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RESEARCH ARTICLE

Response of sweet potato (*Ipomoea batatas* L.) to the combined application of pulverized wood charcoal and inorganic fertilizer under upland acid soil

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Abstract

This study aimed to evaluate the performance of sweet potatoes to the combined application of pulverized wood charcoal (PWC) and inorganic fertilizer under acidic soil. To determine the appropriate fertilizer combination that can provide optimum productivity under acidic conditions, and assess the gross income of sweet potato production to the combined application of PWC and inorganic fertilizer under upland acid soil. An experiment was set out in a Randomized Complete Block Design (RCBD) with the following treatments: T_0- No fertilizer application (control), T_1- 45-45-45 kg ha^{-1} NPK, T_2- 5 t ha^{-1} PWC only, T_3 - 2.5 t ha^{-1} PWC + 45-45-45 kg ha^{-1} NPK, T_4- 2.5 t ha^{-1} PWC + 45-35-35 kg ha $^{-1}$ NPK, T_5- 2.5 t ha^{-1} PWC + 25-25-25 kg ha^{-1} NPK, T_6- 2.5 t ha^{-1} PWC + 25-15-15 kg ha^{-1} NPK. Sweet potato plants applied with inorganic fertilizers at the rate of 45-45-45 kg ha^{-1} NPK (T_1) achieved the longest main vine, broader LAI, and heaviest fresh herbage under upland acid soil but failed to produce high marketable root yield. The application of 2.5 t ha^{-1} PWC combined with 45-35-35 kg ha^{-1} NPK inorganic fertilizer (T_4) enhanced the marketable root yield (2.22 t ha^{-1}) of the sweet potato and gained the highest gross income (USD 1,776.00) compared to the other fertilizer combinations. Thereby, integrated nutrient management is an effective approach for sustainable and cost-effective management of sweet potato cultivation in acidic soil resulting in increasing soil fertility and productivity by contributing no negative effects on the environment.

Keywords: Acidity; Marginal soil; Organic; Pulverized Wood Charcoal.

1. Introduction

Sweet potato (*Ipomoea batatas* L.) is one of the major root crops cultivated in the country and is usually grown in the tropics in areas with sufficient available soil moisture. This crop is considered a drought-tolerant species that thrive in less fertile and acidic soils, particularly in upland conditions. The increasing population reduced the prime agricultural lands mostly uplands because these were converted into residential areas, malls, and factories. This problem leads farmers to cultivate marginal lands where soil tends to be acidic, clayey, and often not ideal for cultivation. These conditions pave the need to find ways to make them productive. Fertilizers for sweet potato production in these areas are necessary to attain better productivity. There are two types of fertilizer materials that are effective in improving soil fertility. These are inorganic and organic fertilizers that are useful materials for proper plant growth and development. Inorganic fertilizers are those materials that are produced synthetically and are readily absorbed by the plants when applied. Organic fertilizers, however, are those materials that can be produced from animal manure, compost, decomposed material, charcoal, and many more. Mclaurin *et al.* (2015) stated that decomposed materials can be used as fertilizer due to their nitrogen, phosphorus, and potassium contents even though in small amounts. On heavy

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or clay soils, compost improves aeration, and drainage and reduces waterlogging damage to plants. The fleshly root size of sweet potato is improved through the addition of farmyard manure (Boru *et al.*, 2017).

Organic fertilizers can be combined with inorganic fertilizers to enhance crop growth and yield performance. One of the materials that can be combined with inorganic fertilizer for sweet potato production is pulverized wood charcoal (PWC). Studies claimed that wood charcoal can increase the effectiveness of inorganic fertilizers. Charcoal can enhance the availability of P, convertible K, total nitrogen, organic carbon, and base saturation in soils which can be beneficial to crops (Ayodele, 2009). Charcoal-like material like biochar has a positive effect on the upland acid soils. Application of biochar derived from timber increased the retention of N in soil and uptake of N into crop biomass (Steiner *et al.*, 2008). Biochar can reduce the leaching of ammonium, maintaining it in the surface soil where it is available for plant uptake (Lehmann *et al.*, 2003). Increased nutrient retention on upland acid soils from the application of charcoal will result in increased fertility of acid soils, which likely increase crop vigor, and thus may enhance disease tolerance.

