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Combined effect of biofertilizers and chemical fertilizers on growth, yield potential of maize (*Zea mays* L.) varieties and economic benefits

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This study was conducted to evaluate the effects of biofertilizers, diammonium phosphate (DAP), and urea fertilizer treatments on maize growth, yield, and economic benefits. The experiment, carried out over two consecutive seasons in 2022, included five treatments: control without fertilizers (T1), biofertilizers only (T2), DAP + urea (T3), biofertilizers + DAP (T4), and biofertilizers + DAP + urea (T5), arranged in a randomized complete block design. Three maize varieties—UH5355, Longe 10H, and Longe 5—were evaluated. The results indicated that the combined application of biofertilizers + DAP + urea (T5) led to the highest plant height, leaf length, leaf width, stem girth, and grain yield. Among the varieties, Longe 5 showed optimal growth, while Longe 10H achieved the highest yield under the T5 treatment. The integration of biofertilizers with DAP and urea (T5) produced the best results in terms of maize growth and yield, although it incurred higher costs. However, compared to the use of DAP + urea alone, integrating biofertilizers helped reduce overall production costs while maintaining optimum yield. Therefore, adopting an integrated application of biofertilizer with DAP and urea fertilizers is recommended for achieving optimal maize yield.

Key words: Soil fertility, nutrient recycling, production costs, maize growth, yield, profitability

INTRODUCTION

Maize (*Zea mays* L.) is widely cultivated worldwide and is a food security crop of nutritional importance in Uganda (Garley and Ricardo, 2017). In Uganda, maize is cultivated on an estimated area of 384,000 ha, with production standing at 522,000 tonnes and a grain yield of 1.3 t/ha (MAAIF, 2018). However, this yield is below the potential of 9 t/ha, mainly due to soil fertility deterioration, erratic rainfall, prevalence of pests and diseases, use of low-yielding varieties, and limited improvement in agronomic and post-harvest technologies (Sserunkuuma, 2005; Kornher, 2018).

The deterioration in soil fertility, associated with

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continuous cropping without the addition of external fertilizers, is one of the most significant constraints in maize production in Uganda (Tindwa et al., 2019). This deterioration is evidenced by the low nutrient contents across farming systems in Uganda. It is estimated that 38.1 kg/ha of nitrogen (N), 16.5 kg/ha of phosphorus (P), and 32.2 kg/ha of potassium (K), totaling 86.8 kg/ha, are lost per year (IFDC, 2017). This has led to low crop yields, including maize, resulting in persistent food insecurity (Apanovich and Mazur, 2018). To increase maize yields, it is crucial to apply organic and chemical fertilizers to restore soil nutrient status. Unfortunately, the use of chemical fertilizers is still very low in Uganda due to their high cost, which is unaffordable for smallholder farmers (UBOS, 2019; Cedrez et al., 2020). Hence, there is a need to consider alternative fertilizers, such as biofertilizers, which have the potential for sustainable maize production. Biofertilizers are substances containing living microorganisms that, when applied to seeds, plant surfaces, or soil, colonize the rhizosphere or the interior of the plant and promote growth by increasing the supply or availability of primary nutrients to the host plant (Kumar et al., 2018). Additionally, biofertilizers are biological preparations of efficient microorganisms that enhance plant growth by improving nutrient acquisition (Meena et al., 2015). Examples of biofertilizers include *Rhizobium, Azotobacter, Azospirillum*, and blue-green algae (BGA), which have been in use for a long time. *Rhizobium* inoculants are used for leguminous crops, while *Azotobacter* can be used with crops like wheat, maize, mustard, cotton, potato, and other vegetables (Naveed et al., 2015). *Azospirillum* inoculations are recommended mainly for sorghum, millets, maize, sugarcane, and wheat. Blue-green algae, belonging to the cyanobacteria genus Anabaena, fix atmospheric nitrogen and are used as inoculants for paddy crops grown under both upland and lowland conditions (Kumar et al., 2018). These biofertilizers enhance soil productivity by fixing atmospheric nitrogen, solubilizing soil phosphorus, and stimulating plant growth. Thus, biofertilizers are required to enhance soil fertility for sustainable production since research indicates that prolonged use of chemical fertilizers degrades the soil and affects crop yield (Mitter et al., 2021).

