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Combined Application of Filter Cake and Macadamia Husk Compost Affects Soil Fertility and Plant Mineral Content of Orange-Fleshed Sweet Potatoes

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Abstract: A greenhouse pot experiment was conducted to investigate the influence of the combined application of filter cake and macadamia husk compost (FC+MHC) on the soil fertility and dry matter partitioning of Beauregard and 199062.1 cultivars of orange-fleshed sweet potato. The effects of the two organic wastes on the mineral nutrients in the leaves and the storage roots of the 199062.1 cultivar were also investigated. In addition to FC+MHC, four other treatments—filter cake only (FC), macadamia husk compost only (MHC), inorganic fertilizer only (IF), a combination of filter cake and inorganic fertilizer (FC+IF), a combination of macadamia husk compost and inorganic fertilizer (MHC+IF), and a control (CONT)—were included in the investigation for the purpose of comparison. To achieve this, 1 kg of compost was homogenized with 20 kg of soil and filled into graduated 25 L buckets. The experimental design was completely randomized. The plants were grown for 4 months. The results indicated that all treatments altered the soil fertility positively. There were indications that both filter cake and macadamia husk compost inhibited the absorption of iron (Fe), copper (Cu), and aluminum (Al). Also, zinc (Zn) and phosphorus (P) deficiencies in the initial soil were corrected after the application of the organic wastes. In terms of yield, FC+MHC was better than all other treatments. The outcome of this study will no doubt greatly benefit the resource-poor farmers of Northern KwaZulu-Natal who are involved in the production of orange-fleshed sweet potatoes.

Keywords: Beauregard; fertility; filter cake; organic wastes; yield

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1. Introduction

Good crop management is very essential for the genetic potential of crops to be fully realized [1,2]. One such crop management practice is to ensure that crops have adequate access to the right quantity of the required soil nutrients [1]. However, in the KwaZulu-Natal province of South Africa and some other places around the world, as access to agricultural land is being reduced due to other societal needs, it has become necessary to continually crop the same plot of land, leading to depletion of soil nutrients, exposure of soil to erosion, and deterioration of soil structure [1].

To address the issue of soil nutrient depletion, inorganic fertilizers have for a long time been extensively used to enhance soil nutrients and ultimately boost the growth and yield of crops [3–5]. However, the cost of inorganic fertilizers is prohibitive to the resource-poor farmers, who constitute most farmers growing orange-fleshed sweet potatoes (OFSP). Hence, waste generated from agricultural products is now receiving tremendous attention [4,6]. The use of waste generated from agriculture for yield enhancements has also become a clever way of disposing of such waste, which hitherto constitute some environmental nuisance or require additional cost for disposal [6]. On the farm, the use of organic wastes for soil amendment is also particularly helpful in droughty situations, fields that are depleted in organic matter, fields that are prone to erosion, and other suboptimal soils [3,7–9].

Soil amendments with organic waste have been reported to alter the nutrient composition of some plants, such as maize [10], sugarcane [5,11,12], carrot [13], and tomato [14]. Also, organic wastes have been reported to influence the nutrient composition of the soil [15]. The influence of organic waste in soil includes increasing soil nutrients and reducing or immobilizing otherwise detrimental soil minerals such as aluminum (Al) [15–17]. The use of organic wastes for soil enhancement has also been reported to improve soil structure and the ability of soil to hold water for plant use [1,7,15]. Unlike inorganic fertilizers, organic waste generated from agricultural activities has been reported to be more persistent in soil and therefore may be useful on the field for more than one planting season, thereby saving on fertilizer purchases and labor requirements for its application in the following planting season [18,19]. Although the uses of filter cake and macadamia husk composts are not yet popular among the farmers in the study area, both organic wastes are being promoted because of their availability at almost zero cost and reported ability to increase crop yield [11,18].

Filter cake is an organic waste derived from sugarcane juice filtration, while macadamia husks are derived from the dehusking of macadamia nuts. Macadamia husks are the outer coating of macadamia nuts. Filter cakes are usually used as organic fertilizer without any form of processing, but macadamia husk undergoes a composting process that may last over 3 months [18]. Both organic wastes have been reported to have high moisture contents and the ability to hold soil water. Also, they increase average weighed diameters of soil crumbs, which in turn have good effects on the infiltration rate of soil water [9,11,20,21]. Macadamia husk compost has a higher moisture content than filter cake [18]. They have been used to improve soil water content and soil water retention. These characteristics of high moisture content and high-water content retention make both filter cake and macadamia husk compost good candidates for ameliorating the recurrent drought problems in the northern area of KwaZulu-Natal Province, South Africa [18].

Filter cake and MHC have some array of nutrients, although information with regards to their nutrient release patterns is still very sketchy to date [18]. Prominent among the nutrients present in both organic wastes is phosphorus (P) [18]. Because of its widespread deficiency in most tropical soils, P supplementation is commonplace in South Africa and other tropical areas [22]. Apart from being a primary macronutrient, P has the capacity for joint precipitation with Fe, Al-oxides, and Al-hydroxides [23,24]. Phosphorus is of special importance to sweet potato production because it is a constituent of many organic compounds that play significant roles in blooming and the development of lateral and fibrous rootlets [23].

In addition to P, other macro- and micronutrients that are present in filter cake and macadamia husk compost include potassium (K), manganese (Mn) and Cu. Filter cake had higher contents of most of the nutrients when compared to macadamia husk compost [18,25]. When these nutrients are released into the soil, they alter the existing soil mineral content and ultimately have the capacity to alter the nutrient composition of the shoot and storage roots of sweet potatoes grown in the soil. The conditioning effects of both organic wastes on the soil also have the capacity to affect the dry matter partitioning of sweet potato plants. The effects of both soil amendments on the plant's mineral contents and storage roots of orange-fleshed sweet potatoes have so far received very little attention in the literature (if any). Although the effects of individual application of filter cake and macadamia husk compost on plant growth have been explored in our previous field study, their combined effects (FC+MHC), which are aimed at harnessing both the higher moisture content in macadamia husk compost and the higher nutrient content of filter cake, have not been explored to the best of our knowledge or after a diligent literature search.

Hence, the aim of this study was to investigate the impact of the combined application of filter cake and macadamia husk compost on soil fertility and the yield of Beauregard and 199062.1 cultivars of OFSP. It was therefore hypothesized that the test plants would harness the advantages inherent in both organic wastes, resulting in the yield of the combined application of both filter cake and macadamia husk compost (FC+MHC) surpassing that of all other previous treatments. The implications of the changes in soil nutrients due to the application of both organic wastes on the nutrient composition of the leaves and storage roots of 199062.1 cultivars were also investigated.

