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Effect of Combined Application of Organic Farming Aid (OFA) and Inorganic Fertilizers on the Growth and Yield of Maize and Soil Microbial Properties in the Guinea Savannah Agro-Ecological Zone of Ghana

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Abstract

The aim of the study was to evaluate the effect of different rates of organic farming aid (OFA) and inorganic fertilizer on the productivity of maize, chemical and microbial properties of soil for higher economic value. Field experiments were conducted during the 2020 and 2021 cropping seasons at the research fields of CSIR-Savanna Agricultural Research Institute located at Nyankpala in the Guinea savannah agroecology of Ghana. The study consisted of five treatment combinations: full rate of OFA, full rate of NPK, ½ OFA + ½ NPK, full OFA + ½ NPK and a control (no OFA and no NPK) which were arranged in a randomized complete block design with four replications. Analysis of variance indicated significant ($P < 0.05$) treatment and year interaction effect for all the growth parameters except for plant height, leaf area and leaf area index. Apart from hundred seed weight, treatment and year interaction effect for all the yield and yield components was significant ($P < 0.05$). Application of full rate of NPK (90:60:60) resulted in the highest grain yield of 4960 $Kg \cdot ha^{-1}$, however it was statistically similar to those obtained by the combined application of full rate of OFA (250 $ml \cdot ha^{-1}$) + ½ NPK and ½ OFA + ½ NPK with grain yield of 4856 $kg \cdot ha^{-1}$ and 4639 $kg \cdot ha^{-1}$ respectively. There was also a yield advantage of 197. 5%, 191.3%, 178.3 and 79.1% over the control for full NPK rate, full OFA rate + ½ NPK rate, ½ OFA rate + ½ NPK and full OFA rate respectively. Application of full OFA rate + ½ NPK enhanced soil basal respiration (evolved CO_2) and mineralizable C, implying that, combination of full OFA rate and NPK fertilizer would be necessary to boost soil microbial activity and soil labile nutrient pool (labile C pool). This suggests that combined use of full OFA rate + ½ NPK fertilizer can be a better strategic tool for improving soil quality. The highest benefit cost ratios (BCR) of 2.58 and 3.77 were obtained following the application of full OFA rate + ½ NPK and ½ OFA rate + ½ NPK respectively. Hence, it could be concluded that complementary use of OFA and NPK is more profitable than using single inputs (either OFA or NPK). Thus, in promoting technology packages to farmers, development practitioners must carefully consider the complementary of inputs that are cost-effective but economically rewarding.

Keywords

Organic Farming Aid, Labile C Pool, Wood Vinegar, Combined Application

1. Introduction

Maize (*Zea mays* L.) is a cereal crop that is cultivated world-wide in a wide range of agro ecological zones. It was introduced into Africa in the 1500s and has since become one of Africa's dominant food crops. It is the most important cereal crop of the world, grown in irrigated and rain-fed areas [1]. Maize is considered a very significant cereal crop and probably has the greatest yield potential among crops in sub-Saharan Africa (SSA) as it occupies more than 50% of aggregate land given entirely to crop production [2]. In Ghana, maize is an important food crop in the domestic market accounting for more than 50% of the country's total cereal production [3]. The bulk of maize produced goes into food consumption and it is arguably the most important food security crop with annual per capita consumption estimated at about 75.91 kilograms in 2020 [4] [5]. According to the Millennium Development Authority [6], maize is the most important commodity crop in the country, second only to cocoa. It contains about 72% of starch, 10% of protein, 4% of fat and 365 Kcal 100 g^{-1} energy density [7]. Notwithstanding the enormous importance of maize to Ghana's economy and food security, yields stand at 1.73 metric ton/ha and 1.92 metric ton/h according to reports from [8] and [9], respectively. The gap between potential and actual yields in Ghana remains large for almost all staple crops. This is due to several interrelated factors, including climate change and declining soil fertility.

Although most soils in Ghana are low in plant nutrients, the situation is worse in the Sudan and Guinea savannah agro-ecological zones of the country [10]. Soils of northern Ghana are low in organic matter and hence soil fertility is generally low [11]. Other studies have also reported that farmers in northern Ghana have often mentioned low soil fertility as a major challenge for producing cereals such as maize in the area [12]. In the past, fallow periods were generally employed for soil reclamation. This practice usually requires a long period ranging from at least 5 years to more than 10 years [13]. However, increasing pressure on land has resulted in the shortening of fallow duration [14]. As such, land availability is of prime importance and determines the length of time the soil can be allowed to recuperate [13]. Consequently, the use of inorganic fertilizers has become one of the strategies adopted to improve the soil fertility status and in turn improve yields of crops in recent times [5].

Nonetheless, enhancing crop growth and yield through the application of mineral fertilizers is a well-known practice among farmers but rising cost and unavailability of mineral fertilizers are the major problems limiting its use among small holder farmers in the study area. However, sustainable agriculture is advanced where the maximum output is gained at the minimal cost [15]. Additionally, excessive use and dependence on inorganic fertilization do not only result in decrease soil organic matter, acidity, soil degradation through soil nutrient imbalance and nutrients uptake, but also keep most residues in vegetables thus, decreasing the quality and security of our food supply [7] [16]. Hence, intensification strategies to increase crop productivity while protecting the environment have become essential to attaining agricultural growth, food needs and nutrition security [17] [18] [19]. As a result, an integration of chemical fertilizer with organic materials has great potential for soils with low levels of organic matter [20] [21]. In addition, the use of organic amendments comprising of crops, stems, straw, green manure, compost, sewage sludge is a viable and effective soil amelioration strategy [22].

In view of this, an alternative approach involving the use of an organic product known as Organic Farming Aid (OFA) that could be integrated into the farming system in order to increase the productivity of crops has been developed. Organic Farming Aid (wood vinegar$^{®}$) contains Pyroligneous Acid (PA) which is a by-product of bio-oil obtained by pyrolysis of the wood [23]. Pyroligneous acid (PA) or wood vinegar is a natural and environmentally friendly by-product of pyrolysis of plant biomass [24]. It is a complex mixture containing 80% - 90% water as a major component and over 200 water-soluble chemical compounds including nitrogen, phenolic, organic acids, sugar derivate, alcohols, and esters [25] [26] [27]. It is used in crop production towards soil quality improvement, pest elimination and plant growth stimulation [28]. The use of wood vinegar alone or in combination with synthetic fertilizers has proven to be effective in crop production and productivity [29] [30].

Wood vinegar can be applied to the soil surface to help increase the population of beneficial microbes and to promote plant root growth [31]. Additionally, wood vinegar has a compound effect of promoting crop growth similar to plant growth regulators and can enhance the biological and abiotic resistance of crops [32]. However, the concentration of wood vinegar applied to promote plant growth varied between studies [29]. [33] also indicated that when pyrolgneous acid or wood vinegar is diluted sufficiently, it can enrich the soil to stimulate plant root and shoot growth, and higher dilution ratios increase microbial activity. For instance, [34] working on tomatoes reported that the application of 1:500 (v/v) pyrolgneous acid increased tomato yield but did not affect fruit nutritional quality, whereas 1:800 pyrolgneous acid enhanced the growth and yield of tomato. Similarly, [35] reported increased in the growth and yield of rock melon (Cucumis melo var. cantalupensis) when soil was drenched with 20% pyrolgneous acid or wood vinegar. Application of wood vinegar increased the number of tillers per hill, 1000 grain weight and filled grains per panicle of rice and consequently the grain yield. [36] also revealed that application of PA increased grain yield of rice.

