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Testing innovations through multisite trials to bridge the gap between research and real-world farming in Northern Ghana

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Report

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Abstract

Maize yield optimisation requires a dual-pronged approach: improve variety selection to leverage genetic potential and precision fertilisation to address nutrient deficiencies. A simplified fertiliser recommendation framework, expressed in bags per unit area, bridges the knowledge gap between scientific guidelines and farmer application. However, this affects the rate of nutrients applied per area because of availability and farmers' preferred fertiliser types. This study examined the disparity between recommended fertiliser rates and farmer practices to determine the impact on maize varieties. The study combined four recommended fertiliser rates ($NP_2O_5K_2O$ ha-1) - 100-40-40 (T1), 100-60-60 (T2), 83.75-25-12.5 + 37.5S+ 5Mg + 0.75Zn (T3) and T3 + 2.5Zn (T4) with three maize varieties – two hybrids (SC719 and Wang-Basig) and an OPV (Sanzal-Sima). A multi-site study was conducted in Ghana, encompassing 12 locations: six in the Upper West Region, five in the Northern Region, and one in the Savannah Region. The fertiliser treatments showed minimal differences in growth parameters, with isolated significant effects observed for plant height (T2 > T1 at week eight) and leaf area (T3 > T1 at week four). However, grain yield was substantially improved in T2, T3, and T4 relative to T1, with no treatment differences within these T2, T3 and T4. Yield and economic optimisation were achieved with T4, T2, and T3 for SC719, Sanzal-Sima, and Wang-Basig, with yields of 4694.7 kg/ha, 4653.4 kg/ha, and 4077.9 kg/ha. SC719 outperformed Wang-Basig in growth, yield and profitability but not Sanzal-Sima. Wang-Basig and Sanzal-Sima had comparable yields. The findings demonstrate the substantial contribution of zinc to maize productivity and profitability, as evidenced in T4. Optimum zinc application emerges as a critical factor in maximising maize production efficiency. The findings also underscore the need for a suitable local hybrid and a site-specific fertiliser recommended for agroecology. The study recommends T4 and SC719 as the best combination to boost maize productivity in the Guinea Savannah zone. By validating the effectiveness of these combinations across diverse soils and conditions, the trials identified farmer-preferred options alongside research-based recommendations. The multisite trials, therefore, generate evidence for developing site-specific fertiliser and variety advisories, providing a foundation for advisory services that move beyond blanket recommendations and align with national commitments.

Introduction

Maize is an important food crop that profoundly impacts food security and economic stability. It is ranked third in global cereal production after wheat and rice, with a yearly production exceeding one billion tonnes (Serna-Saldivar, 2023). Maize is a primary source of carbohydrates and proteins, especially in Latin America and Africa, where it forms a significant part of the diet (Nuss & Tanumihardjo, 2010; Palacios-Rojas et al., 2020). In Ghana, maize accounts for about 50-60% of cereal production (Obour et al., 2022; Wongnaa et al., 2019). For the period 1972 – 2019, a record of 53 maize varieties with different growth rates and yield potentials was documented in Ghana (MoFA, 2019) (Figure 1). Over the recent decades, genetic improvements from breeding programs have increased maize yield potential from <6.5 to 10 (t ha-1) in Ghana. Imported hybrids have the potential to yield 12.8 t ha-1. Despite advances in breeding programs, agro-advisories and good agronomic practices, yield potential remains unattained due to several production constraints, such as suboptimal and imbalanced fertiliser application, and poor crop management (Vanlauwe et al., 2023), and climate change. Low maize yield is a global issue; in most developing countries, average yields range from 2-3 t/ha compared to the global average of 5.6 t/ha (Markos et al., 2023). The average yield on farmers' fields in Ghana is about 0.58 to 1.2 t ha-1 (Kouame et al., 2023). Inadequate, imbalanced fertiliser use and varieties exhibiting low response to fertilisers (Ragasa et al., 2014) are significant yield-limiting factors in Ghana.

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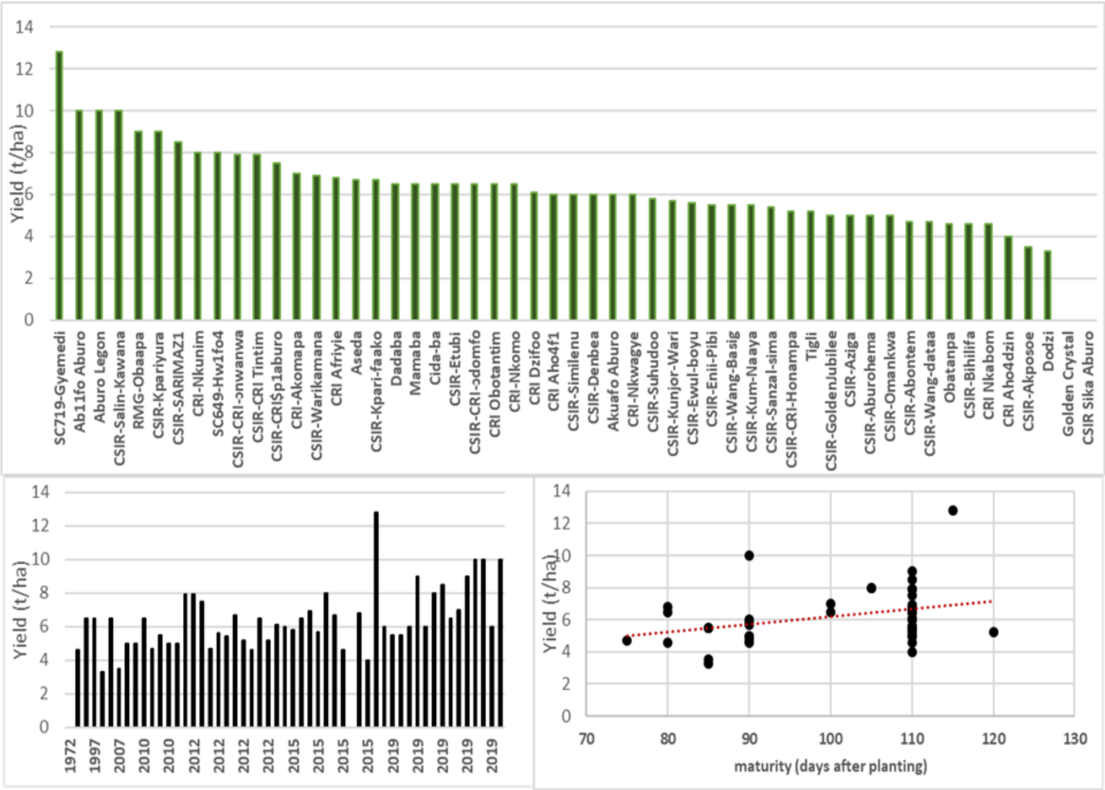


Figure 1: Potential yield of maize varieties released in Ghana over decades and their maturity periods

Providing advice on maximising input to output can be difficult, even in cases where crop response is high. This is because governments and other stakeholders in the value chain often support blanket recommendations (Kouame et al., 2023). The lack of direction has resulted in considerable nutrient losses when fertilisers are excessively applied or low yields when inadequate, resulting in financial and livelihood losses (Adu et al., 2018). Ghana's fertiliser usage has changed over time, from as low as 8 kg ha-1 in 2008 to about 25 kg ha-1 in 2022. This remains significantly less than the 50 kg ha-1 benchmark established by the Africa Union in the Abuja Declaration. With the Fertiliser Summit, the Abuja Declaration, and the recent Moroccan fertiliser policy, the focus of research and development has changed to providing farmers with customised recommendations that minimise losses while maximising profits and improving nutritional quality. The Africa Fertiliser and Soil Health (AFSH) in 2023 detailed key action points to address the major constraints to agricultural growth related to soil health and efficient and effective fertiliser use.

Site-specific fertiliser management has emerged as a vital strategy for optimising crop yields while minimising environmental impacts. Unlike blanket approaches, tailored fertiliser recommendations consider specific factors such as soil type, climate, and crop variety to provide precise guidance on fertiliser application (van Heerwaarden, 2022). The 4R nutrient stewardship framework further underscores its importance. This holistic approach advocates for the judicious use of fertilisers by considering four critical principles: right source, right rate, right time, and right place (Bruulsema et al., 2016). By considering the complex interactions between soil, plant, and fertiliser, farmers can make informed decisions that promote sustainable agricultural practices. As research continues to highlight the benefits of site-specific fertiliser management, its adoption is likely to become increasingly important for ensuring global food security and environmental sustainability.

Research on maize fertiliser recommendations in Ghana dates between the 1940s-1970s, when a blanket recommendation of $NP_2O_5K_2O$ 90-45-0 kg ha-1, respectively, was established (Ofori et al., 2024). The recommendation of 2 bags $NP_2O_5K_2O$ and 1 bag urea per acre has been in use for several decades and is still commonly used despite the differences in available fertiliser blends. Considering that land sizes are largely unknown and inherent differences in soil fertility, the 2:1 bag recommendation result in under- or over-application. To address non-response and negative economic returns realised in different agroecological zones, Tetteh et al. (2018) developed an agroecology-specific recommendation of 100:40:40 kg ha-1 of N-P_2O_5-K_2O for maize in the Guinea Savannah zone. This corresponded to an attainable yield of 4.5 tha-1 for the zone. However, maize varieties respond to fertiliser differently. A meta-analysis of research conducted in Ghana revealed inconsistent and equivocal impacts of variety on crop yield (Nziguheba et al., 2021). The economically optimal rate for N fertiliser for certain varieties may vary; for example, Essel et al. (2020) discovered the optimal N fertilisation rate for the Omankwa variety (a medium maturity) to be 60 t N ha-1 with a corresponding maize yield of 5 t ha−1.

Bua et al. (2020) examined maize response to fertiliser application rates and recommended N rate between 60 and 130 kg ha-1 applied in combination with 45-90 kg P_2O_5 and 45-90 kg K_2O. However, the types of fertiliser available or their easy accessibility to farmers significantly affect the application rate. A common fertiliser available on the market in the Guinea Savannah zone is Yara Actyva (23N – 10 P_2O_5 – 5 K_2O + 2 Mg + 3S + 0.3 Zn), which is mostly applied at 2 bags + 1 bag of sulphate of ammonia (SoA) per acre, resulting in 83.75-25-12.5 $NP_2O_5K_2O$ + 37.5S+5Mg+0.75Zn ha-1.

