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RESEARCH ARTICLE

Economic Effects of Using Improved Maize Varieties, Inorganic Fertilizer and Goat Manure in Smallholder Farms: Evidence from Field Evaluations in Southern Ghana

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ABSTRACT

Maize is a key cereal which contributes to food security with an ever-growing demand in Africa. Therefore, production must be continuously increased to meet demand. One way to achieve increased production is to use improved varieties and soil amendments to enhance productivity. However, the usage of these inputs is low in sub-Saharan Africa including Ghana. To contribute to the literature on the economics of applying soil amendments, especially from season to season, on-farm trials were undertaken in the coastal savannah and semi-deciduous forest zones of Ghana to demonstrate profitability of adopting improved maize varieties and soil amendments. Partial budgeting techniques were employed to compute net benefits and marginal rates of return resulting from a shift in strategy from farmer practice to the use of improved maize varieties and soil amendments. Significantly higher yields were obtained with the improved technologies. Maize plants on the sole inorganic fertilizer had significantly

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($P < 0.05$) higher grain yields for all varieties in the two agro-ecological zones in the major season. In the minor season however, grain yields of maize on the combined treatment of inorganic fertilizer + goat manure was significantly ($P < 0.05$) higher than the rest of the soil amendments for all varieties in both agro-ecological zone. The fertilizer + manure combination yielded the highest net income in both the major and minor seasons. The marginal rates of return for the shift from farmer practice to soil amendments were highest for the fertilizer + manure combination, irrespective of the maize variety and agro-ecological zone. However, the marginal rates of return were minimal for the local maize variety (landrace). In the minor rainy season, net benefit was greater with soil amendment application than with reliance on residual nutrients from the previous season. Thus, residual soil amendment effects alone cannot sustain maize yields and profitability- soil amendments need to be applied continuously.
Keywords: Economic Analysis; Ghana; Maize; Marginal Rate of Return; Partial Budgeting; Soil Amendments

1. Introduction

Numerous poor households in Ghana cultivate Maize (*Zea mays* L.) as their main source of food, with per capita consumption of more than 45 kg/year [1]. It is a widely cultivated and utilized cereal crop [2] that accounts for more than a fifth of the income obtained by the Ghanaian smallholder farmer [3]. This makes maize a prominent crop in the socio-economic lives of smallholder farmers in Ghana, even though its productivity is low and substantially less than the mean for Africa sub of the Sahara [4]. Technical, sociocultural, socioeconomic, and biophysical factors have been identified as major constraints limiting maize productivity among small-scale farmers in parts of southern Ghana [5]. Low adoption of improved varieties and soil amendments by the majority of farmers are key technical factors limiting maize production [5].

Fertilizer application in crop production is low in Ghana and is just about 8 kg per hectare [6] despite the fact that soil nutrient loss in Africa is among the highest [7]. Although Ghanaian smallholder farmers know the benefit of using inorganic fertilizers, the high prices of fertilizers as well as low prices of farm produce limit their acquisition and use [8]. According to Ragasa, Chapoto [2], the forest areas had the lowest fertilizer adoption rates. The average fertilizer application rate in 17% of the forest areas under maize were 27 kg, 16 kg and 16 kg per hectare for N, P and K respectively. The maize area was higher in the coastal savannah zone (37%) just as the average fertilizer application rate of 29 kg N, 17 kg P and17 kg K per hectare [2]. However, the recommended rates in Ghana were much higher; 90 kg, 60 kg, 60 kg per hectare of NPK respectively [9]. This implies that there could be a big gap between potential yield levels and yields that are actually obtained with the existing rates of fertilizer application.

An increase in maize productivity requires increased use of sustainable strategies, including application of mineral fertilizers, compost and improved planting materials use [10] as well as improved agronomic practices that could contribute to raising maize yields. Naturally pollinated maize varieties yield more than landraces [11, 12]. When landraces are replaced with improved naturally pollinated varieties, grain yields increase two-fold [13]. Furthermore, the importance of inorganic fertilizers in maize production cannot be overemphasized; the use of mineral fertilizers in some parts of Kenya resulted in increases in maize yield rising by 63% [14]. Additionally, animal manure usage in crop farming is known to boost fertility and consequently plant yields. In crop-livestock farming, the use of available animal manure on crop farms has improved yields [15]. Plots with animal manure have been reported to have higher average maize yields than those without animal manure [16]. Therefore, animal manure can be used to increase maize yields when available. Moreover, according to Sanginga [17], using inorganic or organic soil amendments alone leads to less benefit than using them together. The combined use of the amendments improves the biological and physico-chemical properties of the soil. Thus, on farm trials were conducted to demonstrate the yield effects of applying soil amendments.

Nevertheless, higher yields arising from the adoption of improved strategies may not necessarily lead to higher profits in maize production, which could hinder the adoption of improved practices. Although maize is said to contribute to the earnings of Ghanaian smallholders, information about change in profitability of maize produced with inorganic fertilizers, organic amendments, and their combination is scarce. Therefore, evidence of profit improvements emanating from the use of these soil amendments can encourage their usage in maize production, thereby improving productivity. Moreover, within the forest and coastal belts, rainfall is bimodal, presenting opportunities for double cropping of maize each year, without irrigation. The first period of rains (April to July) is followed by a second period of rains (September–November). Some farmers apply soil amendments solely in the first period (considered to be the main raining season.). However, in the second period, residual nutrients carried over from the first period may not be sufficient to maintain the improved yield and profit levels achieved during the first season. Some studies on the profitability of using integrated soil fertility management in maize production relate to specific geographical regions such as the forest zone [18] and Guinea savannah zone [19]. Using partial budgeting, a tool that captures the change in net benefits or profits, and marginal rate of return computations, other studies have demonstrated the superiority of inorganic and organic fertilizer combinations over inorganic or organic amendments alone [20–23].