2. Materials and Methods

The experiment was set up in one of the greenhouses of the Faculty of Science, University of Zululand, KwaDlangezwa. Coordinates: 28°51′06″ S; 31°51′08″ E; altitude 102 m. Located in the KwaZulu-Natal coastal belt, the soil in the area is classified as podzolic soil [26]. The soil texture was sandy loam. The average temperature and humidity during the experiment were 18 °C and 71.3%, respectively. The two OFSP cultivars used for the study were Beauregard and 199062.1.

2.1. Acquisition of Sweet Potato Vines and Other Materials

The vines of the selected OFSP were bought from the Agricultural Research Council-Roodeplaat Vegetable and Ornamental Plants, Pretoria. The graduated 25 L plastic buckets and fertilizer were bought at local shops in Empangeni, KwaZulu-Natal, South Africa. Filter cake and the macadamia husks used for the study were free gifts from Tongaat Hulett Sugar Ltd., Felixton, South Africa, and Mayo Mac Macadamias Ltd., Empangeni, South Africa, respectively. While the filter cake was used without any form of processing, macadamia husks were composted using standard procedures [18].

2.2. The Composting Operation

The composting operation was conducted at the orchard unit of the department of agriculture at the University of Zululand. The compost was made from macadamia husks only. The macadamia husks were homogenized with a spade, piled into windrows, and watered. The piles were then covered with polythene sheets. The temperatures of the piles were monitored every 24 h for the first month. For the first month, the piles of compost were turned and mixed weekly. Thereafter, the compost piles were turned fortnightly or when the temperature of the pile of compost was greater than or equal to 55 °C for 3 consecutive days. A sprinkler system was used to water the compost during the 8-week composting period. The filter cake was not composted. It was kept for about a week in the open before use, without further processing.

2.3. Soil Preparation and Experimental Design

Agriculturally productive soil was obtained by scraping the topsoil at a suitable area on the KwaDlangezwa campus of the University of Zululand with the aid of a spade to a depth of 10 cm. The soil was transported to the greenhouse and dried at room temperature. A wire mesh was used to remove unwanted materials such as leaves, roots of trees, and stones from the soil. The soil was then homogenized with a spade. The method of [27] was used to determine the field capacity of the soil.

The soil for the combined application of filter cake and macadamia husk compost (FC+MHC) was prepared as follows: In 25 L graduated plastic buckets were weighed 20 kg of soil and 0.5 kg of filter cake, and 0.5 kg of macadamia husk compost. The soil and the organic wastes were thoroughly mixed manually with the aid of a hand trowel. Other treatments investigated alongside the FC+MHC treatment for the purpose of comparison were filter cake only (FC), macadamia husk compost only (MHC), inorganic fertilizer only (IF), a combination of filter cake and inorganic fertilizer, and a combination of macadamia husk compost and inorganic fertilizer (MHC+IF). Untreated soil served as the control (CONT). Although these other treatments were reported in our earlier field study, which was carried out in Mtubatuba, KwaDlangezwa, and Dlangubo [18], they were included in the current greenhouse study for the purpose of comparison. In the other treatments, 1 kg of either filter cake or macadamia husk compost was used. The buckets were labeled and placed in the green house in a completely randomized design.

Each of the treatments and the controls were replicated 3 times. The pots were arranged 1.0 m apart along the row, and each row was 0.5 m apart. The pots were irrigated to field capacity, and the following day, vines of the test OFSP cultivars (each containing 5 buds) were planted in the buckets. The vines were planted with 3 of the buds inside the soil, and the remaining two buds were outside. Thereafter, each pot was irrigated with 1 L of water (which was about 70% of the field capacity earlier determined) weekly. The plants were grown for 4 months. During the plant's growth, the following data were collected: chlorophyll content, number of leaves, leaf area, and meteorological data (humidity and temperature).

2.4. Determination of Soil Fertility and Soil Analyses

Three samples were randomly taken from the initial soil collected for the study and stored in sample boxes. Soil samples were also taken from all treatments and replicates of the 199062.1 treatments at harvesting. All sampling was carried out in 3 replicates. The samples were dried, ground, homogenized, passed through a 0.1 mm sieve, stored in sample bottles, labeled, and stored at room temperature until needed for analyses. The samples were extracted and analyzed for organic carbon, nitrogen (N), P, and K. Other analyses conducted were calcium (Ca), magnesium (Mg), Zn, Mn, Cu, exchangeable acidity, total cations, pH, and the clay content. All the analyses were conducted using the standard procedures as adopted by the KwaZulu-Natal Department of Agriculture [28].

2.5. Plant Growth and Data Collection

The chlorophyll contents in the leaves were measured 10 weeks after planting using the chlorophyll meter CCM-200. The measurements were taken on five young but fully expanded leaves, which were selected randomly per plant/replicate and for all treatments. Five measurements were taken on each plant (n = 15/treatment). The measurements were taken by placing the measuring lever at the center of the selected leaves [29]. A week before harvesting, the number of leaves was determined by visually counting the leaves on each plant, for all treatments, and for each cultivar. At harvesting, the leaf area (cm^2) was estimated with the CI-173 202 Portable Laser Leaf Area Meter (CID Bioscience, 1554 NE 3rd Ave., Camas, WA 98607, USA).

2.6. Plant Harvesting

The plants were grown for 4 months. About 2 h before harvesting was conducted, the pots were watered to soften the soil. The harvested plants were cut apart into shoots and storage roots with a pair of scissors. Thereafter, the storage roots had the soil on them washed off. The harvested plant parts were put inside paper bags and placed in an oven set at 75 °C until constant mass was attained. Subsequently, the storage root dry biomass and shoot dry biomass were determined.

2.7. Compost and Plant Tissue Elemental Analyses

From the about 1000 kg of filter cake collected from the sugar refinery, 6 samples were taken randomly (n = 6). Similarly, 6 samples of about 500 g each were taken from the collected macadamia husks (n = 6). The samples were oven dried as stated above for the harvested plant parts, labeled, and stored until needed for analyses.