The charcoal application had beneficial effects on certain crops. According to Duo *et al.* (2012), the combined application of inorganic fertilizers and biochar to sweet potatoes increased the size, and weight and improves the sweetness of the fleshy roots. Yamato *et al.* (2006) suggested that charcoal application to soil can lead to the formation of carbon sinks which consequently increased crop yield because charcoal is highly resistant to abiotic and biotic degradation even in the soil environment.

In this context, this study was conducted to evaluate the response of sweet potatoes to the combined application of PWC and inorganic fertilizers under upland acid soil. Determine the appropriate combination that can provide optimum productivity under upland acid soil, and assess the profitability of sweet potato production to the combined application of PWC and inorganic fertilizers at various levels under upland acid soil.

2. Materials and methods

This study was conducted at Barangay Osmeña, Bato, Leyte, the Philippines where the soil is moderately acidic from January 09 to May 09, 2018. An experimental area was plowed and harrowed twice at a weekly interval to remove weeds, pulverized the soil, and improved soil tilth. Ridges were constructed at 0.20 m high at a distance of 0.75 m using a carabao-drawn implement.

Soil samples for initial soil analysis were taken from the experimental area through the use of cleaned shovels. Soil sample representatives were taken from ten sampling points ensuring that each sampling point represents the type of vegetation and a sampling depth of 20 cm. The samples were mixed and underwent quartering to get a composite sample. The composite sample was mixed again to get the sub-sample of the soil that was used for soil analysis. The samples were air-dried, sieved, and submitted for soil analysis at the Central Analytical Statistical Laboratory (CASL), PhilRootcrops, Visayas State University (VSU), Visca, Baybay City, Leyte, the Philippines for soil pH, organic matter, total nitrogen, usable P, and convertible K content.

The experimental field was set out in a Randomized Complete Block Design (RCBD) with three replications. Each replication was divided into seven treatment plots each measuring 4.5 m × 4.0 m (18.0 m^2) with six ridges per plot and 16 hills of sweet potato per ridge. An alleyway of 1.0 m and 0.5 m was constructed between replications and treatments, respectively to facilitate proper management and data gathering. The treatments were designated as follows:

T_0- No fertilizer application (control)

T_1- 45-45-45 kg ha^{-1} N, P_2O_5, K_2O

T_2- 5 t ha^{-1} Pulverized Wood Charcoal (PWC)
T_3- 2.5 t ha^{-1} PWC + 45-45-45 kg ha^{-1} N, P_2O_5 K_2O
T_4- 2.5 t ha^{-1} PWC + 45-35-35 kg ha^{-1} N, P_2O_5 K_2O
T_5- 2.5 t ha^{-1} PWC + 25-25-25 kg ha^{-1} N, P_2O_5 K_2O
T_6 -2.5 t ha^{-1} PWC + 25-15-15 kg ha^{-1} N, P_2O_5, K_2O

Charcoal was purchased at Barangay Osmeña, Bato, Leyte which was made up of assorted woods out of ipil-ipil (*Leucaena leucocephala)*, kakawate *(Gliricidia sepium),* and gmelina (*Gmelina arborea*). It was pulverized using improvised mortar and pestle. A 30 cm wide high wooden tablet served as mortar and 20 cm diameter timber was used as pestle. After the wood charcoal had been pulverized, it was sieved in a 0.5 mm screen net to attain uniformity.

Pulverized wood charcoal was applied three days before the establishment of sweet potato while inorganic fertilizers; i.e., urea (46-0-0) ammophos (16-20-0), and muriate of potash (0-0-60) were applied through side-dressing two weeks after planting. Top cuttings (matured vines) of sweet potato (NSIC Sp30) of about 25-30 cm in length were used. The cuttings were prepared one day before planting and these were planted in the ridges (0.75 cm distance) with at least one-third of the cuttings buried in the soil at a distance of 0.25 m apart.

Hand weeding was manipulated using bolo and the first-hand weeding operation was done 2-3 weeks after planting. The next hand weeding operation was done two months after planting. However, in attaining good soil aeration, off-barring was done two weeks after planting. This was followed by hilling up one week after off-barring to loosen the soil, control weeds, and facilitate the enlargement of storage roots. There was no further cultivation after the said operations to avoid disturbances of the soil which may affect the further development of storage roots. A drainage canal was constructed around the experimental area and between replication to drain excess water and prevent waterlogging during rainy days.

