Socio-Economic Characterisation of Maize Farmers, Profitability,and Yield Performance of Maize under Integrated Nutrient Management in Two Agro-Ecological Zones of Ghana

Emmanuel Baah[1*], Harrison Kwame Dapaah[1], Margaret E. Essilfie[1], Ebenezer Kwasi Ntiri[2]

[1]Department of Crop and Soil Sciences Education, Akenten Appiah-Menka University of Skills Training & Entrepreneurial Development, Ghana

[2]Department of Horticulture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

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ABSTRACT

The study combined a socio-economic survey with multi-season field trials to assess the socio-economic characteristics, yield, and profitability performance of maize under Integrated Nutrient Management (INM) in two Agro-ecological zones of Ghana. The research survey was conducted between December 10, 2022, and March 20, 2023, at the Mampong Municipal and the Ejura Sekyere District Assemblies in Ghana's Ashanti Region. A purposive multi-stage sampling approach was employed to interview 50 maize farmers, while the field experiment utilised a Randomised Complete Block Design (RCBD) with twelve treatments and four replications during the 2023 major and minor cropping seasons at Fumesua (Kumasi) and Asante Mampong. The treatments included Agro Charger, Agro Clean (296 mL per 148 L of water/ha each), poultry manure (10 t/ha), and NPK (250 kg/ha), applied individually and in various combinations. Data were analysed using descriptive statistics, gross margin (cost–return) analysis, and Analysis of Variance (ANOVA) in SAS. Socio-economic results showed that 76% of the respondents were men and 24% were women, with a mean age of 49 years; 64% were married. Education levels were generally low: 40% had no formal education, 34% had completed junior high school, 22% had attained an O-level/SHS Education, and only 4% had reached tertiary education. Profitability analysis indicated that maize production was economically viable across most treatments. Field trial results revealed significant differences in yield between fertilized plots and the control plot. The combination of Poultry Manure + Agro Charger + Agro Clean (PM + A.CH + A.CL) achieved yields of 5.3-6.6 t/ha, compared to 1.6–3.0 t/ha in the control, representing a potential yield increase of up to 120%. These findings suggest that integrating organic and inorganic nutrient sources can substantially enhance maize productivity and should be recommended for adoption by farmers in similar Agro-ecological zones.

INTRODUCTION

Maize (*Zea mays* L.) is a vital food crop worldwide, playing a key role in Ghana's food system as a source of food, livestock feed, and feedstuff. Growing across all Agro-ecological zones, more than 80% of national production occurs in the Forest-Savannah Transition zone (Neupane et al., 2022). Although Ghana has a national food security and a consumption of 43.8 kg/head (Asante et al., 2017), the country has a national average yield of 2.48 MT/ha, which is less than a third of the potential (7 to 8 MT/ha) (Poku et al., 2018). Jayne *et al*. (2016) concluded that Agricultural economies with low levels of inorganic fertilizer use are characterized by low crop yields, low rural incomes, and extreme poverty rates. Low yields and quality maize grains are associated with inefficient utilization of nutrient (incomplete fertilizer absorption), coupled with high cost of inorganic fertilizers, climate change i.e. unreliable rainfall, as well as leaching of nutrients from the soil has resulted in frequent crop failures affecting farmers' incomes, rendering them vulnerable to poverty, and worsen nationwide food insecurity (Obour *et al.,* 2020). Amanullah *et al*. (2016) stated that many researchers have concluded that nitrogen (N) fertilizer application has significantly improved maize growth and yield. In Ghana, fertiliser application (22.6 kg ha-1) is much lower than the 50 kg ha^{-1} recommended by the Abuja Declaration (Bua et al., 2020). Additionally, high prices and dependence on expensive synthetic inorganic fertilisers, particularly Nitrogen Phosphorus-Potassium (NPK), are making production too expensive and the overall profitability of smallholder farmers too low (Amankwah et al., 2024; Ricker-Gilbert et al., 2024). To address these limitations, the use of integrated nutrient management (INM) such as organic manure (Poultry Manure), inorganic fertilizer (NPK) and new organic crop growth enhancers (nanoparticles) applied singly or in combination as sustainable alternatives in reducing costs, environmental impact, and enhancing the efficiency with which nutrients are utilized for the enhancement of crop yield (Bilong et al., 2022). However, the effectiveness of such combined strategies is not limited to increased yield; it must be evaluated in economic terms, particularly for the smallholder farmers, the industry is dominated by, and who are significantly under-resourced. It is crucial to comprehend the socioeconomic demographics of these farmers, including their age, education, and gender, in order to develop effective agricultural extension programs that promote the adoption of profitable technologies (Wahab et al., 2020). The demographics of farmers also affect the adoption of profitable practices, with factors such as educational backgrounds and ages perhaps leading to a lag in adopting new, more complex INM systems, a phenomenon termed the Innovation Deficit. The existing gap is the lack of location-specific data that links the effectiveness of the developed INM methods to comprehensive analyses of costs, benefits, and profitability across the main areas of maize cultivation in Ghana. In view of this, the study aimed to assess the socio-economic characterisation of maize farmers, as well as the profitability and yield performance of maize, as influenced by integrated nutrient management in two agro-ecological zones of Ghana.

METHODOLOGY

Description Of Study Location and Period

This study combined a socio-economic survey with field trials to assess the cost of maize production under integrated nutrient management. The survey component was conducted in the Asante Mampong Municipal and Ejura-Sekyedumase Districts of the Ashanti Region, Ghana, between December 10, 2022, and March 20, 2023, collecting data on farmers' demographics. The Field experiment was conducted in the transition zone between the Forest and the Savannah Ecological Zones in the Ashanti Region of Ghana. The research took place at Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) in Asante Mampong, as well as at the Council for Scientific and Industrial Research - Crop Research Institute (CSIR-CRI) located in Fumesua. The experimental field at the AAMUSTED Faculty of Crops and Soil Science, located in the Mampong Municipal area, was used. At the same time, the CSIR Crop Research Institute, owned and operated by the Ghanaian government, is situated in the Kodie Municipal Assembly. This multi-location study was conducted from March to July 2023, during the major growing season, and from September to December 2023, during the minor growing season. The university is situated in a transitional zone between the forest and savannah, with geographic coordinates of 07°08′N and 01°02′W, at an elevation of 456 meters above sea level. This area experiences two distinct rainy seasons: the major rainy season typically runs from March to July, while the minor rainy season is usually from September to November. Average daily temperatures range from 21 to 23 °C at night to 31 °C during the day. The location receives an average annual rainfall of approximately 1,094.2 mm (FAO, 1988; Asiamah *et al*., 2008). The soil at the experimental site is derived from Voltaian sandstone found in the Afram Plains. It consists of deep, sandy soil free of pebbles and is classified as Savannah ochrosol. The soil contains moderate amounts of organic matter and exhibits adequate drainage, with a suitable water-holding capacity. According to the FAO/UNESCO classification (FAO, 1988; Asiamah *et al*., 2008), it is classified as a Chromic Luvisol and locally referred to as the Bediase series. This type of soil is particularly beneficial for cultivating cereals, legumes, and tuber crops. The soil pH ranges from 5.5 to 6.5. Various crops, including maize, groundnuts, black-eyed peas, and soybeans, have been cultivated at the site. The area is also dominated by grasses such as big grass (Cynodon plectostachus), guinea grass (Panicum maximum), and nut grass (*Cyperus rotundus*). The CSIR-Crops Research Institute is situated in the semi-deciduous forest zone, specifically at latitude 6°45′ 00.58″ N and longitude 1°31′ 51.28″ W. According to the World Reference Base for Soil Resources Legend (FAO, 2015), the soil in Fumesua consists of ferric acrisol and ferric lixisol. The surface soils in Fumesua are characterized by dark brown to brown fine sandy loam and greyish-brown sandy loam (Adjei-Gyapong & Asiamah, 2000). This research site exhibits low soil fertility and limited moisture retention. The rainy season is characterised by two distinct wet periods: a primary wet period from April to July