Given this trend and historical practices, the study sought to investigate the most widely promoted fertiliser recommendation rates and the actual fertiliser application practices of farmers, in response to the challenges facing fertiliser use in agriculture, to identify gaps between recommended and actual fertiliser use and inform strategies for optimising fertiliser application. The fertiliser recommendations used included 100-40-40 $NP_2O_5K_2O$ recommended by the CSIR-Soil Research Institute of Ghana, 100-60-60 $NP_2O_5K_2O$ recommended by the International Fertiliser Development Centre (IFDC) and farmers' practice of 2 bags of Yara Actyva + 1 bag of SoA (83.75-25-12.5 $NP_2O_5K_2O$ + 37.5 S + 5 Mg + 0.75 Zn) recommended and promoted by YARA Ghana. The study also included additional Zn applied at 2.5 kg ha-1 as foliar in combination with the farmer practice. This was to determine whether yield could be further enhanced with increasing Zn rate, considering that the Zn applied by farmers through the YARA recommendation is relatively low (0.75 kg ha-1). Considering that maize varieties have varying responses to fertiliser application, this research used three varieties (SC719, Sanzal-Sima and Wang-Basig) that are readily available to farmers to further expand on this perspective. This research thus endeavours to quantify the impact of maize cultivar and fertiliser interactions on yield and economic returns, providing insights into the development of sustainable and profitable maize production systems.

Materials and Methods

Study Sites

The experiment was established in the Northern and Upper West regions during the 2023 cropping season under rainfed conditions. Trials were established in six communities per region, totalling twelve (Figure 2). The chosen sites fall within the Guinea Savannah agroecological zone, characterised by a single cropping season (180–200 growing days), unimodal rainfall pattern with an annual mean precipitation and temperature of 1100 mm and 26 °C, respectively. The zone experiences a long dry season, which can affect agricultural activities and water availability for crops. The soils in the Guinea Savannah zone are commonly extensively weathered with predominantly light-textured surface horizons.

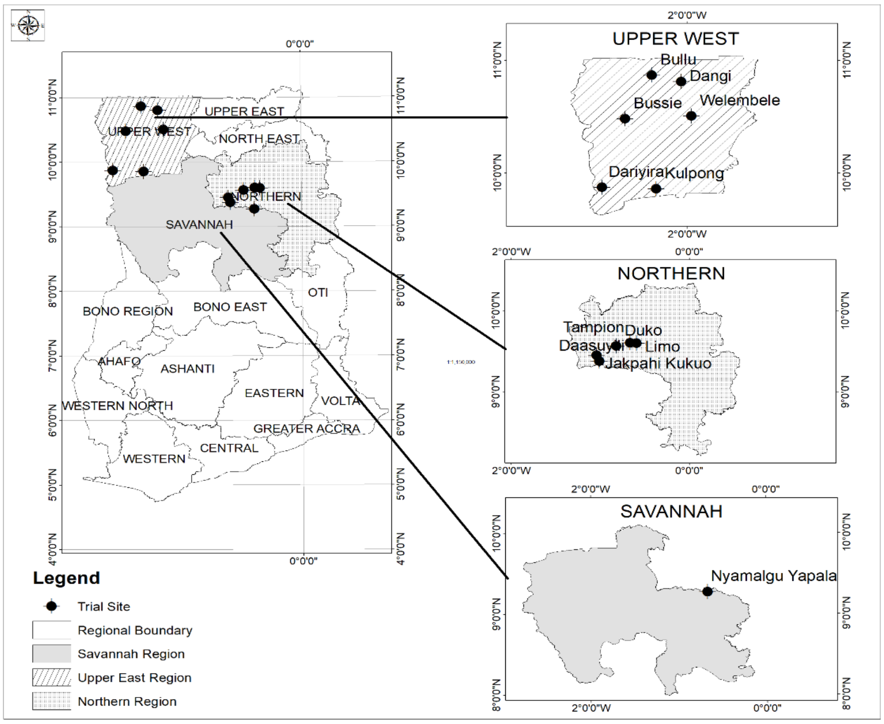


Figure 2: Map of Ghana showing the locations of the experiments. (Black dots represent trial sites)

Land Preparation and Layout

The experimental land was ploughed with a tractor to a depth of 20 – 30 cm. A harrow was used to break up clumps of soil, level the soil surface and create smooth soil tilth. Each plot was quadrilateral, measuring 5 m x 4.5 m with 1 m alleys between plots and 2 m alleys between blocks. The entire experimental unit measured at 55 m X 37.5 m (2,062.5 m2) per site.

Experimental Design and Treatments

The experiment was designed in a split-plot with three maize varieties and four fertiliser treatments. Maize varieties were the main-plot factor, while fertiliser treatments were the sub-plot factor. The experiment was replicated thrice per site. Maize varieties evaluated included two hybrid varieties (SC719 and Wang-Basig) and one open-pollinated variety (Sanzal-Sima). Characteristics of the varieties are presented in Table 1.

Table 1: Characteristics of the maize varieties

Name of Variety	Source	Characteristics	Preferred Ecology	Pedigree Line	Year of Release
CSIR-Sanzalsima	CSIR-SARI/ IITA	Days to physiological maturity:110 days (medium). Potential yield: 5.4 t/ha. Drought-tolerant. Tolerant to lodging.	Guinea savannah, Sudan savannah, Forest savannah transition and Forest	OPV DT SYN 1 W	2015
CSIR-Wang-Basig	CSIR-SARI/ IITA	Days to physiological maturity: 90 (early) Potential yield: 4.7 t/ha Striga and drought-tolerant; tolerant to lodging, tolerant to rust, blight, streak and curvularia.	Guinea and Sudan savannah, and Forest savannah transition	Hybrid	2012
SeedCo SC719 Gyemedi	SeedCo WECA	Days to physiological maturity: 115 - 120 days. Potential yield: 12.8 t/ha Pest/ Disease tolerance	Southern Guinea Savannah and Northern Guinea Savannah	Hybrid	2016

The fertiliser treatments were based on recommendations from CSIR-Soil Research Institute ((MOFA, n.d.), IFDC ((Pelizan, 2019), and YARA Ghana (Agyeman et al., 2023)(The fertiliser treatments are presented in Table 2.

Table 2: Treatment Description

Treatments	Description	Source
T1	Geographiccal area recommendation (Guinea Savannah): 100-40-40 N P2O5 K20	CSIR-SRI
T2	Recommendation from IFDC (100-60-60 N P2O5 K2O)	IFDC recommendation
T3	Farmers recom (83.75-25-12.5 NP2O5K2O + 37.5S+5Mg+0.75Zn i.e. 2 bags of Yara Activa + 1 bag of SOA per acre)	YARA recommendation (Farmer rate
T4	T3 + Zinc (2.5 kg/ha)	Farmer rate + Zinc biofortification

Experimental Design

Wang-Basig and Sanzal-Sima were planted at a spacing of 0.75 m between rows and 0.40 m between plants, with two seeds sown per hill. SC719 was planted at 0.75 m between rows and 0.25 m between plants, with one seed per hill. This plant spacing resulted in population densities of 66,666 and 53,300 plants per hectare for Sanzal-Sima/Wang-Basig and SC719 varieties, respectively. Refilling was done to ensure uniform plants per plot. The nitrogen fertiliser was applied in two equal splits. An initial application was done at planting through NPK fertiliser and the remaining N was supplied through Urea or SOA, depending on the treatment at 6 weeks after planting (WAP). The total phosphorus (P) and potassium (K) were applied at planting through the NPK fertiliser. T1 and T2 were applied using NPK 15-15-15 and urea (46% N) top-up, whereas T3 was applied using (23-10-5 $NP_2O_5K_2O$ + 2 Mg +3 S +0.3 Zn) and SoA (21% N) as top-up. A pre-emergent herbicide was applied after planting to control weeds. Two hand-weeding events were carried out throughout the experimental period.

Data collection

Before initiating the experiment, soil samples were collected using the zig-zag traversing method to ensure representative coverage of the entire experimental plot. The field was divided based on uniform characteristics and samples of 0-20 cm and 20-50 cm depths were taken. Soil cores from various parts of the experimental field were aggregated, air-dried, and then analysed separately for the two distinct depth ranges. An area of 4.5 m2 was demarcated at the centre of each plot for the measurement of agronomic growth and yield data. Six plants were randomly sampled and tagged in each 4.5 m² plot for periodic growth data measurement. Parameters measured included plant height, leaf area, and SPAD chlorophyll readings. Measurements started 2 WAP and were taken at 14-day intervals. Plant height was measured from the base to the tip of the plant using a meter rule at 2, 4, 6 and 8 WAP. SPAD readings were taken from the 5th and 6th leaves on the 6 and 8 WAP using a SPAD chlorophyll meter (SPAD 502Plus, KONICA MINOLTA). Leaf area was calculated as the product of the total length and width at the broadest point on the leaf.

Harvesting was done at physiological maturity; all plants in the pre-demarcated 4.5 m^2 area were harvested. Grain weight was measured at a mean seed moisture content of 14%. Grain yield was estimated using equation 1.

$$\text{GY, kg ha}^{-1} = (10{,}000 * x)/y \qquad \text{eqn 1}$$

Where:

x is the grain weight from harvested plots; and
y is the harvested area.

Maize biomass yield was assessed by cutting the plants at the base, removing cobs while leaving husks attached, and weighing using a hanging scale. Stover weight per hectare was estimated using equation 2.

$$\text{Stover yield (SY, kg ha}^{-1}) = (10{,}000 * x)/y \qquad \text{eqn 2}$$

Where:

x is the stover weight from harvested plots; and
y is the harvested area.

The returns on investment for using the different fertiliser treatments were calculated using Equation 3.

$$\text{Profit} = TR - TC \qquad \text{eqn 3}$$

Where:

TR is the total revenue, and
TC is the total cost of production.

The TC was calculated as the sum of the cost of inputs associated with each technology. These included the costs of land preparation (ploughing and harrowing), seeds, fertiliser, planting, fertiliser application (first and second), weed control (first, second and third), herbicides, spraying, harvesting, post-harvest handling (threshing), sacks, and bagging. The benefit-cost ratios were estimated using Equation 4.

$$B{:}C = \text{Profit}/TC \qquad \text{eqn 4}$$

Statistical analysis: The data collected were subjected to ANOVA at a 5% level of significance ($P \leq 0.05$) using R 4.1.2 software. Before performing the ANOVA, the data were tested for normality and heterogeneity of variance using the Shapiro-Wilk and Levene’s tests, respectively. The Duncan Multiple Range Test (DMRT) was used to separate means when significant differences were observed among the means.