Research has shown that the application of biofertilizers in maize production leads to significantly increased yields and economic gains. The combined use of biofertilizers and inorganic fertilizers has a substantial impact on maize yield. For instance, research conducted in India demonstrated that the application of PSB + *Azotobacter* + $ZnSO_4$ at 30 kg/ha resulted in higher plant height, dry weight, crop growth rate, number of cobs per plant, seed characteristics, grain yield, straw yield, and harvest index, which in turn led to increased gross return, net return, and B ratio (Reddy et al., 2023).

Similarly, an earlier field experiment by Meena et al. (2013) examining the effects of nitrogen doses with and without *Azotobacter* inoculation on maize yield found that the maximum grain yield of 4.3 t/ha was obtained using 150 kg N/ha with 5 t/ha of farmyard manure and *Azotobacter* inoculation. Additionally, a study involving the use of NPK + *Azotobacter chroococcum* + *Bacillus megaterium* + *Pseudomonas fluorescens* + enriched compost in maize production reported the highest plant height (188.13 cm) and grain yield (5.4 t/ha) (Umesha et al., 2014).

Further evidence from Fadlalla et al. (2016) indicates that biofertilizers significantly affect maize yield. The application of biofertilizers in combination with chicken manure increased maize grain yield (t/ha) by 20 and 30% over the control in 2009 and 2010, respectively. This improvement was attributed to the combination of *Azospirillum brasilense* or *Azotobacter* species with chicken manure or urea, which enhanced the fixation of nitrogen (N), potassium (k), and phosphorus (p), essential for optimal plant growth and yield (Anees et al., 2016).

However, McCarty et al. (2017) pointed out that the application of biological fertilizers alone might not suffice, particularly under harsh climatic or weather conditions, where biological fertilizers may lose effectiveness. In such cases, the application of conventional chemical fertilizers containing vital plant nutrients, including N, P, K, and trace elements like calcium (Ca), magnesium (Mg), and boron (B), is necessary. Sivamurugan et al. (2018) concurred, noting that using both biofertilizers and chemical fertilizers ensures higher yields if one fails. However, this depends on not applying both fertilizers simultaneously and ensuring that the rate of chemical fertilizer application does not undermine the effectiveness of the biofertilizers in releasing plant nutrients to boost growth and yield (Mahato and Neupane, 2017).

Overall, the application of biofertilizers in maize production shows promising effects. However, limited studies exist on the effects of integrating biofertilizers and chemical fertilizers and their impact on plant growth and yield, as well as the associated cost implications. Therefore, the objectives of this study were: 1) to examine the effect of biofertilizers, diammonium phosphate, and urea treatments on the growth of maize varieties; 2) to evaluate the combined effect of biofertilizers, diammonium phosphate, and urea treatments on the yield of maize varieties; and 3) to determine the cost implications of applying biofertilizers, diammonium phosphate, and urea fertilizers in maize production.

MATERIALS AND METHODS

Experimental site

This study was conducted at the Uganda Government Prisons Farm in Lugore Parish, Owallo Sub-County, Gulu District, located in Northern Uganda at coordinates 3° 1' 42" N, 32° 20' 41" E. Gulu

Table 1. Soil chemical properties before the experiment.

Parameter	Value
pH	6.34
EC (dS m^{-1})	0.07
Nitrogen (%)	0.17
Phosphorus (mg/kg)	9.00
Potassium (m/kg)	288

District lies at an average elevation of 1,063 m (3,488 ft) above sea level. The district experiences bimodal rainfall, with peaks occurring in April-May and August-October. The average annual rainfall varies between 1,200 and 1,600 mm, decreasing towards the north. Rainfall is primarily convectional, typically occurring in the afternoons and evenings. The average minimum and maximum temperatures are 22.5 and 25.5°C, respectively. The absolute maximum temperature rarely exceeds 36°C, while the absolute minimum rarely drops below 20°C. The month with the highest relative humidity is May (79.87%), and the month with the lowest relative humidity is February (42.55%). The dominant soil types in Gulu District are Ferralsols and Leptosols, with a sandy loam texture, and the topography ranges from flat to gently sloping. The initial soil chemical properties of the experimental site are presented in Table 1.

Experimental design

The experiment was conducted using a Randomized Complete Block Design (RCBD) with five treatments, each replicated three times. The treatments were as follows: T1 = Control (no fertilizers), T2 = Biofertilizers, T3 = DAP + Urea, T4 = Biofertilizers + DAP, and T5 = Biofertilizers + DAP + Urea. Briefly, the control (T1) did not receive any chemical fertilizers or biofertilizers, while T2 involved the application of a biofertilizer formulation containing three strains: Kinyphos (*B. megaterium* var. *phosphaticum* strain No PB1), Kinypotash (*Frateuria aurantia*), and Kinyazoto (*Azotobacter* spp. strain No AC1). These bacterial strains were commercially produced by Kinyara Sugar Limited, Uganda. All biofertilizer treatments included the three strains in the formulation. The biofertilizer solution was prepared by mixing 1000 ml in 200 L of water and applied at a rate of 1000 ml/ha under moist soil conditions with high humidity.