At 12 weeks after planting (WAP), ten young but fully expanded leaves of similar maturity were removed from each replicate of all treatments. The harvested leaves were stored in paper bags, labeled, dried at 65 °C in an oven until the mass became constant, and stored in a fridge until needed for analysis. Only the leaves and storage roots of 199062.1 were analyzed for elemental composition. The dried macadamia husks, filter cake, leaves, and storage root samples were analyzed using the standard methods of the KwaZulu-Natal Department of Agriculture [28].

2.8. Statistical Analyses

All data were subjected to multivariate analysis of variance (MANOVA). The MANOVA was conducted using STATISTICA v14 (TIBCO® Statistica™, TIBCO Software Inc., 3307 Hillview Avenue, Palo Alto, CA 94304, USA). The least significant difference ($LSD_{0.05}$) was used to separate the means of replicates. The Tukey test was used for the post hoc.

3. Results and Discussions

The combined application of filter cake, macadamia husk compost (FC+MHC), and other treatments positively altered the soil fertility (Tables 1 and 2). In most cases, all the treatments exceeded the required soil nutrients for the optimal growth of sweet potatoes. In some cases, despite the application of organic waste, some nutrients were still lower than the optimal soil nutrient's requirement for sweet potatoes; however, in such cases, the need for additional nutrient supplementation was significantly reduced. The FC+MHC treatment was more beneficial in terms of storage root yield and total biomass when compared to individual applications of the soil amendments or their combined application with inorganic fertilizer. There were indications that FC+MHC treatments enhanced the partitioning of dry biomass in favor of the storage roots. Although other treatments except MHC only significantly improved the yield of both cultivars of orange-fleshed sweet potato when compared to the control, the yield was generally lower than that of the FC+MHC treatment. All treatments altered the soil mineral content, the mineral content in the leaves, and the storage root of the 199062.1 cultivar. Both filter cake and macadamia husk compost may have negatively affected the absorption of Cu, Fe, and Al in the 199062.1 cultivar.

3.1. Effect of Soil Amendment on Soil Fertility

The target soil phosphorus in the initial soil (control) was lower than the required P. Hence, P in the initial soil fell short of the optimal P requirement for the growth of orange-fleshed sweet potatoes (Table 1). It has been reported that soil P reserve is good for the plant if the soil P test value is greater than or equal to the target P test value. Soil treatment with both organic wastes successfully corrected the P deficiency in the initial soil. Soil amendment with filter cake has not only increased soil P but also other soil nutrients such as extractable soil Ca and Mg [5,25]. Lack of adequate soil P is a common occurrence in the study area [22,28]. The initial soil used for the study contained enough K to produce sweet potatoes (Tables 1 and 2). It has been reported that a soil K test value $\geq$ target K value is an indicator that the soil contains good soil K for the test crop [30]. MHC-related treatments had more K in the soil than any other treatment (Table 1).

Concentrations of the micronutrients Mn (42.7 ppm), and Cu (5.1 ppm) were adequate to produce sweet potatoes in the study area [28]. However, the micronutrient Zn was deficient in the initial soil (Table 2), because its concentration of 1.1 fell below the 1.5 mg/L critical concentration required for sweet potato production in the study area [28]. The Zn deficiency was corrected by all the soil amendments that were applied. An increase in extractable soil Zn has also been reported in earlier research [5]. The increased concentration of the micronutrients Zn and Cu in the soil of FC-related treatments may be due to the high concentrations of Zn (102 mg/kg) and Cu (61.5 mg/kg) in the filter cake used for the study. The pH of the soil ranged between 5.31 (IF) and 5.75 (FC and FC+MHC). These pH ranges largely fell within the soil pH recommendation for the growth of the sweet potato. Although there were pieces of evidence of some little changes in soil acidity, density, and clay contents, the changes could not be associated with differences in the yield of the various soil amendment treatments (Table 2).

Table 1. Nutrients and lime recommendations on the soil in which 199062.1 cultivars of orange-fleshed sweet potato were grown.

Treatment	N		P			K			Lime				Zn
	Yield Target (t/ha)	Required N (kg/ha)	Sample Soil Test (mg/L)	Target Soil Test (mg/L)	Required P (kg/ha)	Sample Soil Test (mg/L)	Target Soil Test (mg/L)	Required K (kg/ha)	Sample Acid Saturation (%)	PAS (%)	Required Lime (t/ha)	Lime Type	Zn Fertilizer Required?
CONT	30	100	5.7 ^{a}	21	60	354 ^{ab}	150	0	1	10	0	-	Yes
FC	30	100	59.7 ^{b}	16.5	20	405 ^{ab}	150	0	1	10	0	-	No
MHC	30	100	116.3 ^{c}	17.5	20	795 ^{d}	150	0	1	10	0	-	No
IF	30	100	11.7 ^{a}	19	55	399 ^{ab}	150	0	1	10	0	-	No
FC+IF	30	100	53.7 ^{b}	17.5	20	339 ^{a}	150	0	1	10	0	-	No
MHC+IF	30	100	120.0 ^{c}	21	20	635 ^{c}	150	0	1	10	0	-	No
MHC+FC	30	100	52.7 ^{b}	17	20	461 ^{b}	150	0	1	10	0	-	No

The sample soil test and sample acid saturation reflect the soil test values of the sample analyzed. Required P and required K are the approximate amounts of P and K required to raise the soil test to the target value. Lime required is the amount of lime needed to decrease the soil acid saturation to the permissible acid saturation (PAS). The values of sample soil test along the same column with different letters are significantly different.

Table 2. Effect of combined application of filter cake, macadamia husk compost, and other treatments on the soil in which 199062.1 cultivars of orange-fleshed sweet potato were grown.