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and a secondary wet period from September to November, collectively defining its tropical climate. The average temperature range for both minimum and maximum temperatures is from 21 to 32 °C. Both sites experience a bimodal rainfall distribution of 1000–1800 mm yr^{-1} and average daily temperatures of 25.5–30 °C, providing complementary Agro-ecological conditions for robust evaluation of maize growth, yield, and economic outcomes.

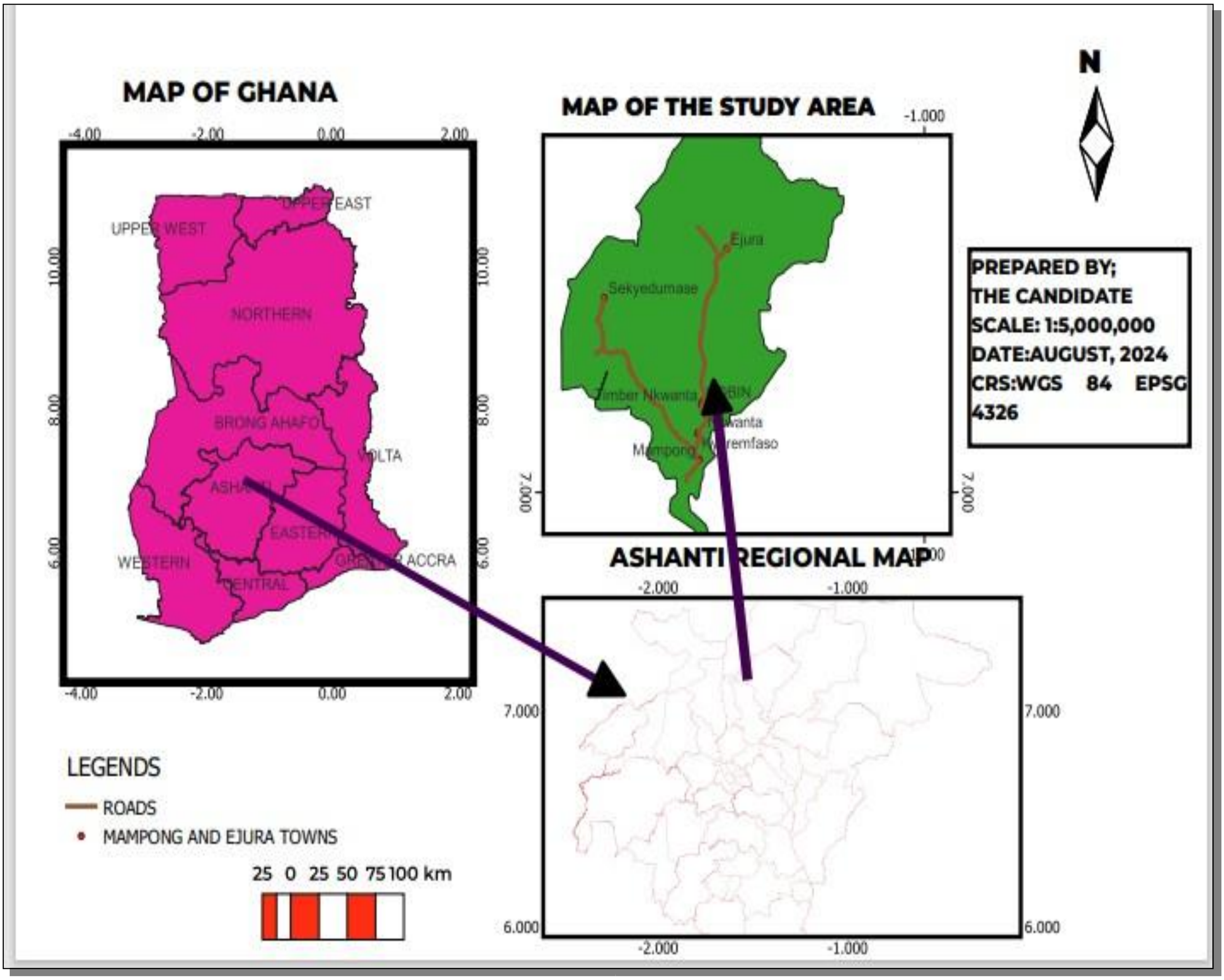

Figure 1. Map of Ghana showing the geographic position of the research area

Population And Sampling Technique

The study employed a sequential mixed-sampling approach that combined random selection at higher administrative levels with purposive selection of the target population. First, all Ministry of Food and Agriculture (MOFA) operational zones in the Mampong and Ejura-Sekyedumase Municipalities, chosen for their significant roles in maize production, processing, and export, were listed. Four zones (Mampong, Kyiremfaso, Nkwanta, and Ejura) were selected at random by folding each zone name onto a slip of paper, placing the slips into a container, and selecting four slips. Second, within each of these zones, three communities were randomly selected using the same paper-in-a-box method, yielding twelve communities (Old Daaman, Nkwanta, Bobin, Abrukutuaso, Brengo Timber-Nkwanta, Kyiremfaso, Abuontem, Adweeho, Frante, New Daaman, and Yonso). Third, extension-agent rosters from these communities identified 258 maize farmers who had exclusively used the growth enhancers Agro Charger and Agro Clean. From this list, fifty farmers who met the usage criterion were purposively selected for face-to-face interviews using a structured, closed-ended questionnaire. The interviews were conducted between December 10, 2022, and March 20, 2023. This design ensured that the

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sample captured detailed experiences of actual product adopters, clarifying that the results speak to this specific group rather than the entire farming population.