For the chemical fertilizers, the recommended basal application of diammonium phosphate (N—P_2O_5—K_2O, 18:46:0) was applied at a rate of 125 kg ha^{-1}, supplying 23 kg N ha^{-1} and 58 kg P_2O_5 ha^{-1} (MAAIF, 2018). Additionally, 58 kg N ha^{-1} was supplied from urea (N—P_2O_5—K_2O, 46:0:0) by applying 125 kg ha^{-1} as a top dressing at the eight-leaf stage.

Therefore, T3 received DAP at planting and urea as a top dressing at the eight-leaf stage under humid soil conditions. T4 received biofertilizers and DAP at planting. The biofertilizer in T4 was applied as a soil treatment near the maize plant root zone 14 days after sowing, followed by a second application prior to tasseling. Similarly, T5 received DAP at planting, biofertilizers as soil treatments 14 days after sowing and at the onset of maize tasseling, and finally urea as a top dressing at the eight-leaf stage.

Three maize varieties—UH5355, Longe 10H, and Longe 5—were selected for the experiment because they are popular varieties grown in Gulu District. The maize varieties were planted in blocks, with each block containing 15 plots measuring 4 x 4 m (16 m^2), on which each treatment was set up and separated by 1 m. All maize varieties were cultivated following recommended agronomic practices, including proper land preparation, weeding, and pest control, during the two seasons of maize production (MAAIF, 2018). The maize seeds were sown on April 14, 2022, and July 2, 2022, for the first and second seasons of maize production, respectively, at a spacing of 75 × 30 cm, resulting in a total of 40 plants per plot and 1800 plants across all experimental replicates.

Growth and yield determination

Plant height (cm), leaf length (cm) and stem girth (cm) were measured at 5, 7 and 9 weeks after sowing while grain yield was determined after harvesting by weighing threshed grains per plot and extrapolating to obtain yield in tons per ha (t/ha).

Economic analysis for biofertilizer use

The economic benefit of using combined biofertilizers and chemical fertilizers was evaluated using the CIMMYT partial budget methodology (CIMMYT, 1988). The cost of fertilizer application was determined by obtaining the market prices of chemical fertilizers (DAP and urea), which were then used for the partial budget analysis. At the time the study was conducted, the price for 50 kg of DAP and urea was estimated at 54 USD each, while biofertilizer was estimated at 8 USD per liter. Additionally, the cost of applying the fertilizers per acre was estimated at 1.3 USD per unit of labor. Other production costs, such as land preparation, planting, weeding, chemical spraying, and harvesting, were considered uniform across all treatments. The total costs were calculated using the formula provided in Equation 1.

TC = Costs of fertilizer + Costs of Labour units used per acre (1)

where TC = Total costs of fertilizers application

The Total Revenue (TR) for each treatment was computed by multiplying the market price of maize grains as shown in Equation 2.

Total Revenue = Yield × Price for maize grains (2)

The Net income was calculated by subtracting the total costs of fertilizer application from Total Revenue (TR) for each treatment as shown in Equation 3 (Table 2).

Net Profit = TR – TC (3)

Data analysis

Data obtained on maize growth responses; plant height, leaf length, grain yield was subjected to three-way factor analysis of variance using GenStat 14 at 5, 1 and 0.1% significance level to determine Fisher's probability (F.pr), grand mean, least significant differences

Table 2. The costs of treatments per hectare.

Costs (USD[1])	Treatments			
	Biofertilizer	DAP + Urea	Biofertilizer + DAP	Biofertilizer + DAP + Urea
Costs of treatment	24	268	158	292
Labour	20	40	40	60
Total costs	44	308	198	352

[1]USD = 3733 UGX.

(L.S.D) and coefficient of variations (% CV).