Results

Climatic conditions of the study regions

The monthly climatic data for 2023 in the Northern and Upper West regions are represented in Figure 3. The peak of precipitation was between June and September. The Northern Region recorded slightly higher annual rainfall. Maximum and minimum temperatures ranged slightly above 37.5 °C and below 20 °C, respectively.

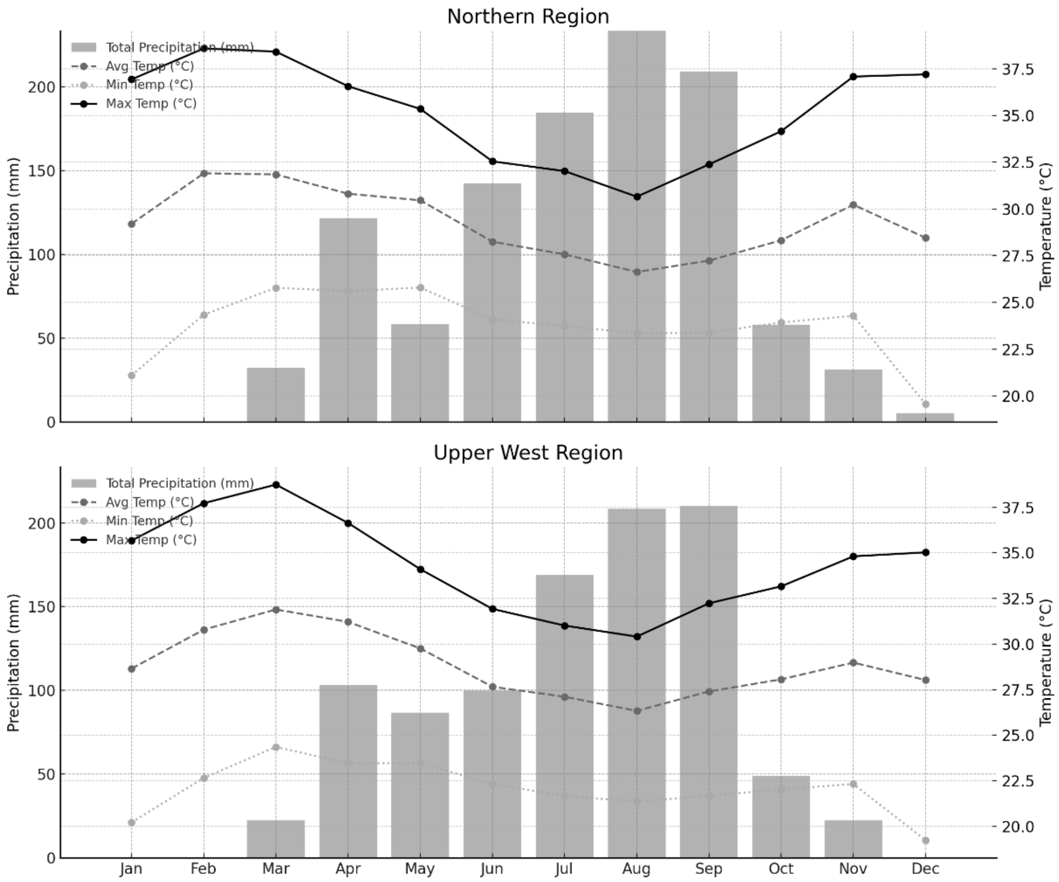


Figure 3: Average temperature and precipitation (2023)

Characteristics of experimental soils

The pH of the soils could be described as moderately acidic to slightly acidic (Table 3). The soils are poor in organic matter, except for the topsoil in Dariyiri, Dasuyili, and Tampion. The soil nutrient analysis revealed relatively modest levels of essential macronutrients. Specifically, nitrogen (N) content was categorised as low to medium, ranging from 0.10% to 0.20%. Phosphorus (P) availability was also limited, with levels falling below 10 mg/kg. Potassium (K) levels varied, spanning from low (<0.15 cmolkg^{-1} soil) to medium (0.15-0.25 cmolkg^{-1} soil). Exchangeable calcium ranged from low (<0.5 cmolkg^{-1} soil) to medium (0.5-10 cmolkg^{-1} soil). Exchangeable magnesium was also considered low (<1.0 cmolkg^{-1} soil) to medium (1.0-3.0 cmolkg^{-1} soil). Soils at the sites also showed low Effective Cation Exchange Capacity (ECEC) values (<0.10 mol kg-1 soil), suggesting limited nutrient retention and exchange capabilities.

Table 3: Soil fertility status at experimental sites

Regions and Communities	pH (1:2.5)	N %	O.M mgkg-1	Av. P m.e/ 100g	Ex. Ca	Ex. Mg	Ex. K	ECEC	PBSi
Upper West									
Dariyiri 0-20 cm	6.30	0.11	1.72	2.47	3.42	1.70	0.18	5.42	98.52
Dariyiri 20-50 cm	6.40	0.04	0.55	1.82	2.68	0.75	0.13	3.72	97.85
Bullu 0-20 cm	5.85	0.05	0.76	2.69	1.71	0.64	0.18	2.75	94.54
Bullu 20-50 cm	5.79	0.04	0.55	1.60	1.71	0.64	0.08	2.67	94.01
Kulkpong 0-20cm	6.34	0.07	1.24	1.89	3.85	2.13	0.17	6.34	98.58
Kulkpong20-50 cm	6.34	0.06	1.17	1.38	5.14	2.98	0.16	8.48	98.82
Welembele 0-20 cm	5.93	0.05	0.76	2.40	2.14	0.43	0.14	2.95	94.91

Welembele 20-50 cm	6.03	0.02	0.34	1.67	1.93	0.64	0.09	2.89	95.16
Dangi 0-20 cm	5.90	0.06	0.96	2.62	2.57	1.07	0.18	4.06	96.31
Dangi 20-50 cm	5.65	0.05	0.83	1.89	1.93	1.49	0.15	3.89	94.86
Bussie 0-20 cm	6.28	0.06	1.03	3.56	3.21	1.49	0.19	5.09	98.03
Bussie 20-50 cm	6.45	0.05	0.55	2.47	3.21	1.70	0.10	5.22	98.47
Northern Region									
Duko 0-20 cm	6.52	0.04	0.89	13.82	2.35	1.39	0.22	4.12	97.57
Duko 20-50 cm	6.46	0.03	0.69	9.09	3	1.28	0.21	4.65	97.64
Yapala 0-20 cm	5.88	0.09	1.51	2.76	3.42	1.39	0.12	5.12	97.07
Yapala 20-50 cm	5.51	0.07	1.1	1.75	3	1.18	0.09	4.49	95.99
Limo 0-20 cm	5.8	0.07	1.24	2.4	3.21	1.61	0.1	5.11	97.26
Limo 20-50 cm	5.67	0.05	0.96	1.53	3	1.71	0.05	4.94	96.97
Jakpati 0-20 cm	5.86	0.06	1.17	5.53	2.78	0.96	0.16	4.07	96.32
Jakpati 20-50 cm	5.76	0.05	0.96	3.2	2.35	0.96	0.11	3.59	95.54
Tampion 0-20 cm	5.55	0.08	1.79	5.53	3.85	1.28	0.3	5.65	96.46
Tampion 20-50 cm	5.9	0.05	1.03	3.42	3.64	1.71	0.23	5.74	97.91
Dasuyili 0-20 cm	5.87	0.07	1.58	7.13	2.14	1.07	0.23	3.56	96.63
Dasuyili 20-50 cm	5.86	0.04	0.69	4.36	2.35	1.25	0.14	3.92	96.94
Maximum	6.52	0.09	1.79	13.82	3.85	1.71	0.3	5.74	97.91
Minimum	5.51	0.03	0.69	1.53	2.14	0.96	0.05	3.56	95.54
Mean	5.89	0.06	1.13	5.04	2.92	1.32	0.16	4.58	96.86
St Dev	0.31	0.02	0.35	3.57	0.55	0.26	0.07	0.75	0.70

Growth parameters

Plant height

Significant variations ($P < 0.05$) were observed among the maize varieties at weeks 2, 6, and 8. SC719 consistently exhibited the tallest height throughout the observation period, as illustrated in Figure 4. In contrast, Wang-Basig and Sanzal-Sima displayed comparable heights, with no significant difference across all observed weeks. The interaction between varieties and treatments did yield significant differences (Figure 5). At week 8, the mean heights of SC719, Wang-Basig, and Sanzal-Sima were 197.8 cm, 167.3 cm, and 163.2 cm, respectively. Analysis of plant height revealed significant treatment effects only at week 8 (Figure 4). At this stage, treatment T2 produced the tallest plants, reaching a height of 180 cm, which was significantly taller than T1 (171.7cm). However, T2 did not differ significantly from T3 (175.9cm) and T4 (176cm). Treatments T3, T4, and T1 showed no significant differences in plant height among themselves at week 8. The variety factor was highly significant for plant height ($F = 75.91$, $p < 0.0001$), underscoring the genetic contribution to this trait. SC719 had the tallest average plant height, indicating its superior growth potential under the given experimental conditions. The fertiliser was not statistically significant for plant height ($p > 0.05$). This suggests that fertiliser formulations and applications did not result in measurable differences in plant elongation, highlighting the inherent stability of this trait across nutrient regimes. The absence of a significant Variety:Fertiliser interaction ($p = 0.5106$) indicates that the plant height response of each variety was consistent across the fertilisers. This uniformity is beneficial for scaling up management practices, as it implies predictable outcomes regardless of specific agronomic interventions.

