



EFFECT OF PLANT SPACING ON THE GROWTH AND YIELD OF MAIZE (*ZEA MAYS*, L.) IN MAKENI, BOMBALI DISTRICT, SIERRA LEONE

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Abstract: Maize (*Zea mays* L.) is a critical food and cash crop in Sierra Leone, yet national yields remain far below potential, partly due to reliance on non-standardized plant spacing practices among smallholder farmers. This study evaluated the effect of four plant spacing arrangements, viz: T1 (75 cm × 25 cm), T2 (60 cm × 30 cm), T3 (50 cm × 25 cm), and T4 (35 cm × 35 cm, control) to explore on the vegetative growth, yield components, and grain yield of maize at the Faculty of Agriculture Experimental Farm, Ernest Bai Koroma University of Science and Technology, Makeni, Bombali District, Sierra Leone. A Randomized Complete Block Design (RCBD) with four replications was used, and treatment means were compared using the Least Significant Difference (LSD) test at the 5% probability level.

Results showed that plant height and Leaf Area Index (LAI) were significantly higher under narrower spacing (T3 and T4), with the control producing the tallest plants (158.8 cm) and highest mean LAI (5.10), while whole plant weight showed no consistent density-dependent pattern. Individual ear-level traits – ear length, kernel row number, ear wet weight, and 1000-grain mass – were consistently superior under wider spacing (T1 and T2), reflecting reduced inter-plant competition. However, grain yield followed the opposite trend: the denser treatments (T3 and T4) significantly outyielded the wider-spaced treatments by 42–45%, achieving 5,420–5,440 kg/ha compared with 3,750–3,830 kg/ha, demonstrating that greater plant population per unit area compensated for smaller individual ears.

The study concludes that total plant population, rather than row-to-intra-row geometry, was the primary determinant of both canopy development and final grain yield. Closer, equidistant spacing (50 cm × 25 cm or 35 cm × 35 cm) is recommended for maximizing grain yield per hectare, while wider spacing remains preferable where individual ear size and grain quality are prioritized, such as for fresh-market or premium-grain production.

Keywords: Maize, plant spacing, row spacing, plant density, leaf area index, grain yield, Sierra Leone.

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1.0 INTRODUCTION

1.1 Background of the Study

Maize (*Zea mays L.*), commonly known as corn, is one of the world's most important cereal crops. It ranks third after wheat and rice in terms of global production and is widely cultivated across tropical and subtropical regions due to its adaptability to a variety of environmental conditions. In Africa, maize is a staple food and a major source of calories for millions of people, including Sierra Leone, where its importance is growing both as a food and cash crop.

In Sierra Leone, particularly in the North-East region encompassing districts such as Bombali, Koinadugu, Falaba, and Tonkolili, maize has become increasingly popular among smallholder farmers. This shift is due to the crop's relatively short growing cycle, multiple uses (grain, fodder, silage), and market demand. However, despite favorable climatic conditions and available arable land, maize yields in this region remain far below their potential. In Sierra Leone, maize is the most important cereal crop produced after rice across the five agro-climatic zones (Savannah woodland, rainforest, transitional forest savannah, coastal plain and hills/mountains). The average annual grain production of maize in Sierra Leone is 79 metric tonnes with a growth rate of 19.3% (IMF, 2011), with modest national yields of 1.8 tons per hectare (FAO & IBRD, 2026), compared to the potential yields of 5 - 7 tons per hectare

Among the various agronomic factors influencing maize productivity, row spacing – the distance between rows of plants in the field – plays a critical role. Row spacing directly affects plant population density, resource competition, canopy development, light interception, and overall crop performance. Optimal row spacing can enhance the efficiency of resource use (e.g., sunlight, water, nutrients), reduce competition among plants, and contribute to higher grain yields (Ameyu & Tesfaye, 2020).

In many parts of Sierra Leone, farmers continue to use traditional or inconsistent spacing methods that are often based on indigenous knowledge rather than scientific research. These practices may lead to overcrowding or underutilization of field space, resulting in suboptimal plant growth and lower yields. Despite the recognition of row spacing as a key agronomic factor, there is limited region-specific research to guide farmers in choosing the most effective spacing for maize under local conditions. Most existing recommendations are generalized and may not consider local variables such as soil fertility, rainfall patterns, and maize variety.

The North-East region of Sierra Leone presents a unique agro-ecological environment with varied elevation, soil types, and rainfall distribution. These conditions can significantly influence the response of maize to different

row spacing. Yet, there is a lack of empirical data evaluating how different spacing regimes affect the growth and yield of maize specifically in this region. As a result, farmers are often left to adopt "one-size-fits-all" practices that may not optimize productivity in their specific local contexts.

Given the current challenges in increasing maize yields and the central role of maize in food security and rural livelihoods, it is important to investigate cost-effective and practical agronomic interventions. One such intervention is optimizing plant spacing through controlled field experiments. This study seeks to evaluate the effect of different row spacings on maize growth and yield in the Bombali District, North-Eastern region of Sierra Leone, with the aim of generating evidence-based recommendations for smallholder farmers.

The outcome of this research could contribute to improved maize production strategies, better land-use efficiency, and enhanced food security in the region. It also aligns with broader national goals of increasing agricultural productivity through climate-smart and resource-efficient practices (GoSL, 2021).

1.2 Statement of the Problem

Yield gap in Maize production, despite its growing significance, in Sierra Leone has been expressed (FAO, 2026). A key factor contributing to this is the widespread use of non-standard or traditional agronomic practices, particularly in relation to plant spacing. Many smallholder farmers in Sierra Leone lack access to scientifically validated information on the optimal row spacing for maize. Consequently, row spacing decisions are often made arbitrarily or based on inherited practices that do not necessarily align with the agro-ecological realities of the region. These practices can result in excessively dense plant populations – leading to competition for light, water, and nutrients – or overly wide spacing, which leads to inefficient land use and lower total yields (Amanullah *et al.*, 2010).

While research in other countries and regions has demonstrated the significance of row spacing in maximizing maize growth and yield, such findings are not always directly transferable due to variations in soil type, rainfall, altitude, and farming systems. The agro-climatic conditions of the North-East region of Sierra Leone, which include both upland and lowland ecologies, require localized research to determine the most appropriate spacing recommendations for optimal maize production. However, there is currently a lack of empirical data or field-based studies evaluating how different row spacings affect maize performance in this region.

This absence of localized agronomic guidance presents a challenge for farmers, extension officers, and policymakers. Without reliable data, farmers continue to rely on trial-and-

error methods, which are not only inefficient but also pose a risk to food security and income stability. Extension services, tasked with advising farmers on best practices, are similarly constrained by the lack of region-specific research findings. As a result, potential productivity gains through low-cost interventions like optimized spacing remain unrealized.

Therefore, the problem this study seeks to address is the lack of scientific data on the effect of different row spacing on the growth and yield of maize in the North-East of Sierra Leone. By conducting a controlled field experiment, this study aims to fill this critical knowledge gap and provide practical, evidence-based recommendations that can help farmers improve productivity, enhance food security, and contribute to sustainable agricultural development in the region.

1.3 Aim and Objectives of the Study

This research is set to evaluate the effect of different row spacing on the growth and yield of maize (*Zea mays L.*) under the agro-ecological conditions of the North-East region of Sierra Leone. It aims to generate empirical evidence that can inform best agronomic practices for local farmers, extension workers, researchers, and policymakers. By focusing on a low-cost, but high-impact factor – row spacing – this study seeks to identify effective spacing strategies that maximize plant health and grain yield without requiring additional financial inputs or access to expensive technologies. Therefore, the objectives of this research include:

1. To assess the effect of different row spacing treatments on the vegetative growth characteristics of maize;
2. To determine the effect of different row spacing treatments on the yield components of maize; and
3. To determine the effect of different row spacing treatments on the yield of maize

1.4 Justification/Rationale of the Study

Sierra Leone's agricultural sector is a cornerstone of the economy, employing over 65% of the labor force and contributing approximately 60% to GDP (SLCCG, 2026). Dominated by smallholder farmers practicing subsistence agriculture, the sector produces staple crops of which maize second to rice in cereal production. In the North-East region of the country, maize (*Zea mays L.*) is increasingly being recognized as a vital crop due to its role in food security, income generation, and its versatility in human consumption, animal feed, and agro-processing. Despite this growing importance, maize productivity in this region remains significantly below its potential. While improved seed varieties and inputs can help close the yield gap, many of these solutions require financial investment beyond the

reach of most smallholder farmers. This reality highlights the need for low-cost, practical agronomic interventions – such as optimizing row spacing – to enhance maize production.