Here, we assessed the outcomes of soil improvement strategies on maize production, as well as the magnitude of these effects per variety. Additionally, we ascertained whether the remnants of the soil nutrients added in the first season are sufficient to sustain production or whether continuous application is required. Accordingly, the studies main objective was to conduct an economic analysis on maize production using soil amendments and different maize genotypes. The following are the specific objectives:

1. to estimate the effect on net benefits arising from the change of soil improvement strategy from farmer practice to manure use, from manure use to fertilizer-manure use, and fertilizer-manure use to sole fertilizer use using three maize genotypes one at a time during the major season in two agro-ecological zones.
2. to ascertain whether net benefit improvements obtained in the major season from the use of manure, fertilizer, or a combination of fertilizer and manure could be sustained in the minor season with residual soil nutrients (without re-applying these amendments in the minor season).

2. Materials and Methods

2.1. Soil Characteristics and Climate of the Study Location

On-farm participatory demonstrations with farmers were conducted on farmers' fields in two districts, one in the Central region representing the Coastal Savannah Zone (CSZ) and the other in the Eastern region representing the Semi-deciduous Forest Zone (SDFZ). Three communities were selected from each district. **Table 1** presents the climate, physical and some soil characteristics of the study location.

Rainfall in the study location has two peaks with one in the main raining season (April–July) and the other in the minor season (September–November). A dry spell occurs in August. **Figure 1** presents a map of the study locations.

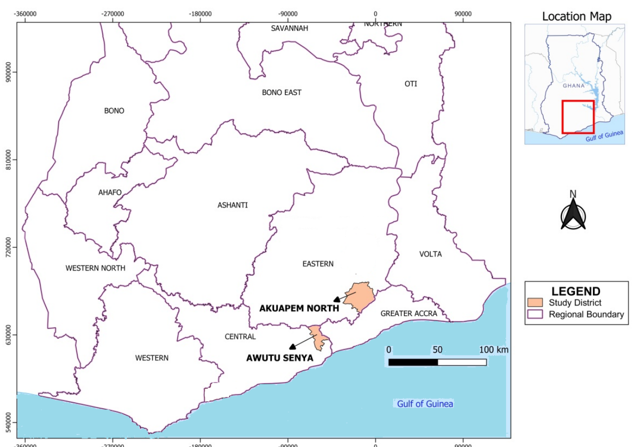


Figure 1. Parts of the map of Ghana showing the study districts in the Central (CSZ) and Eastern (SDFZ) regions of Ghana.

2.2. Treatment/Experimental Design

The soil treatments in the major season were as follows:

Table 1. Soil type, physical properties and climate of study location.

	Central Region	**Eastern Region**
Districts	Awutu Senya	Akuapem North
Agro-eco zone	Coastal Savanna	Semi-deciduous forest
Soil Types (FAO. 1998)	Dystric Leptosols and Haplic Lixisols	Umbric Leptosols and Cambic Arenosols
Soil Texture	Loamy Sand	Sandy Loam
Soil PH	5.91–6.64	5.91–6.64
Rainfall	>1000 mm	990 mm to 1650 mm
Relative Humidity	70% to 81%	70% to 90%
Temperature	21 and 34 °C	21and 34 °C

1. Treatment 1: NPK + Urea at 95, 37.5, 37.5 kgha^{-1}
2. Treatment 2: 50% goat manure (2.5 tons ha^{-1}) + 50% NPK + urea (47.5,18.75,18.75 kgha^{-1})
3. Treatment 3: Goat manure only at (5 tons ha^{-1})
4. Treatment 4: Control (Farmer practice-No application of amendment)

These soil treatments were applied to three varieties of maize: Ahomatea, Obatanpa and Omankwa in the major rainy season of 2017. The randomized complete block design (RCBD) was used and there were four replications of each treatment. In the minor season, the experiment was carried out on the same plots used in the major season. This time each plot apart from the plot with farmer practice (control) was split into two. One half was used without any further amendments while on the other half amendments were applied at the rates used in the major season. Thus there were seven treatments for each of the maize varieties. A split plot design was used and each treatment had four replications.

2.3. General Management

In both agro-ecological zones, seeds of improved genotypes, Omankwa and Obatanpa, were procured from Crops Research Institute (CSIR-CRI), Ghana. The farmers provided the seeds of the local variety; Ahomatea. The plots measured 6.4 m × 5.6 m in the major season and 3.2 m × 5.6 m in the minor season. In all cases, the planting distance was 0.8 m × 0.4 m. The seeding rate was 3 seeds per hill at a soil depth of 5 cm. Fourteen days following germination, the seedlings were thinned to 2 per hill. Thus the plant population became 62,500 plants per hectare. Planting was done in April 2017 during the main season and September 2017 during the minor season.

Manure was applied at a designated spot one week prior to sowing and contained 1.87 % total nitrogen, 1.51% total phosphorus and 0.62% total potassium. The compound fertilizer NPK-15-15-15 which contains 15% N. 15% P, 15% K was applied to the side of the plants two weeks after planting. Urea was however applied 4 weeks after sowing and in order to prevent the exposure of fertilizer to direct sunlight and runoff, the soil was turned a little to get the fertilizer beneath the soil. The combination of urea applied at a rate of 125 kg ha^{-1} and the compound fertilizer NPK applied at a rate of 250 kg ha^{-1} gave the 95 N, 37.5 P, 37.5 K kgha^{-1}.as indicated in treatment 1. The manure provided 93.5 kg N ha^{-1}, 75.5 kg P ha^{-1} and 31 kg K ha when applied at the rate of 5 t ha^{-1}.