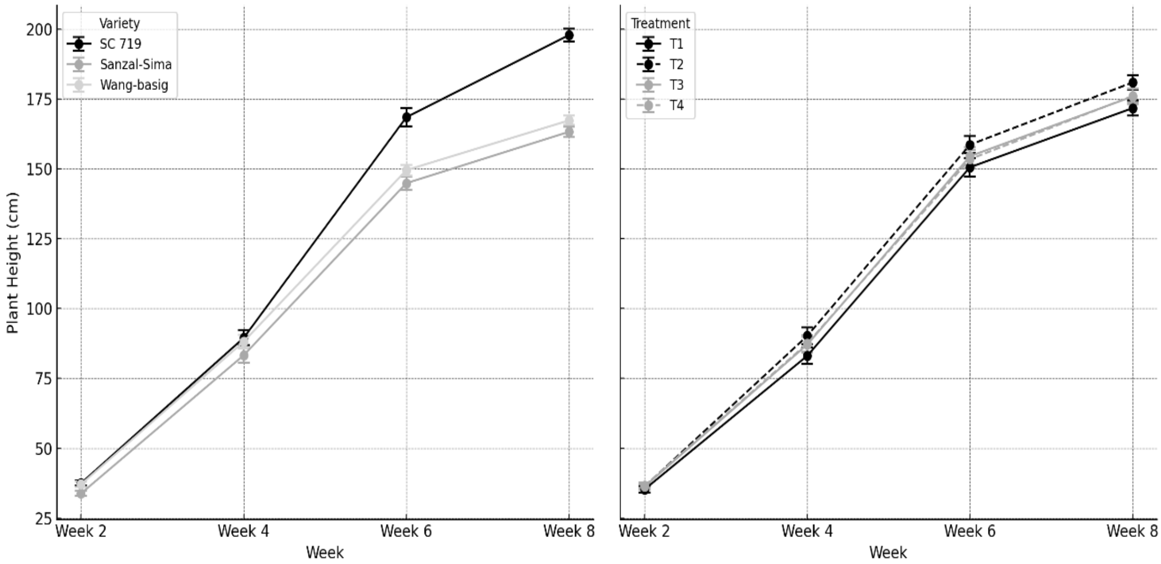


Figure 4: Average plant height per variety (left) and fertiliser treatment (right)

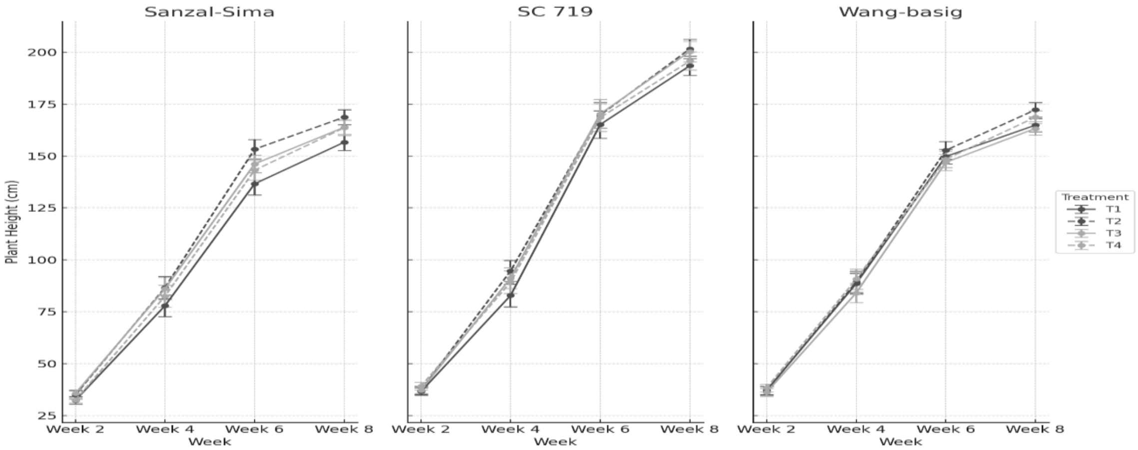


Figure 5: Average plant height for the interaction of variety and fertiliser treatments

Leaf area

The leaf area for varieties was significantly different. SC179 consistently produced a significantly broader leaf area compared to Wang-Basig and Sanzal-Sima (Figure 6). SC719 produced an average leaf area of 320, 518, 598 and 644.7cm2 for weeks 2,4,6 and 8, respectively. Wang-Basig and Sanzal-Sima were similar in terms of leaf area throughout the observed weeks. Leaf area varied among maize varieties after week 6. SC719, a long-duration variety, exhibited an increase in leaf area, whereas Wang-Basig and Sanzal-Sima, being short-duration varieties, had smaller leaf area. Earlier, at week 4, fertiliser treatment significantly impacted leaf area (Figure 6). T1 had a significantly lower leaf area compared to T3, T2, and T4, which had statistically similar leaf areas of 471.7 cm², 471.4 cm², and 458 cm², respectively. However, the interaction between varieties and fertilisers did not yield any significant differences in leaf area (Figure 7).

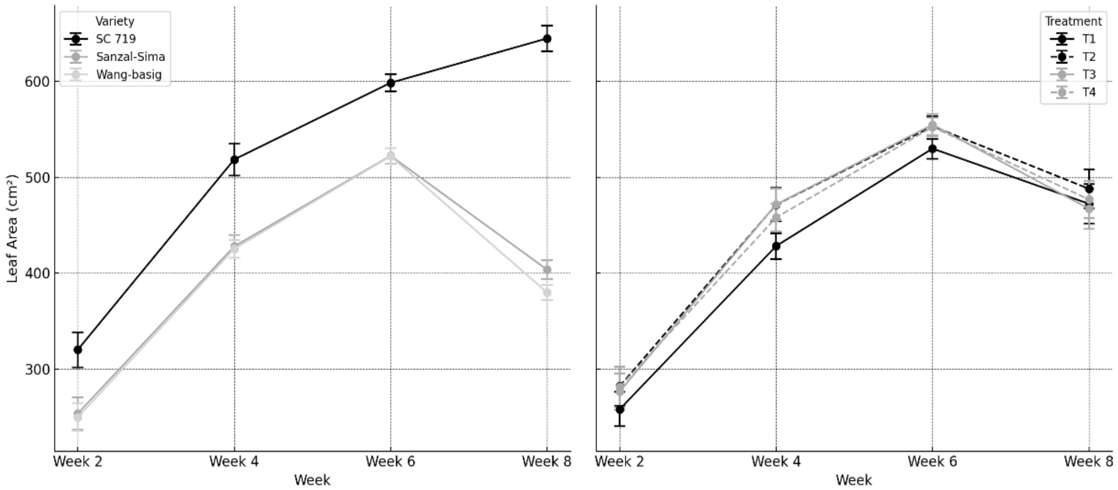


Figure 6: Average leaf area per variety (left) and fertiliser treatment (right)

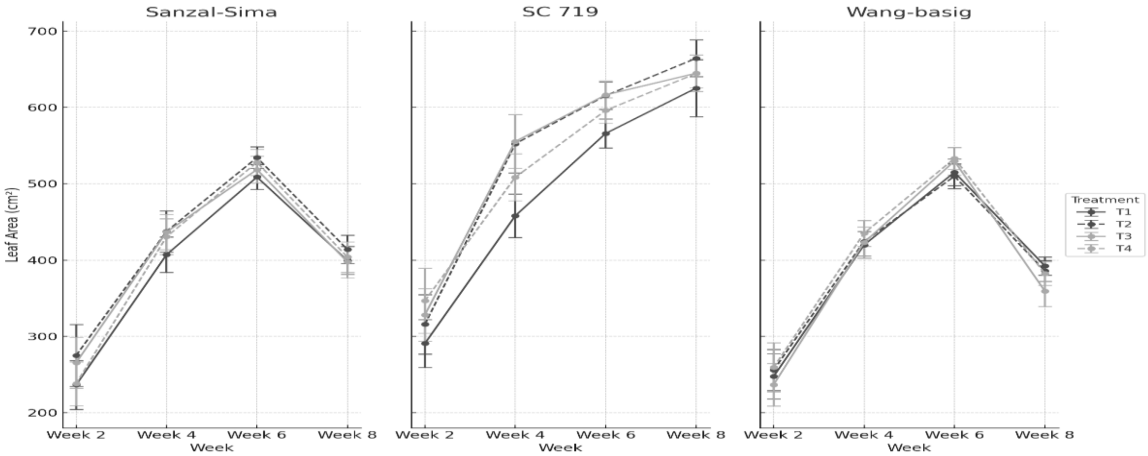


Figure 7: Average leaf area for interaction of variety and fertiliser treatments

Leaf Chlorophyll content

SPAD readings varied significantly among the varieties, but there were no significant differences between the fertilisers and the interaction of varieties and fertilisers (Figures 8 and 9). SC719 and Wang-Basig were statistically similar for both weeks. Only SC719 produced significantly higher SPAD readings compared to Sanzal-Sima (Figure 8). The SPAD readings for SC719, Wang-Basig and Sanzal-Sima were 42.4, 42.1 and 39.6 units for week 6 and 33.6, 32.6 and 30.9 units for week 8, respectively. The order of SPAD readings for the fertilisers was T2> T3> T4> T1 and T3> T4> T2> T1 for weeks 6 and 8, respectively (Figure 8). SPAD readings decreased from week 6 to week 8 as senescence set in, with crops nearing maturity and drying up.

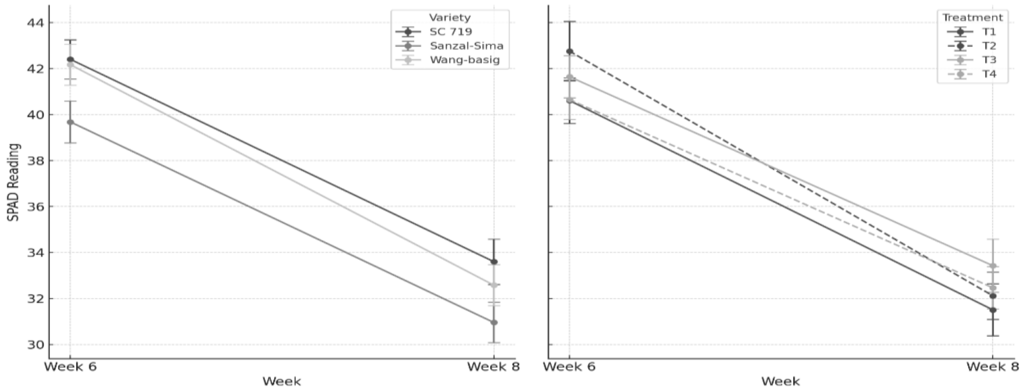


Figure 8: Average SPAD readings per variety and fertiliser treatment

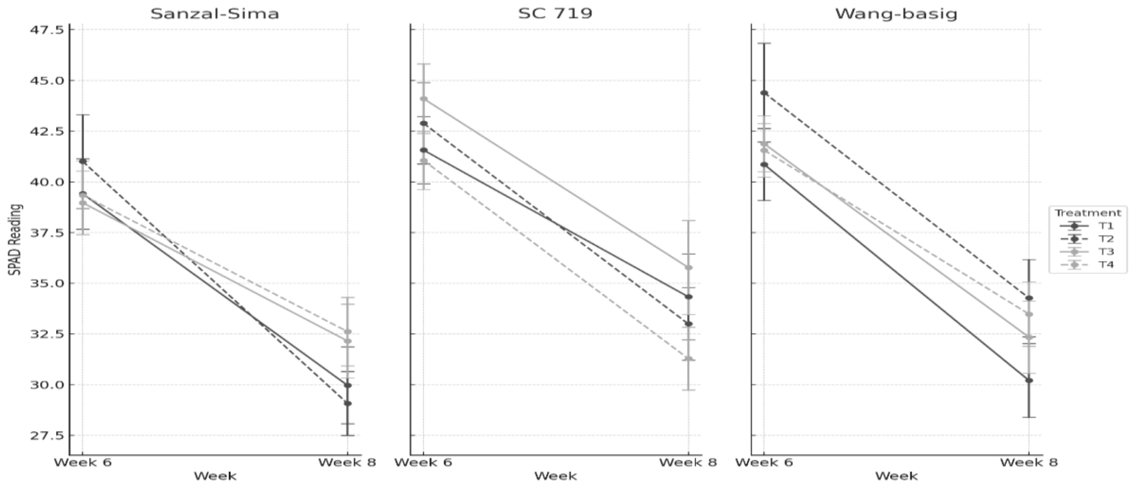


Figure 9: Average SPAD readings for the interaction of variety and fertiliser treatments

Number of cobs and Weight per cob

Fertiliser treatments significantly influenced the number of cobs per plant (Ncobs) (F=2.89, p<0.05), underscoring the importance of nutrient management in enhancing cob production. Treatments T2, T3, and T4, which included balanced applications of macro- and micronutrients, produced significantly higher cob numbers than T1 (Table 2).