In addition, soil biochemical properties can be used as indicators of soil quality as they are more sensitive to changes in management than soil physical or chemical properties [37] [38] [39]. They measure key microbial reactions involved in soil nutrient cycling and can be easily measured [37] [40]. Despite the numerous benefits of wood vinegar in increasing the productivity of crops, it is a new product to the farmers and as such there is little or no information about its efficacy in Ghana's farming system. Hence it is always very important to test the efficacy of the product, validate the results before recommending it for commercial use. Therefore, this study was conducted to evaluate the effect of Organic Farming Aid (OFA) and inorganic fertilizer on the productivity of maize in the Guinea Savannah agro-ecological zone of Ghana. Specifically, the study sought to:

1) Assess the growth and productivity of maize as affected by different rates of organic farming aid (OFA) and inorganic fertilizer.

2) Determine the effect of organic farming aid (OFA) and inorganic fertilizer on the chemical and microbial properties of soil.

3) Determine the economic viability of the different rates of organic farming aid (OFA) and inorganic fertilizer and to guide the adoption of the most yield-enhancing and cost-effective soil amendment rate.

2. Materials and Method

The experiment was conducted in 2021 and 2022 cropping seasons at the CSIR-Savanna Agricultural Research Institute located at Nyankpala (9˚25'N, 0˚58'W) in the Tolon district of the Northern Region of Ghana. The Guinea Savannah zone covers over 40% of the entire land area of Ghana and is characterized by high temperatures and low humidity for most parts of the year [41]. The climate is a warm, semiarid with mono-modal annual rainfall of 1200 mm between May/June and October. The area also experiences a long windy dry season (harmattan) annually from November to April. Intermittent dry spells, often lasting up to two weeks also occur during the rainy season [42]. The land has a gentle slope of about 2%. The soil is well-drained Voltaian sandstone, locally known as the Tingoli series and classified as Ferric Luvisol [43].

2.1. Land Preparation and Planting

The experimental fields used in both years (2021 and 2022) were ploughed and harrowed, after which planting was carried out on 22nd and 30th June, 2021 and 2022 respectively. Each plot measured 4.5 m × 4 m and they were laid out in a randomized complete block design (RCBD) with four replications in both years. An improved open pollinated maize variety, Wang dataa with a maturity period of 90 days and a yield potential of 4.7 $t\cdot ha^{-1}$ was used as the test crop. A planting distance of 0.75 m × 0.4 m was used. Four seeds were sown per stand and later thinned to two plants per stand after emergence.

2.2. Treatment Application

The five treatments applied are shown below (Table 1).

OFA was sprayed twice on the leaves as well as on the soil surface at 2 and 6 weeks after planting (WAP). The NPK in the granular form was applied as deep placement in the soil also at the same time as the OFA. However, 50% of N and entire dose of P and K were applied at 2 WAP. The remaining 50% N in the form of urea was applied as a top dressing at 6 WAP.

2.3. Weed and Insect Control

A pre-emergence herbicide (Pendimethalin) was applied at 2.5 litres ha^{-1} immediately after planting. Afterwards, weeding was done using a hand hoe at 4, 7 and 9 weeks after sowing. Maize plants were protected against insect pests using a systemic insecticide containing Emamectin Benzoate + Acetamiprid at a rate of 20 ml per 15 liters of water at 3 and 7 days after sowing.

2.4. Data Collection and Analysis

Before planting, topsoil (0 - 15 cm) was collected from the experimental field. The soil was bulked and mixed thoroughly to obtain a composite sample. A subsample of 200 g was taken and analyzed for soil texture, pH in water using soil to water ratio of 1:2.5 [44]. Total nitrogen of soil from the experimental plot was determined by Kjeldahl distillation and titration method [45]. Available phosphorus was measured using Bray and Kurtz method [46]. Exchangeable potassium was determined using flame photometry PFP7 after extraction with ammonia acetate. Organic carbon was determined by the wet digestion method [47]. Calcium and Magnesium were determined by atomic absorption spectrophotometer before planting was done. In addition, at the full maturity stage of the maize, about 200 g of rhizosphere soil was collected per plot from four maize

Table 1. Treatment combinations.

Treatment	Rate of application
Full rate of OFA	250 $ml\cdot ha^{-1}$ OFA
Full rate of NPK	90:60:60 NPK
½ rate of OFA + ½ NPK	125 $ml\cdot ha^{-1}$ OFA+ 45:30:30 NPK
Full rate of OFA + ½ NPK	250 $ml\cdot ha^{-1}$ OFA+ 45:30:30 NPK
Control (No fertilizer/No OFA)	Not applicable

OFA—Organic farming aid, NPK—Nitrogen, Phosphorus, Potassium.

plants. The soil samples were air-dried for 72 h, sieved through a 2 mm mesh sieve and bagged. The samples were evaluated for some selected soil microbial properties.

2.4.1. Soil Microbial Biomass Nitrogen (MBN)

Soil microbial biomass nitrogen (MBN) was determined on a 15-g field-moist (oven-dry equivalent) soil sample (sieved) by the chloroform-fumigation-incubation method using 1 M KCl as an extractant. In brief, N (NO_3-N + NH_4-N) from the fumigated (10 days) and non-fumigated (control) soil was quantified using the colorimetric method after KCl extraction. The non-fumigated control values were subtracted from the fumigated values. The MBN was calculated using a KEC factor of 0.54 [48]. Each sample had duplicated analyses, and results expressed on a moisture-free basis. Soil moisture was determined after drying at 105˚C for 48 h.

2.4.2. Permanganate-Oxidizable C (POXC)

Permanganate-oxidizable C (POXC) (or "active soil carbon") was analyzed based on [49]. Briefly, 2.5 g of air-dried soil was weighed into test tubes. To each test tube, 18 ml of deionized water and 2 ml of 0.2 M $KMnO_4$ stock solution were added, and tubes were shaken vigorously for 2 minutes. Tubes were allowed to settle for 10 minutes. After 10 minutes, 0.5 ml of the supernatant was transferred to a second 50-ml test tube and mixed with 49.5 ml deionized water. An aliquot (1000 μl) of each sample was transferred to a new glass vial. A set of internal standards, including a blank of deionized water was prepared. A soil standard and a solution standard (laboratory reference samples) were added to serve as a check. All samples and checks were duplicated. Sample absorbance was measured using a GENESYS 30 spectrophotometer (Thermo Fisher Scientific) at 550 nm. Permanganate-oxidizable C was determined using Equation (2) following [49].

2.4.3. Soil Basal Respiration (SBR) and Mineralizable C

For measurement of soil basal respiration (SBR), 40 g of soil samples (dry weight equivalent) were enclosed in 1 L air-tight jars along with a vial containing two vials of 5 ml 1M NaOH and a vial with 10 ml water (to maintain a humidified environment) and incubated at 30˚C. The alkali traps were changed and titrated at days 1, 3, 6, 12 18, 24 and 30. Unreacted alkali in the NaOH traps was precipitated with 2 ml 1M $BaCl_2$ and back-titrated with 1 N HCl using phenolphthalein indicator to quantify the evolved CO_2-C. After each sampling time, soil moisture content was checked and adjusted to 60% WFPS, and the vials with 5 ml of 1 M NaOH solution were refilled with fresh NaOH and resealed with the lid. The CO_2-C evolved was expressed as mg CO_2-C/100 g whereas the cumulative CO_2 released and C mineralized were calculated based on the amount of CO_2–C released during different intervals of time in each treatment. Basal soil respiration was calculated by subtracting the cumulative 7-day CO_2-C from the cumulative 30-day CO_2-C. All determinations were made in duplication and are expressed on a dry weight basis.