Row spacing is a crucial component of crop management that influences plant population density, canopy development, nutrient uptake, and ultimately crop yield (Amanullah *et al.*, 2010). Research from other regions has demonstrated that modifying row spacing can significantly improve maize performance by enhancing photosynthetic efficiency, minimizing inter-plant competition, and improving soil moisture utilization. However, these findings are not necessarily transferrable to the North-East of Sierra Leone, which features a distinct set of agro-ecological conditions including variations in rainfall, soil fertility, topography, and farming systems. Currently, most farmers in the North-East of Sierra Leone use non-standardized or traditional row spacing practices based on inherited knowledge rather than scientific guidelines. These practices are often inconsistent with optimal plant population densities, leading either to overcrowding (which increases competition and reduces yield per plant) or underutilization of available land (which decreases total yield per hectare). Yet, it is rare to find empirical studies conducted in this region to evaluate how specific row spacings affect maize growth and productivity under local conditions. As a result, both farmers and agricultural extension agents lack the scientific evidence needed to make informed decisions about spacing practices.

This study is therefore justified on several grounds, including, but not limited to the following:

Agronomic Justification: Identifying the optimal row spacing for maize under local conditions can help maximize the crop's biological potential without requiring significant additional inputs. This can lead to better use of available land and resources, which is especially important in areas with high population pressure or land degradation.

Economic Justification: Row spacing is a zero-cost or low-cost agronomic practice that farmers can implement without purchasing additional materials. Optimizing this practice can lead to improved yields and higher incomes, thereby contributing to poverty reduction among rural farming communities.

Scientific Justification: There is a clear gap in local research on the relationship between row spacing and maize performance in this part of the country. Conducting this study will contribute to the body of knowledge on site-specific crop management and support the development of evidence-based extension recommendations.

Policy and Development Justification: This research aligns with the Government of Sierra Leone's agricultural

transformation goals, which prioritize sustainable intensification and climate-smart agricultural practices (GoSL, 2021). The study can inform local extension strategies and contribute to regional and national efforts to improve food security and rural livelihoods.

Capacity Building and Knowledge Transfer: By generating practical and locally relevant agronomic data, the study will strengthen the capacity of local farmers, agricultural extension officers, and institutions to implement improved practices that are tailored to their specific environments.

1.5 Significance of the Study

The significance of this study lies in its potential to address a critical yield-limiting factor – suboptimal row spacing – in maize cultivation within the North-East region of Sierra Leone. This study will generate scientific, practical, and locally relevant knowledge on the effect of different row spacings on the growth and yield of maize. The outcomes will have wide-ranging implications for multiple stakeholders, including farmers, agricultural extension workers, researchers, development partners, and policymakers. Below are the key areas in which this study is significant:

Contribution to Improved Agricultural Productivity: By identifying the most suitable row spacing for maize in the North-East region, the study can help farmers achieve higher yields without incurring significant additional input costs. Optimized row spacing improves plant population density, resource use efficiency (light, nutrients, water), and overall crop performance. In a low-input, resource-constrained farming system, this represents a simple but highly effective means of increasing output per unit area.

Relevance to Smallholder Farmers: Most maize farmers in the study region operate on a small scale with limited access to modern agricultural technologies. Unlike high-cost interventions such as improved hybrid seeds or chemical fertilizers, adjusting row spacing is a low-cost, farmer-accessible practice that can be implemented immediately. The study's recommendations will therefore be both actionable and accessible, especially for low-income farming households seeking to improve food security and livelihoods.

Support for Agricultural Extension Services: One of the major challenges in agricultural development in Sierra Leone is the weak linkage between research and extension. This study addresses this gap by producing locally generated data that extension officers can use to promote evidence-based best practices. Training and advisory materials developed from the study can strengthen extension services and improve farmer adoption rates of recommended practices.

Alignment with National Agricultural Priorities: The study directly supports the Government of Sierra Leone's agricultural development goals outlined in the National Agricultural Transformation (NAT) Programme 2023–2030, which emphasizes sustainable intensification, increased productivity, and resilience in food production systems. By promoting efficient land use and increased yields, the findings of this study contribute to national efforts to reduce hunger, improve rural livelihoods, and promote economic growth through agriculture (MAF, 2019).

Academic and Research Advancement: From an academic perspective, the study adds to the limited body of research on maize agronomy in Sierra Leone, particularly in the North-East region. The findings can serve as a reference point for future studies, and may stimulate further research into other agronomic practices such as fertilizer application rates, intercropping systems, or the impact of climate variability on maize production.

Potential for Regional Scaling: Although the study is localized, its findings may have relevance for neighboring regions with similar agro-ecological characteristics. The insights gained can serve as a pilot model for wider scaling and adaptation across Sierra Leone and potentially in other parts of West Africa facing similar agronomic challenges.

1.6 Scope and Limitations of the Study

1.6.1 Scope of the Study

Geographical Scope: This study was conducted in the upland ecology of the experimental farm site of the Ernest Bai Koroma University of Science and Technology, Makeni Campus, North East Region of Sierra Leone, (Lat. 8.53N, Lon. 12.02W and 100m above sea level). The area lies within the maize belt of Sierra Leone – areas of high dependence on maize farming, having both upland and lowland maize production systems. The results are therefore most directly applicable to the described local agro-ecological conditions.

Crop Focus: The study focuses exclusively on maize (*Zea mays L.*), which is increasingly cultivated in the region for food, fodder, and income. Other cereal crops such as rice, sorghum, or millet are excluded from this research.

Agronomic Focus: The primary variable under investigation is plant spacing, given as the distance between rows of maize plants and the specified distance (center-to-center) between one plant and the next along the same row. The study evaluates a range of plant spacing treatments (75cm x 25cm, 60cm x 30cm, 50cm x 25cm, and 35cm x 35cm) to determine their impact on maize growth and yield.

Growth and Yield Parameters: The study focuses on key growth parameters (such as plant height and leaf area index, LAI) and yield components (including fresh cob weight, cob

length, number of rows per cob, and 1000-grain weight). Grain yield at optimum drying (kilograms per hectare) is the main indicator of performance.

Experimental Scope: The study is based on field trials using a randomized complete block design (RCBD), conducted within the early rain-fed cropping season. All other agronomic practices – such as land preparation, fertilizer application, and weeding – are standardized across treatments to isolate the effect of row spacing.

1.6.2 Limitations of the Study

Temporal Limitation: The study was conducted over a single growing season, which may not fully account for seasonal variations in rainfall, temperature, or pest pressure. Results may differ under varying climatic conditions or in subsequent years.

Environmental Variability: Although efforts were made to select representative sites, variability in soil fertility, drainage, and topography across the experimental plots may have introduced uncontrolled variation that could affect plant growth and yield performance.

Resource Constraints: The study was limited by available resources, including funding, labor, and access to advanced laboratory facilities. As a result, some physiological parameters such as chlorophyll content, root biomass, or water use efficiency were not measured.

Generalizability: Because the research is geographically limited to a specific region (North-East Sierra Leone), the findings may not be directly applicable to other regions with different agro-ecological or socio-economic conditions without further validation.

Uncontrolled Biotic Factors: While pest and disease control measures were implemented, some biotic factors (e.g., bird damage, rodent activity, or minor pest infestations) may have variably affected yield outcomes across treatments.

Farmer Participation and Adoption Factors: The study was conducted under controlled experimental conditions, which may differ from real-world farmer-managed fields. As such, the level of adoption of the recommended spacing by local farmers could be influenced by additional socio-economic factors (e.g., labor availability, cultural practices, or land tenure systems) that were not assessed in this research.

2.0 MATERIALS AND METHODS

2.1 Description of the Study Area

The field experiment was conducted at the Faculty of Agriculture Experimental Farm, located at the Makeni Campus of the Ernest Bai Koroma University of Science and Technology (EBKUST) in the Northern Province of Sierra Leone. This site was strategically chosen for its representative agro-ecological conditions, institutional

support, and relevance to the broader North-East maize production zone.

Geographical Location of the Study Area: The research was conducted at experimental farm within the Faculty of Agriculture enclave of EBKUST Makeni Campus situated in Makeni City, which is the administrative capital of Bombali District, in the Northern Province of Sierra Leone. The city lies approximately 160 km northeast of Freetown, positioned at latitude 8.8833° N and longitude -12.0500° W, with an average elevation of 157 meters above sea level. Bombali District is one of the key administrative divisions in the Northeastern Province and plays a significant role in Sierra Leone's agricultural landscape. The district is predominantly rural, with agriculture serving as the main livelihood for the majority of the population. Makeni, the capital city of Bombali District, is also the largest city in Northern Sierra Leone. It functions as a commercial, educational, and agricultural hub. Its strategic location along major road networks enhance its accessibility for research and agricultural extension.