Methodology For Data Collection

A purposive sampling method was employed to select 50 farmers who exclusively used Agro Charger and Agro Clean in their crop production. Before full rollout, the semi-structured questionnaire was pre-tested through oneon-one interviews using an interview guide and checklist. When clarity issues arose or deeper insight was required, small focus group discussions (comprising 5–7 farmers) were convened. Feedback focused on question wording, response options, and cultural relevance. Revisions were made to ensure consistency and ease of understanding. The survey instrument was structured into three modules, comprising 44 closed-ended items. The first module comprises: Demographic Profile, which includes seven items on personal information and farm location. The second module consists of Farm Data/Profile, which contains 14 items covering enterprise type, farm size, crops grown, and management practices such as fertiliser, manure, and pest control. The final module covers the use of Agro Charger and Agro Clean. This module included 23 items to evaluate farmers' awareness, sourcing practices, application rates, yields obtained, and product effectiveness ratings. To assess the clarity and cultural appropriateness of the questions, a pre-test was conducted with 10 local farmers in the Mampong Municipal and Ejura-Sekyedumase Districts of the Ashanti Region, Ghana.

Data Analysis

Survey data from Study 1 were first cleaned and coded in Microsoft Excel, then exported to SPSS version 26 for analysis. Internal consistency of the instrument was confirmed by Cronbach's alpha coefficients exceeding 0.70. All closed-ended questionnaire items were subjected to descriptive statistical analysis, including frequencies, percentages, means, and standard deviations, to profile farmers' knowledge and usage of organic growth enhancers. Open-ended survey responses and semi-structured interview transcripts were analysed exclusively through thematic coding, in which participant narratives were systematically categorised to identify recurring themes and barriers to adoption. Economic data on production costs, gross profit, and net profit were analysed using partial budgeting to calculate benefit-cost ratios, and trends in key variables were visualised in Excel.

Validity and Reliability

Table 1: Cronbach's Alpha

Items	Cronbach's Alpha	Number of Items
Usage Of Organic Crop Growth Enhancers (Agro Charger and Agro Clean).	0.741	3

In this segment, the reliability and validity of the structures have been examined, along with their relevance. Reliability and validity, as well as other issues that require special consideration from the researcher when handling the data produced by the study (Baillie, 2015; Teusner, 2016). The internal validity of the measurement used in the study was assessed using Cronbach's alpha, with a minimum acceptable level of 0.70. Findings from that research indicate that Cronbach's Alpha for Usage of Organic Crop Growth Enhancers (Agro Charger and Agro Clean) was 0.741 (Nunnally & Bernstein, 1994; George, Darren, & Mallery, 2016). The analysis revealed that the alpha value for the Cronbach exceeded the threshold of 0.70, indicating that the construct is suitable for the ongoing work (Hair *et al*., 2014; Pallant, 2020).

Ethical Considerations

In research, ethics is a set of moral principles that emphasise doing good and avoiding harm to people. (Creswell, 2014). Once the researcher explained the study's purpose to the respondents, they ensured that the data provided would remain private. Before the research began, permission was obtained from the relevant authorities. Regarding the confidentiality and privacy of the data provided, all participants received full assurances of protection.

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Experimental Design and Treatment

The experimental design was organized as a Randomized Complete Block Design (RCBD), encompassing twelve treatments (T1 – T12) with four (4) replications at each experimental site. The study was conducted concurrently at Mampong and Fumesua during both the 2023 major and minor cropping seasons at each location. The replication consisted of twelve treatments: T1 = Agro Charger, T2 = Agro Clean, T3 = Agro Charger +Agro Clean, T4 = NPK, T5 = NPK + Agro Charger, T6 = NPK + Agro Clean, T7 = NPK + Agro Charger + Agro Clean, T8 = Poultry Manure, T9 = Poultry Manure +Agro Charger, T10 = Poultry Manure + Agro Clean, T11 = Poultry Manure + Agro Charger +Agro Clean, T12 = Control. Each plot contained six rows, each with twelve plants, for a total of seventy-two plants per plot. The treatments were randomly distributed across the plots. A plot size of 4.8 m wide × 5 m long was used. Using simple random sampling and random number generators, five plants were randomly chosen and tagged within the harvestable area for data collection. The two central rows of the harvestable area in each plot (treatment) were used for yield component analysis. The amendments were applied at the following rates: Agro Charger (ACH) = 296 ml per 148 litres of water per hectare, Agro Clean (ACL) = 296 ml per 148 litres of water per hectare, NPK = 250 kg per hectare, and Poultry Manure (PM) = 10 tons per hectare. The combined treatments were applied as follows: ACH + NPK = 148 ml per 74 litres of water per hectare + 125 kg per hectare, and ACH + PM = 148 ml per 74 litres of water per hectare + 5 tons per hectare. Certified maize seeds, Opeaburo (Hybrid, white), were obtained from CSIR-CRI research station at Fumesua, Ghana, for planting. Opeaburo maize, a 105- to 110-day medium variety released by CSIR-CRI, and a High-quality protein maize (QPM) variety contribute significantly to improved nutrition and well-being for humans, poultry, and livestock. Often compared to other popular varieties in Ghana, it is recognised for its highyielding potential.

Table 2 Types and Volume of Treatment used

TREATMENT	AMENDMENT	APPLICATION RATE
T1	Agro Charger (ACH)	296 ml per 148 L water/ha
T2	Agro Clean (ACL)	296 ml per 148 L water/ha
T3	ACH + ACL	296 ml per 148 L water/ha (of each)
T4	NPK	250 kg/ha
T5	NPK + ACH	125 kg/ha + 148 ml per 74 L water/ha
T6	NPK + ACL	125 kg/ha + 148 ml per 74 L water/ha
T7	NPK + ACH + ACL	125 kg/ha + 148 ml per 74 L water/ha + 148 ml per 74 L water/ha
T8	Poultry Manure (PM)	10 t/ha
T9	PM + ACH	5 t/ha + 148 ml per 74 L water/ha
T10	PM + ACL	5 t/ha + 148 ml per 74 L water/ha
T11	PM + ACH + ACL	5 t/ha + 148 ml per 74 L water/ha + 148 ml per 74 L water/ha
T12	Control	0

ACL= Agro clean, ACH= Agro charger and PM= Poultry manure

Crop Management and Cultural

Land preparation, poultry manure application and planting. The field experiment site was demarcated, ploughed, harrowed, lined, and pegged on 9th March 2023, during the major cropping season, and on 14th August 2023, during the minor cropping season, respectively. The experiment field had a total of forty-eight (48) plots. Each experimental plot measured 4.8 m in width by 5 m in length (24 m²). The field measured 57.6 m x 26 m, for a total area of 1497.6 m^2. There was a 0.5 m path left between plots and a 1 m gap left between blocks. Poultry manure was applied to the plots according to the treatments for 2 weeks to decompose further. Opeaburo hybrid maize seeds were sown at 5 cm and at a planting spacing of 80 cm x 40 cm. There were six rows per plot, with 24 plants in each row, totalling 144 plants per plot.