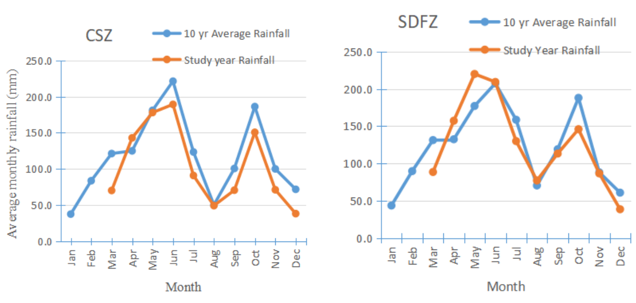
Post emergence herbicide, Nicosulfuron 40 (Nicoking), was used to control weeds. This was applied four and eight weeks after sowing, using a rate of 1.5L per hectare. The active ingredient was Nicosulfuron and it is a selective post-emergence herbicide used to control grass weeds and broad-leaved weeds in maize fields. A more comprehensive presentation of the materials and methods can be found in Marfo-Ahenkora, Taah [24].

2.4. Data Collection

2.4.1. Rainfall and Yield Data

Rainfall—The amount of rainfall on the farm for the period of the experimentation was collected by situating conventional rain gauges at the trial location. A 10 year rainfall data (2007–2017) for the study districts was collected from the Ghana Meteorological Agency (2017).

Figure 2 presents the average monthly rainfall distribution for a ten year period in the study districts and rainfall data collected at the study sites for CSZ and SDFZ respectively.



(**a**) (**b**)

Figure 2. Monthly distribution of average rainfall (mm) over a 10 year period (2007–2017) in the study districts and the study year (2017) rainfall (in locations) for CSZ (**a**) and SDFZ (**b**) respectively.

Grain yields—When the cob turned light brown/straw in colour, indicating that the plants had dried, the maize was harvested from the plots. An area of size 1m x 1m in the interior rows was demarcated. Plant samples were then taken from these marked areas. The grains were dried till a moisture of 14% was reached. The moisture meter used was John Deere Moisture Chek plus. Weights of the dry grains were measured and recorded in kilograms per hectare (kgha^{-1}).

2.4.2. Economic Data

The market prices of inputs at the time of planting and outputs at harvest were obtained from the communities of the trial farms. Maize yields were obtained from experimental farms as described earlier.

2.4.3. Analysis of Data

Yield data analysis—Differences in the mean of yields for the various treatment were analysed using ANOVA. The data was first analysed separately for each Agro-ecological zone and then for the two zones together. The LSD was used to separate means at the significance level of 5%. The Genstat software (12th edition, GenStat 2009) was used for the analysis.

2.4.4. Economic Analysis—Partial Budgeting

Given that there are statistically significant yield differences among treatments, one can proceed with partial budgets. If there are no significant yield differences among treatments, then computing differences in cost among treatments suffices (see for instance, [25]).

Partial budgets are used to measure the effect on net benefit or profit arising from a small change in farm business [26–28]. In tracking change in net benefit due to a change in technology, only incomes and costs that change or vary need to be captured. Incomes and costs that remain fixed irrespective of the change cancel out when change in net benefit is computed. The decision to effect the small change or not (for instance, invest in a new technology) could be assessed using whole farm or complete budgets. However, doing so will mean investing in time and effort to collect and analyse data that would not influence the decision [25, 28].

Let gross benefit be denoted by GB, total cost by TC and net benefit by NB. Then change in net benefit can be expressed as follows:

$$\Delta NB = \Delta GB - \Delta TC \tag{1}$$

Where ΔGB denotes change in total gross benefit, and ΔTC denotes change in total cost.

However, $\Delta TC = \Delta TFC + \Delta TVC$ where ΔTFC denotes change in total fixed cost and ΔTVC denotes change in total variable cost. Accordingly, Equation (1) can be rewritten as

$$\Delta NB = \Delta GB - \Delta TFC - \Delta TVC \tag{2}$$

Notably, $\Delta TFC = 0$ since cost that are fixed do not vary with change in technology. Therefore, Equation (2) becomes

$$\Delta NB = \Delta GB - \Delta TVC \tag{3}$$

A positive change in net benefit indicates improvement in net benefit or income resulting from the change in technology.

Beyond the absolute change in net benefit, farmers or investors are concerned with the rate of return on their investment. Farmers usually have to incur additional cost to adopt a new technology and therefore compare this additional cost to the additional income they get from the investment. The marginal rate of return (MRR) provides one measure for this rate of return. It is defined as the ratio of the change in net benefit to change in total variable cost (Equation (4)) and may be expressed as a percentage.

$$MRR = \frac{\Delta NB}{\Delta TVC} \tag{4}$$

The marginal rate of return also connotes the return on a unit currency invested in the new technology or change.

As indicated above, the net benefits were computed by subtracting the costs that vary for each treatment from the gross benefits obtained from that treatment. Costs that varied were related to the cost of the different maize varieties, the soil amendments (including fertilizer, manure, and their combinations), and labour required for applying these inputs. The cost of inputs required per hectare of land was computed based on the prices prevailing at farm locations. Gross benefits were computed by multiplying the price of harvested maize at the farm level by the yield per hectare obtained from each treatment. Average yield were computed for the two recommendation domains (the Semi-deciduous forest and the Coastal savannah) each having farmers with similar characteristics and circumstances so that the same recommendation can apply to each group [25]. However, the yield was first adjusted to account for the fact that the experimental results may differ from the farmers' yield expectations. Such differences in yield may be attributable to more precise and timely execution of operations on experimental plots, possible overestimation of yields for entire plots from small plots because of errors in the measurement of harvest, and because small plots may be more uniform [25].