Climate and Weather Conditions of the Study Area:

This region is characterized by a tropical monsoon climate, typical of West African savanna agro-ecological zones with basically two seasons. The rainy season begins in May and ends around early November, peaking between July and September. The area receives an average annual rainfall ranging from 1,800 mm to 2,500 mm. The frequency and distribution of rainfall during this period are critical for rain-fed maize cultivation, especially during the vegetative and reproductive stages. The dry season extends from November to April, with minimal rainfall. During this period, Harmattan winds from the Sahara lead to cooler and drier air masses. Arable upland rain-fed farming ceases during this time and vegetable and maize growers cultivate the lowlands – mostly inland valley swamps. The experiment was timed to align with the onset of the rainy season to take advantage of consistent moisture availability, which is essential for maize establishment and optimal growth.

The average annual temperature in Makeni ranges between 24°C and 30°C, with minor variations throughout the year: Maximum temperatures often reach 32–35°C during the peak of the dry season (March–April). Minimum temperatures typically fall to around 20–22°C during the cooler months of December and January. These warm temperatures provide a favorable environment for maize, a C4 plant that thrives under high light intensity and warm weather, enhancing photosynthetic efficiency and biomass accumulation. Relative humidity in Makeni is generally high during the rainy season, ranging from 75% to 95%, and drops significantly in the dry season (as low as 40 - 50%). High humidity during the growing season helps reduce evapotranspiration losses, particularly during the seedling

and tasseling stages of maize. Makeni receives an average of 5–7 hours of sunshine per day, depending on the season. Sunlight availability is critical for maize, as it influences photosynthesis and energy capture, which in turn affects dry matter accumulation and yield. During the dry season, the Harmattan winds – dry and dust-laden – blow from the northeast. However, during the experiment period (rainy season), wind speeds are generally moderate and pose no significant risk to crop lodging.

The prevailing weather condition during the period of the experiment (June to August, 2025) is given below:

- Overall Average Temperature: 27°C (81°F)
- Total Average Rainfall: 1,265 mm (49.8 inches) over the four months.
- Average Daylight: Approximately 12.5 hours of daylight per day.
- Average Sunshine: Roughly 4 to 5 hours of direct sunshine per day (due to heavy cloud cover).

The combination of reliable rainfall, warm temperatures, and high humidity during the maize growing season provided suitable climatic conditions for this field study. These conditions allowed for:

- Uniform crop emergence and stand establishment
- Optimal vegetative growth and tasseling
- Effective evaluation of the impact of different row spacing treatments under realistic rain-fed conditions

All meteorological data during the experimental period (e.g., rainfall, temperature, humidity) were collected from the SLARI meteorological station in Makeni ensuring accuracy in analyzing how weather may have influenced plant performance across the spacing treatments.

Soil Type and Topography of the Study Area:

The experimental site at the Faculty of Agriculture Experimental Farm, EBKUST Makeni Campus, is characterized primarily by tropical ferruginous soils, commonly found across the Northern Region of Sierra Leone. These soils belong to the broader class of Ultisols and Alfisols, which are typical in savanna agro-ecological zones with pronounced wet and dry seasons.

- The soil is predominantly loamy to sandy loam in texture, providing a good balance between drainage and water retention capabilities, essential for maize cultivation.
- The color of the soil is generally reddish-brown, indicative of iron oxide presence, which is common in well-drained, weathered tropical soils.

- Organic matter content was found to be moderate, reflecting typical savanna soil conditions, with potential to be improved through appropriate agronomic management such as crop residue incorporation and fertilizer application.
- Nutrient status indicated moderate nitrogen and phosphorus levels, while potassium was found to be sufficient for maize growth; however, supplemental fertilization was recommended to optimize plant nutrition during the experiment.

The soil's physical and chemical properties provide an adequate environment for maize root development and nutrient uptake but also highlight the need for tailored agronomic practices to enhance productivity.

Topography:

The topography of the EBKUST experimental farm is characterized by:

- Gently undulating terrain, with slopes generally less than 5%, which facilitates good surface drainage and minimizes waterlogging.
- The site does not exhibit significant elevation changes, allowing for uniform application of treatments and minimal variation in microclimatic conditions across plots.
- The gentle slope ensures that soil erosion risk is low during the rainy season, although some minor measures such as contour planting was employed to conserve soil moisture and nutrients.

The flat to gently sloping nature of the terrain supports mechanized or manual farming activities and enables effective plot management for experimental consistency.

Agro-Ecological Significance:

The experimental farm lies within the upland – inland valley ecosystem, typical of maize-growing zones in the North-East region of Sierra Leone. This agro-ecological zone is characterized by:

- Moderate soil fertility with potential for improvement through proper agronomic practices.
- Adequate rainfall distribution for a single cropping season.
- High potential for maize productivity if appropriate planting densities and spacing are applied.

The conditions at the site closely mirror those in surrounding rural farming communities, making the results of this study applicable to broader maize production systems in the Northern and North-Eastern regions of the country.

Justification for Site Selection:

The choice of the EBKUST Makeni Campus experimental farm as the study area was based on the following:

- *Ecological Relevance* – The farm's environment mirrors the maize-growing conditions of the North-East region.
- *Controlled Conditions* – Being a managed academic facility, the farm allows for consistent monitoring and reduced external disturbances.
- *Institutional Accessibility* – Proximity to faculty offices, and human resources facilitated data collection and technical support.
- *Replication Potential* – The site serves as a demonstration platform for scalable practices, ensuring that the results can be communicated to local farmers through extension services and outreach.

2.2 Experimental Design

A Randomized Complete Block Design (RCBD) was employed to minimize the effects of environmental variability within the experimental field.

Experimental Layout:

Randomization – Within each block, the treatments (different plant spacings) were randomly assigned to the plots, ensuring that the effect of uncontrolled variables is evenly distributed and that the treatment comparisons remain unbiased. Randomization of treatments within blocks was carried out using random numbers to avoid systematic bias.

Replication – The experiment included four replications (blocks), which provided an adequate sample size for statistical analysis and increased the reliability and reproducibility of results. Data from all four replications were pooled for statistical analysis, allowing for the assessment of treatment effects with consideration of within-block variability.

Structure of the RCBD:

Blocks – The experimental field was divided into four (4) homogeneous blocks (replications) to provide adequate replication and allow for statistical analysis. Each block was treated as a replicate containing all four row spacing treatments. Treatments were randomized within each block to ensure unbiased distribution.

Plot Size – Each experimental plot measured 5 meters in length and 2.5 meters in width, providing sufficient area for sampling and minimizing border effects.

Spacing Between Blocks – A buffer zone of 1.0 meter was maintained between blocks to avoid cross-treatment interference.

Spacing Between Plots – Within blocks, plots were separated by 1.0 meters to reduce competition and edge effects.

Treatments:

Different row spacing treatments constituted the main factor under investigation. Each treatment was randomly assigned within each block. The treatments consisted of four distinct spacings, of which some were standard, while some mimic farmers practice. All treatments varied in row and intra-row spacing. The treatments were as follows: T1 = 75 cm x 25 cm; T2 = 60 cm x 30 cm; T3 = 50 cm x 25 cm; T4 = 35 cm x 35 cm

Rationale for Treatment Selection:

- T1 (75 cm x 25 cm) reflects the wider spacings normally recommended for seed production; allowing more space for each plant to access nutrients, water, and sunlight but resulting in fewer plants per unit area.
- T2 (60 cm x 30 cm) and T3 (50 cm x 25 cm) represent medium or optimum spacings often recommended for grain production; intermediate levels that might optimize resource use efficiency, balancing competition and plant density.
- T4 (35 cm x 35 cm) represents narrower row spacing commonly practiced by smallholder farmers seeking to maximize plant population and potentially yield.

Expected Effects of Treatments:

- Narrower plant spacing is hypothesized to increase plant density, which could potentially enhance total yield per hectare if individual plants maintain adequate growth.
- Wider plant spacing is expected to reduce intra-specific competition for nutrients, water, and light, possibly improving individual plant vigor but potentially reducing overall yield due to lower plant populations.

Implementation of Treatments:

- Plots were marked out according to the assigned plant spacing treatments.
- Maize seeds were manually sown in rows spaced according to the treatment specification, ensuring uniform seed placement and depth.
- Other cultural practices (fertilization, weeding, pest control) were uniformly applied to all plots to ensure that row spacing was the primary variable influencing outcomes.