Treatment	* Density g/mL	P mg/L	K mg/L	Ca mg/L	Mg mg/L	Acidity cmol/L	Total Cations cmol/L	pH (KCl)	Zn mg/L	Mn mg/L	Cu mg/L	Carbon %	Nitrogen %	CN Ratio
CONT	1.09 ± 0.020 ^{b}	5.7 ± 0.3 ^{a}	354 ± 1 ^{ab}	1567 ± 30 ^{d}	549 ± 16 ^{c}	0.080 ± 0.006 ^{a}	13.34 ± 0.27 ^{c}	5.59 ± 0.009 ^{bc}	1.10 ± 0.00 ^{a}	42.7 ± 1.5 $_{abc}$	5.1 ± 0.2 $_{bc}$	2.60 ± 0.04 $_{cd}$	0.24 ± 0.002 $_{bc}$	10.92 ± 0.12 $_{a}$
FC	1.01 ± 0.003 ^{a}	59.7 ± 0.3 ^{b}	405 ± 2 ^{ab}	1299 ± 5 ^{bc}	424 ± 3 ^{a}	0.087 ± 0.003 ^{a}	11.09 ± 0.06 ^{ab}	5.75 ± 0.003 ^{c}	4.03 ± 0.12 ^{b}	41.3 ± 1.8 $_{ab}$	5.6 ± 0.1 ^{c}	1.97 ± 0.01 $_{b}$	0.11 ± 0.003 $_{a}$	17.41 ± 0.55 $_{b}$
MHC	0.99 ± 0.026 ^{a}	116.3 ± 1.5 ^{c}	795 ± 55 ^{d}	1254 ± 27 ^{ab}	473 ± 5 ^{abc}	0.080 ± 0.006 ^{a}	12.29 ± 0.06 ^{bc}	5.33 ± 0.084 ^{a}	3.73 ± 1.01 ^{ab}	48.7 ± 0.9 $_{c}$	4.6 ± 0.2 $_{ab}$	3.03 ± 0.21 $_{d}$	0.27 ± 0.025 $_{c}$	11.34 ± 0.25 $_{a}$
IF	1.04 ± 0.012 ^{ab}	11.7 ± 0.9 ^{a}	399 ± 14 ^{ab}	1431 ± 31 ^{cd}	522 ± 10 ^{bc}	0.060 ± 0.012 ^{a}	12.56 ± 0.22 ^{bc}	5.31 ± 0.033 ^{a}	2.70 ± 0.64 ^{ab}	40.3 ± 0.3 $_{ab}$	4.5 ± 0.1 $_{ab}$	2.25 ± 0.01 $_{bc}$	0.20 ± 0.000 $_{b}$	11.27 ± 0.04 $_{a}$
FC+IF	1.03 ± 0.025 ^{ab}	53.7 ± 6.4 ^{b}	339 ± 11 ^{a}	1118 ± 73 ^{a}	425 ± 29 ^{a}	0.077 ± 0.003 ^{a}	10.04 ± 0.63 ^{a}	5.67 ± 0.035 ^{c}	4.53 ± 0.75 ^{b}	36.3 ± 0.3 $_{a}$	4.8 ± 0.0 $_{ab}$	1.39 ± 0.02 $_{a}$	0.08 ± 0.000 $_{a}$	17.33 ± 0.29 $_{b}$
MHC+IF	1.10 ± 0.009 ^{b}	120.0 ± 4.9 ^{c}	635 ± 14 ^{c}	1401 ± 4 ^{bc}	508 ± 6 ^{bc}	0.070 ± 0.000 ^{a}	12.59 ± 0.28 ^{bc}	5.39 ± 0.043 ^{ab}	2.60 ± 0.36 ^{ab}	46.3 ± 2.6 $_{bc}$	4.4 ± 0.0 ^{a}	2.74 ± 0.00 $_{cd}$	0.25 ± 0.003 $_{bc}$	11.17 ± 0.12 $_{a}$
MHC+FC	1.03 ± 0.007 ^{ab}	52.7 ± 2.6 ^{b}	461 ± 22 ^{b}	1305 ± 19 ^{bc}	461 ± 25 ^{ab}	0.077 ± 0.003 ^{a}	11.65 ± 0.58 ^{abc}	5.75 ± 0.072 ^{c}	3.97 ± 0.03 ^{b}	43.0 ± 0.6 $_{bc}$	5.1 ± 0.2 $_{bc}$	1.82 ± 0.19 $_{ab}$	0.10 ± 0.012 $_{a}$	17.64 ± 0.32 $_{b}$

For each cultivar, means along the same column with different superscript letters were significant. * Density = bulk density.

Contrary to the report of [17], in this study there was no indication that filter cake increased the concentration of soil N, probably because of the relatively low N concentrations in the filter cake used for the study (Table 3). The relatively low N content of the filter cake used for the study may have been influenced by the type of sugarcane from which the filter cake was generated, the filtration process of the refinery, and the soil in which the canes were grown [9,18,31]. In both cultivars, C is significantly higher in MHC than in all other treatments. In both cultivars, the C/N ratio was significantly higher in FC, FC+IF, and FC+MHC in comparison to other treatments. A high C/N ratio is an indicator of higher C mineralization [32,33]. Hence, the better yield of the MHC+IF treatment when compared to MHC may be attributable to the IF component of the treatment. In this study, inorganic fertilizer may have also increased the mineralization of some other minerals contained in MHC. It has been reported that inorganic fertilizer expedites the mineralization of C in organic wastes [10,32]. Because the soil test was conducted after cropping, other factors that may have affected the soil composition include irrigation and cropping.

In this study, both filter cake and macadamia husk compost contain an array of soil nutrients, most of which were at the optimal level of soil nutrient sufficiency or within the fertilizer recommendation for sweet potatoes [28,34]. The concentrations of soil minerals such as sodium (Na), Fe, and Al were above the safe limits in the soil [35,36]. Although such higher-than-required/safe concentrations have been reported to be counterproductive, the higher concentrations were not of concern because organic nutrients are released slowly into the soil [20]. Also, in the case of Al, extractable acidity is comprised predominantly of exchangeable aluminum (Al^{3+}), which may have been neutralized, thereby protecting the plants from aluminum toxicity [37]. A reduction in Al concentration in soil because of filter cake application has also been reported [3].

3.2. Effects of Combined Application of Filter Cake and Macadamia Husk Compost on the Growth of Two Orange-Fleshed Sweet Potato Cultivars

In our earlier field research, the efficacy of both organic wastes was attributed to the array of nutrients (for filter cake) and the ability of the compost to hold water (for macadamia husk compost) [18]. In this study, we hypothesized that the test plants would harness both advantages, resulting in the yield of the combined application of both filter cake and macadamia husk compost (FC+MHC) surpassing that of all other treatments (FC, FC+IF, MHC, MHC+IF, IF, and CONT). This study confirmed the hypothesis. For instance, in Beauregard, the root mass, number of leaves, total biomass, and leaf area per plant were significantly higher than those of any other treatments. While the root mass in the FC+MHC treatment increased 2.6 folds, the root mass of FC, IF, FC+IF, and MHC+IF increased 1.96, 1.76, 2.24, and 1.94 folds, respectively (Table 4). In the 199062.1 cultivar, the number of leaves in the FC+MHC treatments was significantly higher than that of all other treatments. In other parameters such as root mass, leaf area, and total biomass, although the values for FC+MHC were generally higher than those of all other treatments, they shared some statistical similarity with FC+IF treatments. While the root mass of the FC+MHC treatment increased by 2.8 folds, that of the other treatments increased by 2.15 (FC), 1.8 (IF), 2.66 (FC+IF), and 1.98 (MHC+IF) folds (Table 4). In both cultivars, the higher root mass led to a reduced shoot/root ratio, and the changes in most of the investigated parameters because of MHC treatments were insignificant (Table 4).