The marginal rate of return (MRR) was computed as the ratio of the additional benefit obtained from switching from one amendment to another to the additional cost incurred for switching. In the case of multiple alternatives, the change is from one alternative to the next more costly one. Thus, in this study, the MRR was computed for switching from farmer practices to manure use, manure use to combined fertilizer and manure use, and finally combined fertilizer and manure use to exclusive fertilizer use.

3. Results

Generally, the monthly average rainfall over10 years (**Figure 2a,b**) follows a similar leaning as the 2017 monthly average rainfall collected at the study location in the CSZ. The monthly average rainfall values over 10 years appears to be slightly higher than the 2017 figures. However, in some of the months (May and August) the figures were about same. Similarly, in the SDFZ, the monthly rainfall trend was similar for both the ten year average and the 2017 monthly rainfall values collected at the study location. There are some months (March-May) in which the 2017 rainfall were slightly higher than the 10 year average. After June, the 10 years average rainfall appear to be slightly higher than that of 2017 values collected at the study location but similar rainfall figures were recorded in 3 of the months (June, August and November). Generally, the rainfall amount and distribution in the study locations in 2017 are typical of the 10 year average values.

3.1. Grain Yield (Grains in kg ha^{-1})

3.1.1. Major Rainy Season

Plots with soil amendments applied, had significantly (P < 0.05) higher yields compared to plants on the control plots for all the maize varieties and in both CSZ and SDFZ. Within the varieties, plants on sole fertilizer treatments had significantly (P < 0.05) higher yields than the rest of the soil amendments applied in both agro-ecological zones except for Ahomatea in the CSZ where sole fertilizer treatment and the fertilizer + manure treatment were not significantly different (**Figure 3**).

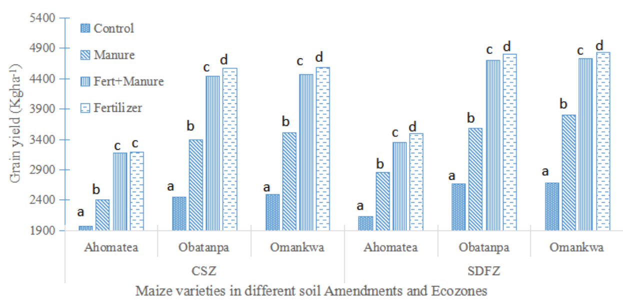


Figure 3. Maize grain yields (kg ha^{-1}) under different soil treatments in the coastal savannah (CSZ) and semi deciduous forest zones (SDFZ) in the major rainy season.

Fert + Manure = Inorganic Fertilizer + Manure

3.1.2. Minor Rainy Season

In the minor season, plants on the fertilizer + manure treatment had significantly (P < 0.05) higher yields than plots on which other soil improvement strategies were employed for all maize varieties in both the CSZ and SDFZ. Plots with residual nutrients had significantly ($P < 0.05$) lower yields than plots on which nutrients were reapplied (**Figure 4**). Plots with soil amendments either reapplied or residual had significantly ($P < 0.05$) higher yields compared to plants on the control plots for all the maize varieties and in both agro-ecological zones. Generally, there were significant differences ($P < 0.05$) among the soil amendments within the maize varieties (**Figure 4**).

A detailed presentation of the agronomic results can be found in Marfo-Ahenkora, Taah [24].

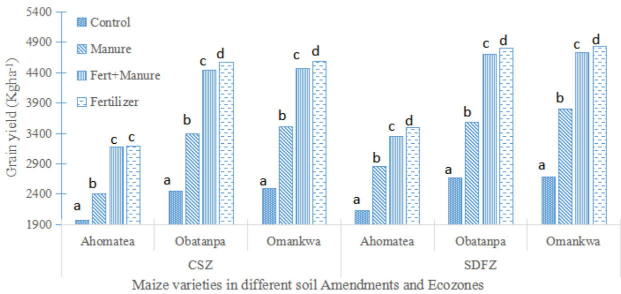


Figure 4. Maize grain yields (kg ha^{-1}) under different soil treatments in the coastal savannah (CSZ) and semi-deciduous forest zones (SDFZ) in the minor rainy season.

Control=farmer practice (no amendments applied); No fertilizer= Residual nutrient sole inorganic fertilizer; No Fert+ manure= Residual nutrients sole fertilizer + Goat Manure; No manure= residual nutrient goat manure; Manure = Goat Manure; Fertilizer= Inorganic Fertilizer; Fert+ manure= Inorganic fertilizer + Goat Manure

3.2. Net Benefit and Marginal Returns

3.2.1. Major Rainy Season

Table 2 shows gross profits, total variable cost, and net income with the use of various soil amendments across the three maize varieties in the semi-deciduous forest zone during the main rainy season. Also shown are the marginal rate of return for switching from one amendment to the other.

For each maize variety, the cost that varied was highest with fertilizer, followed by the fertilizer—manure combination, manure only, and farmer practice (no soil amendment). For fertilizer use, the cost that varied were between 42% and 46 percent more than cost that varied with fertilizer-manure combination and between 146–172 percent more than cost that varied with manure. However, compared with farmer practice, the cost that varied with fertilizer were between 1034% and 3445 percent more. In all cases, the cost differences were larger with local (unimproved) seed use than with improved seed use.