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Poultry manure preparation

Poultry manure was obtained from APOGEE Farms in Mampong and heaped under shade, covered with a polythene sheet, for 30 days to facilitate further decomposition before incorporation into the soil.

Table 3: Chemical properties of poultry manure used for the study

	TOTAL N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	OC (%)	pH	C: N RATIO
POULTRY MANURE	2.92	1.35	2.29	1.43	0.37	0.026	40.96	6.92	14.03

Source: KNUST – Soil Lab.

Planting Material

Opeaburo is a hybrid maize variety capable of yielding up to 8 tons per hectare, with a maturity period of 110 to 115 days. It features long, slender grains with a pleasant aroma and performs well across all growing seasons. The variety exhibits early tasseling and silking relative to some other types and attains good plant height. For maximum productivity, it requires proper spacing, a seed rate of 10 kg per acre (25 kg per hectare), and balanced fertilization with compound and nitrogen fertilizers; urea is best applied by incorporating it into the soil. Seeds were sown two per hill and thinned to one plant after two weeks. Agro Charger and Agro Clean were applied at a rate of 296 ml per 148 L of water per hectare. For NPK alone, Yara Activa 23-10-5 fertilizer was applied at a rate of 250 kg/ha (equivalent to 5 bags/ha). In combined treatments, Agro Charger and Agro Clean were applied at the same rate, while Yara Activa was applied at a reduced rate of 125 kg/ha (equivalent to 2.47 bags/ha). Weeding commenced at the same two-week mark, using a hoe for general weed removal, while hand-pulling was employed in areas where weeds were near the plants. Additional weed control measures were taken 6 weeks after planting through continued hoeing and hand-pulling.

To address pest and disease management, Warrior Super Insecticide, containing Emamectin benzoate as the active ingredient, was mixed at a rate of 30 ml per 15 L of water. This equates to approximately 296.4 ml/ha when using a total of 148.2 L of water. This formulation was applied to effectively control infestations of fall armyworms, leaf cutters, ants, and stem borers. Typically, a high level of farm hygiene was upheld to achieve optimal productivity. Surrounding the trials, alternate host plants were routinely removed.

Table 4: Initial chemical and physical properties of the soils

SOIL	EC (µS/cm)	pH	AVAIL P	%TOTAL N	Exch. Bases (cmol/kg)				Exch. Acidity		% Org.	% Org.
			mg/kg		K	Ca	Mg	Na	Al		Carbon	Matter
MAMPONG Major season	97	5.8	5.44	0.138	0.37	2.63	1.28	0.0560	0.246	0.251	1.746	3.009
MAMPONG Minor season	451	5.4	5.85	0.134	0.58	2.21	1.72	0.0635	0.251	0.257	1.362	2.348
FUMESUA Major season	568	6.37	7.83	0.163	1.95	6.40	1.50	0.0533	0.267	0.270	1.401	2.416
FUMESUA Minor season	369	5.42	5.17	0.123	1.82	2.80	1.76	0.0533	0.265	0.270	1.398	2.410

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Data collected

Before land preparation, soil samples were randomly collected from the upper 30 cm of the soil and analysed for their physicochemical and biological properties across both cropping seasons. A minimum of 20 soil samples were collected for analysis. After conventional tillage to a depth of 15 cm and harrowing, the field was demarcated into the designated experimental plots. The poultry manure displayed a slightly alkaline pH, elevated levels of total nitrogen and potassium, and a high organic carbon content. However, it showed low concentrations of total phosphorus, calcium, and magnesium. Table 4 illustrates the initial chemical and physical properties of the soils at experimental locations during the major and minor seasons of 2023 at AAMUSTED AsantiMampong and CSIR - CRI Fumesua, respectively. During the 2023 major season at AAMUSTED, the soil was moderately acidic (pH 5.79), had moderate organic matter content (3.009), and low nitrogen levels (0.14) (London, 1991). Similarly, during the main season at CSIR - CRI, the soil was slightly acidic (pH 6.37) with a moderate organic matter content (2.42). For the 2023 minor season at AAMUSTED Asanti-Mampong, the soil was moderately acidic (pH 5.35), had moderate organic matter content (2.35), and low total nitrogen levels (0.13). During the minor season at CSIR, the soil pH was moderately acidic (5.42), with a moderate organic matter content (2.41%) and low total nitrogen levels (0.12%). At experimental sites, for AAMUSTED AsantiMampong in both major and minor seasons, the available phosphorus levels (5.44 and 5.85) were moderate, as were the levels of exchangeable bases (calcium, magnesium, and sodium) and total potassium. At CSIR CRI Fumesua during both the 2023 major and minor seasons, the exchangeable cations (calcium, magnesium, and sodium) showed similar patterns, with moderate levels of calcium and magnesium for both seasons, and high potassium levels for both seasons.
Tables 5, 6, and 7 present detailed information on the nanomaterial used in the research, including summaries of crop growth enhancer data, ingredient composition, and the physical and chemical properties of Agro Charger concentrates.

Agro Charger functions as a nutrient uptake enhancer rather than a fertilizer, as it contains plant-based ingredients that improve the plant's ability to absorb fertilizers and other essential nutrients more effectively. Agro Charger concentrate is entirely biodegradable and unlikely to bioaccumulate. It is composed of naturally occurring substances that are non-pathogenic, non-hazardous, and non-toxic, with no potential contribution to ozone depletion, photochemical ozone formation, or global warming (Shukla, 2022).

Table 5: Summary information of crop growth enhancer

Product Name	Agro Charger Herbal Concentrate
Product Code	Agro Charger Herbal Concentrate
Family / Group	Crop Enhancer
Chemical Formula	Mixture
Other Designations	Liquid formulation containing a Nano blend made from organic extract

Source: Shukla (2022)

Table 4: Initial soil chemical and physical characteristics for Mampong and Fumesua in 2023

Components	Composition (%) W/W
Alkyl Polyglucoside extract of Sugar cane	20%
Alkyl Polyglucoside extract of Potato	5%
Alkyl Polyglucoside extract of coconut	26%
Alkyl Polyglucoside extract of Palm	16%
Alkyl Polyglucoside extract of Maize	30%
Alkyl Polyglucoside, Herbal extracts and tree saps	3%

Non-Chlorinated Water	Q.s.

Source: Shukla (2022)

Table 6: Physical of Agro charger

	Physical state	Liquid
1.	Colour	Amber to brown
2.	Odour	Mild, as per standards
3.	Miscibility	Soluble in water
4.	Stability	Stable at normal storage conditions
5.	Corrosion	Noncorrosive
6.	Flash Point	>220°C
7.	% Volatile volume	0%
8.	Vapour pressure	Not determined
9.	Boiling Point	>100°C
10.	Freezing Point	<0°C

Source: Shukla (2022)

Table 7: Chemical characteristics of the Agro charger used for the study.