Table 2 Anova table for number of cobs per plant

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F Value	Pr(> F)
Block	2	864.6157	432.3079	8.49	0.0002
Variety (Var)	2	7215.5602	3607.7801	70.82	0.0000
Fertiliser (Fert)	3	441.2407	147.0802	2.89	0.0354
Variety x Fertiliser (Var:Fert)	6	408.7176	68.1196	1.34	0.2392
Error	418	21294.8287	50.9446		
Total	431	30224.9630			

Weigh per cob was significantly influenced by varieties but not fertiliser (Figure 10). The interaction between varieties and fertilisers did not also result in significant differences (Figure 11). SC719 produced significantly heavier cobs (689 g) than the other two varieties. Cob weights of Sanzal-Sima and Wang-Basig were statistically similar (495 g, and 472 g, respectively). T2 produced the heaviest cobs (572 g), followed by T4, T1 and T3 (552 g, 549 g, and 536 g, respectively).

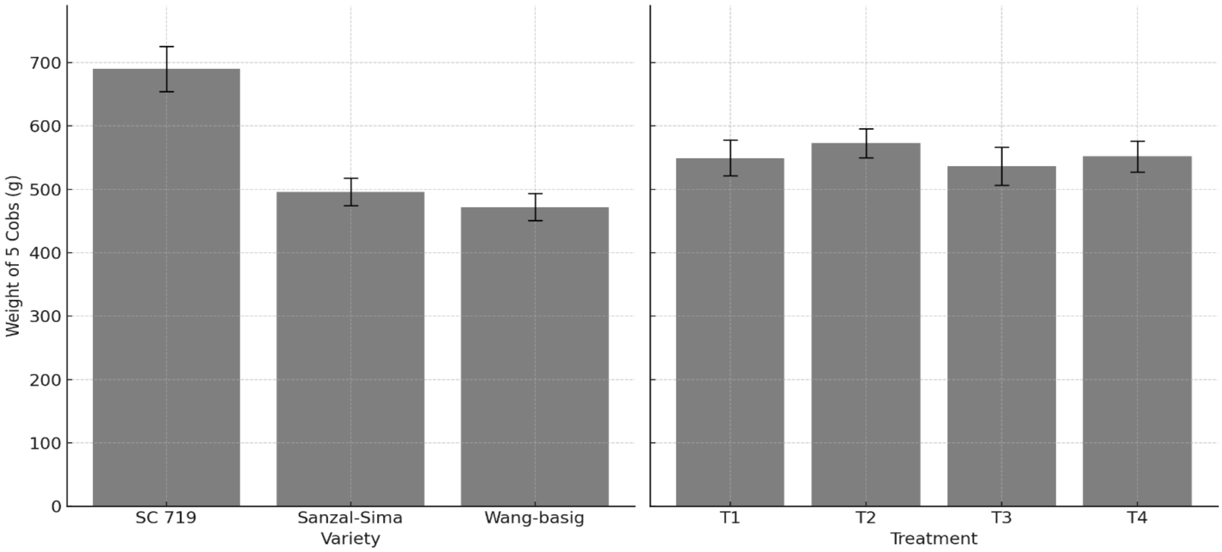


Figure 10: Average cob weight per variety and fertiliser treatments

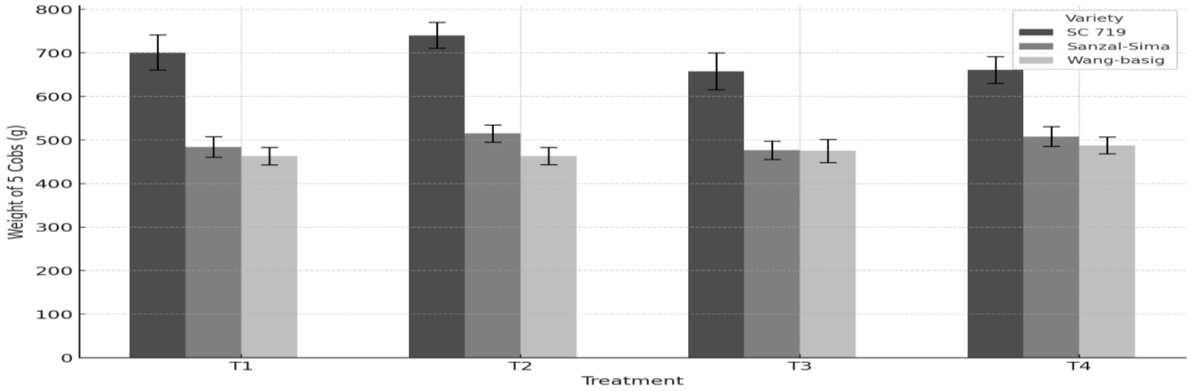


Figure 11. Average weight per cob for the interaction of variety and fertiliser treatments

Biomass yield

Biomass yield significantly differed among varieties and fertilisers (Figure 12). However, the interaction of the two did not have a significant difference in biomass yield (Figure 13). SC719 produced the highest biomass yield of 14, 367 kg/ha (Figure 11), which was significantly greater than that of Sanzal-Sima (8,425 kg/ha). Similarly, Sanzal-Sima produced significantly higher biomass compared to Wang-Basig (6,388 kg/ha). T2 produced a significantly higher biomass yield (10,884 kg/ha) than T3, T1 and T4, which were statistically similar (9,506 kg/ha, 9,320 kg/ha and 1,997 kg/ha) (Figure 12).

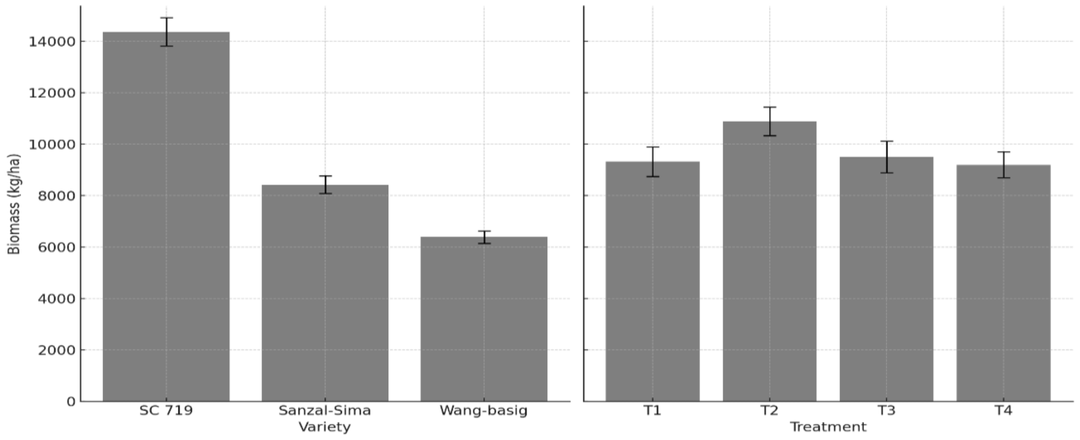


Figure 12: Average biomass yield per variety and fertiliser treatment

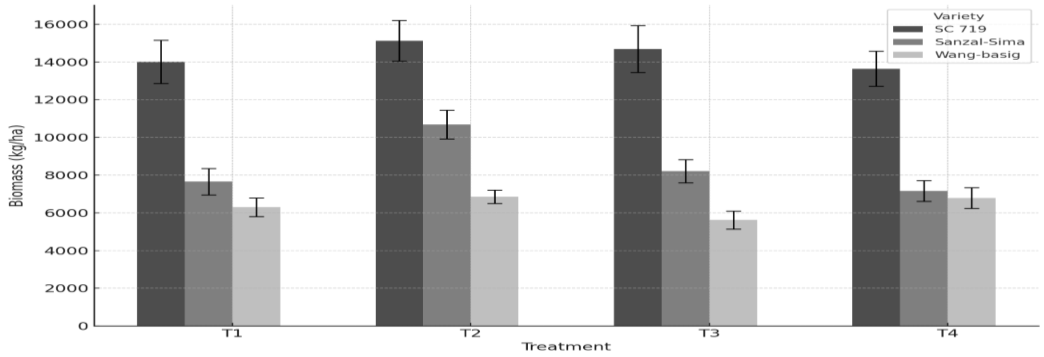


Figure 13: Average biomass yield for interaction of variety and fertiliser treatments

Shelling Percentage

Shelling percentage was significantly different among varieties, but fertilisers and the interaction between varieties and fertilisers did not result in significant variations (Figures 14 and 15). The shelling percentage of Wang-Basig was significantly higher (86.29%) than SC719 (82.95%) and Sanzal-Sima (82.78%). Shelling percentages as a result of fertiliser application was 84.51%, 84.08%, 83.85% and 83.59% for T3, T2, T1 and T4, respectively.