2.4.4. Soil Enzyme Activities

Dehydrogenase activity was assayed following the procedure of [50], based on a colorimetric assay of 2,3,5-triphenylformazan (INTF) produced by the microorganism reduction of 2,3,5-triphenyltetrazolium chloride (TTC). The INTF was measured spectrophotometrically using GENESYS 30 spectrophotometer (Thermo Fisher Scientific) at 485 nm.

A-Glucosidase activity was assayed by a colorimetric method, using 4-nitrophenyl-α-D-glucopiranosyde as a substrate: soil samples were incubated at 37˚C for 60 minutes; the reaction product *p*-nitrophenol was determined at 410 nm [51] using GENESYS 30 spectrophotometer (Thermo Fisher Scientific).

Acidic phosphatase activity determination was based on the hydrolysis of *p*-nitrophenyl phosphate added to the soil samples following [52]. The phosphate releases *p*-nitrophenol, which was detected colorimetrically at 410 nm using GENESYS 30 spectrophotometer (Thermo Fisher Scientific), and Acidic phosphatase activity was expressed as mg of p-nitrophenol kg^{-1} soil h^{-1}

Arylsulfatase activity was determined by a colorimetric method, using *p*-nitrophenyl sulfate as a substrate: soil samples were incubated at 37˚C for 1 h and the reaction product (*p*-nitrophenol) was extracted by dilute alkali ($CaCl_2$ 0.5 M and NaOH 0.5 M) and determined at 410 nm [53] using GENESYS 30 spectrophotometer (Thermo Fisher Scientific).

The GMea (a general index to integrate information from variables that possess different units and range of variation) of the assayed enzyme activities was calculated for each sample as follows: Gmea = (α-Glucosidase × Acidic phosphatase × Arylsulfatase activity) 1/4 [54].

The topsoil (0 - 15 cm) was collected from the experimental field. The soil was bulked and mixed thoroughly to obtain a composite sample. A subsample of 200 g was taken and analysed for soil texture, pH in water using soil to water ratio of 1:2.5 [44]. Total nitrogen of soil from the experimental plot was determined by Kjeldahl distillation and titration method [45]. Available phosphorus was measured using Bray and Kurtz method [46]. Exchangeable potassium was determined using flame photometry PFP7 after extraction with ammonia acetate. Organic carbon was determined by the wet digestion method [47]. Calcium and Magnesium were determined by atomic absorption spectrophotometer before planting was done. All growth and physiological parameters were measured 10 weeks after planting. Plant height, stem girth, number of leaves were measured for each of the five randomly selected tagged plants and average calculated for each plot. Leaf area in maize was computed using the formula, Leaf Area = leaf length × maximum leaf width × 0.74 [55]. Leaf chlorophyll index was measured by using SPAD Chlorophyll meter (SPAD 502 plus, Minolta, Japan). Leaf area index (LAI) was measured using AccuPAR model LP-80 PAR/LAI Ceptometer (Decagon Devices, Pullman WA, USA). The number of days required for 50% tasseling and silking was also recorded. Yield parameters measured included, cob length, cob width, cob weight, grain yield, stalk yield and hundred seed weight. The shelled grains obtained from the two central rows were sun dried to 13% moisture content using a moisture meter. These were weighed and each weight converted to kilogram per hectare. After harvesting, stalks from the two central rows were allowed to dry in the sun, then weighed and converted to kilogram per hectare to determine the stalk yield for each plot. A random sample from the yield of the two central rows was taken out and hundred seeds were counted and weighed on an electronic balance for 100 seed weight determination. Harvest index was calculated using formula suggested by [56]:

$$\text{Harvest Index} = \frac{\text{Economic yield}\left(\text{kg}\right)}{\text{Total biological yield}}$$

where, economic yield is the grain yield and the total biological yield is the summation of the total stalk and grain yield plus cob husk.

Data collected were subjected to analysis of variance using GenStat software 12th edition [57] and the least significant difference at 5% probability was used for mean separation.

2.4.5. Economic Analysis

We conducted economic analysis to ascertain the profitability of five treatments regarding different rates of inorganic fertilizer (NPK) and organic farming aid (OFA) for maize production. The analysis was conducted in 2021 and 2022 to establish the most economic viable treatment to guide adoption of the most yield-enhancing and cost-effective fertilizer application rate. To do this, we used the partial budget analysis developed by [58]. The total crop revenue for each treatment was computed at harvest using seasonal average maize price and the production quantities. The variable cost was computed using the cost associated with labour and inputs (certified seed, OFA, and Urea). Based on the computed total crop revenue and variable cost for each of the treatments, we computed the net revenue as the difference between the total crop revenue (gross revenue) and the total variable costs. For ease of comparison across treatments, we computed the benefit cost ratio (BCR). The formula for the BCR is specified as:

$$\text{Crop Revenue} = \text{Output} * \text{Unit price of output} \tag{1}$$

$$\text{Total variable cost} = \sum_{i}^{k} w_i Z_i \tag{2}$$

$$\text{BCR} = \frac{\text{Crop Revenue}}{\text{Total variable cost}} \tag{3}$$

where w_i is the input price for input i and Z_i is the quantity of input k used, and BCR is the benefit cost ratio. Based on the computation of BCR for all the treatments, the decision criteria are as follows: If BCR is equal to 1 (*i.e.*, BCR = 1), then the treatment is breakeven point; If BCR > 1, then the treatment is profitable or economically viable while a BCR < 1 indicates that the treatment is not economically viable.

3. Results

3.1. Weather Conditions during the Period of the Experiment

The years (2021 and 2022) differed in total rainfall amounts, mean temperature, and relative humidity (**Figure 1**). The total rainfall recorded in 2022 (1313.2 mm) was higher than that recorded in 2021 (991.1 mm). Mean monthly temperature recorded in 2021 was higher (29.3) than in 2022 (28.3 mm). Higher relative humidity was also recorded in 2022 (72%) than in 2021 (65%).

3.2. Baseline Soil Analysis

Table 2 shows the physico-chemical properties of the soils from the two experimental fields used in the two trial years. Higher values of soil pH, organic carbon and total nitrogen were recorded in the first year as compared to the second year. The soil pH recorded in the first year (5.50) was 0.51 units higher than that of the second year (4.99). Organic carbon and total nitrogen contents were respectively, 5 and 2 times as much in the first year (0.78% and 0.06%) as in the second (0.14% and 0.03%). The higher amount of organic matter in the soil used in year one may have led to more N and C being mineralized relative to that of year 2. The larger organic matter content in the soil used in year one may have also offered it a higher buffering capacity against change in soil pH hence, its higher pH. The P, K, Ca and Mg contents of the soil used in year 2 however, were higher than those of year one. The more acidic nature of the soil used in year two may have caused more dissolution of these nutrients, making them more available. The soil used in year one was classified as a loamy sand whilst that of year two was a sandy loam (according to the USDA classification system).