	% Total N	% Org. N	%Water-Soluble N	% Water in soluble N	% Urea N	% Ammonium N	% Nitrate N	%Total Org. Carbon	%Total Carbon
Agro Charger	**4.04**	**3.80**	**2.78**	**0**	**0.89**	**1.84**	**2.22**	**34.55**	**4.07**

Source: Gujarat Lab (2018)

Table 8 presents detailed information on Agro Clean, outlining its ingredients and their respective proportions. Agro Clean functions as an organic plant protector and stress regulator, specifically shielding plants from sucking pests and fungal and bacterial infections that can cause harm. It is safe for beneficial organisms such as predators, natural enemies, pollinators, and farmers, thereby protecting crops, people, and the environment.

Table 8: Summary information of Agro Clean used for the study

Ingredient	Botanical Name	Composition (100%)
Processed Coconut Extracts	Cocos nucifera	20%
Processed Corn Extracts	Zea mays	20%
Processed Extract of Sugarcane	Saccharum officinarum	26%
Water		19%
Citronella oil	Cynlcopogon	0.1%
Cinnamon oil	Cinnamomum verum	0.1%

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Cedar oil	Cedrus deodara	0.1%
Mint oil	Mentha piperita	0.1%
Spear Mint oil	Mentha arvensis	0.1%
Geranium oil	Gerranium wallichianum	0.1%
Water Lily oil	Nymphaea alba	0.1%
Karanja oil	Pongamia -pinnata	0.1%
Neem oil	Azadirachta indica	0.1%
Excipient		Qs 4%

Source: Shukla (2022)

Yield and Yield Components

100 Grains Weight

The weight of 100 randomly selected grains was taken from cobs.

Total Grain Yield (t/h)

Grain yield (t ha^{-1}) was calculated from the weight of grain obtained by a given area covered. An electronic balance was used to measure grain yield per plot, which was then converted to hectares after adjusting for a 12.5% moisture content.

Economic Benefits Analysis

The economic viability and profitability of the cropping systems were assessed using production costs, gross profit, and net profit for each of the twelve (12) treatments. To calculate the economic advantages at both experimental locations.

Production Cost, Gross Profit, and Net Profit

To assess the profitability of maize production at the CSIR-Crops Research Institute station in Fumesua and the AAMUSTED College of Agriculture Education campus in Mampong, Ashanti, financial metrics such as production cost, gross profit, and net profit were evaluated. Production cost encompasses all expenses incurred to bring a crop to harvest. It is subdivided into variable (operating) costs and fixed (ownership) costs. Gross profit is the difference between total revenue from sales and total variable production costs. The metric is calculated as:

$$\text{Gross Profit} = \text{Total Revenue} - \text{Variable Costs}$$

Net profit measures overall financial health by subtracting both variable and fixed costs from total revenue. A positive net profit signals a sustainably profitable operation, while a negative net profit indicates a loss. The formula is expressed as:

$$\text{Net Profit} = \text{Total Revenue} - \text{Total Production Cost}$$

2.4 **Statistical analysis**

The collected field data were analysed using Analysis of Variance (ANOVA) in SAS Version 9. Statistically significant mean differences were separated and compared using Tukey's Honestly Significant Difference (HSD) test at a 5% probability level.

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RESULTS AND DISCUSSION

Socio-Economic Characteristics of Maize Farmers

The socio-economic characteristics assessed in this study included the sex, age, marital status, education level, principal occupation, and farm location of maize farmers. A summary of respondents' distribution by these characteristics is presented below. Of the 50 farmers interviewed, 38 (76%) were male and 12 (24%) were female, indicating that maize farming in the study area is predominantly a male-dominated activity. This observation is consistent with Adeagbo et al. (2021), who also reported male dominance in maize production. The lower female participation suggests that women are more engaged in other parts of the maize value chain, such as weeding and post-harvest handling, as noted by Philip and Itodo (2012). In terms of age, 46% of farmers were aged 30–41, followed by 42% aged 42–60. These age groups represent Ghana's economically active labour force (World Bank Open Data, 2025), combining physical strength and substantial farming experience. Farmers within this range are generally more productive and manage resources efficiently. However, Masi et al. (2022) observed that younger farmers tend to adopt modern, climate-smart agricultural technologies more rapidly, suggesting a potential generational gap in the adoption of these technologies.

Regarding marital status, 64% of respondents were married, 22% were single, 8% were divorced, and 6% were widowed. The predominance of married farmers suggests a family-oriented farming structure that relies heavily on family labour. In matrilineal societies, marriage often facilitates access to family land and strengthens community support networks, which are essential for mobilizing labour and financial assistance during critical farming periods (Bigombe & Khadiagala, 2004; Barker et al., 2022).

In terms of education, 40% of farmers had no formal education, 34% had completed primary or junior high school, 22% had secondary education (O Level/SHS), and only 4% had tertiary education. Economic constraints such as school fees, uniforms, and the opportunity cost of losing farm labour often compel families to withdraw children from formal education after basic school (Mwamadi & Seiffert, 2012). In such contexts, informal apprenticeships or on-farm work become more common, and the lack of parental education perpetuates low academic aspirations. Cultural factors, such as early marriage and caregiving responsibilities, particularly among girls, further reduce school attendance (Larsen, 2014; Akurugu, 2022). Regarding occupation, 96% of respondents identified farming as their primary occupation, while only 4% were engaged in trading. This highlights a strong dependence on agriculture and limited occupational diversity. As Gatare et al. (2015) noted, trading requires access to capital, transport, and storage infrastructure, which are often lacking in rural communities, leading smallholder farmers to prioritise subsistence and market-oriented maize production. Overall, the socio-economic profile suggests that maize farming in the study areas is predominantly driven by males, with a majority of middle-aged, married farmers possessing limited formal education and few alternative income sources, underscoring the need for targeted interventions in education, training, and technology adoption (Table 9).