RESULTS AND DISCUSSION

Effect of biofertilizer, DAP and urea on maize growth

Plant height

The results presented in Tables 3 and 4 indicate a significant ($p < 0.001$) difference in maize plant height due to the different fertilizer treatments. Averaged across seasons and varieties, maize plants under the DAP + biofertilizer + urea treatment achieved the highest plant height (149.8 cm), compared to DAP + urea (147.2 cm), biofertilizer (135.6 cm), DAP + biofertilizer (128.2 cm), and the control (128.1 cm). Within the seasons, plant height across varieties was significantly ($p < 0.001$) higher in season 2 (141.99 cm) than in season 1 (133.64 cm). This variation could be attributed to the higher moisture content during the second season of maize production. Typically, the second season in Northern Uganda receives more rainfall and experiences fewer drought occurrences than the first season. As a result, crops planted in the second season tend to perform better due to the availability of moisture for plant growth and yield.

Among the maize varieties, Longe 5 (157.39 cm) attained a significantly ($p < 0.001$) greater plant height compared to Longe 10H (139.64 cm) and UH5355 (116.7 cm). Additionally, significantly ($p < 0.001$) higher plant height was observed at 9 WAS (157.39 cm) compared to 7 WAS (134.28 cm) and 5 WAS (119.55 cm). There was also a significant ($p < 0.001$) interaction between treatment and maize variety, treatment and weeks, as well as treatment, maize variety, and weeks.

The findings indicate that the combined application of DAP, biofertilizer, and urea on maize plants resulted in the most optimal plant height, with the effect being most pronounced in the Longe 5 maize variety during the second season of production and at the maturity stage (9 WAP). This can be attributed to the availability of essential nutrients such as nitrogen, phosphorus, and potassium, which are crucial for optimizing maize growth. These results align with the observations of Meena et al. (2015), who noted that biofertilizers are biological preparations containing efficient microorganisms that enhance plant growth by improving nutrient acquisition. Biofertilizers increase soil productivity by fixing atmospheric nitrogen, solubilizing soil phosphorus, and stimulating plant growth. They contribute nutrients through natural processes such as nitrogen fixation and phosphorus solubilization, while also promoting plant growth through the synthesis of growth-promoting substances (Bargaz et al., 2018).

Moreover, the integration of DAP and urea proved more effective in increasing the availability of nutrients necessary for plant growth compared to biofertilizers alone. Talboys et al. (2016) describe DAP as an excellent source of P and N for plant nutrition, as it is highly soluble and quickly dissolves in soil to release plant-available phosphate and ammonium. The nitrogen and phosphorus from DAP facilitate rapid plant growth (Razaq et al., 2017). P, in particular, supports root development, flowering, seed formation, and enhances plant resilience against diseases, pests, and adverse weather conditions (Malhotra et al., 2018). Alikhani et al. (2017) also support the idea that a small dosage of urea fertilizer is crucial for aiding the photosynthesis process, thereby allowing plants to thrive. Additionally, Purwani and Nurjaya (2020) found that a combined application of NPK and biofertilizer resulted in the highest growth rates and taller maize plants.

Chen (2006) highlighted that integrating biofertilizers with chemical fertilizers is effective in enhancing plant growth responses. While biofertilizers are beneficial under moist conditions, chemical fertilizers like DAP and urea compensate for nutrient limitations in poor-quality soils and dry conditions where microbes may not survive. A sole application of biofertilizer may not provide all the necessary nutrients during the early stages of plant development. Batool (2024) also observed that maize, being a heavy feeder, requires a high nutrient uptake, making a balanced nutrient supply essential for sustained growth. This necessitates the application of both chemical and organic fertilizers at specific stages of plant growth.

Leaf length

The results in Tables 5 and 6 indicate that the application of treatments on maize plants had a significant ($p < 0.001$) effect on maize leaf length. The combined

Table 3. Plant height (cm) of maize varieties under different fertilizers treatments.