Table 3. Mineral composition of filter cake and macadamia husk compost.

Organic Wastes	C (%)	S (%)	N (%)	Ca (%)	Mg (%)	K (%)	Na (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	P (%)	Al (mg/kg)	Moisture (%)	C:N Ratio
FC	6.5 ± 0.5^{a}	0.08 ± 0.02^{a}	0.15 ± 0.10^{a}	2.5 ± 0.3^{a}	0.50 ± 0.04^{a}	0.58 ± 0.08^{a}	798 ± 77^{a}	102 ± 8^{a}	61 ± 3^{a}	1030 ± 102^{a}	$22{,}146 \pm 2264^{a}$	0.65 ± 0.09^{a}	$16{,}920 \pm 1610^{a}$	40.1 ± 1^{a}	43.3^{a}
MHC	51.2 ± 0.4^{b}	0.04 ± 0.00^{b}	0.71 ± 0.29^{b}	1.3 ± 0.8^{a}	0.17 ± 0.09^{b}	0.59 ± 0.34^{a}	874 ± 480^{a}	74 ± 39^{a}	18 ± 9^{b}	174 ± 95^{b}	7332 ± 4397^{b}	0.19 ± 0.12^{b}	7462 ± 4595^{b}	55.8 ± 0.1^{b}	72.1^{b}

The values of minerals contained in filter cake (FC) and macadamia husk compost (MHC) along the same column with different letters are significantly different.

Table 4. Effect of combined application of filter cake, macadamia husk compost, and other treatments on the biomass, leaf area, number of leaves, and shoot/root ratio of Beauregard and 199062.1 cultivars of orange-fleshed sweet potato.

Cultivar	Treatment	Root Mass (g)	Shoot Mass (g)	Total Biomass (g)	Leaf Area (cm^2)	Number of Leaves	Shoot/Root Ratio
Beauregard	CONT	46.2 ± 2.3^{a}	16.8 ± 0.7^{a}	63 ± 3^{a}	2280 ± 134^{a}	32 ± 2^{a}	0.36 ± 0.02^{b}
	FC	90.5 ± 0.9^{b}	24.6 ± 1.1^{bc}	115 ± 1^{b}	3960 ± 42^{c}	55 ± 1^{c}	0.27 ± 0.01^{a}
	MHC	53.6 ± 2.3^{a}	20.2 ± 1.4^{ab}	74 ± 3^{a}	2928 ± 87^{b}	41 ± 1^{b}	0.38 ± 0.02^{b}
	IF	81.4 ± 1.0^{b}	25.6 ± 2.5^{bc}	107 ± 2^{b}	3816 ± 42^{c}	53 ± 1^{c}	0.32 ± 0.03^{ab}
	FC+IF	103.5 ± 2.1^{c}	24.3 ± 1.1^{bc}	128 ± 1^{c}	4176 ± 72^{c}	58 ± 1^{c}	0.24 ± 0.01^{a}
	MHC+IF	89.5 ± 2.7^{b}	26.6 ± 0.4^{c}	116 ± 3^{bc}	2928 ± 87^{b}	41 ± 1^{b}	0.30 ± 0.01^{ab}
	FC+MHC	121.5 ± 2.7^{d}	28.9 ± 0.3^{c}	150 ± 3^{d}	4872 ± 63^{d}	68 ± 1^{d}	0.24 ± 0.00^{a}
199062.1	CONT	88.0 ± 6.2^{a}	26.8 ± 1.4^{a}	115 ± 6^{a}	1852 ± 89^{a}	18 ± 1^{a}	0.31 ± 0.03^{b}
	FC	189.4 ± 10.3^{b}	42.9 ± 3.3^{b}	232 ± 14^{b}	4478 ± 89^{bc}	44 ± 1^{bc}	0.23 ± 0.01^{ab}
	MHC	92.1 ± 5.0^{a}	26.8 ± 0.1^{a}	119 ± 5^{a}	2155 ± 89^{a}	21 ± 1^{a}	0.29 ± 0.02^{b}
	IF	158.1 ± 5.5^{b}	39.6 ± 1.8^{b}	198 ± 6^{b}	4107 ± 121^{b}	41 ± 1^{b}	0.25 ± 0.01^{ab}
	FC+IF	234.3 ± 12.5^{c}	44.4 ± 2.4^{b}	279 ± 10^{c}	4848 ± 117^{c}	48 ± 1^{c}	0.19 ± 0.02^{a}
	MHC+IF	155.4 ± 6.5^{b}	37.5 ± 3.7^{ab}	193 ± 9^{b}	4141 ± 58^{b}	41 ± 1^{b}	0.24 ± 0.02^{ab}
	FC+MHC	246.0 ± 4.6^{c}	42.6 ± 1.7^{b}	289 ± 4^{c}	6430 ± 89^{c}	64 ± 1^{d}	0.17 ± 0.01^{a}

The means of the treatments (along same column) for same cultivar with different letters were significantly ($p < 0.05$) different.

From the above results of this study, FC+MHC was undoubtedly the best in terms of enhancing the growth and yield of both cultivars. This is noticeable in the following parameters: the production of more leaves, leaves with larger leaf areas (Table 4), and leaves with higher chlorophyll contents (Figure 1) when compared to the control. The factors that may have contributed to this may be the combined strength of the consortium of nutrients in both FC and MHC. While FC may have mineralized rapidly and provided the needed nutrients such as P and K at the early stages of plant growth, MHC may have mineralized later and supplied some critical minerals such as N and C (which had relatively low concentrations in filter cake) at the later stages of plant growth. Carbon plays a crucial role in photosynthesis as the primary source of energy. It is also a building block for plant nutrients such as starch, protein, and carbohydrate, which are very essential in sweet potato growth [38]. Nitrogen assists in cell division and the development of chlorophyll [38,39]. Earlier studies have suggested that filter cake mineralizes relatively rapidly while macadamia mineralization is very slow [18,20]. The FC+MHC treatment may have also benefited from the combined moisture contents of both filter cake and macadamia husk compost and their ability to hold soil moisture. The positive effect of filter cake on the soil and consequently plant growth has been reported to include increasing total porosity, cation exchange capacity, and water and nutrient retention capacities [40].