Table 9: Economic characteristics of respondents

Study Variable	Frequency	Percentage
Average Age of Respondent		
Male	38	76
Female	12	24
Age		
18-29	3	6
30-41	23	46
42-60	21	42
61 years and above	3	6
Marital Status		

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Married	32	64
Single	11	22
Divorce	4	8
Widow/widower	3	6
Level of Education		
Primary/JHS	17	34
O Level/SHS	11	22
Tertiary	2	4
Non-formal education	20	40
Main Occupation		
Farmer	48	96
Trader	2	4

Source: field survey, 2023

Farmers' Awareness, Use, and Perceived Effectiveness of Crop Enhancers and Organic Protectors

All respondents (100%) reported using crop enhancers, with Agrocharger being the most popular (32%), followed by Dehigro (30%), Adepa (16%), and Apex 10 (4%). Most farmers (98%) used Agrocharger in combination with Agro Clean, demonstrating strong acceptance of integrated applications. Usage varied seasonally: 44% applied them year-round, 38% during the rainy season, and 18% in the dry season. Information on Agrocharger mainly came from AEA/MoFA (58%), agrochemical dealers (18%), and radio or fellow farmers (12%), emphasizing the key role of formal extension services. Agrocharger was mainly used on maize (46%) and carrots (42%), with smaller use on cabbage (8%) and cowpea (4%). Application rates differed: 56% used 40 ml/15 L, 40% used 30 ml/15 L, and 4% used 15 ml/15 L, suggesting a preference for higher doses. Yield outcomes were positive, with 52% achieving 3–4 t/ha, 32% achieving 2–3 t/ha, and 14% exceeding 4 t/ha, while only 2% yielded below 2 t/ha. This suggests a strong correlation between the use of Agrocharger and increased productivity. All respondents also used organic crop protectors, with Adepa (38%) and Neemazal (26%) being the most common, followed by Agro Clean (14%), Agogo (12%), Bypel (8%), and Diapel (2%), reflecting a preference for proven, accessible organic options (Table 10). The positive yield response, which is large in scale, may be explained by the soil conditions, including P and K deficiencies and the low amount of soil organic matter (SOM), which allows for inferences about the functional profile of Agrocharger. Agrocharger is a complex system that has been demonstrated to enhance nutrient uptake efficiency and mitigate yield loss resulting from common abiotic stress conditions in tropical agriculture (Li et al., 2022).

Table 10: Farmers' Knowledge, Usage, and Perceived Effectiveness of Crop Enhancers and Organic Crop Protectors (n=50)

Study Variable	Frequency	Percentage
Have you ever used crop enhancer on your crops?		
Yes	50	100.0
If yes, what type of crop enhancer did you use?		
Adepa	8	16.0
Agrocharger	16	32.0
Agyenkwa	4	8.0
Apex 10	2	4.0
Dehigro	15	30.0
Supergro	5	10.0

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Have you used both Agro charger and Agro clean together?		
Yes	49	98.0
No	1	2.0
If yes, when did you use it?		
During the wet season	19	38.0
Dry season	9	18.0
Wet and dry	22	44.0
Where information on the Agro charger and Agro clean is received		
Colleague farmer	6	12.0
AEAM/MoFA	29	58.0
Radio/Programme/Advert	6	12.0
Agrochemical seller/Stores	9	18.0
Stores		
What type of crop was Agro Charger applied to		
Carrot	21	42.0
Cabbage	4	8.0
Maize	23	46.0
Cowpea	2	4.0
Quantity of Agro charger used		
15mls/15l	2	4.0
30mls/15l	20	40.0
40mls/15l	28	56.0
Average yield after application of Agro charger		
1-2t/ha	1	2.0
2-3t/ha	16	32.0
3-4t/ha	26	52.0
> 4 t/ha	7	14.0
Have you ever used organic crop protector on your crop?		
Yes	50	100.0
If yes, what type of crop protector was used?		
Adepa	19	38.0
Agoo	6	12.0
Agro clean	7	14.0
Bypel	4	8.0
Diapel	1	2.0
Neemazal	13	26.0

Source: Field data 2023

Application Practices, Yield Benefits and Farmers' Perceived Effectiveness

All respondents (100%) have used fertiliser, Agro Charger and Agro Clean. Seasonal use patterns showed that 46% applied them year-round, 38% only during the rainy season, and 16% only during the dry season, reflecting adaptation to crop growth needs. Agro Clean was mainly used on maize (44%) and carrots (44%), with smaller

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use on cabbage (8%) and cowpea (4%). Application rates varied: 48% used 40 ml/15 L, 46% used 30 ml/15 L, and 6% used 15 ml/15 L, suggesting a preference for higher doses. Yield results showed 50% achieved 3–4 t/ha, 32% had 2–3 t/ha, and 18% exceeded 4 t/ha. All farmers confirmed productivity gains from Agrocharger, mainly through higher yields (90%), reduced organic fertiliser use (8%), and reduced inorganic fertiliser use (2%). Similarly, 100% affirmed that Agro Clean improved output by reducing pest incidence (72%), enhancing crop growth (10%), and lowering pesticide use (18%). Agrocharger and Agro Clean were rated as highly effective by 38% and 52% of users, respectively, and as effective by 54% and 48%, respectively. The combined use was valued and deemed successful by 44% and 56% of farmers, underscoring its complementary benefits (Table 11). The overall yield results show that regional yield disparities were effectively resolved. Just 18% of the respondents produced yields greater than 4 t/ha, whereas half were able to obtain yields between 3 and 4 t/ha. When compared to the average smallholder maize indicators in Sub-Saharan Africa (SSA), which typically range between 1.8 and 3.2 t/ha, the high-performance level of 68 per cent of farmers attaining 3 t/ha or higher is excessive (Leroux et al., 2019). Because of the environmental damage caused by traditional reliance on agrochemicals, sophisticated, low-impact inputs have become necessary. Biostimulants and biopesticides, which can enhance plant physiology and provide targeted control over pests, are a critical solution that has been discovered to enable this change (Shang et al., 2019). The products mitigate yield declines characteristic of adverse environmental conditions and contribute to improved resource management (Koleska et al., 2017).

Table 11: Use, Yield Benefits and Effectiveness of Agro Charger and Agro Clean (n=50)

Yes	50	100
If yes, when did you use it?		
During the wet season	19	38.0
Dry season	8	16.0
Wet and dry	23	46.0
What type of crop was Agro Clean applied to		
Carrot	22	44.0
Cabbage	4	8.0
Maize	22	44.0
Cowpea	2	4.0
Quantity of Agro Clean used		
15mls/15l	3	6.0
30mls/15l	23	46.0
40mls/15l	24	48.0
Average yield after application of Agro Clean (Crop protector)		

Study Variable	**Frequency**	**Percentage**
Have you used fertilizer, Agro charger, and Agro clean together?		

Study Variable	**Frequency**	**Percentage**
Have you used fertilizer, Agro charger, and Agro clean together?		