Irrespective of maize variety, gross benefit (profit) was highest with fertilizer, followed by the fertilizer-manure combination, manure, and farmer practices. However, the net benefit was highest with the fertilizer-manure combination, followed by fertilizer, manure, and farmer practices. The net benefit with fertilizer was 4–5 percent less than that with fertilizer-manure combination, 3–14 percent more than net benefit with manure, and 24–50 percent more than that with farmer practice. In all cases, the net benefit (profit) was higher with improved seeds (Omankwa and Obatanpa).

The results for coastal savannah followed a similar pattern (**Table 2**). Costs in the coastal savannah were very similar to those in the semi-deciduous forest zone.

Irrespective of the maize variety, the cost that varied was highest with fertilizer, followed by the fertilizer – manure combination, manure only, and farmer practice. The cost that varied were with fertilizer use were between 42% and 46 percent more compared to cost that varied with fertilizer-manure combination, and 146–172 (percent) more compared to cost that varied with manure. However, costs that varied with fertilizer use were between 1034 and 3445 percent more than cost that varied with farmer practice. In all cases, the cost differences were larger with local (unimproved) seed use than with improved seed use.

Irrespective of the maize variety, gross profit was highest with fertilizer, followed by the fertilizer-manure combination, manure, and farmer practices. However, net income was the highest with the fertilizer-manure combination, followed by fertilizer, manure, and farmer practices. The net benefit with fertilizer was between 4 and 10 percent less than that of fertilizer-manure combination, it was between 11% and 17 percent more than manure, and 19% and 51 percent more than farmer practice. In all cases, the net profit was higher with improved seeds (Omankwa and Obatanpa).

The marginal rates of return (MRR) of moving from a lower-cost soil amendment to one with the next highest cost were calculated. The costs of the amendments were highest for fertilizer alone, followed by fertilizer plus manure, manure, and farmer practice.

Regardless of the maize variety used, moving to ma-

Table 2. Marginal analysis, seed variety and soil amendments experiment in the semi-deciduous and Coastal savannah zones and major rainy season.

	Semi-Decidudous Forest				Coastal Savannah			
Seed Variety/Soil Amendment	**Gross Benefit (GhC)**	**Cost That Vary (GhC)**	**Net Benefit (GhC)**	**MRR (%)**	**Gross Benefit (GhC)**	**Cost That Vary (GhC)**	**Net Benefit (GhC)**	**MRR (%)**
Local								
Farmer practice (control)	2637	30	2,607		2439	30	2,410	
Manure	3528	391	3,137	147	2964	391	2,573	45
Fert + Manure	4138	727	3,411	81	3922	727	3,195	185
Fertilizer	4310	1,064	3,246	−49	3933	1,064	2,869	−97
Obatampa								
Farmer practice (control)	3235	100	3,195		3027	100	2,927	
Manure	4425	461	3,964	213	4198	461	3,737	224
Fert + Manure	5805	797	5,007	310	5473	797	4,676	279
Fertilizer	5921	1,134	4,787	−65	5637	1,134	4,503	−51
Omankwa								
Farmer practice (control)	3311	100	3,211		3085	100	2,985	
Manure	4696	461	4,235	284	4340	461	3,879	248
Fert + Manure	5843	797	5,046	241	5525	797	4,728	253
Fertilizer	5963	1,134	4,829	−64	5654	1,134	4,520	−6280

Note: Fert = fertilizer
In 2017, 1 U.S dollar was equivalent to 4.35 Ghana Cedis (GhC).

nure from farmer practice, in the semi deciduous forest elicited marginal rate of return of over 100% in the major season.

For the local seed, moving from farmer practice (no soil amendment) to the use of manure elicited an MRR of 147 percent. Changing from manure to a combination of fertilizers and manure further increased the MRR by 81 percent. However, a change in amendment from the combination of manure and fertilizer to sole fertilizer elicited a reduction in net benefits, thereby making MRR negative (**Table 2**).

The Marginal Rate of Return (MRR) increased for all maize varieties when the amendment was changed from farmer practice to manure and from manure to a combination of fertilizer and manure in the coastal belt.

However, it became negative when the amendment was switched from manure plus fertilizer to fertilizer only. The MRR was highest with fertilizer plus manure and over 200 percent with the Obatanpa and Omankwa seed varieties. The MRR with local (unimproved) seeds was the lowest and under 200 percent (**Table 2**).

3.2.2. Minor Rainy Season

Table 3 shows minor season gross income, total variable cost, and net income for residual fertilizer, residual fertilizer and manure combination, residual manure, and repeated use of farmer practices, manure, combined fertilizer and manure, and fertilizer in the semi-deciduous forest zone and the coastal savannah zone.

For the semi-deciduous zone, costs of soil amendments and seeds in the minor season were the same as those in the major rainy season.

Gross profits were highest for repeated soil amendments, fertilizer, fertilizer-manure combination, and manure, followed by residual soil amendments and farmer practices. For repeated soil amendments, gross profit was highest with the fertilizer-manure combination, followed by fertilizer and manure. A similar pattern was obtained for net profits, where net profits with repeated soil amendments were higher than those with residual soil amendments, and that with farmer practice was the least.

The net benefit with repeated fertilizer was 17–37 percent more than the net benefit with residual fertilizer. The net benefit with repeated fertilizer–manure combination was 30–46 percent more than the net benefit with residual fertilizer–manure combination. The net benefit with repeated manure was 7–26 percent more than the net benefit with residual manure application.

Compared to farmer practices, net benefits with repeated soil amendments were 26–53 percent, 40–66 percent, and 21–46 percent more for fertilizer, fertilizer – manure combination, and manure, respectively.

In addition, for coastal savannah zone, the cost of the minor season's soil improvement strategies and seeds were same as those in the major season.

