; Taranet, Harper, Kirchhof, Fujinuma, & Menzies, 2017). Although no specifications are advanced for the actual critical soil nitrogen required to maximize optimum sweet potato performance, Fernandes, Campos, Senna, da Silva, and Assunção (2018) underlined that too little N will retard growth, while too much N will favour aboveground biomass and adventitious root growth at the expense of storage root formation. Therefore, there is a need to control soil N replenishment to enhance sweet potato growth and yield. The organic C status of the two soil types was slightly below the 2.45 % reported for equatorial forest agroecozones (depth 0-20 cm) by Vanlauwe et al. (2010). Organic C from the soil and amendments are absorbed and transported to the mesophyll cells to fuel cellular processes and constitutes the main building blocks of sucrose and starch. Organic C to total N ratio (C/N), an important physiological indicator of growth and tuberization in roots and tubers (Zheng et al., 2018) showed statistically significant variation (F ratio 5442.49, Prob>F < 0.0001) between the soils and the organic amendments. The C/N ratio of PL (10.69) in our study was greater than the 6.12 in Adekiya et al. (2020). A high C with low N means a high ratio that favours the early formation of tubers in potato (Solanum tuberosum L) plants (Zheng et al., 2018). The C/N ratio being constant for soils (Gowariker, Krishnamurthy, Gowariker, Dhanorkar, & Paranjape, 2009) implies its variation solely depends on the C and N content of the amended inputs. C/N is the most used metric for soil eco-functionality, reflecting fertility and healthiness (Hoffland, Kuyper, Comans, & Creamer, 2020). All of the organic amendments had C/N ratios < 30; this entails rapid decomposition and release of mineral N (Bonanomi et al., 2019) which depends on the lignin and polyphenol composition of the manure (Grzyb, Wolna-Maruwka, & Niewiadomska, 2020).

The available P in the *Tithonia diversifolia* was greater than the 0.52 reported in Adekiya et al. (2020). Only the FC had a greater available P than the two soil types, indicating that its decomposition by soil microbes could lead to the additive increase of P in the soil (Mackay, Macdonald, Smernik, & Cavagnaro, 2017). The K^+ content of *Tithonia diversifolia* (3.04 %) and PL (3.37 %) in Adekiya et al. (2020) surpassed the values in our study, likewise for RHB (0.87 to 5.00 cmol/kg) in Tsai and Chang (2020) and 17.45 cmol/kg in Mosharrof et al. (2021). K^+ intervenes in resistance to biotic and abiotic stress. It also facilitates the translocation of sugars and starches and enhances nitrogen use efficiency and yield. It is also a cofactor of many enzyme systems, confers a large size in sweet potato, increases storage root number and affects skin morphology (Byju & George, 2005; Du et al., 2021).

The Ca^{2+} in the Andosol soil corroborated the level reported in Tize et al. (2021) for the monomodal forest agro-ecological zone. Ca^{2+} was highest in the soils compared to the organic amendments in which PL (0.17 cmol(+)/kg) emerged best. The Ca^{2+} in the RHB was comparable to the range in Tsai and Chang (2020) but less than the 19.46 cmol/kg in Mosharrof et al. (2021). Exchangeable Ca^{2+} is mostly supplied by the soil and rarely from fertilizers, especially in smallholder-own systems where NPK and urea are dominant. Calcium is a signal molecule involved in the early stages of plant growth, cell division, stem and root elongation, storage root thickening and the translocation of assimilates across membranes (De Bang, Husted, Laursen, Persson, & Schjoerring, 2021; Thor, 2019). The Mg^{2+} in this study was less than that reported for PL, *Tithonia diversifolia* and RHB in Partey, Thevathasan, Zougmore, and Preziosi (2016) and Adekiya et al. (2020). Mg^{2+} is rarely supplied through fertilization, compelling plants to depend on soil reserves, which are prone to depletion in acidic and heavy rainfall environments (Wang et al., 2020). In exchangeable Mg^{2+} deficient soils, chlorosis is common, resulting in retarded growth and considerable yield reduction, low biomass accumulation and impaired starch synthesis in carbohydrate storage organs (Farhat et al., 2016).

4.2. Growth and Harvest Index Components of the Sweet Potato Varieties in the Two Soil Environments

Sweet potato genotypes are adapted to specific environments as per our observation that growth performance depends on soil type. Specifically, for LAI, Kinoshita, Yano, Sugiura, and Nagasaki (2014) confirmed this observation after investigating seasonal changes in tomato under controlled-release fertilizer application. LAI and specific leaf area are linearly related to N application, which enhanced the photosynthetic capacity and yield of Miscanthus in Savoy, Illinois, USA (Wang et al., 2012). HI is a measure of yield efficiency expressed as the ratio of storage root to total biomass such that when storage root weight is far greater than the weight of vines and leaves, HI is directly reflecting good yield. The strong effect of variety on HI in our study corroborated (Mukhongo et al., 2017). Taffouo, Nono, and Simo (2017) reported HI of 0.43 to 0.87 for three sweet potato varieties in Cameroon, moderately affected by fertilizer and weakly by variety and variety × fertilizer. Minda, Van, Vilà-Guerau, Chulda, and Struik (2019) showed that potato branch number cultivated in the Gamo highlands of Ethiopia was influenced by seasonal climate, corroborating our observation that agro-ecological soils moderately influenced branch development.