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Have you ever used both Agro charger and Agro clean		
Yes	50	100.0
What was the effectiveness level?		
Highly effective	22	44.0
Effective	**28**	**56.0**
2-3 t/ha	16	32.0
3-4 t/ha	25	50.0
> 4 t/ha	9	18.0
Did applying an Agro charger improve your production?		
Yes	50	100.0
If yes, how did it improve your production?		
Increased the number of economic parts (yield)	45	90.0
It reduced the amount of organic fertilizer/manure applied	4	8.0
It reduced the amount of inorganic fertilizer applied	1	2.0
Did the application of Agro Clean improve your production?		
Yes	50	100.0
If yes, how did it improve your production?		
Reduced the incidence of pests	36	72.0
Improved the crop performance in terms of growth	5	10.0
It reduced the number of inorganic pesticides used on the crops	9	18.0
Rating of the Agro charger as an effective crop enhancer		
Highly effective	19	38.0
Effective	27	54.0
Moderately effective	4	8.0
Rating of Agro Clean as an effective crop enhancer		
Highly effective	26	52.0
Effective	24	48.0

Source: Field data 2023

Grain Yield

At Fumesua, grain yield ranged from 1.6 t/ha in the control to 6.6 t/ha under the PM + A.CH + A.CL treatment during the major season, while in the minor season, the highest yield recorded was 6.3 t/ha under the same treatment. The results showed significant differences among treatments ($P < 0.001$), with the combination of

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Agro Charger, Agro Clean, and organic or inorganic fertilizers consistently producing higher yields. Poultry manure and its combinations also significantly boosted grain yield, confirming the strong contribution of organic inputs to maize productivity. At Mampong, yield performance followed a similar trend, with slightly lower baseline values in the control and slightly lower peak yields than at Fumesua. Grain yield ranged from 1.5 t/ha in the control to 6.4 t/ha in the PM + A.CH + A.CL treatment during the major season, and from 1.3 t/ha to 6.0 t/ha in the minor season under the same treatment. The inclusion of growth enhancers and organic fertilisers also resulted in significant yield improvements, underscoring their role in boosting maize production. Both sites showed positive responses to the integrated application of crop growth enhancers, inorganic, and organic fertilisers, with Fumesua recording the highest yield (6.6 t/ha) compared with Mampong's 6.4 t/ha. However, Mampong's lower control yield (1.3 t/ha vs. 1.8 t/ha) indicated a comparatively lower baseline soil fertility before treatment (Table 12). The maximum grain yield was 100,000 plants/ha, and the minimum was 166,664 plants/ha; the optimum was estimated at 9.74 plants/m² (97,400 plants/ha) (Ghaffari et al., 2011). The harvested amount of plants in the present study was 24 (PM+CH+CL) between the major and minor seasons, with a range of 16 (NPK+CL) and 20 (CH). The results, which showed a high percentage of harvested plants using poultry manure (PM), Agro Charger (CH), Agro Clean (CL), and NPK, were due to the synergistic effects of these inputs. The poultry manure enhanced the water and soil structure, which are essential in the imbibition of seeds and their uniform germination (Calamai et al., 2020; Ngosong et al., 2020), and the growth factors (CH and CL) probably supplied the plant hormones (auxins, cytokinins) and microorganisms that promoted initial cell division, root growth, and general seedling vigour, enhancing the faster establishment and survival (Shreenidhi et al., 2023; Bhowmick et al., 2024).

Table 12: **Influence of crop growth enhancers, inorganic, and organic fertilizers on maize grain yield in the major and minor seasons of 2023.**

Treatments	**Fumesua**		**Mampong**	
	Grain Yield(ton/Ha)		**Grain Yield(ton/Ha)**	
	Major	Minor	Major	Minor
Agro charger	3.6	2.7	4.0	3.5
Agro clean	2.8	2.2	3.0	3.0
A. CH. + A. CL	1.9	1.9	4.5	4.0
N.P. K	2.9	2.0	4.0	3.0
N.P. K +A.CH	5.7	5.4	6.0	5.3
N.P. K + A.CL	3.1	2.4	4.0	3.5
N.P. K + A.CH + A.CL	5.0	5.4	6.0	6.0
Poultry Manure	3.0	1.8	3.3	3.3
PM + A.CH	6.2	5.4	6.3	5.1
PM + A.CL	4.5	4.3	3.4	3.3
PM + A.CH + A. CL	6.6	6.3	6.4	6.0
Control	1.6	1.8	1.5	1.3
CV (%)	22.0		22.0	
Season	HSD (0.05) =0.35 P=<0.0001		HSD (0.05) =0.31 P=<0.0001	
Treatment	HSD (0.05) =1.46 P=<0.0001		HSD (0.05) =1.30 P=<0.0001	
S X T	HSD (0.05) =1.22 P=<0.0001		HSD (0.05) =1.09 P=0.0053	

Source: Analysed Field Data, 2023

Production costs (ghc) associated with maize cultivation in fumesua and mampong during the major and minor seasons

Table 13 presents the production costs of maize (Zea mays L.) under combined applications of organic growth enhancers, inorganic fertilizers, and organic fertilizers at Fumesua and Mampong during both major and minor seasons. The findings revealed a significant difference ($P < 0.05$) in production costs among treatments with organic growth enhancers, inorganic fertilisers, and organic fertilisers. Costs ranged from GHC 1390.50 for the control (lowest) to GHC 2117.50 for the NPK treatment (highest). The integrated Poultry Manure + Agro Charger + Agro Clean (PM + A.CH + A.CL) treatment resulted in a balanced cost of GHC 1,850.50 (Table 13). The high cost of NPK fertilizer was attributed to its synthetic, nitrogen-based composition and energy-intensive production process (Smith et al., 2020). Treatments combining PM, A.CH, and A.CL used a reduced NPK rate (125 kg/ha). Although poultry manure and biostimulants added to total costs, the 50% reduction in NPK helped lower total production costs.

Table 13: Costs and Returns of Maize Production

Treatments	Production Cost (GHC)
Agro charger	1697.50^{g}
Agro clean	1697.50^{g}
A. CH. + A. CL	1450.50^{h}
N.P. K	2117.50^{a}
N.P. K +A.CH	1922.50^{c}
N.P. K + A.CL	1922.50^{c}
N.P. K + A.CH + A.CL	1952.50^{b}
Poultry Manure	1790.50^{f}
PM + A.CH	1820.50^{e}
PM + A.CL	1820.50^{e}
PM + A.CH + A. CL	1850.50^{d}
Control	1390.50^{i}

Source: Analysed field data, 2023

Gross And Net Profit (Ghc) Of Maize Production in Fumesua and Mampong During the Major and Minor Seasons