Justification of Treatment Selection:

Plant spacing was selected as the independent variable because it directly influences plant density, competition for resources (light, nutrients, water), and ultimately, crop growth and yield. The variability of the treatments reflects common farming practices in Sierra Leone and nearby regions, allowing for practical recommendations to farmers based on study outcomes.

2.3 Land Preparation and Cultural Practices

Standardized land preparation and cultural practices were employed across all experimental plots to ensure uniformity and to isolate the effect of row spacing on maize growth and yield.

Land Preparation: Prior to planting, the experimental plots were cleared of vegetation and debris, then tilled using manual hoes and shovels to create a uniform seedbed. Soil samples were collected from multiple points within the experimental area for laboratory analysis of texture, pH, organic matter, and nutrient content. The fertilizer application rates and other agronomic inputs were tailored to optimize maize growth under the different row spacing treatments. Essentially land preparation proceeded with:

Surface clearing – The experimental field at EBKUST's Faculty of Agriculture Experimental Farm was first cleared of all vegetation, crop residues, and debris to prepare a clean seedbed.

Tillage – The land was plowed manually using hand hoes, which is the predominant practice in the region. The soil was then harrowed and leveled to break up clods, improve aeration, and provide a fine tilth suitable for maize seedbed establishment.

Plot demarcation – The field was subdivided into plots according to the experimental design (RCBD). Plot boundaries were clearly marked using stakes and string lines to ensure accurate spacing and minimize border effects.

Soil preparation consistency – Efforts were made to ensure uniform tillage depth and soil texture across plots, thereby reducing variability that could affect germination and root development.

Planting: Seed Variety – A high-yielding maize variety (PVASYN9), commonly cultivated in Sierra Leone, was used for the experiment to ensure suitability to the agro-ecological conditions of the North-East region.

Seed Quality – Certified seeds with high germination rates (90%) and free from seed-borne diseases were sourced from Sierra Leone Agricultural Research Institute (SLARI) to ensure uniform plant stand.

Sowing Time – Planting was done in Mid-June when the soil was adequately moist, and it was the last week for early rain

season planting, which has the advantage of higher soil temperatures. *Sowing Method* – Seeds were planted manually in furrows according to the specified row and intra-row spacing treatments. Care was taken to plant seeds at a depth of approximately 2 – 3 cm to ensure optimal soil contact and moisture retention. Seeds were placed synchronous with fertilizer (basal application) per hole.

Seed Rate – The number of seeds sown per plot varied according to the plant spacings. To achieve complete stands, 2 seeds were planted per hole and thinned to 1 at 12 days after planting.

Fertilizer Application: Type and Rate – A balanced fertilizer regime was applied uniformly across all plots to supply essential nutrients. The fertilizer used was NPK 15:15:15, applied at a rate of 100 kg/ha, based on soil fertility recommendations for maize in Sierra Leone (Conteh & Kamara, 2020).

Application Timing – Fertilizer, basal only, was applied synchronous with seed placement per hole. *Application Method* – Fertilizer was mixed with soil to avoid direct contact with seeds, and to maximize nutrient uptake and minimize losses.

Weed and Pest Management: Weeding – Manual weeding was carried out at 4, 6 and 8 weeks after planting to reduce competition from weeds. Consistent weed control was necessary to prevent confounding effects on maize growth due to resource competition.

Pest and Disease Control – Regular monitoring for common maize pests and diseases was conducted. At 6 weeks after planting the plots were sprayed with Emacot 019EC (emamectin benzoate) at the recommended rate to control army worm attack which was mild at the moment.

Irrigation: The experimental farm relied primarily on rainfall, and no supplementary watering was provided since there was enough moisture to prevent moisture stress, particularly during the critical tasseling and grain-filling stages.

Thinning: Thinning was carefully carried out by hand two weeks after emergence to remove weak or excess seedlings, ensuring uniform plant populations in accordance with the designed spacing treatments.

Crop Monitoring: Regular observation for lodged, malformed or damaged plants, and soil surface defects were conducted throughout the growing season to evaluate treatment effects on crop development. Lodged plants were promptly raised or supported, while channeling of soil surface was routinely corrected by plot border soil raising.

2.4 Data Collection

Data were collected on key growth parameters and yield components at various growth stages, using standardized procedures to ensure consistency and reliability.

Growth Parameters: The following growth parameters were measured periodically throughout the maize growing season:

Plant Height (cm) – This was measured from the soil surface to the tip of the innermost protruding leaf on 10 randomly selected plants per plot at 6, and 8 weeks after planting and at harvest – 85 days after planting (DAP). This parameter indicates vegetative growth vigor and canopy development.

Leaf Area and Leaf Area Index (LAI) – The leaf area of all noticeable leaves from plants within representative 1 meter area of each plot were measured with tape and ruler, and leaf area index (LAI) was calculated using the standard formula applied each case for fully expanded leaves and the non-fully expanded at 6 and 8 weeks after planting and at harvest – 85 days after planting (DAP) to determine LAI.

Yield and Yield Components:

At physiological maturity, maize plants from a net harvest area (excluding border rows to avoid edge effects) within each plot were harvested for yield evaluation. The following parameters were recorded:

Ear Length (cm) – This was the length of the ear from base to the tip.

Number of Rows per Cob – This was the number of rows of grains on the cobs of the selected plants.

Cob Wet Weight (g) – This was the weight of fresh cobs weighed using a spring balance, a necessary market measure predominant in the study area.

One Thousand (1,000) Grain mass (g) – This was the weight of 1,000 randomly selected kernels from each plot measured using an electronic balance.

Grain Yield (kg/ha) – Grain from the net plot was harvested, dried to a moisture content of approximately 14%, and weighed using a precision balance. Grain yield was then extrapolated to kilograms per hectare.

Plant Fresh Weight (kg/ha) – Ten (10) plants were randomly selected from each plot at harvest and their total above-ground biomass weighed on a spring balance to assess total plant productivity.

2.5 Data Analysis

All data collected were recorded in Excel sheets, from which means and mean of means were calculated. All variables were tested at four (4) levels of maize plant spacing. All treatment means that resulted from this field experiment were subjected to Analysis of variance and were statistically evaluated at the 5% level of probability based on the Least Significant Difference (LSD) test.

4.0 RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter contains analyzed information obtained from periodic and final harvest data collected on plant maize during the period of experimentation. Growth characteristics assessed include plant height, Leaf Area Index (LAI), whole plant weight at harvest. Data was also collected on quantitative productivity variables, including ear length, kernel rows per ear, ear wet weight and 1,000 grain mass of maize. All variables were tested at four (4) levels of maize plant spacing. All treatment means that resulted from this field experiment were statistically evaluated at the 5% level of probability based on the Least Significant Difference (LSD) test.

4.2 Effect of Plant Spacing on Vegetative Growth of Maize

4.2.1 Effect of Row Spacing on Plant Height of Maize

This report presents and discusses trends in plant height of maize at 6, 8, and 12 weeks after planting (WAP) – at harvest, as influenced by row spacing treatments.

Table 1: Plant Height (cm) of Maize as Influenced by Row Spacing

Treatment (Row Spacing)	6 WAP	8 WAP	12 WAP	Mean
T1 (75 cm x 25 cm)	79.9a	149.5c	188.3b	139.2c
T2 (60 cm x 30 cm)	84.3a	164.5b	199.7ab	149.5b
T3 (50 cm x 25 cm)	84.1a	173.9a	192.70bc	150.2b
T4 (35 cm x 35 cm – control)	91.9a	181.4a	202.95a	158.8a

Note: Means followed by the same letter within a column are not significantly different (LSD, $p \leq 0.05$).

At 6 weeks after planting, plant height did not differ significantly among treatments (all values carry the superscript "a": 79.9-91.9 cm). This indicates that in the early vegetative stage, row spacing/plant density had not yet exerted a measurable effect on stem elongation - young maize plants at this stage have not formed enough canopy to trigger competition for sunlight which promotes stem elongation. At 8 weeks after planting, clear differentiation emerged. The two widest-spaced treatments - 50 cm x 25 cm (173.9a) and 35 cm x 35 cm control (181.4a) - were significantly taller than 60 cm x 30 cm (164.5b) and 75 cm x 25 cm (149.5c), which recorded the shortest plants. This is a somewhat unusual pattern in that it does not follow a simple "narrower spacing = taller plants" trend seen for leaf area index; rather, the control and the 50 x 25 cm treatment produced the tallest plants, while 75 x 25 cm - despite having the widest row spacing - produced the shortest. At 12 WAP (Harvest), the control (202.95a) remained tallest, followed by 60 x 30 cm (199.7ab), 50 x 25 cm (192.70bc), and 75 x 25 cm (188.3b). The differences among treatments narrowed by this stage compared to 8 WAP, though the control retained a statistical edge. Across the season, however, the control (158.8a) was significantly the tallest, followed by 60 x 30 cm and 50 x 25 cm (149.5b, 150.2b - statistically similar to each other), with 75 x 25 cm (139.2c) consistently the shortest.