3.3. Crop Performance

3.3.1. Analyses of Variance for Growth and Yield Components

Analysis of variance (ANOVA) indicated that variances due to treatment main effects for all the growth and yield parameters measured in this study were significant ($P < 0.05$) (**Table 3** and **Table 4**). Similarly, variances due to year effects

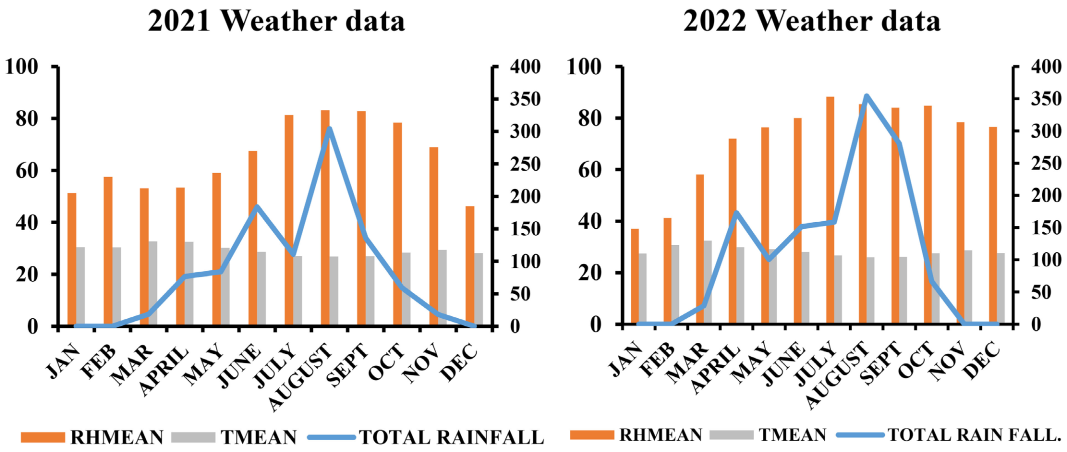

Figure 1. Monthly mean temperature, relative humidity and rainfall for the 2021 and 2022 cropping season.

Table 2. Physio-chemical properties of soils from the two sites used in the first and second year.

Year	pH	O.C (%)	N (%)	P (mg/kg)	K (mg/kg)	Ca (Cmol+/kg)	Mg (Cmol+/kg)	Sand (%)	Silt (%)	Clay (%)
2021	5.50	0.78	0.06	9.46	65	1.8	0.8	84.40	13.60	2.00
2022	4.99	0.14	0.03	10.78	78	2.4	1.8	57.88	34.00	8.12

Table 3. Mean squares for growth parameters measured at 10 weeks after sowing.

Source of variation	Degree of freedom	Plant height (cm)	Stem girth (mm)	Number of leaves	Leaf area (cm^2)	Leaf chlorophyll content (SPAD)	Leaf area index (LAI)	Days to 50% tasselling	Days to 50% silking
Replication	3	796.9	44.92	0.692	3064	34.64	0.4081	2.067	1.500
Treatment	4	8466.4***	128.90*	28.662***	99,074***	1241.03***	15.1827***	28.400***	33.538***
Year	1	547.0NS	175.26*	9.025***	78,938***	898.70***	17.5673***	22.500*	62.500***
Treatment × Year	4	811.5NS	105.47*	2.352*	5032NS	111.92***	0.9417NS	23.875**	24.188**
Residual	27	398.4	35.70	0.691	2710	14.56	0.3611	4.363	4.296

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; NS—Not-significant.

Table 4. Mean squares for yield and yield parameters of maize.

Source of variation	Degree of freedom	Cob length (cm)	Cob width (mm)	Grain yield, ($kg \cdot ha^{-1}$)	Stalk yield ($kg \cdot ha^{-1}$)	100 seed weight (g)	Harvest Index (HI)
Replication	3	3.36	22.11	232,741	250,340	11.907	0.001
Treatment	4	45.27***	443.17***	16,753,927***	6,696,196***	33.992***	0.029***
Year	1	1.41NS	11.04NS	8,087,492***	67,648NS	1.296NS	0.034***
Treatment × Year	4	7.57*	91.26**	1,418,083***	4,395,139***	11.436NS	0.007*
Residual	27	2.09	20.36	230,498	321,410	5.044	0.002

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; NS—Not-significant, CV—Coefficient of variation, NPK—Nitrogen, PP—Phosphorus and Potassium, OFA—Organic farming aid, Control—No NPK or OFA, LSD—Least significant difference.

were also significant ($p < 0.05$) for stem girth, number of leaves plant^{-1}, leaf chlorophyll content (SPAD), leaf area, leaf area index, days to 50% tasseling, days to 50% silking, cob weight, grain yield and harvest index. Apart from plant height, leaf area, leaf area index and hundred seed weight, interaction effects due to treatment × year was significant ($p < 0.05$) for the other parameters including stem girth, number of leaves plant^{-1}, leaf chlorophyll content (SPAD), days to 50% tasseling, days to 50% silking, cob length, cob width cob weight, grain yield, stalk yield and harvest Index.

3.3.2. Comparison of Grain Yield and Growth Parameters of Maize for the First and Second Year

Grain yield and growth of maize results for each of the years are shown in Figure 2. Growth and yield parameters recorded in year one for all the treatments, except the full NPK, were generally higher (in most cases significant) than what

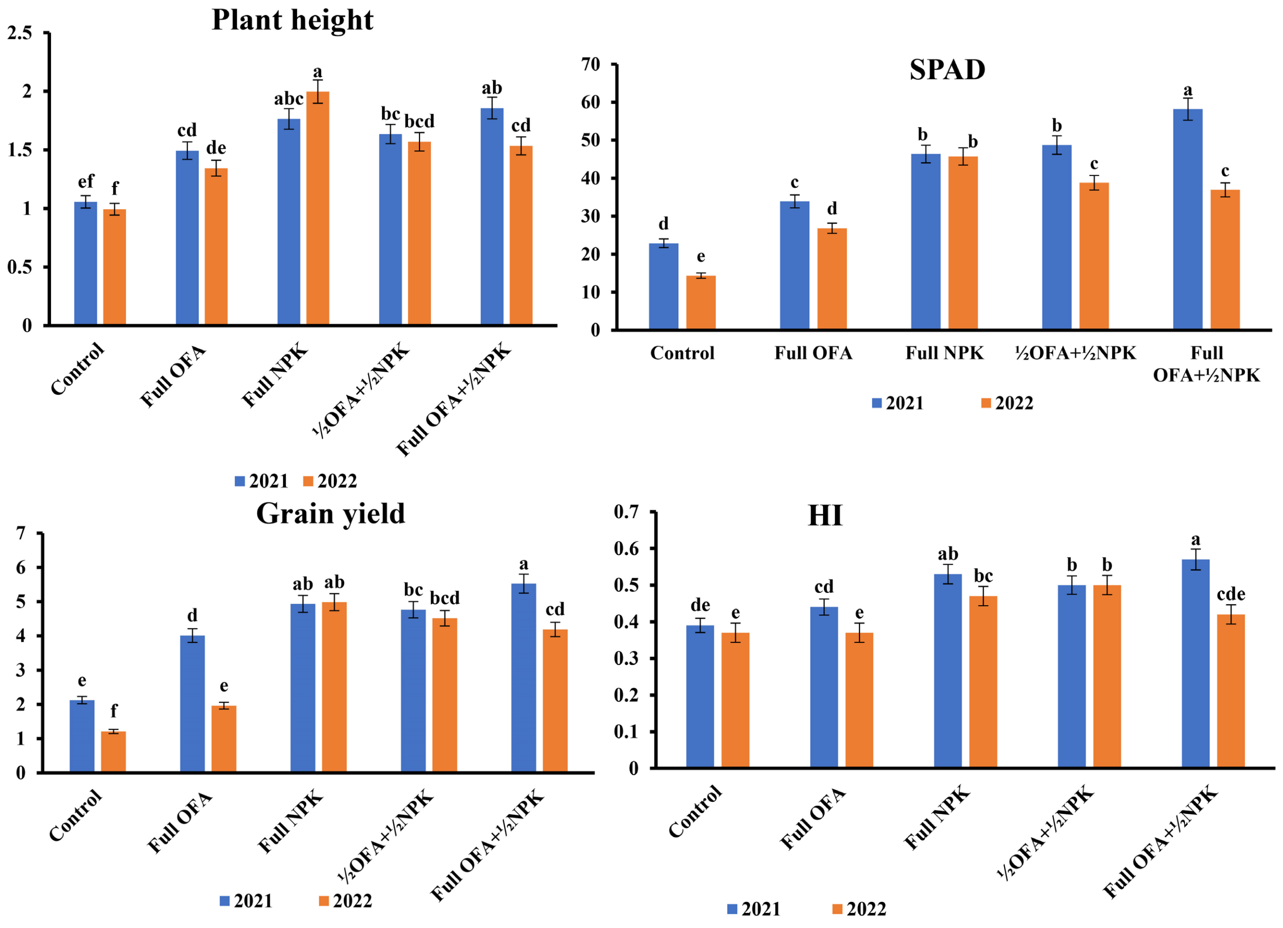

Figure 2. Interaction effects of treatment × year for yield and yield parameters measured.