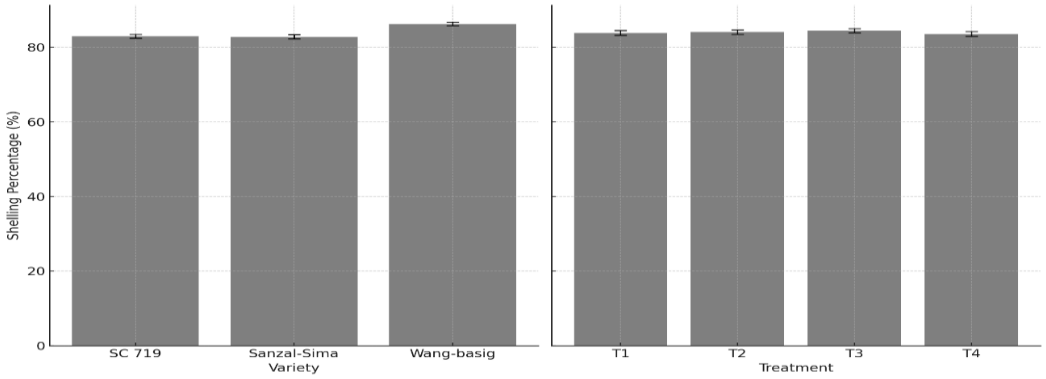


Figure 14: Average shelling percentage per variety and fertiliser treatment

Grain Yield

Grain yield was significantly different among varieties and fertilisers, however, the interaction of the two factors (varieties and fertiliser) did not result in significant differences (Figures 15 and 16). SC71 gave an average yield of 4,430 kg/ha, statistically higher than Sanzal-Sima (3,859 kg/ha) and Wang-Basig (3,773 kg/ha). Sanzal-Sima and Wang-Basig were statistically similar in grain yield. Among the fertilisers, T2, T4 and T3 produced statistically similar grain yields of 4,360 kg/ha, 4,118 kg/ha, and 4,045 kg/ha, respectively, and significantly higher than T1 (3,546 kg/ha). Although there were no significant differences with respect to the interactions, T2 with SC719 produced the highest grain yield (4,600 kg/ha). All the fertiliser treatments applied to SC719 produced higher grain yields compared to their application on the other two varieties (Figure 15). Also, Variety and treatment performance under the two regions (Northern and Upper West) were statistically similar (Figure 17).

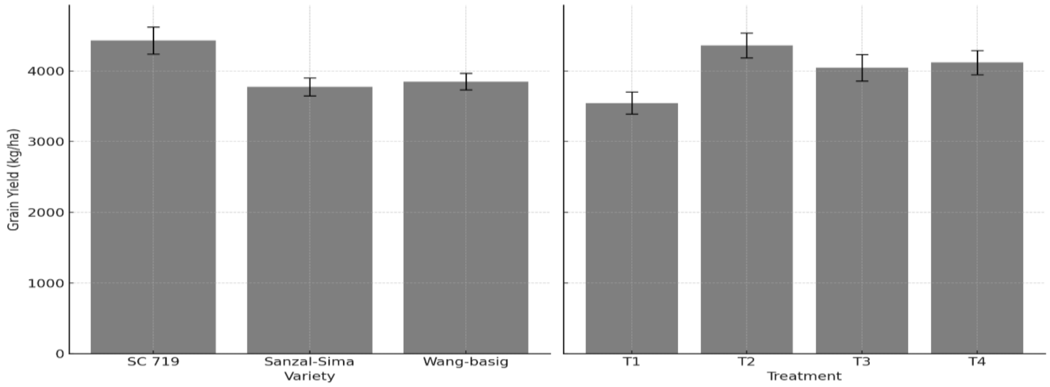


Figure 15: Average grain yield per variety and fertiliser treatment

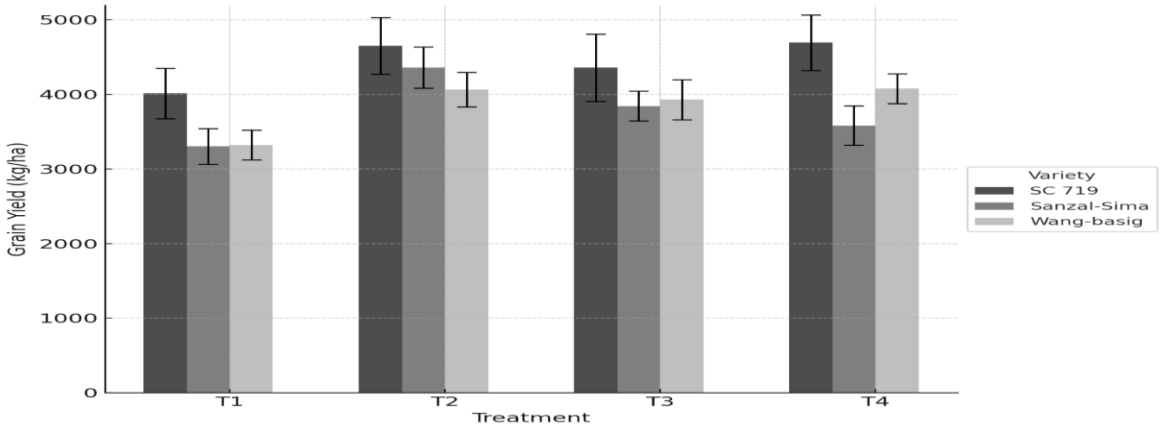


Figure 16: Average grain yield for interaction of variety and fertiliser treatments

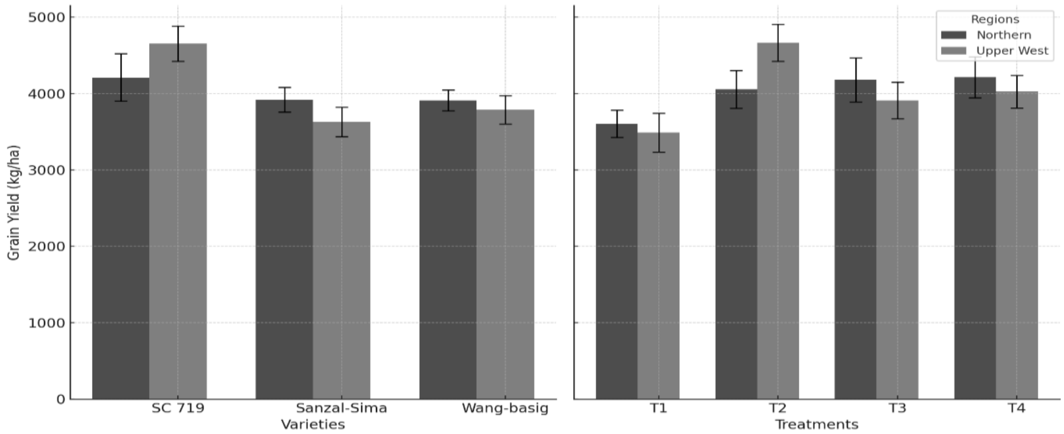
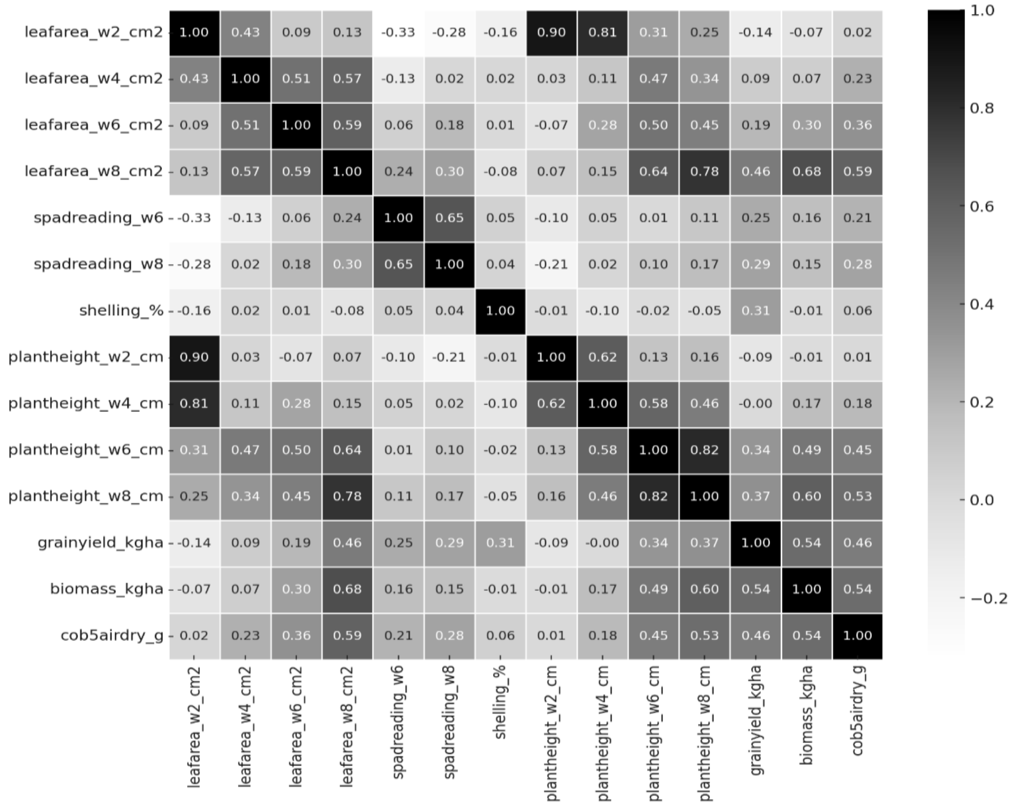


Figure 17: Average grain yield of varieties and fertiliser treatments per region

Correlation

The correlation heat map shows significant positive relationships between grain yield and several agronomic parameters (Figure 18). Grain yield showed a strong positive correlation with biomass (0.54) and a moderate correlation with cob dry weight (0.46). These relationships suggest that higher above-ground biomass and heavier cobs contribute significantly to increased grain yields, highlighting the importance of robust vegetative and reproductive growth for maximising productivity. Leaf area at week 8 (0.46) and plant height at week 8 (0.37) were positively correlated with grain yield. These findings indicate that larger canopy size and taller plants support higher photosynthetic capacity and resource capture, ultimately contributing to better grain development. Leaf chlorophyll content showed weaker correlations with grain yield at weeks 6 (0.21) and 8 (0.28). While chlorophyll content is an important indicator of nitrogen status, its lower correlation suggests that other factors, such as nutrient partitioning and reproductive efficiency, may play a more significant role in determining grain yield.