All plants from the four inner rows in each plot, excluding one plant at both ends in each row were harvested at maturity (120 days after planting). The roots within the harvestable area were dug after cutting the vines. Extra care was observed to minimize the damage to the fleshy roots. Soils adhering to the fleshy roots were removed gently. The roots were classified into marketable and non-marketable roots. Marketable roots are those roots that measure at least 6.5 cm in length, with a root diameter of 2.5 cm, free of mechanical injuries and damage from insect pests and diseases. Non-marketable roots are those roots that do not pass the marketable size standard including those large-sized roots with damages and abnormalities caused by pests and other environmental factors.

2.1. Data Gathered

2.1.1. Agronomic Characteristics

The agronomic parameters gathered were the length (cm) of the main vine at harvest, the number of primary lateral vines per plant, leaf area index (LAI), and fresh herbage yield (t ha^{-1}). For an in-depth data gathering of LAI, this was gathered through an actual data gathering protocol, to wit:

Leaf area index (LAI) - is the ratio of the leaf area to the ground area occupied by the crop within the quadrat of 50 cm × 50 cm. Only one quadrat was used per treatment plot to measure the LAI. This was gathered 60 days after planting by measuring the fully opened and functional leaves within the 50 cm × 50 cm quadrat. The product of the length and width was multiplied by the correction factor of 0.59 (Bocboc, 2007). The leaf area index was calculated by using the formula:

$$\text{Leaf Area Index} = \frac{\text{Total leaf area} = \sum \text{L} \times \text{W} \times \text{CF}\ (0.59)}{\text{Area of the quadrat}\ (50\ \text{cm} \times 50\ \text{cm})}$$

2.1.2. Yield and Yield Components and Harvest Index

The yield and yield components gathered in these parameters are the number of marketable and non-marketable roots per hill, the weight (t ha^{-1}) of marketable and non-marketable roots per hill, and the total root yield (t ha^{-1}), and the harvest index (HI). The weight of marketable and non-marketable roots per hectare was calculated per plot basis. Then, the weight was converted into tons per hectare by using the formula.

$$\text{Root Yield (t ha}^{-1}\text{)} = \frac{\text{Plot yield kg plot}^{-1}}{\text{Harvestable area (10.5 m}^2\text{)}} \times \frac{10{,}000\ \text{m}^2\ \text{ha}^{-1}}{1{,}000\ \text{kg ton}^{-1}}$$

2.2. Gross Income Analysis, Meteorological Data, and Statistical Analysis

Gross income was determined by multiplying the marketable root yield (t ha^{-1}) of each treatment plot by the current price of the fleshy roots.

Data on weekly rainfall (mm), the daily average temperatures °C (minimum and maximum), as well as % relative humidity from planting up to harvesting, were obtained from the records of the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) Station, Capitol Site, Maasin City, Southern Leyte, Philippines.

All the data gathered were computed and analyzed using the ANOVA of RCBD and run completely using a Statistical Tool for Agricultural Research (STAR). A comparison of means was done using Tukey's HSD test.

3. Results and discussion

3.1. Climatic Conditions

The data on the total weekly rainfall (mm), average daily minimum and maximum temperatures (°C), and relative humidity during the conduct of the study were taken from PAGASA Station, Capitol Site, Maasin City, Southern Leyte (Table 1). The entire duration of this study had a total weekly rainfall of 1,218.6 mm, weekly minimum and maximum temperatures ranged from 23.05 - 24.81 and 27 - 31.78 °C respectively, and relative humidity ranged from 80.57 - 89.14 %.

The average temperature and relative humidity in the area were both favorable for the vegetative growth of the crop. According to Ramirez, (1991), sweet potato grows well in temperatures that ranged from 25 - 30 °C during the day while at 15 - 20 °C during the night. Meanwhile, the data suggest that the weekly rainfall during the first, second, fifth, and seventh weeks experienced heavy rainfall resulting in excess water in the experimental area. Feriol, (2015) mentioned that sweet potato thrives well with total rainfall from 750 – 1,050 mm. In this study, the total rainfall was abundant which is 168.6 mm higher than the recommended. To prevent losses of fertilizers from designated plots, dikes were constructed around treatment plots. Although heavy rainfall was experienced during the first and second week of the experiment, the nutrients of the applied fertilizer were retained due to the presence of pulverized wood charcoal as observed during the 3rd week from planting wherein the variation of plant growth was evident. Plants applied with 2.5 t ha^{-1} + 25-25-25 kg N, P_2O5, and K_2O ha^{-1} (T_5) showed greener and more developed leaves compared to those plants applied with inorganic fertilizer alone at the rate of 45 - 45- 45 kg ha^{-1} N, P_2O K_2O (T_1).