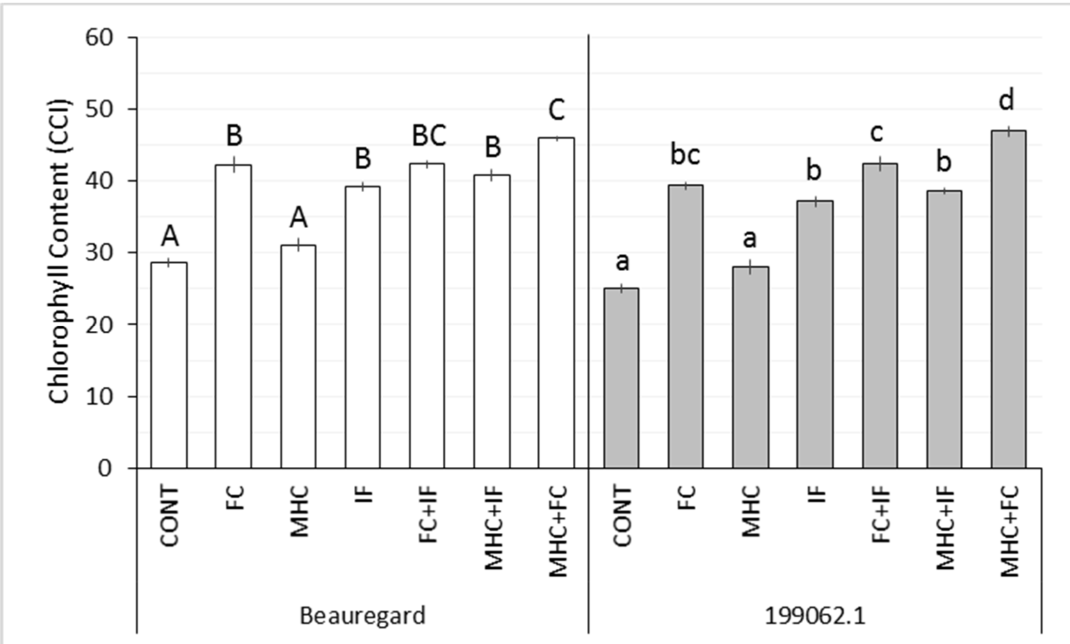

Figure 1. Effect of combined application of filter cake, macadamia husk compost, and other treatments on the chlorophyll content in the leaves of Beauregard and 199062.1 cultivars of orange-fleshed sweet potato. Each bar represents the average of the 6 chlorophyll content measurements taken per replicate and for the 3 replicates ($n = 18$) at 10 weeks after planting. Bars with different letters for each cultivar were significantly ($p < 0.05$) different.

Dry matter partitioning is a function of the flow of assimilates from source organs such as leaves through a transport path to the sink organs such as storage roots in sweet potatoes [41–43]. In this study, the partitioning of dry matter to the storage root was enhanced by the FC+MHC treatment in the 199062.1 cultivar. In Beauregard, in addition to FC+MHC, dry matter partitioning to the root was also favored by all filter cake-related treatments (FC, FC+IF, and FC+MHC). In Beauregard, the root of the plants of the FC+MHC treatments constituted 80.8% of the total biomass; FC and FC+IF had 78.6 and 80.9% of their total biomass partitioned to the root, respectively (Figure 2). Also in 199062.1, partitioning of dry matter to the storage root was significant in FC+MHC and FC+IF treatments, accounting for 85.2 and 84% of the total biomasses, respectively. MHC-only and IF-only treatments had the lowest influence on dry matter partitioning to the root when compared with other treatments and the control in both cultivars (Figure 2). The higher partitioning of the dry matter to the root in filter cake-related treatments may have been due to early initiation and faster growth of the storage roots [42]. Phosphorus, which is abundantly present in filter cake, has been implicated in promoting early root growth, stimulating tillering, and increasing water use efficiency [44]. The application of organic compost has been reported to favor the partitioning of dry matter to the root of sweet potatoes [41,42].