	leafarea_w2_cm2	leafarea_w4_cm2	leafarea_w6_cm2	leafarea_w8_cm2	spadreading_w6	spadreading_w8	shelling_%	plantheight_w2_cm	plantheight_w4_cm	plantheight_w6_cm	plantheight_w8_cm	grainyield_kgha	biomass_kgha	cob5airdry_g
leafarea_w2_cm2	1.00	0.43	0.09	0.13	-0.33	-0.28	-0.16	0.90	0.81	0.31	0.25	-0.14	-0.07	0.02
leafarea_w4_cm2	0.43	1.00	0.51	0.57	-0.13	0.02	0.02	0.03	0.11	0.47	0.34	0.09	0.07	0.23
leafarea_w6_cm2	0.09	0.51	1.00	0.59	0.06	0.18	0.01	-0.07	0.28	0.50	0.45	0.19	0.30	0.36
leafarea_w8_cm2	0.13	0.57	0.59	1.00	0.24	0.30	-0.08	0.07	0.15	0.64	0.78	0.46	0.68	0.59
spadreading_w6	-0.33	-0.13	0.06	0.24	1.00	0.65	0.05	-0.10	0.05	0.01	0.11	0.25	0.16	0.21
spadreading_w8	-0.28	0.02	0.18	0.30	0.65	1.00	0.04	-0.21	0.02	0.10	0.17	0.29	0.15	0.28
shelling_%	-0.16	0.02	0.01	-0.08	0.05	0.04	1.00	-0.01	-0.10	-0.02	-0.05	0.31	-0.01	0.06
plantheight_w2_cm	0.90	0.03	-0.07	0.07	-0.10	-0.21	-0.01	1.00	0.62	0.13	0.16	-0.09	-0.01	0.01
plantheight_w4_cm	0.81	0.11	0.28	0.15	0.05	0.02	-0.10	0.62	1.00	0.58	0.46	-0.00	0.17	0.18
plantheight_w6_cm	0.31	0.47	0.50	0.64	0.01	0.10	-0.02	0.13	0.58	1.00	0.82	0.34	0.49	0.45
plantheight_w8_cm	0.25	0.34	0.45	0.78	0.11	0.17	-0.05	0.16	0.46	0.82	1.00	0.37	0.60	0.53
grainyield_kgha	-0.14	0.09	0.19	0.46	0.25	0.29	0.31	-0.09	-0.00	0.34	0.37	1.00	0.54	0.46
biomass_kgha	-0.07	0.07	0.30	0.68	0.16	0.15	-0.01	-0.01	0.17	0.49	0.60	0.54	1.00	0.54
cob5airdry_g	0.02	0.23	0.36	0.59	0.21	0.28	0.06	0.01	0.18	0.45	0.53	0.46	0.54	1.00

Figure 18: Correlation heat map for grain yield and various agronomic parameters

Economic Analysis

The economic analysis showed that SC719 with T4 gave the highest profit of GH₵8408.07 and a cost-benefit ratio of 0.66 (Table 4). This shows that it is the most economically efficient combination. The fertiliser treatment with the lowest revenue and benefit-cost ratio is T1, for all the varieties. T2 and T4 gave the highest profits of GH₵ 6572.28 and GH₵ 5998.40, with benefit-cost ratios of 0.5 and 0.49 for Sanzal-Sima and Wang-Basig, respectively. The combination of fertiliser rates and SC719 gave the highest profits compared to applying the same fertiliser rates with Sanzal-Sima and Wang-Basig.

Table 4: Economic returns for varieties and fertiliser treatment

Variety	Fertiliser Treatment	Cost of production (GH ₵)	Revenue (GH ₵)	Profit (GH ₵)	B:C ratio

SC719	T1	12685.21	18067.01	5381.80	0.42
	T2	13608.69	20940.27	7331.59	0.54
	T3	12351.03	19620.34	7269.32	0.59
	T4	12718.15	21126.22	8408.07	0.66
Sanzal-Sima	T1	11986.35	14867.35	2881.00	0.24
	T2	13056.70	19628.98	6572.28	0.50
	T3	11720.69	17301.70	5581.01	0.48
	T4	11879.42	16128.28	4248.86	0.36
Wang-Basig	T1	12292.61	14947.90	2655.29	0.22
	T2	13253.09	18296.85	5043.76	0.38
	T3	12050.63	17686.66	5636.03	0.47
	T4	12352.27	18350.68	5998.40	0.49

Discussions

Soil responsiveness to fertiliser treatments

The soil pH across the sampled sites ranged from 5.51 - 6.52, with a mean of 5.89 ± 0.31, classifying the soils as moderately to slightly acidic. This pH range falls within the optimal range for nutrient availability (5.50–6.50), where most macro- and micronutrients are readily accessible to crops (Motsara & Roy, 2008). However, sites with lower pH values, such as 5.51 at Yapala (20–50 cm) and 5.55 at Tampion (0–20 cm), may experience potential challenges such as reduced availability of calcium and magnesium. For these acidic conditions, T4 (83.75–25–12.5 N–P_2O_5–K_2O + 37.5 S + 5 Mg + 0.75 Zn, supplemented with 2.5 kg/ha zinc for biofortification) is particularly relevant. The addition of zinc and sulfur in T4 can help address deficiencies in secondary nutrients and trace elements, while the lime component aids in neutralising soil acidity, enhancing overall nutrient availability.

The nitrogen (N) content in the soils was generally low, ranging from 0.03% to 0.11%, with an average of 0.06% ± 0.02%. N is critical for plant growth, influencing chlorophyll synthesis and vegetative development. Similarly, organic matter (O.M.) content was low, ranging from 0.69 mg/kg to 1.79 mg/kg, with a mean of 1.13 ± 0.35 mg/kg. Low organic matter reduces the soil's capacity to supply nutrients, retain moisture, and support microbial activity. (Sreedevi et al., 2018). The use of T3 (83.75–25–12.5 N–P_2O_5–K_2O + 37.5 S + 5 Mg + 0.75 Zn) and T4 (T3 + zinc fortification) addresses these deficiencies effectively. The sulfur (S) and magnesium (Mg) inputs in these treatments promote nitrogen uptake and chlorophyll formation, while zinc biofortification in T4 improves enzyme function and plant metabolism. Additionally, the use of organic components in these treatments enhances microbial activity and contributes to the buildup of soil organic matter.

Available phosphorus (P) showed significant variability across the sites, ranging from 1.53 m.e/100 g to 13.82 m.e/100 g, with a mean of 5.04 ± 3.57 m.e/100 g. P is critical for root development and energy transfer in crops, but its availability in acidic soils can be limited due to fixation by aluminium and iron oxides (Sreedevi et al., 2018). Sites with particularly low P levels, such as Bullu (20–50 cm) at 1.60 m.e/100 g, require immediate phosphorus supplementation. Among the treatments, T1 (100–40–40 N–P_2O_5–K_2O) and T2 (100–60–60 N–P_2O_5–K_2O) offer direct and soluble sources of P for immediate uptake by plants. Meanwhile, T3 and T4, with their organic components, contribute to the gradual release of phosphorus over time, providing sustained nutrient availability and minimising losses due to fixation.

The Effective Cation Exchange Capacity (ECEC) across the sites ranged from 3.56 to 8.48 m.e/100 g, with an average of 4.58 ± 0.75 m.e/100 g, indicating a generally low capacity to retain essential nutrients such as calcium (Ca), magnesium (Mg), and potassium (K). The sandy texture of many soil samples exacerbates this limitation, making the soils prone to nutrient leaching under rainfall or irrigation. T3 and T4 are highly effective in improving the retention of nutrients under such conditions. Including S, Mg, and Zn in these treatments enhances the nutrient-holding capacity of soils while promoting crop growth and development. Additionally, Zn biofortification in T4 supports plant metabolic activities, ensuring better performance even in soils with lower inherent fertility.

Variety responsiveness to fertiliser treatments

The differences in growth, yield, and nutrient responsiveness among the maize varieties (SC719, Wang-Basig, and Sanzal-Sima) highlight the critical role of varietal traits in shaping agricultural productivity. These findings carry several implications related to crop physiology, nutrient use efficiency, and the potential for targeted breeding and management strategies. Fertiliser treatments significantly influenced plant height and leaf area, particularly at later stages of crop growth. Superior plant height attained with T2 compared to T1 can be attributed to its higher P and K levels. This aligns with the essential roles of P and K in root development and vegetative growth, as supported by Ahmad et al. (2019). Similarly, leaf area at week 4 was significantly lower under T1 compared to T2 and T3, emphasising the importance of balanced P and K levels and the contribution of secondary and micronutrients in T3. The comparable leaf chlorophyll content recorded across the fertilisers is likely because all the fertiliser treatments supplied sufficient N. However, the presence of S, Mg, and Zn in T3 and the extra Zn in T4 may have compensated for their lower NPK rates compared to T1. This is consistent with findings that secondary nutrients enhance photosynthesis and crop performance (Narayan et al., 2023; He et al., 2023).

Variety had a more significant effect on growth parameters than the fertiliser treatments. The hybrid SC719, with its superior genetic potential, consistently showed higher growth performance compared to the open-pollinated variety (OPV) Sanzal-Sima and the locally bred hybrid Wang-Basig. SC719's leaf area continued to expand up to weeks 6–8, unlike the other two varieties, which exhibited declines due to earlier maturity (90–110 days for Wang-Basig and Sanzal-Sima). This is consistent with findings by Abayomi et al. (2006), which linked hybrids' yield advantage to their larger leaf area, improving light interception and resource utilisation. Biomass production was significantly influenced by fertiliser treatments, with T2 outperforming the other fertilisers. This was expected, as maize responds well to balanced NPK fertilisation (Li et al., 2024). While T1, T3, and T4 yielded statistically similar biomass, the addition of secondary and micronutrients in T3 and T4 likely compensated for their reduced NPK levels.

Grain yield followed a similar pattern, with T1 producing significantly lower yields than T2, T3, and T4, which were statistically similar. T2's higher P and K levels likely improved grain filling and kernel development, while T3 and T4 benefited from secondary and micronutrients (S, Mg, and Zn) that enhance nutrient uptake and yield formation (Potarzycki & Grzebisz, 2009). Increasing the Zn rate in T4 further boosted grain yield, as Zn supports chlorophyll content, photosynthesis, and reproductive development (Liu et al., 2016). SC719 significantly outperformed Wang-Basig and Sanzal-Sima in grain yield and biomass production, reaffirming the yield potential of hybrids over OPVs. Although Sanzal-Sima produced more biomass than Wang-Basig, the latter's ability to produce multiple cobs per plant likely accounted for its slightly higher grain yield. SC719's superior leaf area and late maturity allowed it to maintain higher productivity throughout the growing period, consistent with earlier studies (Olasoji et al., 2023; Keteku et al, 2024). Cob weight and shelling percentage also varied significantly among varieties, with SC719 showing significantly higher cob weights but lower shelling percentages than Wang-Basig, which had a higher proportion of grain to cob. This indicates that Wang-Basig might be more efficient in converting biomass to grain under specific conditions, despite its lower overall yield. The superior yield potential of the hybrid variety SC719, compared to the open-pollinated variety (OPV) Sanzal-Sima and the locally bred hybrid Wang-Basig under varying fertiliser regimes, highlights the genetic advantage of hybrids in resource capture and conversion. The stability of SC719 across treatments and blocks suggests that hybrids with robust physiological traits can perform well under diverse agroecological conditions. This aligns with existing theories on hybrid vigour, where heterosis results in superior biomass accumulation and reproductive output.