was recorded in year 2. Thus, for the control, full OFA, ½ OFA + ½ NPK and full OFA + ½ NPK treatments, a comparison between the first-year values of the growth and yield parameters, against their corresponding second year values revealed generally higher (in most cases significant) values in the former. This corresponded with significantly ($p < 0.05$) higher grain yield values in the first-year relative to the second, of the aforementioned treatments except in the ½ OFA rate + ½ NPK treatment, where the value was higher but statistically similar ($p > 0.05$). Differences in the physio-chemical properties of the soils involved in the two sites used (Table 2) (as analyzed prior to each year's trial) may have accounted for the observed differences between the two years' results. Notable among them is the soil pH of 4.99 in the second year at which pH there is a likelihood of toxic levels of some elements to retard crop growth and development.

3.3.3. Growth and Yield Parameters as Affected by the Different Treatments

Significantly taller plants were obtained from the application full NPK. However, application of full OFA rate+ ½ NPK resulted in plants that were significantly similar in height to those produced by full NPK. Plant height obtained by the full

OFA rate + ½ NPK was statistically similar to those produced by the application of ½ OFA rate + ½ NPK. Plant height obtained from the application of full OFA differed significantly from those obtained from the application of full NPK and full OFA rate + ½ NPK. The control treatment produced the shortest plants which was significantly different from plant height obtained from the application of all the other treatments (**Table 5**). Maize treated with full rate NPK obtained significantly the highest leaf area but it was statistically similar to the leaf area obtained when maize was treated with full OFA rate + ½ NPK and ½ OFA rate + ½ NPK. Application of full OFA rate resulted in significantly the lowest leaf area among the soil amendments, which differed significantly from the control treatment (**Table 5**). In terms of leaf area index, maize treated with full OFA rate + ½ NPK had significantly, the highest leaf area index. Application of full OFA rate resulted in the lowest leaf area index which was significantly lower than those recorded in soil amendments plots but significantly higher than those recorded in the control plots (**Table 5**).

Application of full NPK in 2022 produced plants with the biggest stems which were statistically similar to those recorded from plots that received ½ OFA rate + ½ NPK in 2021 and full OFA rate + ½ NPK in 2022. Stems obtained from plants that were treated with full NPK in 2021 were significantly bigger than those obtained in 2022 under the same treatment. In both years, the control plots produced the smallest stems which were statistically similar to those from plots that received full NPK in 2021, ½ OFA rate + ½ NPK in 2021 and full OFA rate (**Table 6**). On the average for the years, plants that received full NPK produced the biggest stems which were statistically similar to plants that received full OFA rate + ½ NPK rate. Plants raised from the control plots recorded the smallest stems which were significantly different from those of other treatments (**Table 5**). Number of leaves obtained from plants treated with full OFA rate + ½ NPK rate in 2022 was significantly higher than those produced in 2021 under the

Table 5. Average effect of organic farming aid and inorganic fertilizers for growth parameters of maize.

Treatment	Stem girth plant^{-1} at 10 WAS (cm)	Number of leaves plant^{-1} at 10 WAS	Chlorophyll content plant^{-1} at 10 WAS	Leaf area plant^{-1} at 10 WAS (cm)	Plant height plant^{-1} at 10 WAS (cm)	Leaf area index at 10 WAS	Days to 50% tasselling	Days to 50% silking
Control (No fertilizer)	14.6	9.6	18.61	276.6	102.5	1.77	54.9	58.8
Full OFA	18.5	11.4	30.36	416.5	141.8	2.87	54.4	57.8
Full NPK	23.8	13.8	46.04	557.9	188.1	4.71	50.9	54.4
½ OFA + ½ NPK	22.8	12.8	43.76	506.2	160.2	4.46	51.1	54.5
Full OFA + ½ NPK	23.6	14.3	47.55	510.2	169.6	4.96	51.8	54.9
Grand mean	20.6	12.38	37.27	453.5	153.4	3.75	52.6	56.1
LSD	6.13	0.85	3.91	53.41	20.48	0.62	2.14	2.13
CV%	28.9	6.7	10.2	11.5	13.1	16.0	4.0	3.7

*WAS—Weeks after sowing, NPK—Nitrogen, PP—Phosphorus and Potassium, OFA—Organic farming aid, LSD—Least significant difference, CV—Coefficient of variation.

Table 6. Interaction effects of treatment × year for growth parameters measured in 2021 and 2022 cropping seasons.

Treatment	Days to 50% tasselling		Days to 50% silking		Stem girth plant^{-1} at 10 WAS (cm)		Number of leaves plant^{-1} at 10 WAS		Chlorophyll content plant^{-1} at 10 WAS	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Control (No fertilizer)	52.25	57.50	55.3	62.25	17.5	11.7	9.5	9.8	22.88	14.35
Full OFA	51.75	57.00	55.0	60.50	18.5	18.5	11.8	11.1	33.90	26.83
Full NPK	51.50	50.25	54.5	54.25	17.8	29.8	13.7	12.0	48.73	38.80
½ OFA + ½ NPK	51.25	51.00	54.3	54.75	17.8	27.7	13.9	13.7	46.35	45.73
Full OFA + ½ NPK	52.50	51.00	55.0	54.75	21.1	26.1	15.5	13.1	58.17	36.92
Grand mean	52.6		56.1		26.6		12.4		37.3	
LSD	3.031		3.007		8.69		1.21		5.54	
CV%	4.0		3.7		28.9		6.7		10.2	

same treatment. Plants that received full OFA rate + ½ NPK rate produced the highest number of leaves that were statistically similar to those recorded by plants that received full NPK but significantly higher than those recorded from other treatments in both years. Application of ½ OFA rate + ½ NPK rate resulted in more leaves in 2021 compared to those obtained in 2022 (Table 6). The control treatment obtained fewer number of leaves (Table 5).

The chlorophyll content obtained from full OFA rate + ½ NPK rate in 2021 was significantly ($P < 0.05$) higher than that obtained from full OFA rate + ½ NPK rate in 2022. Similarly, maize plants treated with full OFA rate + ½ NPK rate in 2021 had significantly the highest chlorophyll content compared with all the other treatments in both years. SPAD values obtained from the application of ½ OFA rate + ½ NPK rate in year 1 differed significantly from those obtained from ½ OFA rate + ½ NPK in 2022, full OFA rate + ½ NPK in 2022, full OFA rate in 2021 and 2022 as well as the control treatment in 2021 and 2022. However, it was statistically similar to those obtained from full NPK in 2021 and 2022 (Table 6). On the average for the years, full OFA rate + ½ NPK rate obtained the highest SPAD value which was significantly higher than those recorded under other treatments. The lowest SPAD value was obtained by the control treatment which was significantly lower than those of other treatments (Table 5).