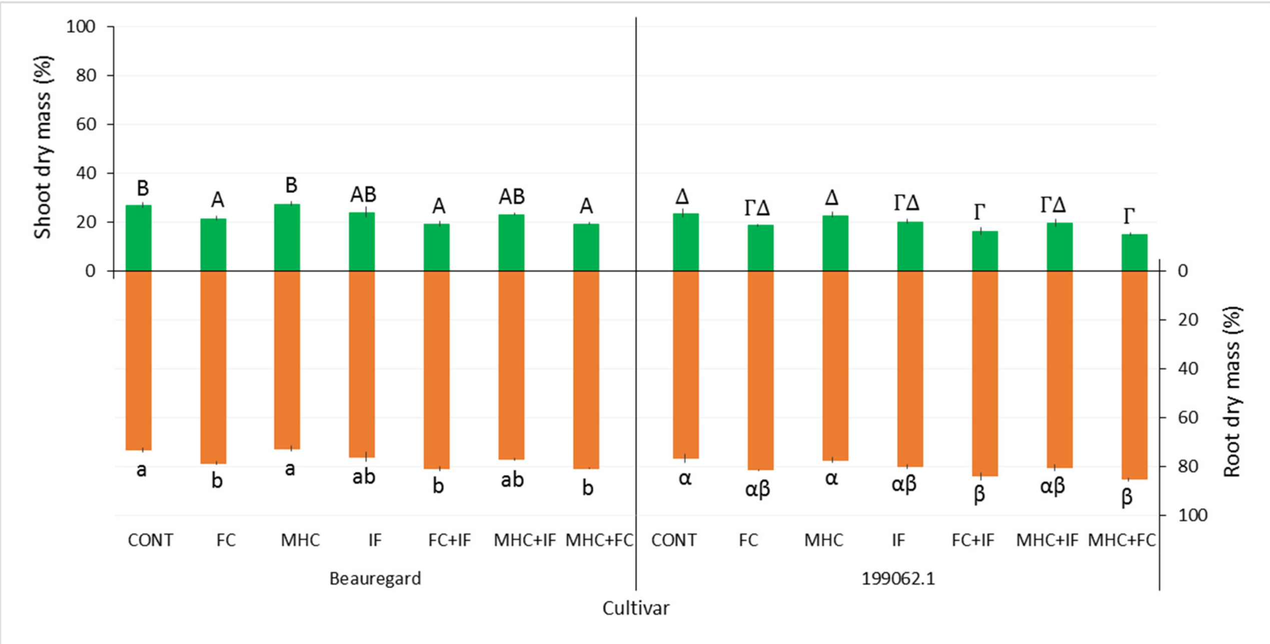

Figure 2. Effect of combined application of filter cake, macadamia husk compost, and other treatments on the dry matter partitioning of Beauregard and 199062.1 cultivars of orange-fleshed sweet potato. Each bar represents the average of each treatment. Bars along the same row with different letters/symbols for each cultivar are significantly ($p < 0.05$) different.

3.3. Effect of Soil Amendment on the Mineral Content in the Leaves and Storage Roots of 199062.1 Cultivar of Orange-Fleshed Sweet Potato

Combined application of filter cake and macadamia husk compost (FC+MHC) and other treatments investigated altered the nutrient content in the leaves and storage root of the 199062.1 cultivar of orange-fleshed sweet potato. It has been reported that the application of soil amendments alters the mineral content in the leaves and storage roots of plants [45]. However, it must be noted that the changes that occurred in the nutrient composition of the test plants were more prominent in the leaves when compared to the changes that occurred in the storage roots.

Although there were changes in the concentration of N in the leaves and storage roots in all the treatments, significant changes occurred only in the macadamia husk compost-related treatments. For instance, N concentration significantly increased 1.19-, 1.22-, and 1.25-folds in MHC, MHC+IF, and FC+MHC, respectively (Table 5). Also, in the storage roots of the test cultivars, N was significantly higher than the control in the FC+MHC treatment (Table 5). The increases in N concentration of the macadamia husk-related treatments may be attributable to the higher contents of N in macadamia husks (Table 4).

Table 5. Effect of the combined application of filter cake, macadamia husk compost, and other treatments on the mineral contents in the leaves and storage root of 199062.1 cultivar of orange-fleshed sweet potato.

Leaf/Root	Treatment	N (%)	Ca (%)	Mg (%)	K (%)	Na (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	P (%)	Al (mg/kg)
Leaf	CONT	3.73 ± 0.04 [a]	1.00 ± 0.01 [a]	0.59 ± 0.04 [a]	4.26 ± 0.03 [ab]	1026 ± 10 [a]	28.9 ± 0.6 [b]	21.3 ± 0.4 [b]	127 ± 1 [a]	721 ± 60 [b]	0.17 ± 0.01 [a]	1030 ± 3 [c]
	FC	4.16 ± 0.08 [ab]	1.02 ± 0.06 [a]	0.65 ± 0.06 [a]	4.72 ± 0.16 [abc]	615 ± 11 [a]	30.2 ± 1.4 [b]	16.7 ± 0.2 [a]	160 ± 1 [b]	348 ± 80 [a]	0.29 ± 0.01 [ab]	551 ± 28 [a]
	MHC	4.45 ± 0.09 [b]	1.13 ± 0.10 [a]	0.63 ± 0.01 [a]	4.26 ± 0.12 [ab]	919 ± 56 [a]	27.9 ± 1.0 [b]	15.3 ± 0.4 [a]	124 ± 3 [a]	334 ± 90 [a]	0.21 ± 0.01 [ab]	560 ± 11 [a]
	IF	3.78 ± 0.19 [a]	1.23 ± 0.21 [a]	0.55 ± 0.06 [a]	3.88 ± 0.31 [a]	987 ± 25 [a]	19.8 ± 0.6 [a]	14.7 ± 1.0 [a]	133 ± 7 [a]	533 ± 97 [ab]	0.20 ± 0.04 [ab]	884 ± 25 [b]
	FC+IF	4.30 ± 0.05 [ab]	1.17 ± 0.06 [a]	0.67 ± 0.02 [a]	5.19 ± 0.21 [c]	679 ± 52 [a]	31.2 ± 0.8 [bc]	16.1 ± 0.5 [a]	160 ± 1 [b]	418 ± 68 [a]	0.33 ± 0.01 [b]	563 ± 29 [a]
	MHC+IF	4.61 ± 0.12 [b]	1.38 ± 0.27 [ab]	0.64 ± 0.03 [a]	4.28 ± 0.19 [ab]	956 ± 35 [a]	28.3 ± 0.7 [b]	15.4 ± 0.3 [a]	127 ± 7 [a]	328 ± 40 [a]	0.20 ± 0.06 [ab]	577 ± 12 [a]
	FC+MHC	4.73 ± 0.18 [b]	1.97 ± 0.03 [b]	0.71 ± 0.03 [a]	4.96 ± 0.04 [bc]	1009 ± 57 [a]	34.6 ± 1.0 [c]	16.8 ± 0.6 [a]	167 ± 2 [b]	443 ± 35 [a]	0.47 ± 0.01 [c]	597 ± 39 [a]
Storage Root	CONT	0.97 ± 0.09 [a]	0.12 ± 0.01 [a]	0.10 ± 0.01 [a]	2.12 ± 0.06 [a]	789 ± 10 [a]	12.8 ± 0.2 [ab]	9.1 ± 0.2 [a]	18 ± 1 [a]	234 ± 6 [abc]	0.16 ± 0.01 [a]	287 ± 6 [b]
	FC	1.30 ± 0.06 [ab]	0.12 ± 0.00 [a]	0.13 ± 0.01 [ab]	2.38 ± 0.04 [a]	979 ± 2 [b]	13.2 ± 0.1 [ab]	9.9 ± 0.1 [ab]	21 ± 0 [b]	245 ± 2 [abc]	0.22 ± 0.03 [ab]	258 ± 6 [ab]
	MHC	1.23 ± 0.12 [ab]	0.13 ± 0.01 [a]	0.11 ± 0.01 [ab]	2.23 ± 0.19 [a]	837 ± 61 [a]	13.2 ± 0.2 [ab]	9.9 ± 0.7 [ab]	20 ± 1 [ab]	216 ± 3 [a]	0.17 ± 0.03 [ab]	253 ± 5 [ab]
	IF	1.39 ± 0.16 [ab]	0.13 ± 0.01 [a]	0.11 ± 0.01 [a]	2.37 ± 0.09 [a]	876 ± 22 [ab]	13.1 ± 0.1 [ab]	10.1 ± 0.6 [ab]	20 ± 1 [ab]	245 ± 2 [abc]	0.20 ± 0.03 [ab]	297 ± 8 [b]
	FC+IF	1.24 ± 0.16 [ab]	0.13 ± 0.00 [a]	0.14 ± 0.02 [ab]	2.43 ± 0.03 [a]	927 ± 27 [ab]	13.3 ± 0.1 [ab]	10.1 ± 0.5 [ab]	22 ± 1 [b]	259 ± 15 [c]	0.24 ± 0.04 [ab]	276 ± 28 [ab]
	MHC+IF	1.28 ± 0.12 [ab]	0.14 ± 0.01 [a]	0.11 ± 0.00 [ab]	2.15 ± 0.12 [a]	852 ± 27 [ab]	12.6 ± 0.3 [a]	10.4 ± 0.6 [ab]	21 ± 0 [b]	219 ± 4 [ab]	0.19 ± 0.01 [ab]	246 ± 6 [ab]
	MHC+FC	1.58 ± 0.07 [b]	0.16 ± 0.01 [a]	0.17 ± 0.01 [b]	2.52 ± 0.05 [a]	794 ± 12 [a]	13.6 ± 0.2 [b]	12.0 ± 0.1 [b]	21 ± 1 [b]	254 ± 12 [bc]	0.31 ± 0.04 [b]	224 ± 6 [a]