The maturity periods of the varieties significantly influenced their growth patterns and resource allocation. The late-maturing SC719 (120 days) exhibited prolonged vegetative and reproductive growth, resulting in higher biomass and grain yield, whereas the early-maturing Wang-Basig (90 days) and Sanzal-Sima (110 days) reached senescence earlier. The extended leaf area duration in SC719 highlights the role of delayed senescence (stay-green trait) in improving light interception and photosynthetic efficiency, which are crucial for yield formation. Early-maturing varieties like Wang-Basig and Sanzal-Sima may be better adapted to regions with shorter growing seasons or terminal drought stress, where late-maturing varieties may fail to complete their growth cycles. The physiological trade-off observed in Sanzal-Sima, which allocated more resources to biomass than grain yield, reflects differences in carbon partitioning efficiency. This suggests that future breeding efforts could target varieties with optimised biomass-to-grain conversion ratios.

The results suggest that Sanzal-Sima may prioritise vegetative growth over reproductive output, reducing harvest index (HI). This provides a basis for exploring genetic or agronomic interventions to enhance resource allocation toward grain production. Varieties like Wang-Basig, which efficiently partition resources to produce multiple cobs, may benefit from management strategies that further optimise reproductive growth. The absence of significant variety-by-fertiliser interaction effects indicates that the varieties responded similarly to the tested nutrient regimes. However, SC719's consistently higher yields, regardless of fertiliser treatment, suggest superior nutrient uptake and utilisation efficiency. The comparable yields of T2 and T4 for SC719 highlight the potential of micronutrients like Zn to compensate for reduced macronutrient application. This supports emerging research emphasising the role of micronutrients in enhancing nutrient use efficiency and crop productivity. The findings suggest that hybrid varieties like SC719 may be better suited to precision nutrient management systems, where balanced fertilisation strategies can maximise their genetic potential.

Modelling number of cobs as an indication of grain yield

The results from the ANOVA for number of cobs (Ncobs) suggest that both genetic and environmental factors significantly influence cob formation in maize. Based on the results, a linear model was developed to describe the observed variability in Ncobs as a function of fixed effects for block, variety, and fertiliser, along with their interaction. The model is represented as follows:

$$\mathrm{Ncobs}_{ijk} = \mu + B_i + V_j + T_k + (V \times T)_{jk} + \epsilon_{ijk}$$

Where:

M is the overall mean of Ncobs (25.7425.7425.74 from the summary statistics)
Bi is the effect of the ith block, representing environmental variability
Vj is the effect of the jth variety, reflecting genetic differences
Tk is the effect of the kth fertiliser, representing fertiliser regimes
(V×T)jk is the interaction effect between variety and fertiliser
ϵijk is the random error term accounting for unexplained variation, assumed to follow a normal distribution ~N(0, σ2)

Interpretation of the Model Components

i. Overall Mean (μ): The grand mean of the number of cobs (Ncobs) across all factors was estimated as 25.74. This serves as the baseline for interpreting deviations due to specific factors.
ii. Block Effect (Bi): The block effect (p=0.0002) was highly significant, indicating that environmental conditions, such as soil fertility, moisture availability, and microclimate differences, played a substantial role in influencing cob formation. Blocks with higher soil fertility or better water availability likely supported enhanced cob production.
iii. Variety Effect (Vj): The variety effect (p<0.0001) was the most significant factor, reflecting the strong genetic control over cob formation. Wang-Basig produced the highest number of cobs (mean = 29.42), followed by Sanzal-Sima (27.76), with SC719 trailing significantly (20.04). These differences highlight the genetic predisposition of Wang-Basig for enhanced reproductive performance and the potential sensitivity of SC719 to environmental or management limitations.
iv. Fertiliser Effect (Tk): The fertiliser effect (p=0.0354) indicates that fertiliser regimes significantly influenced cob formation. Treatments T2, T3, and T4, which included supplemental nutrients such as magnesium, sulfur, and zinc, supported higher cob production compared to T1, emphasising the role of balanced nutrient management in reproductive success.
v. Variety-Fertiliser Interaction ((V×T)jk): The interaction between variety and treatment was not significant (p=0.2392), suggesting that varietal performance was consistent across all treatments. This stability implies that Wang-Basig and Sanzal-Sima can reliably produce cobs under various nutrient management regimes, whereas SC719 may require specific interventions to achieve comparable results.
vi. Error Term (ϵijk): The residual variability, estimated from the mean square error (MSError=50.9446), represents unexplained variation, likely due to uncontrolled factors such as minor soil heterogeneity or individual plant differences.

The model provides a framework for understanding and predicting cob formation in maize under different genetic and management scenarios. Genetic and agronomic optimisation is vital for improving maize production. The significant variety effect clearly shows that genetics play a key role in cob formation. To maximise cob production, breeding programs should focus on varieties like Wang-Basig, while also enhancing SC719's ability to efficiently use nutrients and adapt to less-than-ideal growing conditions. To optimise maize production, fertiliser management must be tailored to specific site conditions. Balanced fertilisation is critical, and supplementing fertilisers with essential secondary and micronutrients such as magnesium, sulfur, and zinc can significantly enhance cob formation. This targeted approach is especially important in resource-limited systems, where maximising yields and crop health is crucial. Environmental variability plays a significant role in maize production, and accounting for this heterogeneity is crucial in field trials. The impact of environmental differences within a field, known as block-level variability, can be mitigated through practices like soil testing and precision agriculture.

Economic implications of treatment effects

The economic analysis revealed significant differences in profit using benefit-cost ratios (B:C) across maize varieties and fertiliser treatments, underscoring the importance of aligning agronomic practices with economic efficiency to maximise returns. Among the combinations tested, SC719 with T4 generated the highest profit of GH₵ 8,408.07 and the highest B:C ratio of 0.66, establishing it as the most economically efficient combination (Table 4). The superior revenue associated with SC719 reflects its genetic potential for high yield, particularly when paired with advanced fertiliser treatments like T4, which incorporate secondary and micronutrients. These nutrients likely enhanced nutrient-use efficiency and grain filling, contributing to higher marketable yields and revenues. The higher profitability of SC719 across all fertilisers indicates its ability to maximise the return on investment in fertiliser inputs, making it a reliable choice for high-input, profit-driven farming systems. This highlights the synergy between hybrid vigour and nutrient-rich fertilisers in boosting both productivity and economic returns. For Sanzal-Sima, T2 produced the highest profit (GH₵ 6,572.28) and a B:C ratio of 0.50, followed closely by T3 with a profit of GH₵ 5,581.01 and a B:C ratio of 0.48. Wang-Basig showed a similar trend, with T4 yielding the highest profit of GH₵ 5,998.40 and a B:C ratio of 0.49. Both varieties displayed lower overall profitability than SC719, reflecting their moderate yield potential. However, they provided acceptable returns under T2, T3, and T4, emphasising the role of balanced fertiliser management in enhancing economic performance.

These varieties suit resource-constrained farming systems where profitability is important, but input costs must be carefully managed. The analysis consistently identified T1 as the least profitable fertiliser treatment for all varieties, with the lowest revenues and B:C ratios across the board. For SC719, T1 produced a profit of GH₵ 5,381.80 (B:C ratio: 0.42), while for Sanzal-Sima and Wang-Basig, profits were significantly lower at GH₵ 2,881.00 (B:C ratio: 0.24) and GH₵ 2,655.29 (B:C ratio: 0.22), respectively. The consistent profitability of T4 across all varieties demonstrates the value of balanced nutrient management. T4 improved grain yield and economic returns, particularly for SC719. T2 and T3 offered strong economic performance for Sanzal-Sima and Wang-Basig, generating higher profits compared to T1. Although T4 provided the highest returns, its slightly higher production cost necessitates careful evaluation for smallholder farmers. T2 and T3 offer a more cost-effective alternative while maintaining strong economic performance. SC719 is the most economically viable varietal option for farmers aiming to maximise profit, especially when paired with advanced fertiliser treatments like T4. This hybrid variety's ability to generate higher revenues justifies the investment in nutrient-rich fertilisers, making it suitable for commercial farming systems.

Advanced fertiliser formulations that include secondary and micronutrients not only enhance grain yields but also ensure better financial efficiency. While T4 provided the highest returns, T2 and T3 emerged as viable alternatives for farmers with limited resources, particularly when paired with adaptable varieties like Sanzal-Sima and Wang-Basig. These combinations offer a balance between input costs and returns, supporting sustainable intensification in low-input systems. The consistently poor performance of T1 underscores the limitations of blanket NPK fertiliser recommendations. Transitioning to advanced nutrient formulations is critical for achieving higher productivity and profitability in maize farming.

Conclusion

This study highlights the critical interplay between fertiliser management and varietal selection in enhancing maize productivity in the Guinea Savannah agroecological zone. The superior performance of SC719 demonstrates the potential of hybrids for achieving higher yields under optimised nutrient regimes, though their reliance on precise management limits their applicability in low-input systems. Wang-Basig and Sanzal-Sima exhibited greater stability across treatments, offering viable options for resource-constrained farmers. Fertiliser treatments incorporating secondary and micronutrients, such as T3 and T4, proved effective in sustaining grain yield and profitability. The economic advantage of T4, driven by its Zn supplementation, reinforces the role of trace elements in maximising crop returns. The study also underscores the importance of site-specific nutrient management, emphasising soil testing and tailored recommendations to address regional variability in soil fertility and crop response.

The fertiliser treatments tested in the model (particularly T2, T3, and T4) also suggest that the use of secondary and micronutrients can maximise high-input farming systems where the goal is to increase cob formation and, invariably, lead to increased grain yield. For instance, T4, which had more balanced nutrients, resulted in the highest number of cobs, showing its potential for maximising reproductive output in nutrient-rich environments. Rather than relying solely on basic NPK fertilisers, the inclusion of nutrients like Mg, S, and Zn can improve the overall nutrient-use efficiency of maize. This can reduce the environmental impact of fertiliser application by preventing nutrient imbalances and promoting soil health. This information is vital for guiding input-intensive systems, where fertiliser optimisation can directly translate into higher yield potential. The research thus provides an evidence-based framework for optimising fertiliser use in ways that support both high productivity and long-term soil sustainability.

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Testing innovations through multisite trials to bridge the gap between research and real-world farming in Northern Ghana

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