Table 1. Total weekly rainfall (mm), relative humidity (%), and average daily minimum and maximum temperatures (°C) from planting to maturity of sweet potato (January 9, 2018, to May 9, 2018)

Week No.	Relative Humidity (%)	Rainfall (mm)	Air Temperatures (°C)	
			Minimum	Maximum
1	87.28	105.00	23.64	28.00
2	89.14	196.80	23.10	27.00
3	88.42	58.20	23.22	27.25
4	85.71	67.80	23.05	29.42
5	82.57	311.60	23.58	29.40
6	83.71	20.60	24.00	28.68
7	84.71	116.00	23.41	29.62
8	83.00	2.20	24.14	31.32
9	80.57	72.80	23.61	30.01
10	80.71	13.60	24.15	30.37
11	86.71	57.60	23.20	30.01
12	86.28	58.80	23.40	29.37
13	85.71	41.40	24.04	29.72
14	82.14	6.40	24.64	31.78
15	84.42	31.80	24.74	30.65
16	82.14	24.80	24.35	31.38
17	85.85	33.20	24.81	30.40
Total	1,439.07	1,218.60	405.08	494.38
Mean	84.65	71.68	23.82	29.08

3.2. Soil Analysis

The initial soil analysis of the experimental area showed that it had a pH value of 5.20, organic matter of 0.55%, total nitrogen of 0.063%, usable phosphorous content of 1.340 mg kg^{-1}, and convertible K content of 0.067 $me100g^{-1}$ (Table 2). The initial soil analysis indicated that the soil had very low total nitrogen, usable phosphorous, OM, and convertible potassium contents while having strongly acidic soil. Final soil analysis revealed that the soil pH reduced from 5.20 to 5.09 while there was a clear reduction in the amounts of usable P, total N, organic matter, and convertible K in unfertilized plots. However, there was an increase in the amounts of organic matter and convertible K but only a slight increase in the percent total N of the fertilized plots. The decrease in the amounts of usable P, total N, organic matter, and convertible K in unfertilized plots might be due to the utilization of nutrients by the growing crop. However, an increase in the amounts of organic matter and convertible K in fertilized plots might be attributed to the application of PWC and inorganic fertilizer in the aforementioned plots. The result of the final soil analysis is construed with the output of Jing *et al.* (2013) that combined application of biochar with inorganic fertilizer increased soil pH, soil organic carbon, and available P contents at booting, flowering, and ripening stages of oil rape plants. According to Ding *et al.*, 2013, the application of biochar could not only improve the soil pH, and increase soil organic matter content but can also affect soil microbial community structure including the abundant proliferation of soil microorganisms (bacteria & fungi). They further stipulated that biochar application could improve the soil environment and soil microorganisms eventually resulting in promoting the soil microbial ecological system.

Table 2. Soil analysis of the experimental area before and after planting of sweet potato (NSIC Sp-30) as influenced by the combined application of pulverized wood charcoal and inorganic fertilizer

Treatment	Soil pH (1:2.5)	Organic Matter (%)	Total N (%)	Usable P (mg kg^{-1})	Convertible K (me100 g^{-1})
Initial Composite	5.20	0.55	0.063	1.34	0.067
T_0 = Control (No fertilizer application	5.02	0.51	0.03	0.54	0.06
T_1 = 45-45-45 kg N, P_2O_5, K_2O ha^{-1}	5.13	0.75	0.07	0.61	0.18
T_2= 5 t ha^{-1} Pulverized Wood Charcoal	5.12	0.56	0.06	0.06	0.14
T_3 = 2.5 t ha^{-1} PWC + 45-45-45 kg N, P_2O_5, K_2O ha^{-1}	5.11	0.59	0.07	0.51	0.26
T_4 = 2.5 t ha^{1} PWC + 45-35-35 kg N, P_2O_5, K_2O ha^{-1}	5.12	0.57	0.05	0.62	0.34
T_5 = 2.5 t ha^{1} PWC + 25-25-25 kg N, P_2O_5, K_2O ha^{-1}	5.12	0.69	0.06	0.44	0.19
T_6 = 2.5 t ha^{1} PWC + 25-15-15 kg N, P_2O_5, K_20 ha^{-1}	4.99	0.54	0.04	0.40	0.14
Mean	5.09	0.70	0.06	0.62	0.21