In 2022, plants that received full NPK recorded the shortest mean days to 50% tasseling which was statistically similar to those recorded by the other treatments except for full OFA rate and the control treatment whose plants recorded the longest period to attain 50% days to tasseling (Table 6). On the average for the years, plants that received full NPK took the shortest period to reach 50% days to tasseling which was significantly ($P < 0.05$) shorter than those recorded under other treatments. Plants raised under the control treatment recorded the longest period which was significantly longer than those recorded under other treatments (**Table 5**).

In 2021, plants that received full OFA rate + ½ NPK rate recorded the shortest mean days to 50% silking which was significantly similar to those obtained by plants under other treatments except for full OFA rate. In 2022, plants raised under the control treatment took the longest period to reach 50% days to silking which was statistically similar to those recorded by plants that received full OFA rate (**Table 6**). On the average for both years, plants that received full NPK took the shortest period to reach 50% days to silking which was significantly shorter than those recorded under other treatments. Plants raised under the control treatment recorded the longest period which was significantly longer that those recorded under other treatments (**Table 5**).

In terms of cob length, application of full OFA rate + ½ NPK in 2021 resulted in longer cobs which were statistically at par with those obtained from the application of full NPK in 2021 and 2022 as well as ½ OFA rate + ½ NPK. Control treatment produced the shortest cobs which were significantly shorter than those recorded under other treatments (**Figure 2**). Plants that received full NPK obtained the longest cobs which were significantly longer than those that received other treatments. This was followed by plants that received full OFA rate + ½ NPK rate. Plants raised under the control treatment recorded the shortest cobs that were statistically shorter than those under other treatments (**Table 7**).

Plants that received full OFA rate + ½ NPK rate produced significantly wider cobs than those recorded under other treatments. The cob girth produced under full OFA rate + ½ NPK rate were statistically similar to cobs produced by maize treated with 100% NPK, ½ OFA + ½ NPK and full OFA rate + ½ NPK rate. Plants under the control treatments produced significantly the narrowest cobs compared to all the other treatment combinations except for full OFA rate (**Figure 2**). Plants treated with full NPK produced the widest cobs which were significantly wider than those under other treatments, followed by plants that received full OFA rate + ½ NPK rate. Plants raised under the control treatment produced the narrowest cobs which were significantly narrower than those recorded under other treatments (**Table 7**).

Table 7. Average effect of organic farming aid and inorganic fertilizers on grain and yield parameters of maize.

Treatment	Grain yield ($kg{\cdot}ha^{-1}$)	Cob length (cm)	Cob width (cm)	100 Seed weight (g)	Harvest Index (HI)
Control	1667	8.6	26.79	23.03	0.37
Full OFA	2986	10.5	34.82	24.83	0.40
Full NPK	4960	14.2	44.76	28.20	0.50
½ OFA+ ½ NPK	4639	13.0	40.68	26.55	0.50
Full OFA+ ½ NPK	4856	13.8	43.74	27.28	0.49
Grand mean	3822	12.0	38.2	25.9	0.48
LSD	492.5	1.48	4.63	2.30	0.06
CV%	12.6	12.1	11.8	8.6	12.0

For grain yield, plants treated with full OFA rate + ½ NPK rate produced the highest grain yield which was statistically similar to grain yields recorded by plants that received full NPK (**Figure 2**). Grain yields obtained by the application of ½ OFA + ½ NPK in 2021 was statistically at par with those obtained by the application of ½ OFA + ½ NPK and full OFA + ½ NPK in 2022. Plants raised under control treatment produced low grain yields that were significantly lower than those recorded under all the other treatment combinations. Plants that received full NPK produced the highest grain yield which was significantly higher than those recorded under other treatments. This was followed by those that received full OFA + ½ NPK and then ½ OFA + ½ NPK. Here again plants raised under the control treatment produced the lowest grain yield which was significantly lower than those recorded under other treatments (**Table 7**).

Plants that received full OFA + ½ NPK recorded the highest stalk yield which was significantly higher than those recorded under other treatments (**Table 7**). Stalk yield under this treatment was however not statistically different from plants that received full NPK and full OFA. Stalk yield produced by plants that received ½ OFA + ½ NPK was statistically at par with those recorded by plants that received ½ OFA + ½ NPK, full NPK and full OFA + ½ NPK. Plants raised under the control treatment recorded stalk yield that were significantly lower than those from other treatments combinations.

Plants that received full NPK produced the highest seed weight which were significantly similar to the seed weight produced by plants that received full OFA + ½ NPK and ½ OFA + ½ NPK. Plants raised under the control treatment produced significantly higher seed weight than those of other treatments. The seed weight under the control treatments did not however, differ significantly from seeds produced by full OFA (**Table 8**).

In terms of harvest index, application of full OFA + ½ NPK resulted in highest harvest index in year 1 which did not differ from the harvest index obtained when full NPK was applied to maize. Harvest index obtained by the application of ½ OFA + ½ NPK in 2022 was statistically similar to those obtained by the

Table 8. Average effect of treatments on selected soil chemical properties in 2021 and 2022 cropping seasons.

Treatment	Soil pH	Soil NH_4-N	Soil NO_3-N	Soil N (NO_3-N + NH_4-N)	Soil P (Bray 1)	Soil N:P
			mg·kg^{-1} soil			
Control	5.37	0.104	0.21	0.31	1.99	0.156
Full OFA	5.35	0.094	0.19	0.28	2.18	0.128
Full NPK	5.15	0.116	0.16	0.28	2.58	0.108
½ OFA+ ½ NPK	5.23	0.099	0.25	0.34	2.55	0.135
Full OFA+ ½ NPK	5.28	0.103	0.23	0.33	2.34	0.142
LSD	0.152	0.02	0.06	1.50	0.06	0.076

application of full NPK in 2021 (**Figure 2**). In both seasons, plants that received ½ OFA + ½ NPK recorded the highest harvest index that was statistically higher than those recorded under other treatment. This was followed closely by plants that received full NPK and then full OFA + ½ NPK. The lowest harvest index was obtained by plants under the control treatment (**Table 7**).

3.4. Average Effect of Treatments on Some Soil Chemical Properties

Effects of treatments on some soil chemical and biological properties are shown in **Table 8**. Soil pH, soil nitrate (NO_3-N), available N (NO_3-N + NH_4-N) and phosphorus (P) were not significantly ($p > 0.05$) affected by the treatments applied. Application of ½ OFA + ½ NPK fertilizer stimulated higher mean values of soil nitrate (NO_3-N) and available N (NO_3-N + NH_4-N).

3.5. Average Effect of Treatments on Selected Soil Enzymes and Microbial Properties

There was no significant ($p > 0.05$) treatment effect on soil POXC, microbial biomass, alpha glucosidase (α-glucosidase), dehydrogenase, acidic phosphatase, total enzyme activity and geometric mean enzyme activity (GMEA) (**Table 9** and **Table 10**). Higher values of total enzyme as well as GMEA were recorded for the full OFA treatment (88 mg p-nitrophenol kg^{-1} soil h^{-1} and 9.27 respectively) as compared to the others. These values were however not significantly different from those of the full NPK and full OFA+ ½ NPK treatments.

3.6. Economic Analysis

Table 11 shows the fertilizer treatments and their respective economic viability for 2021 and 2022 farming seasons in the Tolon District of Ghana. The experiments were conducted in 2021 and repeated in 2022 at the same locations. Panels A and B show the 2021 and 2022 economic analysis of the different fertilizer treatments. Based on the net returns in 2021, we found that treatment full OFA + ½ NPK recorded the highest net returns while treatment 50% OFA + 50% NPK recorded the highest net returns in 2022.