The result conforms with the assertion in maize agronomy that early growth stage (represented by 6 WAP in this study) is largely density independent. The absence of significant differences at 6 WAP reflects a growth period before competition for light and soil resources becomes intense enough to affect morphological development, since canopy closure and resource competition typically become significant later in the season (Haarhoff and Swanepoel, 2022). In contrast, the mid-to-late season (represented by 8 and 12 WAP in this study) divergence is also confirmed as

portrayed by the emergence of significant height differences within this period. This is consistent with reports that plant height increases significantly with increasing plant density, as denser stands trigger a shade-avoidance response – plants elongate internodes to compete for light within the canopy (Kovacs and Pepo, 2015). This helps explain why the control (35 x 35 cm) produced the tallest plants; more even resource distribution per plant and reduced intra-row competition likely allowed better individual plant vigor and vertical growth.

Considering row geometry versus plant height, it is notable that height did not track leaf area index in the same direction as evident that the treatments with the highest LAI (50 x 25 cm, 35 x 35 cm) were not simply the "most crowded." This supports observations that narrow row spacing can support plant height development in early-to-mid growth stages, but these differences tend to diminish by harvest (Ge *et al.*, 2023), suggesting that early vigor differences driven by spacing geometry are partly compensated for as the season progresses. Further with the agronomic significance of the results herein, the consistently shorter plants under 75 x 25 cm spacing (widest rows) despite intermediate density suggest that wide row spacing with narrow intra-row spacing may not favor vertical growth as effectively as more balanced/equidistant arrangements. This could have implications for lodging resistance (shorter plants often being more lodging-resistant) and for canopy light interception, which in turn affects photosynthesis and yield potential.

4.2.2 Effect of Row Spacing on Leaf Area Index (LAI) of Maize

This report presents and discusses trends in leaf area index (LAI) of maize at 6 weeks after planting (WAP), 8 WAP, and mean LAI, as influenced by row spacing treatments.

Table 2: Leaf Area Index (LAI) of Maize at Specific Growth Stages as influenced by Row Spacing

Treatment (Row Spacing)	LAI at 6 WAP	LAI at 8 WAP	Mean LAI
T1 (75 cm x 25 cm)	2.21b	3.11b	2.66b
T2 (60 cm x 30 cm)	2.75b	3.21b	2.98b
T3 (50 cm x 25 cm)	4.21a	5.33a	4.87a
T4 (35 cm x 35 cm – control)	4.78a	5.42a	5.10a

Note: Means followed by the same letter within a column are not significantly different (LSD, $p \leq 0.05$).

At 6 WAP, the row spacing treatments show significant differences in LAI. The 35 cm x 35 cm – control and 50cm x 25cm treatments recorded the highest LAI (4.78 and 4.21) respectively, and statistically similar to each other. The 60 cm x 30 cm and 75cm x 25cm treatments had lower LAI (2.75 and 2.21) respectively, which were significantly lower but significantly higher than 35 cm x 35cm – control and 50cm x 25cm. At 8 WAP, the LAI values have generally increased across all treatments, indicating continued plant growth and canopy development, and the same trend of superiority of T4 and T3 over T2 and T1 with a significant difference between the two “sets” was quite conspicuous. This observation was reinforced by the mean LAI.

The data show a clear and consistent pattern: narrower row/plant spacing produced significantly higher LAI values than wider spacing at both 6 and 8 weeks after planting (WAP), and in the mean LAI. Statistically, the four treatments separate into two sets, as shown by the letter superscripts: Set "a" (close spacing treatments and higher LAI) – T3 (50 cm x 25 cm) and T4 (35 cm x 35 cm), with mean LAI of 4.87 and 5.10, respectively, nearly double the values of the wide-spacing treatments; Set "b" (wide spacing treatments and lower LAI) – T1 (75 cm x 25 cm) and T2 (60 cm x 30 cm), with mean LAI of 2.66 and 2.98, respectively. Emphasizing the effect of plant density/spacing on canopy development, as spacing narrowed (higher plant population per unit area), LAI increased substantially. This is consistent with established agronomic principles: reduced inter-plant spacing increases the number of plants per unit ground area, which directly raises total leaf area per unit land area, even though it may reduce leaf area per individual plant. This aligns with findings that increasing planting density boosted LAI, light interception, and dry-matter accumulation in maize, though it can reduce chlorophyll content and photosynthetic rate per leaf (Ge *et al.*, 2023). A seeming temporal trend of LAI development is shown considering 6 WAP to 8 WAP, just before tasseling – might not be consistent with the reproduction phase (Week 9 to 12 for the variety herein): All treatments show an increase in LAI between 6 and 8 WAP, reflecting the normal vegetative growth pattern of maize, where leaf expansion continues rapidly until around tasseling. The magnitude of increase was similar in proportional terms across treatments, but the closely spaced treatments (T3, T4) maintained a consistently higher canopy leaf area throughout this period, indicating faster canopy closure.

From the viewpoint of row spacing versus plant density, however, it is worth noting that T3 and T4 achieved similarly high LAI despite different row configurations, suggesting that total plant population (density), rather than row spacing arrangement alone, is the primary driver of LAI in this dataset. This supports work showing that, for a given

planting rate, LAI differs meaningfully among row-spacing arrangements, and that optimizing row spacing can improve light distribution and interception efficiency (Wang *et al.*, 2021). A high LAI is generally desirable up to a threshold, since it improves light interception and photosynthetic capacity of the canopy, but excessively high LAI (as could occur with T4, the narrowest spacing) can also lead to self-shading, increased inter-plant competition for light, water, and nutrients, and greater lodging risk.

The dataset further presents agronomic significance: The consistently higher LAI in T3 and T4 suggests these treatments would likely translate into greater light interception and biomass accumulation, provided that competition effects (for water and nutrients) do not offset the leaf area advantage. Conversely, T1 and T2, despite lower LAI, may allow better light penetration to lower canopy leaves and reduced competition, which could still be advantageous under moisture-limited conditions.

4.2.3 Effect of Row Spacing on Whole Plant Weight of Maize at Harvest

This report presents and discusses whole plant weight of maize at harvest as influenced by row spacing treatments.

Table 3. Whole Plant Weight (kg) of Maize at Harvest as Influenced by Row Spacing

Treatment (Row Spacing)	Whole Plant Weight (kg)
T1 (75 cm x 25 cm)	13.25ab
T2 (60 cm x 30 cm)	13.65a
T3 (50 cm x 25 cm)	12.80b
T4 (35 cm x 35 cm – control)	13.29a

Note: Means followed by the same letter within a column are not significantly different (LSD, $p \leq 0.05$).

Table 3 presents the whole plant weight of maize at harvest under different plant spacings, measured in kilograms (kg). The whole plant weight data at harvest show relatively modest but statistically significant differences among row spacing treatments, ranging from 12.80 kg (50 cm x 25 cm) to 13.65 kg (60 cm x 30 cm). The 60 cm x 30 cm (13.65a) and 35 cm x 35 cm control (13.29a) recorded the highest whole plant weights, while the 50 cm x 25 cm (12.80b) recorded the lowest whole plant weight, and was not significantly different from 75 cm x 25 cm (13.25ab), which was intermediate and not significantly different from either the highest or lowest groups, spanning both statistical groups.

The result show that a weak relationship exists between plant density/geometry and total biomass. Unlike leaf area index and plant height, whole plant weight did not follow a

consistent pattern with row spacing narrowness. Notably, 50 cm x 25 cm, one of the treatments with the highest LAI and among the tallest plants, had the lowest whole plant weight, while 60 cm x 30 cm, a comparatively wider-spaced lower-density arrangement, had the highest. This suggests that individual/whole plant weight is influenced more by resource availability per plant than by total canopy leaf area or height alone. This is consistent with reports that under higher planting density, root size and root biomass per plant decrease even as overall grain yield per unit area improves, because increased plant density inhibits per-plant growth despite compensatory canopy-level gains (Wang *et al.*, 2021). A trade-off between plant density and per-plant biomass is also exhibited. The general agronomic principle is that as planting density increases (i.e., spacing narrows), biomass accumulation per unit land area tends to rise, but biomass accumulation per individual plant tends to fall, due to intensified competition for light, water, and nutrients among neighboring plants. This is supported by findings that increasing plant density affects yield components such as ear length, weight, and diameter, with these parameters decreasing significantly as density increases, even when total dry matter per hectare rises (Cheng *et al.*, 2025). The lower whole plant weight in the 50 x 25 cm treatment may

reflect this individual-plant competition effect, despite this treatment showing strong vegetative growth (LAI and height) earlier in the season.