Gross profits were highest for repeated soil amendments, fertilizer, fertilizer-manure combination, and manure, followed by residual soil amendments and farmer practices. For repeated soil amendments, the gross profit was highest with the fertilizer-manure combination, followed by fertilizer and manure. Again, net profits follow a pattern similar to that of gross profits. Net profits with repeated soil amendments were higher than those with residual soil amendments, and those with farmer practices were the lowest (**Table 3**).

The net benefit with repeated fertilizer was 11–38 percent more than the net benefit with residual fertilizer. The net benefit with repeated fertilizer–manure combination was 24–49 percent more than the net benefit with residual fertilizer–manure combination. The net benefit with repeated manure was 3–26 percent more than the net benefit with residual manure application (**Table 3**).

Compared to farmer practices, net benefits with repeated soil amendments were 20–58 percent, 39–72 percent, and 14–47 percent more for fertilizer, fertilizer–manure combination, and manure, respectively.

The minor season experiment aimed at ascertaining whether repetition of soil improvement strategies during the rainy season will increase returns. For the semi-deciduous zone, repetitions of the major season's soil amendments in the minor season with local seeds resulted in positive marginal rates of return, except when manure was repeated. The marginal rate of return was highest when manure and fertilizer combinations were repeated. The MRR was generally high for the Obatanpa and Omankwa maize varieties (127–268 percent) (**Table 3**).

Additionally, for the coastal savannah zone, repetition of the major season soil amendments in the minor season resulted in positive marginal rates of return. Although the rate was reduced when the manure was repeated with local (unimproved) seeds, it did not turn negative. The marginal rate of return was generally the greatest when manure and fertilizer combinations were repeated, irrespective of maize variety. The only deviation was in the case of the Omankwa variety, where the MRR with repeated application of manure exceeded that of combined manure-fertilizer application. However, across all soil amendments, the MRR was higher with Obatanpa and Omankwa maize varieties (133–247 percent) (**Table 3**).

4. Discussion

Grain yields were greater when sole fertilizer was used in the major season than when fertilizer-manure combination was used, the converse was true for the minor season. Thus, the yield response to manure application is not elicited fully in the season of application. The results is in accordance with [19]; they showed that maize productivity significantly increased with application of inorganic fertilizer and manure combinations every year compared to yields from sole inorganic fertilizer application; however, this increase occurred only from the third year of a five-year on-farm trial. Additionally, the higher maize grain yields in the minor season following the major season confirm that nitrogen fertilizer is more efficiently utilized with higher manure or soil carbon content [19, 20, 29].

The net income in the major rainy season across the semi-deciduous forest zone and coastal savannah zone showed that all treatments were profitable. However, the use of improved seeds and the use of manure, fertilizer, fertilizer and manure combination significantly improved net income. The potential effects of soil amendments could not be exploited significantly with the use of local (unimproved) seeds. Although the use of improved maize seeds under farmer practice (no amendment) led to some improvement in net income, the application of fertilizer, manure, and a combination of fertilizer and manure further improved net income. This is in line with the suggestion by Awunyo-Vitor, Wongnaa [30] that to increase productivity, and by extension incomes, farmers should make maximal use of technologies available to them.

An MRR of 200 percent means that when a farmer invests an additional one Ghana cedi (GhC 1) in adopting a new technology, he will earn an additional two Ghana cedis (GhC 2). This rate of return is likely greater than the acceptable minimum rate of return [25]. However, the

Table 3. Marginal analysis, seed variety and soil amendments experiment in the semi-deciduous zone and Coastal savannah in the minor rainy season.

		Semi-Decidudous Forest				Coastal Savannah			
	Soil Amendment	**Gross Benefit (GhC)**	**Cost That Vary (GhC)**	**Net Benefit (GhC)**	**MRR (%)**	**Gross Benefit (GhC)**	**Cost That Vary (GhC)**	**Net Benefit (GhC)**	**MRR (%)**
Local	Residual fertilizer	2806	30	2,776		2603	30	2,573	
	Fertilizer	4322	1,064	3,259	47	3944	1,064	2,880	30
	Residual manure	2952	30	2,922		2699	30	2,669	
	Manure	3531	391	3,140	60	3141	391	2,750	22
	Residual fert+man	2818	30	2,788		2698	30	2,668	
	Fert and manure	4356	727	3,629	121	4045	727	3,318	93
Obatanpa	Residual fertilizer	3620	100	3,520		3253	100	3,153	
	Fertilizer	5965	1,134	4,832	127	5662	1,134	4,529	133
	Residual manure	3711	100	3,611		3492	100	3,392	
	Manure	5061	461	4,600	274	4704	461	4,243	236
	Residual fert + man	3675	100	3,575		3393	100	3,293	
	Fertilizer + manure	6031	797	5,234	238	5778	797	4,981	242
Omankwa	Residual fertilizer	3656	100	3,556		3426	100	3,326	
	Fertilizer	5998	1,134	4,864	127	5713	1,134	4,579	121
	Residual manure	3774	100	3,674		3460	100	3,360	
	Manure	5102	461	4,641	268	4714	461	4,253	247
	Residual fert + man	3707	100	3,607		3442	100	3,342	
	Fertilizer + manure	6086	797	5,289	241	5781	797	4,984	236

Note: In 2017, 1 U.S dollar was equivalent to 4.35 Ghana Cedis (GhC).

extra benefit of moving to sole fertilizer from the fertilizer and manure combination does not cover the extra costs required. The fertilizer-manure combination yields high marginal returns because manure is cheaper than inorganic fertilizer, and at the same time, the net benefit is higher. This agrees with [18] who also found that fertilizer-manure combination dominates sole fertilizer in the forest zone of Ghana.