A MANOVA was performed across the 7 treatments. Means along the same column with different letters were significantly different ($p < 0.05$).

Although P and K altered the concentration of nutrients in both the leaves and storage roots of the cultivar, the changes were significant only in a few of the treatments (Table 5). In the leaves of 199062.1, there was a general increase in P concentration, but it was only significantly higher than the control in FC+MHC and FC+IF, where the concentrations increased 1.94- and 2.76-fold, respectively. In the storage root, the only significant increase in P in all the treatments occurred in the FC+MHC treatment. Both filter cake and macadamia husk are rich in P. In the process of mineralization, P may have been mineralized and absorbed by sweet potato plants [46].

The concentrations of Zn in the leaves and storage roots of the cultivars were not significant except for the concentration of Zn in the leaves of plants derived from FC+MHC treatment. There was a general increase in Mn concentrations in the leaves and storage roots of plants derived from MHC-related and FC-related treatments. However, most of the increases occurred in FC+MHC and some other FC-related treatments. For instance, significant increases of 14.2% (FC), 14.2% (IF), 22.2% (FC+IF), and 14.2% (FC+MHC) occurred in the storage roots of the 199062.1 cultivar.

Except for the IF treatment, there was a general decline in the concentrations of Cu, Fe, and Al in the leaves of plants derived from all other treatments (Table 5). For instance, in 199062.1, a significant decline of 46.5% (FC), 45.63% (MHC), 14.17% (IF), 47.96 (FC+IF), 43.98 (MHC+IF), and 42.04% (FC+MHC) occurred (Table 5). Also, the Al concentration in the leaves of the plants was significantly lower than what was obtainable in the control, declining by 46.5% (FC), 45.6% (MHC), 45.3% (FC+IF), 44% (MHC+IF), and 42% (FC+MHC) (Table 4). All these declines in Cu, Fe, and Al concentration in the leaves may have been responsible for a general non-significance in the concentration of Cu, Fe, and Al in the storage roots in most of the treatments investigated (Table 5). As earlier stated, both organic wastes are rich in P. Phosphorus has a high ability to adsorb to soil colloids and is also involved in joint precipitation with Fe, Al-oxides, and Al-hydroxides [24,46] All these may have accounted for the decline in the concentration of Cu, Fe, and Al in the leaves and consequently in the storage root of the plants (Table 5).

3.4. Conclusions and Recommendations

Previous research has indicated that filter cake and macadamia husk compost could improve the growth of orange-fleshed sweet potatoes either when applied alone or in combination with inorganic fertilizers [18]. The strength of filter cake was traceable to its array of nutrients, especially its ability to release those nutrients almost immediately [9]. The faster release of the nutrients in filter cake when compared to MHC is supported by the lower C/N ratio of FC (Table 3). It has been reported that the lower the C:N ratio, the higher the rate of mineralization of organic waste, leading to faster release of nutrients such as N into the soil for immediate crop use [47]. On the other hand, macadamia husk compost has a higher moisture content, the ability to form soil crumbs, and a higher water holding capacity when compared to filter cake. With their many benefits, both organic wastes would no doubt be beneficial to the drought-prone and podzolic soils of the KwaZulu-Natal coastal belt, where the study was located. Hence, this study was aimed at harnessing the benefits of the combined application of both organic waste (FC+MHC).

The results clearly indicated that the biomass of the combined application of filter cake and macadamia husk compost (FC+MHC) is greater than the biomass yield of individual applications (FC only and MHC only) and that of the combined application of either FC or MHC with inorganic fertilizer (FC+IF, MHC+IF). There were indications that partitioning of dry biomass to the storage root was favored by the FC+MHC treatment, which is of special advantage to farmers because orange-fleshed sweet potatoes are principally grown for their storage roots. All treatments investigated in this study altered the mineral composition of the soil, leaves, and storage roots of the 199062.1 cultivar of orange-fleshed sweet potato. This study successfully harnessed the benefits inherent in both organic wastes. The combined use of filter cake and macadamia husk compost (FC+MHC) to improve the yield of Beauregard and 199062.1 cultivars of orange-fleshed sweet potato and ameliorate the impact of drought is largely novel. Hence, it is currently being promoted among the resource-poor farmers of KwaZulu-Natal Province, South Africa. It is recommended that the effects of soil treatment with both amendments on phytonutrients such as carotenoids, total antioxidants, the ferric-reducing ability of plasma assays, total phenolics, and flavonoid concentrations be explored in future studies. The effects on other nutrients such as beta-carotene, ascorbic acid, soluble sugars, and starch also need to be explored. This study has taken the lead in addressing the twin problems of prevalent soil nutrient deficiency and drought that are daily confronting sweet potato farmers in the Northern KwaZulu-Natal province of South Africa.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available because this research is for the award of a degree and the study is still in progress.

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