3.3. Agronomic Characteristics

Statistical analysis revealed that the length of main vines (cm), leaf area index (LAI), and fresh herbage yield (t ha^{-1}) were markedly affected by the treatments adopted but not by the number of primary lateral vines (Table 3). Sweet potato plants applied with 45-45-45 kg ha^{-1} N, P_2O_5, and K_2O (T_1) significantly achieved the longest main vine length of 273.54 cm compared to all other treatments especially on unfertilized control (T_0) with the main vine length of 65.60 cm. According to Brobbey, (2015), sweet potato plants increase their main vine length and leaf area when applied with complete fertilizer where nitrogen element is present and is readily available for plants as compared to organic farmyard manure which had a slow release of nutrients to the soil. For LAI, sweet potato plants applied with 2.5 t ha^{-1} PWC and 45-35-35 kg ha^{-1} N, P_2O_5, and K_2O (T_4) developed the largest LAI than that of unfertilized plants (T_0), and plants applied with pure PWC at the rate of 5 t ha^{-1} (T_2). This was comparable to those plants that adopted a combined application of PWC at 2.5 t ha^{-1} and varying rates of inorganic fertilizers (T_3, T_5, and T_6) and also those plants applied with pure inorganic fertilizer (T_1). The treatments with inorganic fertilizer increased in agronomic characteristics of sweet potato but not so much on its yield and yield components.

The result could be attributed to the fact that the application of pure inorganic fertilizer at the rate of 45-45-45 kg ha^{-1} N, P_2O_5, and K_2O (T_1) developed longer main vines and produced larger LAI and this might have contributed to significant differences in fresh herbage yield than that of all other treatments. The differences in the aforementioned parameters could be attributed to a different amount of macronutrients that supported the growth and development of the longer main vine, broader LAI, and higher fresh herbage yield of sweet potato in marginal upland acid soil.

Relative to herbage yield (t ha^{-1}), plants applied with pure inorganic fertilizer at the rate of 45-45-45 kg ha^{-1} N, P_2O_5, K_2O (T_1) produced significantly heaviest herbage yield of 8.92 t ha^{-1} followed by T_5 and T_4 plants with 5.88 kg ha^{-1} and 5.48 kg ha^{-1}, respectively. On the other hand, the lowest herbage yield was obtained in control plants (T_0) with only 0.82 t ha^{-1}, but comparable to plants applied with 2.5 t ha^{-1} PWC + 25-15-15 kg ha^{-1} N, P_2O_5, K_2O (T_6). The result of the study construed with the report of Roba, (2018) stipulated that inorganic fertilizer provides urgent and fast effects to the fertilized crops due to the availability of accessible nutrients for crop growth and development.

Table 3. Agronomic characteristics of sweet potato (NSIC Sp-30) as influenced by the combined application of pulverized wood charcoal and inorganic fertilizer

Treatment	Length (cm) of main vines	Number of primary lateral vines	Leaf area index	Fresh herbage yield (t ha^{-1})
T_0 = Control (No fertilizer application	65.60 e	1.37	0.22 c	0.82 e
T_1 = 45-45-45 kg N, P_2O_5, K_2O ha^{-1}	273.54 a	3.77	1.14 a	8.92 a
T_2 = 5 t ha^1 PWC only	109.73 d	2.17	0.57 b	3.38 cd
T_3 = 2.5 t ha^{-1} PWC + 45-45-45 kg N, P_2O_5, K_2O ha^{-1}	132.55 cd	3.80	0.83 bc	4.38 bc
T_4 = 2.5 t ha^1 PWC + 45-35-35 kg N, P_2O_5, K_2O ha^{-1}	167.48 c	2.63	1.16 a	5.48 b
T_5 = 2.5 t ha^1 PWC + 25-25-25 kg N, P_2O_5, K_2O ha^{-1}	220.28 b	3.90	1.12 a	5.88 b
T_6 = 2.5 t ha^1 PWC + 25-15-15 kg N, P_2O_5, K_20 ha^{-1}	139.15 cd	2.27	0.82 bc	1.33 de
Mean	158.33	2.84	0.84	4.31
CV (%)	7.98	46.33	20.36	16.67