In Table 14, the gross and net profit of the combined use of organic crop growth enhancers, inorganic fertilizers, and organic fertilizers on maize (Zea mays L.) production at Fumesua and Mampong during the major and minor seasons was presented. The results revealed that gross profit and net profit varied significantly *($p<0.05$)* among the treatments applied in maize cultivation. The gross profit at Fumesua reached as high as GHC 33000 with the PM + A.CH + A.CL treatment compared to a mere GHC 8000 for the control, while at Mampong, the highest gross profit was GHC 32000 against GHC 15000 for the control in the major season. A similar pattern was observed in the minor season, where Fumesua recorded GHC 33000, while the control recorded GHC 8000. Additionally, during the minor season in Mampong, the gross profit ranged from GHC 15,000 to GHC 30,000, as recorded by PM, A.CH, and A.CL, respectively. In addition, the net profit followed a similar pattern; the PM + A.CH + A.CL treatment produced the highest net profit of GHC 31149.50 at Fumesua and GHC 30149.50 at Mampong, whereas the control yielded the lowest net profit at GHC 6609.50 and GHC 13609.50, respectively. The dynamics lie in profit, which is a function of yield minus cost and is linked to the efficient use of nutrients. NPK, despite its high cost and effectiveness, does little to improve soil health and can even contribute to soil acidification and a decline in soil organic matter, reducing the soil's natural fertility and water-holding capacity. Profit efficiency among Ghanaian maize farmers is low, with a mean efficiency of around 48.4%, indicating that a significant portion of potential profit is lost to production inefficiencies (Wongnaa et al., 2019). In the current research, the efficient ways of cultivating maize were evaluated, with clear indications that PM + A.CH + A.CL resulted in a 312.5% increase in gross profit at Fumesua during the major and minor seasons, while Mampong resulted in a 113.33% increase, respectively. Additionally, both Fumesua and Mampong recorded percentage increases of 371.3% and 121.53%, respectively, in net profit from maize cultivation during the major season. In comparison, 371.3% and 106.8% were recorded by Fumesua and Mampong during the minor season.

Table 14: Gross and Net Profit (GHC) from Maize Production in Fumesua and Mampong During the Major and Minor Seasons

	Gross Profit (GHC)				**Net Profit (GHC)**			
	Fumesua		**Mampong**		**Fumesua**		**Mampong**	
Treatments	**Major**	**Minor**	**Major**	**Minor**	**Major**	**Minor**	**Major**	**Minor**
Agro charger	18000^{f}	18000^{f}	20000^{e}	17500^{e}	16302.5^{f}	16302.5^{f}	18302.5^{f}	15802.5^{f}
Agro clean	14000^{j}	14000^{j}	15000^{h}	15000^{g}	12302.5^{j}	12302.5^{j}	13302.5^{l}	13302.5^{k}
A. CH. + A. CL	9500^{k}	9500^{k}	22500^{d}	20000^{d}	8049.5^{k}	8049.5^{k}	21049.5^{e}	18549.5^{e}
N.P. K	14500^{i}	14500^{i}	20000^{e}	15000^{g}	12382.5^{i}	12382.5^{i}	17882.5^{h}	12882.5^{l}
N.P. K +A.CH	28500^{c}	28500^{c}	30000^{c}	26500^{b}	26577.5^{c}	26577.5^{c}	28077.5^{c}	24577.5^{d}
N.P. K + A.CL	15500^{g}	15500^{g}	20000^{e}	17500^{e}	13577.5^{g}	13577.5^{g}	18077.5^{g}	15577.5^{g}
N.P. K + A.CH + A.CL	25000^{d}	25000^{d}	30000^{c}	30000^{a}	23047.5^{d}	23047.5^{d}	28047.5^{d}	28047.5^{c}
Poultry Manure	15000^{h}	15000^{h}	16500^{g}	16500^{f}	13209.5^{h}	13209.5^{h}	14709.5^{j}	14709.5^{h}
PM + A.CH	31000^{b}	31000^{b}	31500^{b}	25500^{c}	29179.5^{b}	29179.5^{b}	29679.5^{b}	23679.5^{a}
PM + A.CL	22500^{e}	22500^{e}	17000^{f}	16500^{f}	20679.5^{e}	20679.5^{e}	15179.5^{i}	14679.5^{i}
PM + A.CH + A. CL	33000^{a}	33000^{a}	32000^{a}	30000^{a}	31149.5^{a}	31149.5^{a}	30149.5^{a}	28149.5^{b}
Control	8000^{l}	8000^{l}	15000^{h}	15000^{g}	6609.5^{l}	6609.5^{l}	13609.5^{k}	13609.5^{j}

Source: Analysed Field Data, 2023

CONCLUSION

The integration of survey findings and field experiment results provides strong evidence of the effectiveness, profitability, and practicality of combining Agrocharger and Agro Clean in maize cultivation.

Survey data showed unanimous farmer approval, with 100% of respondents confirming productivity gains from Agrocharger and Agro Clean. Agrocharger was primarily credited with yield improvement (90%) and reduced fertilizer dependency, both organic (8%) and inorganic (2%). Similarly, Agro Clean was recognized for lowering pest incidence (72%), improving crop growth (10%), and reducing pesticide use (18%). Farmers rated Agrocharger and Agro Clean as highly effective (38% and 52%, respectively) and effective (54% and 48%, respectively). Their combined use was valued by most respondents (44% highly valuable, 56% successful), indicating a strong belief in the complementary effects of their use.

These perceptions were validated by field experiment results, which demonstrated that the integrated Poultry Manure + Agro Charger + Agro Clean (PM + A.CH + A.CL) treatment provided the most efficient and profitable production system. Despite a moderate production cost (GHC 1850.50), this treatment achieved remarkable gains, gross profit increases of 312.5% at Fumesua and 113.33% at Mampong, and net profit increases of 371.3%

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and 121.53%, respectively, during the major season. Comparable improvements were observed in the minor season, with 371.3% and 106.8% increases in net profit.

The PM + A.CH + A.CL treatment also produced the highest grain yields (5.3–6.6 t/ha) across both locations and seasons. The integrated approach effectively reduced NPK application by 50% (125 kg/ha), offsetting the higher cost of synthetic fertilisers while maintaining high productivity levels. This aligns with farmers' perceptions that Agrocharger and Agro Clean enhance yield and efficiency while minimizing reliance on costly inputs.

Overall, both the survey and experimental results confirm that integrating Agrocharger and Agro Clean with organic manure optimises resource use, improves crop performance, and substantially increases profitability, providing a sustainable, cost-effective alternative to sole inorganic fertilizer use.

RECOMMENDATIONS

Based on the findings, the following recommendations were made.

It is therefore recommended that farmers prioritizing maize production adopt the integrated use of poultry manure, Agro Charger, and Agro Clean at rates of 5 t/ha + 148 ml per 74 L water/ha + 148 ml per 74 L water/ha (PM + A.CH + A.CL) respectively, to achieve maximum yield, and secure higher economic return.

Alternatively, farmers who prefer inorganic fertilisers are advised to apply half the recommended inorganic fertiliser rate, alongside Agro Charger at 125 kg/ha + 148 ml per 74 L water/ha (NPK + A.CH), to optimise yields and profitability.

Author Contributions

E.K.B. responsibly planned, set up, and ran all analyses and wrote the manuscript. H.K.D. provided supervision, editing and reviewing of the manuscript. E.N. was involved in planning, supervision, reviewing, and editing, making contributions to the write-up. M.E.E. was part of the supervision team and was involved in reviewing and editing the manuscript.

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Conflicts of Interest

The authors declare that they have no conflict of interest. The funders had no role in the design of the study, the collection, analysis, or interpretation of data, the writing of the manuscript, or the decision to publish the results.

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