Table 9. Average effect of treatments on selected soil enzymes and their properties in 2021 and 2022 cropping seasons.

Treatment	Alpha glucosidase	Acid phosphatase	Aryl sulphatase	Dehydrogenase	Total enzymes	GMEA
	mg p-nitrophenol kg^{-1} soil h^{-1}			mg TPF kg^{-1} soil h^{-1}	mg p-nitrophenol kg^{-1} soil h^{-1}	
Control	25.8	25.6	22.5	75.14	74.1	8.50
Full OFA	32.3	29.6	26.1	96.09	88.0	9.27
Full NPK	25.0	35.4	22.0	69.32	82.4	8.96
½ OFA+ ½ NPK	20.5	28.4	22.7	89.82	71.7	8.37
Full OFA+ ½ NPK	22.3	37.6	22.0	75.14	82.0	8.92
LSD	7.14	17.92	5.08	27.16	21.76	1.16

GMEA—Geometric mean enzyme activity, TPF—Triphenylformazan.

Table 10. Average effect of treatments on selected soil microbial properties in 2021 and 2022 cropping seasons.

Treatment	Microbial biomass N	POXC	Cumulative evolved CO_2-C (mg C g^{-1} soil)	Potentially mineralizable C (mg C g^{-1} soil)
	mg kg^{-1} soil		mg C g^{-1} soil	
Control	0.33	186	29.1	117.5
Full OFA	0.47	207	25.2	116.9
Full NPK	0.28	162	27.2	129.8
½ OFA + ½ NPK	0.53	153	31.1	126.9
Full OFA + ½ NPK	0.55	162	33.1	145.1
LSD	0.254	36.4	5.36	30.46

Table 11. Effect of soil amendment on economic viability.

Treatment	Revenue (USD)	Total variable cost (USD)	Net benefit (USD)
Panel A - 2021 BCR analysis			
Control	517.95	404.06	113.89
Full OFA	977.80	420.48	557.31
Full NPK	1203.43	623.57	579.86
½ OFA + ½ NPK	1161.87	517.47	644.39
Full OFA + ½ NPK	1347.67	521.13	826.54
Panel B - 2022 BCR analysis			
Control	414.75	358.59	56.16
Full OFA	672.51	373.16	299.35
Full NPK	1708.70	638.53	1070.17
½ OFA + ½ NPK	1547.60	459.23	1088.36
Full OFA + ½ NPK	1435.17	462.48	972.69

Figure 3 shows the benefit cost ratio (BCR) for the five different treatments of fertilizer application on maize. Compared across the treatments, the control experiment recorded the lowest BCR in 2021 and 2022. A unit cost (USD1) of investment in maize cultivation without NPK and OFA leads to 1.28 and 1.50 increase in revenue in 2021 and 2022, respectively. This suggests that without the treatments (NPK and OFA), profitability of maize is likely to be low compared to using NPK and OFA. The treatment ½ OFA + ½ NPK treatment in 2022 dominated across all the other treatments while treatment full OFA + ½ NPK dominated across all the treatments in 2021. Comparing across the treatments in 2021, full OFA + ½ NPK recorded the highest BCR of 2.58 followed by full OFA (2.37), ½ OFA + ½ NPK (BCR of 2.25), full NPK (BCR of 1.94), and control treatments (BCR of 1.28). In 2022, ½ OFA + ½ NPK recorded the highest

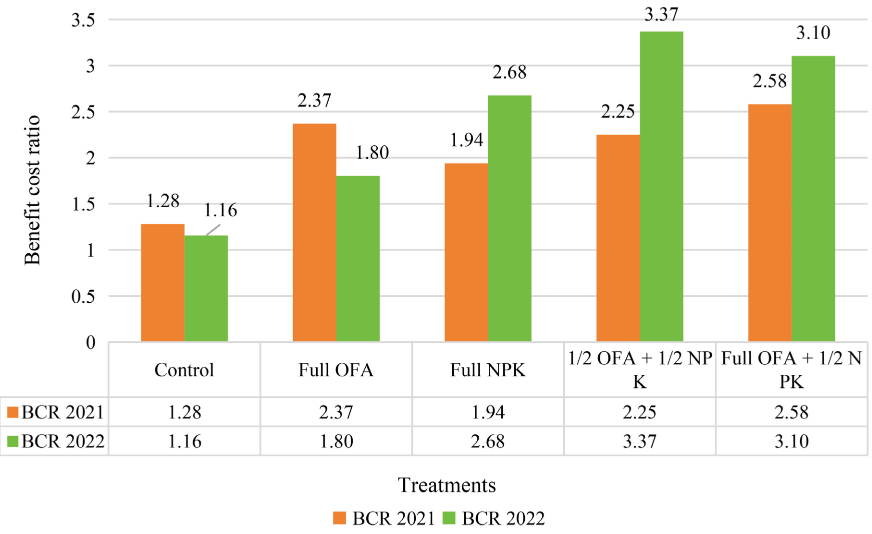

Figure 3. Benefit cost ratio analysis of different fertilizer treatments.

BCR of 3.37 followed by full OFA + ½ NPK (BCR of 3.10), full NPK (BCR of 2.68), full OFA (BCR of 1.80), and control treatments (BCR of 1.16).

4. Discussion

4.1. Impact of Weather and Soil Conditions on Crop Performance

Variations in the amount and distribution of rainfall as recorded for the two years (Figure 1) might have also contributed to the differences in the growth and yield results recorded. Even though a higher amount of total rainfall was recorded during the study period in the second year (1313.2 mm) as compared to the first (991.1 mm), the latter was better distributed especially during the vegetative period. The huge amounts of rainfall recorded in the later part of the growing season, might have potentially leached significant amount of soil nutrients in the poorly structured soil of the second year. The soil pH in the second year was 4.99 and at this pH there was a likelihood of toxic levels of some elements to retard crop growth and development. Typically, trivalent aluminum (Al) is the most abundant form in the soil at pH < 5 and has the greatest impact on plant growth. At pH > 5 - 6 (as recorded for the soil used in the first year, 5.5), the dominant species of aluminium are $AlOH^{2+}$ and $Al\left(OH\right)_2^+$, which are not as toxic to plants as Al [59].

The huge difference in the amount of organic carbon in the two soils used might have also contributed to the observed differences in the growth and yield of maize. Soil organic carbon contents of 0.78% and 0.14% as recorded in the first and second years respectively (Table 2) means, the former even though sandier (84.4% sand), is likely to have a better structure and hence, an improved water holding capacity. The resultant effect is an increased water availability for the crops and decrease in both runoff and nutrient leaching [60]. A higher soil organic carbon (organic matter) also implies, more nutrients potentially mineralized in the course of the season to add up to the fertility level of the soil in the first year. Soil N, which is the major determinant of the growth and yield of cereals was twice contained in the soil of the first year as that of the second. The implication of this was evident in significantly higher SPAD readings in all treatments of the first year as compared to the second, with the exception of the full NPK treatment. Hence, the higher soil pH, organic carbon and nitrogen of the soil used in the first year as compared to that of the second, might have played a role in better crop growth and yield of maize.