The net income from relying on residual nutrients from the previous season was significantly lower than the net income obtained with reapplication of the soil amendment used in the last season. This means that for yield and net income levels to be sustained throughout the year, soil amendments should be applied continuously. The MRR of switching from residual nutrients from the previous season to the reapplication of the major season soil amendment in the minor season was mostly positive. The MRR was low when local seeds were used but was appreciably higher when improved seeds were used. This finding of positive MRR with repeated use of soil amendments is somewhat consistent with Franke, Schulz [19] who observed that the annual use of fertilizer and fertilizer-manure combinations in maize resulted in positive MRR in most years.

The level of fertilizer subsidy could influence the profitability of manure-fertilizer combinations relative to sole fertilizer. It is noteworthy that even though inorganic fertilizer was bought at full market price for this study, relatively high net incomes were recorded for the use of fertilizer alone and fertilizer-manure combinations. Fertilizer subsidies in Ghana ranged from 21percent in 2015 to 50 percent in 2017 [31]. Thus, as observed by [32] the profitability of fertilizer use varies with the subsidy level. The lower the level of subsidy, the higher the profitability of manure and manure-fertilizer combinations compared to fertilizer alone.

Besides the possible improvement in farmers' income from the use of manure or manure-fertilizer combinations in maize production, there are other socioeconomic implications for countries that are dependent on mineral fertilizer imports. The importing country stands to gain from reduced fertilizer imports by saving foreign exchange. In addition, in times of fertilizer shortages, the use of manure ensures that productivity levels are maintained or not significantly reduced. However, the bulkiness of manure and associated cost of transportation to farms may limit its use. This limitation may, in turn, be ameliorated if manure is first converted into compost to reduce bulkiness.

5. Conclusions

This study sets out to access the profitability of integrated soil improvement strategies. Specifically, it estimated the profitability of the use of three [3] soil amendments on three [3] maize varieties. Irrespective of the maize variety and agro-ecological zone, the net benefits and marginal rates of return were highest with the use of combined manure and fertilizer. However, soil amendments application with maize landraces (local) resulted in the lowest yields, net income, and marginal rates of return. The application of manure only, fertilizer only and combined fertilizer-manure in addition to improved maize seeds, greatly improved productivity and net income. The manure and fertilizer combinations gave the highest net profit, followed by the sole fertilizer.

Marginal rates of return are sufficiently high to warrant switching from farmer practice to manure and further from manure to manure-fertilizer combination, but not from manure-fertilizer combination to sole fertilizer. Furthermore, relying on residual nutrients from the previous season leads to a decline in yield and net income. The reapplication of soil amendments in the subsequent minor season is required to sustain yield and net income levels.

Where manure is available and accessible, applying mineral fertilizer in combination with manure is recommended alongside improved maize varieties. In the absence of manure, fertilizer alone can be used. Because the pattern of net returns and marginal rate of returns are similar for coastal savannah and semi-deciduous forest agro-ecological zones, these recommendations apply equally to them.

It should be noted that these conclusions regarding the profitability of soil amendments were not influenced by the fertilizer subsidy policy regime pertaining to the country at the time of the study. The fertilizer for the study was purchased at the full market price, even though the subsidy on fertilizer price was approximately 50 percent at the time of the study. Thus, for farmers (including smallholder maize farmers) who qualify to purchase fertilizer at subsidized rates, their profits relative to the profits of farmers producing maize under the sole manure and manure-fertilizer combination increases.

This study provides further evidence of the superiority of combining organic and inorganic fertilizers over application of any of them alone. In addition, it provides evidence of more efficient land use through the combination of improved varieties and soil amendments. This study shows the potential of crop-livestock systems to enhance crop yields and net income while mitigating climate change. Proper manure management and subsequent use in crop production could decrease the emission of greenhouse gases and possibly provide more quality crop residues that could be fed to animals, thus achieving a circular economy.

As a policy recommendation, extension agents should educate farmers to use manure and inorganic fertilizer together on crop farms to close yield gaps in maize production, improve farmers' net income, and mitigate climate change. The rates recommended in this study may be applied.

Author Contributions

E.M.-A.: Conceptualization, Methodology, Investigation, Writing, Reviewing and Editing. G.Y.A.: Methodology, Formal analysis, Writing Original draft , Reviewing and Editing. K.J.T.: Supervision, Validation. E.A.-B.: Supervision, Validation. C.Y.F.D.: Field Data Collecting, Reviewing and Editing.

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Data Availability Statement

The data supporting the outcomes of the study can be accessed from the corresponding author (estha-

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Conflicts of Interest

The authors are of the view that, there are no competing interests.

References

[1] Ministry of Food and Agriculture, 2016. Agriculture in Ghana: Facts and Figures 2016. Ministry of Food and Agriculture, Statistics Research and Information Directorate: Accra, Ghana.

[2] Ragasa, C., Chapoto, A., Kolavalli, S., 2014. Maize productivity in Ghana. Intl Food Policy Res Inst.: Washington, DC, USA.

[3] Acquah, H.D., Kyei, C.K., 2012. The effects of climatic variables and crop area on maize yield and variability in Ghana. Russian Journal of Agricultural and Socio-Economic Sciences. 10(10), 10–13.

[4] Food and Agriculture Organisation of the United Nations, 2018. Statistical databases and data-sets. Available from: www.fao.org/faostat/eg/#data/QCL

[5] Marfo-Ahenkora, E., 2020. Strategies for Sustainable Productivity of Maize (*Zea mays* L.)-Based Farming Systems of Smallholder Farmers in Ghana. University of Cape Coast.

[6] Henao, J., Baanante, C., 2006. Agricultural production and soil nutrient mining in Africa: Implications for resource conservation and policy development. IFDC: Muscle Shoals, AL, USA.