High branching is a desirable trait in creeping stems as it confers large canopy cover and the effectiveness to suppress invasive weeds (Shen et al., 2019). Since the effect of variety on branch number (Table 3) was strong, branching can be exploited during breeding to select sweet potato varieties with a high growth rate and dominant competition against weeds for essential nutrients (Shen et al., 2019). The effect of soil × sweet potato, soil × fertilizer and soil × sweet potato × fertilizer on main stem length was weak. This is indicative that although significantly different between the varieties (Table 3), the sweet potato vine length is influenced by growth conditions (farmer management and climate) and so could only be used in combination with other parameters in breeding programs. The petiole length of 737 sweet potato accessions of the USDA ARS germplasm ranged from 5.0 to 34.3 cm (Jackson, Harrison, Jarret, & Wadl, 2020) covering the range reported for the two genotypes in our study. Therefore, being an intrinsic varietal property, fertilizer can alter petiole length for the same genotype. Petiole length and its inclination are essential in the upright positioning of leaves to optimize efficient light interception for photosynthesis. The fact that the soil × varietal interaction did not affect petiole length contradicts (Darko, Yeboah, Amoah, Opoku, & Berchie, 2020) who found that at $p < 0.05$ level of significance, variety × environmental interaction influenced vine and petiole lengths.

Sweet potato storage roots are formed from cell differentiation and thickening of adventitious roots following down-regulation of lignification and low nitrogen supply (Villordon, LaBonte, Solis, & Firon, 2012). Storage root initiation occurs under the controlled activity of the primary cambium and the polyarchy stele regulated by abscisic acid, water, auxin-cytokine signal pathway, temperature and nutrients in the first two weeks after planting (Firon et al., 2009; Ravi, Naskar, Makeshkumar, Babu, & Krishnan, 2009). On the other hand, gibberellin promotes lignification, inhibiting the differentiation of adventitious roots to storage roots (Singh et al., 2019). The strong effect of fertilizer, sweet potato × fertilizer and soil on adventitious root formation in this study corroborates (Villordon, Gregorie, & LaBonte, 2020) who showed that the environment and genotype influenced sweet potato root architectural adaptation to inorganic phosphorus availability. The aboveground biomass of sweet potato is composed of vines, petioles and leaves, which are rich in protein, low in fibre and thus suitable as animal feed. Irrespective of the amendment, biomass production was highest in Andosol compared to Nitisol (Table 3). The effect of soil type on dry biomass is in line with (Mukhongo et al., 2017) who found that soil type and season significantly influenced vine dry weight. Darko et al. (2020) found that fertilizer, variety, location and variety × location affected sweet potato biomass in Ghana.

Therefore, we cannot generalize the weak and moderate effects of soil, fertilizer, variety and the resulting interactions on biomass from this study. Depending on the variety, soil type, or agroecology and the fate of vine and leaf production, appropriate organic or inorganic amendments are essential, as biomass production does not reduce storage root yield (Mukhongo et al., 2017). Ngeve and Bouwkamp (1993) reported average yields of 6.6 t/ha and 4.8 t/ha in the dark volcanic Andosol and reddish-brown Nitisol soils of Njombé and Nkolbisson for 20 sweet potato clones without the use of fertilizers. Sweet potato yields for the years 2017, 2018 and 2019 in Cameroon were 5.9, 5.7 and 5.8 t/ha. These yields are below the averages of 6.4, 6.2 and 6.3 t/ha over the same period in Africa (FAO, 2021). World sweet potato average yield during 2017, 2018 and 2019 stood at 11.9, 12.0 and 11.8 t/ha (FAO, 2021). The yields from the control plots for the OFSP and the WFSP in the two soil types were less than the global average, confirming the observation that yield improvement through breeding, for instance, is sometimes not attainable due to limited nutrient input, poor farm management techniques, abiotic and biotic constraints (Ittersum et al., 2013). In this study, low yields were common in the Nitisols (Table 3) and confirmed by the strong significant effects of soil type on total yield (Table 4). This result is also in line with Mukhongo et al. (2017) who reported variability in sweet potato yields to location and season in Uganda. In AEZs with low rainfall, sweet potato yields are generally low. The low rainfall recorded in the bimodal humid forest during the production season might explain the low yield in the marketable storage root in the Nitisol soil (Abukari, Shankle, & Reddy, 2015). Darko et al. (2020) also found that variety and location exerted strong effects while variety × location expressed weak effects on sweet potato marketable yield. However, they did not find that fertilizer, fertilizer × variety, fertilizer × location and fertilizer × variety × location had any effect on marketable yield. This difference might be because they used only inorganic fertilizer

(NPK15-15-15 plus muriate of potash, with no organic manure) with slight differences in the dose applied and because the meteorological data from their sites were not highly contrasting.

5. CONCLUSION

In this study, we investigated the effects of Andosol and Nitisol soils on the growth and harvest index of OFSP and WFSP under integrative soil fertility management. We found that fast compost, the blend of PL/NPK20-10-10 and RHB/NPK20-10-10 produced the best performance for primary branch number, LAI, petiole length, HI, total and marketable yield in the two soils for the two sweet potato varieties. Irrespective of the fertilizer type, primary branch number, LAI, dry biomass, total yield and marketable yield were best for the OFSP and in the Andosol soil compared to the WFSP on the Nitisol soil. Soil type exerted strong effects on total yield that performed best for the OFSP on RHB/NPK20-10-10 and PL/NPK20-10-10 and for the WFSP on NPK20-10-10, FC/NPK20-10-10 in the Andosol soil and fast compost in the Nitisol soil. Soil type did not affect main stem length or the harvest index nor did sweet potato variety affect LAI. Our results therefore suggest that the integrative management of fast compost, PL/NPK20-10-10 and RHB/NPK20-10-10 on dark volcanic Andosol could increase soil nutrients and boost the yield of sweet potato in general and of the OFSP in particular. This study provides useful directives on the choice of soil and fertilizer regimes for sweet potato cultivation. However, studies of the economic feasibility of the best fertilizer regimes are warranted before promotion for implementation in the context of low-cost and low-input ecological agriculture.

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