3.4. Yield and Yield Components and Harvest Index

The yield and yield components and harvest index of sweet potato particularly the number of marketable and non-marketable roots, marketable root yield (t ha-^{1}), and total root yield (t ha^{-1}) were significantly influenced by the combined application of PWC and varying rates of inorganic fertilizers under upland acid soil (Table 4). However, the non-marketable root yield and harvest index were not significantly affected by the treatments tested. Sweet potato plants applied with 2.5 t ha^{-1} PWC + 45- 35- 35 kg ha^{-1} N, P_2O_5, and K_2O (T_4) obtained significantly a greater number of marketable roots per plot of 11.67 compared to all treatments except those plants applied with combined application of PWC and inorganic fertilizers at the rate of 2.5 t ha^{-1} + 25-25-25 kg ha^{-1} N, P_2O_5, K_2O (T_5). In terms of the number of non-marketable roots per hectare, plants under T_5, T_4, and T_1 produced a greater number of non-marketable roots and are comparable to those plants in T_3, T_6 and T_2 applied purely with PWC at the rate of 5 t ha^{-1}.

The marketable root yield (t ha^{-1}) of sweet potato plants fertilized at 2.5 t ha^{-1} PWC + 45- 35- 35 kg ha^{-1} N, P_2O_5, K_2O (T_4) produced significantly the highest marketable roots of 2.22 t ha^{-1} followed by plants applied with 2.5 t ha^{-1} + 45-45-45 kg ha^{-1} N, P_2O_5, K_2O (T_3) with 1.90 t ha^{-1} than that of other treatments, especially unfertilized plants that failed in producing marketable roots.

Table 4. Yield and yield components and the harvest index of sweet potato (NSIC Sp30) as influenced by the combined application of pulverized wood charcoal and inorganic fertilizer

Treatment	Root number plot^{-1}		Root yield (t ha^{-1})		Total root yield (t ha^{-1})	Harvest index
	Marketable	Non Marketable	Marketable	Non Marketable		
T_0 = Control (No fertilizer application	0 d	4 b	0 d	0.07	0.07 c	0.21
T_1 = 45-45-45 kg N, P_2O_5, K_2O ha^{-1}	4 cd	30 a	0.47 cd	1.50	1.97 abc	0.55
T_2 = 5 t ha^1 PWC only	5 bc	16 ab	0.48 cd	1.21	1.69 abc	0.59
T_3 = 2.5 t ha^{-1} PWC + 45-45-45 kg N, P_2O_5, K_2O ha^{-1}	5 bc	28 ab	1.90 ab	1.25	3.15 ab	0.69
T_4 = 2.5 t ha^1 PWC + 45-35-35 kg N, P_2O_5, K_2O ha^{-1}	11.67 a	34 a	2.22 a	1.99	4.22 a	0.67
T_5 = 2.5 t ha^1 PWC + 25-25-25 kg N, P_2O_5, K_2O ha^{-1}	8.33 ab	37 a	1.09 bc	1.51	2.59 abc	0.55
T_6 = 2.5 t ha^1 PWC + 25-15-15 kg N, P_2O_5, K_20 ha^{-1}	3.0 cd	20 ab	0.47 cd	0.70	1.17 bc	0.66
Mean	5.29	24.14	0.95	1.17	2.12	0.56
CV (%)	27.02	34.48	38.02	61.48	43.48	34.46

As for the total root yield, plants applied with combined fertilization of PWC at 2.5 t ha^{-1} and inorganic fertilizer at the rate of 45-35-35 kg ha^{-1} N, P_2O_5, K_2O (T_4) produced markedly the highest total root yield of 4.22 t ha^{-1} compared to unfertilized plants (T_0) and plants applied with

2.5 t ha^{-1} PWC + 25-15-15 kg ha^{-1} N, P_2O_5, K_2O (T_6). The lowest yield recorded was on plants receiving no fertilizer (T_0). The high total root yield of sweet potato in T_4 plants was attributed mainly to the abundant number of marketable roots produced in the aforementioned treatment.