[7] Fuentes, M., Hidalgo, C., Etchevers, J., et al., 2012. Conservation agriculture, increased organic carbon in the top-soil macro-aggregates and reduced soil CO_2 emissions. Plant and Soil. 355(1), 183–197.

[8] Wiredu, A.N., Gyasi, K.O., Abdoulaye, T., et al., 2010. Characterization of maize producing households in the Northern Region of Ghana. IITA: Ibadan, Nigeria. Report No.: 9785000451.

[9] Adu, G.B., Abdulai, M.S., Alidu, H., et al., 2014. Recommended production practices for maize in Ghana. AGRA/CSIR: Accra, Ghana.

[10] Zingore, S., Murwira, H.K., Delve, R.J., et al., 2007. Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. Agriculture, Ecosystems & Environment. 119(1–2), 112–126.

[11] Kpotor, P., 2012. Evaluation of newly released maize varieties in Ghana for yield and stability under three nitrogen application rates in two agroecological zones. Kwame Nkrumah University of Science and Technology.

[12] Ewool, M., Dankyi, A.A., Akromah, R., 2016. Marginal Rate Of Returns of Local and Improved Open Pollinated Maize Varieties Compared With Quality Protein Maize Hybrids in Ghana. International Journal of Science and Technology. 5(3), 123–129.

[13] Pixley, K., Banziger, M., Cordova, H., et al., 2009. Past and future innovations in tropical maize improvement. CIMMYT report: Mexico.

[14] Ayuke, F., Rao, M., Swift, M., et al., 2004. Effect of organic and inorganic nutrient sources on soil mineral nitrogen and maize yields in western Kenya. Bationo, A. (ed.). Academic Science Publishers: Nairobi.

[15] Abunyewa, A., Karbo, K., 2005. Improved fallow with pigeon pea for soil fertility improvement and to increase maize production in a smallholder crop–livestock farming system in the subhumid zone of Ghana. Land Degradation & Development. 16(5), 447–454.

[16] Ragasa, C., Dankyi, A., Acheampong, P., et al., 2013. Patterns of adoption of improved rice technologies in Ghana. International Food Policy Research Institute Working Paper. 35(2), 6–8.

[17] Sanginga, N., 2012. Closing the yield gap through integrated soil fertility management. Canberra, Australia: Crawford Fund for International Agricultural Research. 9–10.

[18] Dapaah, H., Ennin, S., Asafu-Agyei, J., 2008. Combining inorganic fertilizer with poultry manure for sustainable production of quality protein maize in Ghana. Ghana Journal of Agricultural Science. 41(1), 1–12.

[19] Franke, A., Schulz, S., Oyewole, B., et al., 2008. The role of cattle manure in enhancing on-farm productivity, macro-and micro-nutrient uptake, and profitability of maize in the Guinea savanna. Experimental Agriculture. 44(3), 313–328.

[20] Chamberlin, J., Jayne, T.S., Snapp, S., 2021. The role of active soil carbon in influencing the profitability of fertilizer use: Empirical evidence from smallholder maize plots in Tanzania. Land Degradation & Development. 32(9), 2681–2694.

[21] Alemayehu, M., Jemberie, M., Yeshiwas, T., et al., 2020. Integrated application of compound NPS fer-

tilizer and farmyard manure for economical production of irrigated potato (*Solanum tuberosum* L.) in highlands of Ethiopia. Cogent Food & Agriculture. 6(1), 1724385.

[22] Wanjiku, J., Kimenye, L.N., 2007. Profitability of kale and tomato production under different soil fertility replenishment technologies in Western Kenya. Journal of Sustainable Agriculture. 29(3), 135–148.

[23] Habte Werede, M., Smith, J.U., Boke Ambaye, S., 2018. Integrated soil fertility management for sustainable teff (Eragrostis tef) production in Halaba, Southern Ethiopia. Cogent Food & Agriculture. 4(1), 1519008.

[24] Marfo-Ahenkora, E., Taah, K., Owusu Danquah, E., et al., 2023. On-farm experimentation with improved maize seed and soil amendments in Southern Ghana: Productivity effects in smallholder farms. International Journal of Agronomy. 2023.

[25] CIMMYT, 1988. From agronomic data to farmer recommendations: An economics training manual. International Maize and Wheat Improvement Center (CIMMYT).

[26] Soha, M.E.-D., 2014. The partial budget analysis for sorghum farm in Sinai Peninsula, Egypt. Annals of Agricultural Sciences. 59(1), 77–81.

[27] Micheni, A., Kanampiu, F., Kitonyo, O., et al., 2016. On-farm experimentation on conservation agriculture in maize-legume based cropping systems in Kenya: Water use efficiency and economic impacts. Experimental Agriculture. 52(1), 51–68.

[28] Kay, R.D., Edwards, W.M., Duffy, P.A., 2020. Farm management. McGraw-Hill: New York, NY, USA.

[29] Marenya, P.P., Barrett, C.B., 2009. State-conditional fertilizer yield response on western Kenyan farms. American Journal of Agricultural Economics. 91(4), 991–1006.

[30] Awunyo-Vitor, D., Wongnaa, C.A., Aidoo, R., 2016. Resource use efficiency among maize farmers in Ghana. Agriculture & Food Security. 5(1), 1–10.

[31] Tsiboe, F., Egyir, I.S., Anaman, G., 2021. Effect of fertilizer subsidy on household level cereal production in Ghana. Scientific African. 13, e00916.

[32] Theriault, V., Smale, M., Haider, H., 2018. Economic incentives to use fertilizer on maize under differing agro-ecological conditions in Burkina Faso. Food Security. 10(5), 1263–1277.