This study shows a non-linearity of spacing effects. The fact that 75 x 25 cm (intermediate weight, "ab") does not significantly differ from either extreme suggests that whole plant weight is a less spacing-sensitive trait than LAI or height in this trial, or that compensatory growth mechanisms (better light penetration in less dense stands) offset some of the density-related biomass reduction. Furthermore, in agronomic significance, since whole plant weight is often closely tied to total forage/biomass yield (particularly relevant for silage maize), the significantly higher weight under 60 x 30 cm and the control suggests these spacing arrangements may be more favorable for biomass-focused production goals, whereas 50 x 25 cm may favor other traits (e.g., canopy development) at some cost to individual plant biomass accumulation.

4.3. Effect of Plant Spacing on Yield Components and Yield of Maize

This report presents and discusses yield components and yield of maize as influenced by row spacing treatments.

Table 4: Yield Components and Yield of Maize as Influenced by Row Spacing

Treatment (Row Spacing)	Ear Length (cm)	Kernel Row / Ear	Ear Wet Weight (kg)	1000-Grain Mass (g)	Yield (kg/ha)
T1 (75 cm x 25 cm)	12.8ab	13.3ab	0.117a	144.5a	3,750
T2 (60 cm x 30 cm)	13.0a	13.6a	0.115ab	145.8a	3,830
T3 (50 cm x 25 cm)	12.0c	13.2bc	0.113bc	125.8bc	5,420
T4 (35 cm x 35 cm – control)	12.5bc	12.8c	0.111c	124.5c	5,440

Note: Means followed by the same letter within a column are not significantly different (LSD, $p \leq 0.05$).

4.3.1 Effect of Row Spacing on Ear Length of Maize at Harvest

The data show significant differences in ear length among row spacing treatments, ranging from 12.0 cm with the 50 cm x 25 cm treatment to 13.0 cm with the 60 cm x 30 cm treatment. Treatment 60 cm x 30 cm (13.0a) recorded the longest ears and was statistically superior to all others. The 75 cm x 25 cm treatment (12.8ab) was intermediate and not significantly different from the widest-spaced treatment or from the control. Treatment 35 cm x 35 cm - control (12.5bc) was intermediate-low and statistically overlapping with both treatment 75 x 25 cm and 50 x 25 cm. Treatment 50 cm x 25 cm (12.0c) recorded the shortest ears, significantly lower than 60 x 30 cm and 75 x 25 cm.

The result presents that wider spacing is associated with longer ears. The treatment with the widest overall spacing and lowest plant density (60 cm x 30 cm) produced the

longest ears, while 50 cm x 25 cm – a narrower, higher-density arrangement – produced the shortest. This pattern is consistent with numerous reports that ear length decreases with decreased intra-row spacing (increased plant density), with longer ears at lower plant population likely due to greater available space and reduced competition for resources (Alemu *et al.*, 2019). Further, a resource competition mechanism is also portrayed. The reduction in ear length under denser spacing (50 x 25 cm) reflects intensified inter-plant competition. This aligns with findings that plant density and row spacing significantly affect ear length, weight, and diameter, with these parameters decreasing significantly as planting density increases (Cheng *et al.*, 2025), since more closely spaced plants compete more intensely for light, water, and nutrients during the critical ear-development period, limiting the resources available for ear elongation.

Contending with row spacing versus intra-row spacing effects, the control (35 x 35 cm, uniform spacing) did not produce the longest ears despite being the least dense on an equidistant basis – it was statistically similar to both 75 x 25 cm and 50 x 25 cm. This suggests that the specific combination of row and intra-row spacing (rectangularity) matters, not just overall density. The 60 x 30 cm treatment's wider inter-row combined with wider intra-row spacing may have offered a more favorable balance of light interception and reduced competition specifically around the ear-bearing node, supporting observations that ear traits respond to both row configuration and plant density interactively rather than to density alone. Also, since ear length is a component of yield potential (correlating with kernel row length and, indirectly, grain yield per ear), the significantly shorter ears under 50 x 25 cm spacing suggest this treatment – despite earlier showing strong vegetative growth (high LAI, tall plants) – may be less favorable for maximizing individual ear size, even if higher plant population could still compensate at the whole-field yield level through greater ear numbers per unit area. This is a worth noting agronomic significance.

4.3.2 Effect of Row Spacing on Kernel Row Number per Ear of Maize at Harvest

The data show statistically significant, though numerically modest, differences in kernel row number among row spacing treatments, ranging from 12.8 (control) to 13.6 (60 cm x 30 cm). The 60 cm x 30 cm treatment (13.6a) recorded the highest kernel row number and was statistically superior to the control. The 75 cm x 25 cm treatment (13.3ab) was intermediate and not significantly different from either 60 x 30 cm or 50 x 25 cm. Treatment 50 cm x 25 cm (13.2bc) was also intermediate, overlapping statistically with 75 x 25 cm and the control. Further, treatment 35 cm x 35 cm – control (12.8c) recorded the lowest kernel row number, and was significantly lower than treatment 60 x 30 cm.

The study indicates a relatively stable kernel row number, a genetically anchored trait. Unlike ear length or kernel number per row, kernel row number is largely determined early in ear development (around the time of tassel/ear initiation) and is strongly under genetic control, making it generally less responsive to agronomic management than other yield components. This is consistent with reports that row spacing and seeding rate did not influence the number of kernel rows per ear, unlike other yield components such as ear density and kernels per row, which were affected by planting configuration (Noland *et al.*, 2025). The relatively narrow range observed here (12.8-13.6) supports this – the differences, while statistically detectable, are numerically small compared to the wider swings seen for ear length or whole plant weight. Where differences did emerge, the pattern broadly aligns with the general trend that higher planting density can constrain ear development. This is

supported by findings that plant density affects yield components such as kernel number per ear, with these traits significantly decreasing as planting density increases (Cheng *et al.*, 2025). The lower kernel row number in the control (35 x 35 cm) compared to 60 x 30 cm may reflect this competition-driven constraint, even though the effect on this particular trait is smaller than typically seen for ear length or kernel weight.

The impact of row geometry against absolute density was also shown. As with ear length, the treatment with wider inter- and intra-row spacing (60 x 30 cm) again produced the most favorable result, reinforcing the idea that a more balanced (less rectangular) spacing arrangement may support better ear architecture by reducing localized competition around the developing ear, independent of overall plant population. Of much agronomic essence also, because kernel row number contributes directly to total kernel number per ear (kernel rows x kernels per row), even small, statistically significant reductions – such as the control's lower value – can have a cumulative effect on grain yield per ear. This suggests that, while less dramatically affected than other traits, kernel row number should still be considered when selecting optimal spacing for yield optimization.

4.3.3 Effect of Row Spacing on Ear Wet Weight of Maize at Harvest

The data show a consistent, statistically significant decline in ear wet weight as row spacing narrows (i.e., as plant density increases), ranging from 0.111 kg (control, 35 cm x 35 cm) to 0.117 kg (75 cm x 25 cm). Treatment 75 cm x 25 cm (0.117a) recorded the highest ear wet weight, while Treatment 60 cm x 30 cm (0.115ab) was intermediate and not significantly different from either the highest or the next group. The 50 cm x 25 cm (0.113bc) treatment was also intermediate, overlapping statistically with both 60 x 30 cm and the control. The 35 cm x 35 cm control (0.111c) recorded the lowest ear wet weight, significantly lower than the widest-spaced treatment.

The result shows an inverse relationship between plant density and individual ear weight. The trend observed here – widest row spacing (75 x 25 cm) producing the heaviest ears, and the narrowest/densest arrangement (control) producing the lightest – is a classic manifestation of the density-yield component trade-off widely documented in maize. This is consistent with reports that higher plant density leads to a decrease in stalk area, leaf greenness, and cob length, and negatively affects kernel weight and the number of kernels per row (Sangoi *et al.*, 2015), all of which directly reduce individual ear mass even as the number of ears per unit area may increase. An inference to competitive resource allocation also applies. As plant density increases (narrower spacing), individual plants have access to proportionally less light, water, and nutrients, which

constrains dry matter and water accumulation in each ear. This is supported by findings that as density increases, plants may compete more intensely for resources such as light, water, and nutrients, leading to a shift in dry matter allocation toward roots, stems, and leaves at the expense of allocation to the ears (Zhang *et al.*, 2025), which would directly explain the reduced ear wet weight under the closer-spaced treatments in this trial.