The result of the study proved the findings of Yamato *et al.* (2006) in their statement that cowpea and peanut yields were abundant when applied with charcoal and inorganic fertilizers. Similarly, Oguntunde *et al.* (2003) reported that the application of charcoal increased the yield and biomass of maize. According to Duo *et al*. (2012), the combined application of biochar and inorganic fertilizers to sweet potatoes increased the size, and weight, and improve the sweetness of the fleshy roots. The higher marketable and total root yields of sweet potato, proved the findings of Yamato *et al.* (2006) as they suggested that charcoal application into the soil can lead to the formation of carbon sinks which consequently increased crop yield because charcoal is highly resistant to abiotic and biotic degradations in a given soil environment. The result of the study was realistic since according to Trupiano *et al.* (2017) mentioned that even the application of biochar alone can suffice the need for fertilized plants to achieve remarkable plant growth and biomass yield. Zhao *et al.* (2011) confirmed that the combined use of organic and inorganic fertilizers increases the product ranges from 0.8% to 9.4% when compared to a single application of synthetic fertilizer.

3.5. Cost and Return Analysis

The cost and return analysis of sweet potato production as influenced by the combined application of PWC and inorganic fertilizers under upland acid soil are shown in Table 5. Sweet potato plants applied with 2.5 t ha^{-1} PWC and 45-35-35 kg ha^{-1} N, P_2O_5, and K_2O (T_4) obtained the highest gross income of USD 1,776.00 followed by plants with similar rates of PWC (2.5 t ha^{-1}) and fertilized with 45-45-45 kg ha^{-1} N, P_2O_5, K_2O (T_3) with USD 1,520.00 due to higher marketable root yields of 2.22 t ha^{-1} and 1.90 t ha^{-1}, respectively. Plants that received no PWC and inorganic fertilizer (T_0) had no gross income due to the non-production of marketable roots.

Table 5. Gross analysis (USD) ha^{-1} on sweet potato (NSIC Sp-30) production as influenced by the combined application of pulverized wood charcoal and inorganic fertilizer

Treatment	Marketable Roots (t ha^{-1})	Gross Income (USD)
T_0 = Control (No fertilization)	0	0
T_1 = 45-45-45 kg N, P_2O_5, K_2O ha^{-1}	0.47	376.00
T_2 = 5 t ha^1 PWC only	0.48	384.00
T_3 = 2.5 t ha^{-1} PWC + 45-45-45 kg N, P_2O_5, K_2O ha^{-1}	1.90	1,520.00
T_4 = 2.5 t ha^1 PWC + 45-35-35 kg N, P_2O_5, K_2O ha^{-1}	2.22	1,776.00
T_5 = 2.5 t ha^1 PWC + 25-25-25 kg N, P_2O_5, K_2O ha^{-1}	1.09	872.00
T_6 = 2.5 t ha^1 PWC + 25-15-15 kg N, P_2O_5, K_20 ha^{-1}	0.47	376.00

Price of sweet potato roots = US Dollar 0.80 kg^{-1} at PHP 50.00 per 1 US Dollar

4. Conclusion

The sweet potato was significantly affected by the different fertilizer combinations most especially in all agronomic parameters except the number of primary lateral vines when grown under upland acid soil. The yield and yield parameters of the crop were significantly increased by the treatments applied especially on plants applied with $2.5\ t\ ha^{-1}$ PWC + 45-35-35 $kg\ ha^{-1}$ N, P_2O_5, K_2O (T_4). Thus, the T_4 significantly produced higher marketable roots (2.22 t ha^{-1}) and total root yield (4.22 t ha^{-1}) and achieved the highest gross income of USD 1,776.00.

5. Recommendation

For sweet potato production under upland acid soil, it is recommended that the adoption of a combined application of PWC at 2.5 t ha^{-1} and inorganic fertilizers at the rate of 45-35-35 kg ha^{-1} N, P_2O_5, K_2O (T_4) to produce an abundant yield of marketable roots. Application of PWC for sweet potato production is recommended in upland acid soil since we speculated that this material can neutralize acidity and might favor the utilization of the macronutrients present in the acidic soil for better plant growth and root development.

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Institutional Review Board Statement

All Institutional Review Board Statements are confirmed and approved.

Data Availability Statement

Data presented in this study are available on fair request from the respective author.

Ethics Approval and Consent to Participate

This work was carried out in the Agronomy department and followed all the department instructions.

Consent for Publication

Not applicable.

Conflicts of Interest

The authors disclosed no conflict of interest starting from the conduct of the study, data analysis, and writing until the publication of this research work.

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