4.2. Crop Performance

Acids and phenols which are found to be the main components of wood vinegar have high biological activity and promote plant growth [32]. Consequently, plant height obtained with the combined application of full OFA + ½ NPK was comparable to those obtained by full NPK. [36] observed significant increase in plant height of rice when NPK was used in combination with pyroligneous acid (wood vinegar). Similarly, stems that were produced by plants that received full OFA + ½ NPK were as big as those that were produced by plants that received full NPK in the present study. These stems were again comparable to those produced by plants that received ½ OFA + ½ NPK. Leaves play an essential role by capturing sunlight for photosynthesis. Our result indicated that combined application of full OFA + ½ NPK increased the number of leaves produced by the maize plants. The highest leaf area obtained by full NPK was comparable to those obtained by the combined application of full OFA + ½ NPK. Chlorophyll content was highest with the application of full NPK and was similar to those that resulted from the combined application of full OFA + ½ NPK. Application of full OFA + ½ NPK accelerated the growth process and also had some effects on delaying the senescence of the leaves. This can be an indication that wood vinegar and its compounds could delay plant senescence [32]. Leaf area index which characterizes plant canopies was found to be highest in plants that received a combination of full OFA + ½ NPK. As a cereal crop, maize responded well to exposure of its leaves to light, and its uptake of essential nutrients might be attributed to the synergistic action of inorganic fertilizer and organic amendments [61].

The results from our study also indicated that, although the rate of application of inorganic fertilizer was reduced in the combined application, complementation with nutrients from wood vinegar resulted in robust vegetative growth. This could be attributed to the fact that the components of wood vinegar might have aided in the dissolution of inorganic substances in the inorganic fertilizers, rendering nutrients more available for plant uptake [62]. [63] and [64] also explained that the phenolic substances in wood vinegar, especially dihydric phenols and polyphenols, can also significantly promote plant growth at low concentrations. [65] working on tomatoes found out that wood vinegar could stimulate the increase of auxin, gibberellins and various enzyme activities and promote plant growth and nitrogen absorption. [32] observed vigorous vegetative growth in a study on rapeseed and attributed it to the acids in the wood vinegar. They explained that after the H^+ in the acid substance enters the leaf tissue, it can cause intercellular acidification, and enhance the cell activity, thereby increasing the vigor of the plant. Although plants that received full NPK took the shortest period to reach days to 50% tasseling and silking, this period was not statistically different from those recorded by plants that received ½ OFA + ½ NPK and full OFA + ½ NPK. This suggests that combined use of Inorganic fertilizer and organic farming aid can shorten the days required by the plants to reach 50 % tasseling and silking.

Grain yield differed significantly due to application of the different soil amendments. Plants that received full NPK recorded the highest grain yield which was statistically similar to grain yields by plants that received full OFA + ½ NPK and ½ OFA + ½ NPK. This result corroborates assertions made by [66] who reported that combination of organic and mineral fertilizer nutrient sources has been shown to result in synergistic effects and improved synchronization of nutrient release and uptake by crop. Additionally, in research on tea (*Camellia sinensis*), it was reported that application of pyroligneous acid increased the level of useable phosphoric acid by three times. Root exudates in the rhizosphere comprise organic acids, which dissolve phosphoric acid to make it more available for root uptake. Organic acids in pyroligneous acid (PA) have been suggested to have similar effect in the soil [25]. Similar findings were made by other authors [36] [67].

In summary, plants that received ½ OFA + ½ NPK, full OFA + ½ NPK and full NPK recorded statistically similar performance in terms of growth and yield, which were significantly higher than those recorded by plants that received full OFA only. This might have resulted from the inherent poor nature of the soils in the Guinea Savannah zone which cannot support plant growth without the addition of soil amendments. Wood vinegar (pyroligneous acid) enhances the plants ability to uptake nutrients better if sufficient amount of nutrients is in the soil. Significantly shorter and slender plants were obtained by the control treatment and this might be due to depletion of nutrients over time hence, plants exhibited stunted growth due to an inadequate supply of nutrients [15] [61].

4.3. Effect of Treatments on Some Selected Soil Enzymes and Microbial Properties of the Soil

The interactive effect of full OFA and the mineral fertilizer (full OFA+ ½ NPK) might have resulted in changes in some biochemical properties of the soil to cause lower values of alpha glucosidase (22.3 mg p-nitrophenol kg^{-1} soil h^{-1}), POXC (162 $mg\cdot kg^{-1}$ soil) and dehydrogenase activity (75.14 mg TPF kg^{-1} soil h^{-1}). Application of the full OFA only however resulted in the lowest soil basal respiration (evolved CO_2) (25.2 mg C g^{-1} soil). Low soil basal respiration (evolved CO_2) could be an indication of temporal stress imposed on the soil microbial communities due to the addition of the full OFA rate. [68] also observed that the application of Pyroligneous acid (PA) induced a low production of CO_2 due to a temporary stress experienced by the microflora. In addition, the low soil basal respiration (evolved CO_2) may imply OFA can minimize the mineralization or decomposition of organic matter by microbes. Hence, OFA can contribute to soil organic matter stabilization as observed in the lowest potentially mineralizable C (116.9 mg C g^{-1} soil) in that treatment. Combining OFA with mineral fertilizer (full OFA + ½ NPK or ½ OFA + ½ NPK) resulted in the highest values of soil microbial N, basal respiration (evolved CO_2) and available N. This suggests that combined OFA + mineral fertilization have the potential to liberate more potentially mineralizable C. Perhaps the mineral fertilization helped to balance the C:N ratio of the soil organic matter pool, which then stimulated increased microbial activities and then released more mineralizable C. Soil mineralizable C is a store house of plant nutrients. This is in agreement with [69] who reported that co-application of biochar and wood distillate can be a potential strategy to enhance the nutrient use efficiency of mineral fertilizer, especially N and P fertilizers. Thus, co-application of OFA and NPK fertilizer can help enhance nutrient use efficiency in crops. This could explain the improved growth parameters and subsequent better grain yield associated with full OFA+ ½ NPK and ½ OFA+ ½ NPK treatments in this study. The readily available and sufficient N, P and K associated with the full NPK treatment may also explain its equally improved grain yield recorded.

4.4. Economic Analysis

Economic analysis carried out in this study showed that the highest BCRs of 2.58 and 3.77 were obtained by full OFA + ½ NPK in 2021 and ½ OFA + ½ NPK in 2022 respectively. Although, full NPK obtained the highest grain yield, it did not translate into a higher economic return as a result of higher input cost. Thus, the findings indicate that complementary use of OFA and NPK is more profitable than using their single inputs, either OFA or NPK.

5. Conclusion

Treatment and year interaction effect was significant for grain yield and most of the growth and yield parameters measured indicating that the treatments responded differently to the conditions in the different years and soil. Combined application of half recommended rate of organic farming aid (OFA) or full rate of OFA with half recommended rate of NPK resulted in similar yields as those obtained by full NPK, which implies that OFA application can be a substitute for half the recommended rate of NPK without affecting the yields of maize. In addition, there was a yield advantage of 197. 5%, 191.3%, 178.3 and 79.1% over the control for full NPK rate, full OFA rate + ½ NPK rate, ½ OFA rate + ½ NPK and full OFA rate respectively. The full OFA rate + ½ NPK fertilizer enhanced soil basal respiration (evolved CO_2) and mineralizable C, implying that, combined application of full rate of OFA and half rate of NPK fertilizer would be necessary to boost soil microbial activity and soil labile nutrient pool (labile C pool). This suggests that combined use of full OFA rate + ½ rate of NPK fertilizer can be a suitable strategy for preserving soil quality. However, further studies are needed to better understand the links between plant and soil. The treatments applied, either sole OFA, sole mineral NPK fertilizer or combined OFA and NPK fertilizer had no effects on soil enzyme. The economic analysis indicated that complementary use of OFA and NPK is more profitable than using single inputs (either OFA or NPK). In promoting technology packages to farmers, development practitioners must carefully consider complementary inputs that are cost-effective and economically rewarding.

Recommendations

Combined application of either full or half rate of OFA and half rate of recommended mineral NPK is therefore recommended for maize productivity in the study area.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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