This pattern mirrors the trends seen for ear length and kernel row number in this same trial, where wider-spaced, lower-density treatments (75 x 25 cm and 60 x 30 cm) consistently outperformed the higher-density control. Together, these results reinforce that individual ear-level traits (length, weight, kernel rows) tend to respond similarly and inversely to increasing plant density, even when canopy-level traits like LAI show the opposite trend. It is, therefore, worth noting that while the control treatment showed advantages in some vegetative traits (e.g., mean plant height), its ears were consistently the lightest and shortest at harvest. This illustrates the classic yield-component trade-off in maize: higher plant density often boosts vegetative growth and total biomass per unit area, but can reduce the size and weight of individual ears – a critical consideration when the crop is intended for fresh/green ear or cob-market use, where individual ear size and weight are commercially important, rather than only total biomass yield.

4.3.4 Effect of Row Spacing on 1000-Grain Mass of Maize at Optimum Drying

The data reveal a sharp, statistically significant divide in 1000-grain mass between the two wider-spaced treatments and the two narrower/denser treatments, ranging from 124.5 g (control, 35 cm x 35 cm) to 145.8 g (60 cm x 30 cm). Treatment 60 cm x 30 cm (145.8g) and 75 cm x 25 cm (144.5g) – the wider spaced treatments – recorded the highest 1000-grain mass, and were quite significantly different from the other two narrower spaced treatments. The 50 cm x 25 cm (125.8g) treatment was substantially lower, overlapping statistically with the control, while treatment 35 cm x 35 cm control (124.5g) recorded the lowest 1000-grain mass, and was significantly lower than both wider-spaced treatments. Notably, the gap between the two groups (roughly 19-21 g, or about 15-16%) is much larger than differences seen in the earlier traits (ear length, kernel row number), indicating that grain filling/kernel weight is highly sensitive to plant spacing/density in this trial.

A density-driven reduction in kernel weight was observed. The markedly lower 1000-grain mass under the narrower-spaced treatments (50 x 25 cm and the control) is consistent with well-documented density effects on grain filling. This aligns with findings that as planting density increases, both grains per ear and thousand-kernel weight decrease, with

planting density having a measurable impact on thousand-kernel weight across maize varieties (Ci *et al.*, 2018). Denser stands increase competition for assimilates during the grain-filling period, limiting the amount of photosynthate translocated to each developing kernel and resulting in smaller, lighter grains. The physiological basis for this performance can be presented on the grounds of source-sink limitation. The reduction in kernel weight under high density is often linked to reduced individual-plant photosynthetic capacity due to mutual shading, as well as a shift in dry matter partitioning away from grain. This is supported by evidence that a reduction in 1000-kernel weight under high density indicates impaired grain-filling efficiency, with smaller kernel size resulting from increased competition for resources such as light, water, and nutrients under denser planting (Han *et al.*, 2025). Because grain filling occurs late in the season when canopy competition is most intense, kernel weight is often one of the yield components most sensitive to density-induced stress. As with ear length and ear wet weight, the wider row and intra-row spacing treatments (75 x 25 cm, 60 x 30 cm) again outperformed the narrower arrangements, reinforcing a consistent trend across this trial: individual grain/ear-level traits benefit from reduced competition, even though this may come at some cost to total biomass or LAI, which favored the narrower spacings. This suggests row geometry effect beyond density alone.

Obviously, since 1000-grain mass is directly linked to grain yield (yield = ears per unit area x kernels per ear x kernel weight) and to grain quality/marketability, the substantially lower kernel weight under 50 x 25 cm and the control spacing is agronomically important. It suggests these denser arrangements may need to compensate through a higher number of ears or kernels per unit area to achieve competitive total grain yield, while the wider-spaced treatments may offer a quality advantage in terms of larger, heavier, and potentially higher-value grain.

4.3.5 Effect of Row Spacing on Grain Yield of Maize at Optimum Drying

The yield data show a clear, statistically significant split into two groups: the narrower-spaced treatments (50 cm x 25 cm and the control, 35cm x 35 cm) significantly outyielded the wider-spaced treatments (75 cm x 25 cm and 60 cm x 30 cm) by a wide margin – roughly 1,600 - 1,700 kg/ha, or about 42 - 45% higher yield. The control treatment, 35 cm x 35 cm (5,440a), and 50 cm x 25 cm treatment (5,420a) were statistically similar to each other and formed the higher-yielding group. The 60 cm x 30 cm treatment (3,830b) and 75 cm x 25 cm treatment (3,745b) were statistically similar to each other and formed the lower-yielding group, with no significant difference between them despite the LSD test detecting real separation from the higher group.

It can thus be seen that population compensates for smaller individual ear traits. Although treatment 75 x 25 cm and treatment 60 x 30 cm consistently produced the longest ears, heaviest ear wet weight, and heaviest 1000-grain mass in earlier tables, their much lower plant population per hectare could not compensate on an area basis. This is consistent with reports that although increasing planting density reduces yield per individual plant, higher densities produce greater overall grain yield due to an increased number of kernels per unit area (Wang *et al.*, 2025), confirming that land-area yield in maize is generally governed more by population density than by individual plant/ear vigor. Furthermore, a yield component compensation mechanism is evident. This pattern reflects the classic yield-component trade-off in maize, where the crop only moderately compensates for changes in planting density through per-plant ear adjustment. This is supported by evidence that although single-plant yield potential is reduced in terms of ear weight and thousand-kernel weight under high planting density, final grain yield still increases in most production situations due to the compensatory effect of greater plant number per unit area (Sangoi *et al.*, 2015), which directly explains why 50 x 25 cm and the control, despite their inferior ear-level traits, achieved the highest yields in this trial. The results also support row geometry as the dominant causal effect over plant density. The similarity in yield between 50 x 25 cm and the control (despite different row/intra-row configurations) but their shared superiority over 60 x 30 cm and 75 x 25 cm, reinforces that total plant population, rather than the specific row-spacing arrangement, was the primary determinant of final yield in this trial, echoing the pattern already seen for leaf area index.

These results support recommending closer plant spacing (50 x 25 cm or narrower, equidistant arrangements similar to the control) over wider row configurations (75 x 25 cm, 60 x 30 cm) when the primary objective is maximizing grain yield per hectare, even though the wider spacings may offer advantages in individual ear size, kernel weight, and potentially grain quality/marketability for fresh-market or premium-grain purposes.

5.0 Summary, Conclusion and Recommendations

5.1 Summary

This study evaluated the effect of four plant spacing arrangements – T1 (75 cm × 25 cm), T2 (60 cm × 30 cm), T3 (50 cm × 25 cm), and T4 (35 cm × 35 cm, control) – on the vegetative growth, yield components, and grain yield of

maize. Treatment means were compared at the 5% level of probability using the Least Significant Difference (LSD) test.

5.1.1 Effect of plant Spacing on Vegetative Growth of Maize

Plant height showed no significant differences among treatments at 6 weeks after planting (WAP), but clear divergence emerged by 8 and 12 WAP. The control (35 cm × 35 cm) consistently produced the tallest plants (158.8 cm mean), while 75 cm × 25 cm produced the shortest (139.2 cm mean). Leaf Area Index (LAI) separated treatments into two distinct groups: the narrower-spaced 50 cm × 25 cm and 35 cm × 35 cm, control, achieved substantially higher LAI (4.87 and 5.10) than the wider-spaced 75 cm × 25 cm and 60 cm × 30 cm (2.66 and 2.98), driven primarily by plant population density rather than row geometry. Whole plant weight, however, did not track height or LAI – T2 (60 cm × 30 cm) and T4 (35 cm × 35 cm, control) recorded the highest weights (13.65 kg and 13.29 kg, respectively) while T3 (50 cm × 25 cm), despite high LAI and tall plants, recorded the lowest (12.80 kg), indicating that per-plant biomass is more sensitive to individual resource availability than to canopy-level traits.

5.1.2 Effect of plant Spacing on Yield Components of Maize

Ear length, kernel row number, ear wet weight, and 1000-grain mass all followed a consistent inverse relationship with plant density – the wider-spaced T1 (75 cm × 25 cm) and T2 (60 cm × 30 cm) outperformed the denser T3 (50 cm × 25 cm) and T4 (35 cm × 35 cm, control) on every individual ear-level trait. The 1000-grain mass gap was especially pronounced (approximately 124.5–125.8 g in T3/T4 versus 144.5–145.8 g in T1/T2, a 15–16% difference), pointing to strong density sensitivity during grain-filling.

5.1.3 Effect of plant Spacing on Grain Yield of Maize

Despite their inferior individual ear traits, the denser treatments T3 (50 cm × 25 cm) and T4 (35 cm × 35 cm, control) produced markedly higher yields (5,420 and 5,440 kg/ha, respectively) compared with 3,750 and 3,830 kg/ha in T1 (75 cm × 25 cm) and T2 (60 cm × 30 cm), respectively, a 42–45% yield advantage. This confirms that higher plant population per unit area compensated for smaller individual ears, consistent with the classic yield-component trade-off in maize.

Table 5: Summary Table of Key Findings

Parameter	T1 (75cm×25cm)	T2 (60cm×30cm)	T3 (50cm×25cm)	T4 (35cm×35cm, control)
Mean Plant Height (cm)	139.2c	149.5b	150.2b	158.8a
Mean LAI	2.66b	2.98b	4.87a	5.10a
Whole Plant Weight (kg)	13.25ab	13.65a	12.80b	13.29a
Ear Length (cm)	12.8ab	13.0a	12.0c	12.5bc
Kernel Row / Ear	13.3ab	13.6a	13.2bc	12.8c
Ear Wet Weight (kg)	0.117a	0.115ab	0.113bc	0.111c
1000-Grain Mass (g)	144.5a	145.8a	125.8bc	124.5c
Grain Yield (kg/ha)	3,750b	3,830b	5,420a	5,440a

Note: Means followed by the same letter within a row are not significantly different (LSD, $p \leq 0.05$).

5.2 Conclusion

Plant spacing significantly influenced maize growth, development, and yield, but its effects were trait-dependent and often ran in opposite directions. Wider spacing (T1 – 75 cm x 25 cm, T2 – 60 cm x 30 cm) favored individual plant and ear performance – longer ears, heavier ear wet weight, and higher 1000-grain mass – while narrower, denser spacing (T3 – 50cm×25cm and T4 – 35cm×35cm, control) favored canopy-level development (LAI) and, most importantly, final grain yield per hectare.

Total plant population per unit area, rather than the specific row-to-intra-row geometry, was the dominant driver of both LAI and grain yield, since T3 – 50cm×25cm and T4 – 35cm×35cm, control, achieved statistically similar (and superior) outcomes despite differing row configurations. This confirms that, in maize, land-area yield is governed more by population density than by individual plant vigor, and that closer spacing achieves higher total yield primarily through greater ear numbers per unit area rather than through improved per-ear quality.

5.3 Recommendations

- For maximizing grain yield per hectare: Adopt closer, more equidistant plant spacing similar to T3 (50 cm × 25 cm) or T4 (35 cm × 35 cm), as these consistently produced the highest yields (5,420–5,440 kg/ha) despite smaller individual ear size.
- For fresh-market, cob, or premium-grain production where individual ear size, kernel weight, and visual grain quality matter more than total tonnage, wider spacing such as T2 (60 cm × 30 cm) or T1 (75 cm × 25 cm) should be considered, since these produced

longer ears, heavier ear wet weight, and higher 1000-grain mass.

- For silage or forage-focused production, T2 (60 cm × 30 cm) and the control T4 (35cm×35cm) are preferable given their higher whole plant weight at harvest.
- Further trials should examine the interaction between row geometry and plant density more directly (e.g., testing narrow row spacing at equal population densities) to isolate whether rectangularity itself, rather than density alone, is driving the ear-trait differences observed between T2 and T3/T4.
- Given the strong density-sensitivity of 1000-grain mass and ear wet weight, farmers targeting both yield and grain quality may explore intermediate densities or split-plot trials to identify an optimal balance point not directly tested in this study.

References

1. Alemu, D., Tolera, T., & Debelo, T. (2019). Effects of varieties and intra row spacing on yield of maize (*Zea mays* L.) under supplementary irrigation at Guliso, Western Ethiopia. *International Journal of Environmental Sciences & Natural Resources*, 17(1). <https://doi.org/10.19080/IJESNR.2019.17.556024>
2. Amanullah, M., Asif, M., Nawab, K., Shah, Z., Hassan, M., Khan, A. Z., Khalil, S. K., Hussain, Z., Tariq, M., & Rahman, H. (2010). Impact of planting density and P-fertilizer source on the growth analysis of maize. *Pakistan Journal of Botany*, 42(4), 2349–2357.
3. Ameyu, T., & Tesfaye, G. (2020). Effect of intra and inter row spacing on yield, yield components and

- growth parameter of hybrid maize at Mettu. *Journal of Environment and Earth Science*, 10(1).
4. Conteh, A. R., & Kamara, A. (2020). Improving the efficiency of fertilizer utilization in Sierra Leone. *IOSR Journal of Agriculture and Veterinary Science*, 13(6), 45–56. <https://doi.org/10.9790/2380-1306034556>
 5. Food and Agriculture Organization & International Bank for Reconstruction and Development/The World Bank. (2026). *50x2030 data smart agriculture: Survey brief. Focus: Production, methods and environment. Agricultural year 2023/24 Sierra Leone*.
 6. Fuksa, P., Hrevušová, Z., Szabó, O., & Hakl, J. (2023). Effect of row spacing and plant density on silage maize growth, dry matter distribution and yield. *Agronomy*, 13(4), Article 1117. <https://doi.org/10.3390/agronomy13041117>
 7. Gao, J., Lei, M., Yang, L., Wang, P., Tao, H., & Huang, S. (2021). Reduced row spacing improved yield by optimizing root distribution in maize. *European Journal of Agronomy*, 131, Article 126327. <https://doi.org/10.1016/j.eja.2021.126327>
 8. Government of Sierra Leone. (2021). *National adaptation plan, Sierra Leone*. https://files.acquia.undp.org/public/migration/sl/SierraLeone_iNAP_Final.pdf
 9. Haarhoff, S. J., & Swanepoel, P. A. (2022). Plant population and row spacing affects growth and yield of rainfed maize in semi-arid environments. *Frontiers in Plant Science*, 13, Article 761121. <https://doi.org/10.3389/fpls.2022.761121>
 10. International Monetary Fund. (2011). *Sierra Leone: Poverty reduction strategy paper—Progress report, 2008–2010* (IMF Country Report No. 11/95).
 11. Kovacs, P., & Pepo, P. (2015). Effect of plant density and row spacing on maize (*Zea mays* L.) grain yield in different crop years. *Columella – Journal of Agricultural and Environmental Sciences*, 2(1). <https://www.researchgate.net/publication/281982235>
 12. Li, R., Zhang, G., Xie, R., Hou, P., Ming, B., Xue, J., Wang, K., & Li, S. (2021). Optimizing row spacing increased radiation use efficiency and yield of maize. *Agronomy Journal*, 113(6), 4806–4818. <https://doi.org/10.1002/agj2.20828>
 13. Ministry of Agriculture and Forestry. (2019). *National agricultural transformation programme 2023–2030: Priority components and strategic interventions*.
 14. Noland, R., Dowdy, M., & Harris, G. (2025). Maize row spacing and seeding rate informed by space-per-plant geometry. *Agronomy*, 15(2), Article 374. <https://doi.org/10.3390/agronomy15020374>
 15. Sangoi, L., Cassol, L. C., Zanin, C. G., [additional authors not listed in source]. (2015). Maize grain yield enhancement through high plant density cultivation with different inter-row and intra-row spacings. *European Journal of Agronomy*. <https://doi.org/10.1016/j.eja.2015.10.005>
 16. Sierra Leone Country Commercial Guide. (2026). *Agriculture sector*. International Trade Administration. <https://www.trade.gov/country-commercial-guides/sierra-leone-agriculture-sector>
 17. Tang, L., Ma, W., Noor, M. A., Li, L., Hou, H., Zhang, X., & Zhao, M. (2018). Density resistance evaluation of maize varieties through new “Density–Yield Model” and quantification of varietal response to gradual planting density pressure. *Scientific Reports*, 8, Article 17281. <https://doi.org/10.1038/s41598-018-35275-w>
 18. Wang, J., Chen, Z., Liang, Z., Yin, Y., Huang, S., Meng, Q., Cui, Z., & Wang, P. (2025). Interactive effects of planting density and row spacing on maize root distribution and yield. *Agronomy*, 15(11), Article 2552. <https://doi.org/10.3390/agronomy15112552>
 19. Xie, L., Su, B.-J., Zhang, Y.-N., Zhang, D.-S., Han, J.-J., Li, H.-M., Feng, W.-J., Du, T.-Q., Cui, F.-Z., & Xue, J.-F. (2025). Optimizing plant density and row spacing enhances growth, yield and quality of waxy maize on the Loess Plateau. *Plants*, 14(18), Article 2902. <https://doi.org/10.3390/plants14182902>