Season	Treatment	Maize variety	5 WAS	7 WAS	9 WAS	Mean
		Longe 10 H	108.3	125.9	143.3	125.8
	Biofertilizer	UH5355	95.0	113.4	133.3	113.9
		Longe 5	130.7	144.4	189.2	154.8
		Longe 10 H	116.2	133.9	150.4	133.5
	DAP + Urea	UH5355	109.7	127.9	145.4	127.7
		Longe 5	144.8	139.2	217.4	167.1
		Longe 10 H	142.7	138.1	154.1	144.9
Season 1	DAP + Biofertilizer	UH5355	93.2	111.3	130.3	111.6
		Longe 5	102.6	115.1	132.3	116.7
		Longe 10 H	132.8	152.5	165.7	150.4
	DAP + Biofertilizer + Urea	UH5355	101.4	119.2	138.4	119.7
		Longe 5	146.9	165.3	185.9	166
		Longe 10 H	107.4	118.9	136.5	120.9
	Control	UH5355	81.2	99.6	120.9	100.6
		Longe 5	137.6	151	164.5	151.1
		Longe 10 H	113.8	133.2	154.3	133.8
	Biofertilizer	UH5355	96.6	117.2	139.9	117.9
		Longe 5	139.9	156.4	206.6	167.6
		Longe 10 H	122.1	141.6	162	141.9
	DAP + Urea	UH5355	111.6	132.1	152.7	132.1
		Longe 5	154.9	150.8	237.4	181
		Longe 10 H	150.0	146.1	165.9	154
Season 2	DAP + Biofertilizer	UH5355	94.8	115	136.8	115.5
		Longe 5	109.8	124.7	144.5	126.3
		Longe 10 H	139.6	161.4	178.5	159.8
	DAP + Biofertilizer + Urea	UH5355	103.2	123.1	145.4	123.9
		Longe 5	157.2	179	203	179.7
		Longe 10 H	112.9	125.8	147	128.5
	Control	UH5355	82.6	102.9	126.9	104.2
		Longe 5	147.2	163.6	179.7	163.5
P-value			<0.001	<0.001	<0.001	<0.001
LSD			4.06	4.843	3.894	4.06
CV (%)			37.2	27.4	22.1	33.1

V = Variety, S = season, T=treatment, WAS = weeks after sowing, LSD = least square difference, CV = coefficient of variation, DAP = diammonium phosphate.

application of biofertilizer, DAP, and urea (87.2 cm) resulted in the longest leaves compared to DAP + urea (84.6 cm), biofertilizers (82.2 cm), and the control (78.1 cm). The results also show that seasonal variations significantly ($p < 0.001$) influenced plant growth, leading to longer leaves. Specifically, longer maize leaves were recorded during the second season (89.8 cm) compared to the first season (79.84 cm). Additionally, the Longe 5

Table 4. Source of variation of plant height under different treatments, maize varieties, Seasons and weeks after planting.

Source of variation	df	ms	p-value
Treatment	4	86330	<0.001***
Season	1	70514	<0.001***
Maize variety	2	561322	<0.001***
Weeks after planting	2	554001	<0.001***
Treatment × season	4	92	0.998
Treatment × maize variety	8	54515	<0.001***
Season × maize variety	2	6066	0.123
Treatment × weeks	8	8542	0.003**
Season × weeks	2	2943	0.362
Maize variety × weeks	4	14974	<0.001***
Treatment × season × maize variety	8	76	1
Treatment × season × weeks	8	18	1
Treatment × maize × variety × weeks	16	7249	<0.001***
Season × maize variety × weeks	4	39	1
Treatment × season × maize variety × weeks	16	12	1
Residual	3958	2895	

***Significant at 0.1%, **Significant at 1%, *Significant at 5%, ns = non-significant, MS = mean square, df = degrees of freedom.

maize variety (89.81 cm) exhibited significantly ($p < 0.001$) longer leaves compared to the Longe 10 H (80.45 cm) and UH5355 (76.61 cm) varieties. Furthermore, there was a significant ($p < 0.001$) interaction between treatments and maize variety, with the optimal leaf length being achieved in Longe 5 maize plants treated with the combination of DAP, biofertilizer, and urea (98.98 cm).

The findings clearly indicate that the combined application of DAP, biofertilizers, and urea significantly influenced maize growth, leading to longer leaf lengths. This optimal growth rate was achieved during the favorable rainfall conditions present in the second production season. Additionally, the optimal leaf growth was observed in the Longe 5 maize variety. The maximum leaf growth was attained when biofertilizers were combined with DAP and urea, due to the adequate supply of N, P, and K, which are essential for rapid plant growth. Moreover, this combination also helped prevent common pests, including the fall armyworm, which could otherwise affect vegetative growth. The microorganisms in the biofertilizer provided the plants with growth-promoting compounds such as indole acetic acid (IAA), amino acids, and vitamins, thereby aiding plant growth and resulting in longer leaves (Parikh and James, 2012; Daniel et al., 2022). Diammonium phosphate contains nitrogen and phosphorus, primary macronutrients essential for plant growth, while urea provides nitrogen and potassium, also crucial for plant development, leading to longer leaves. The findings of this study are consistent with Ticman and Ticman (2022), who found that the application of a commercial biofertilizer containing nitrogen-fixing bacteria such as *Azotobacter, Azospirillum*, and *Pseudomonas* inoculated on seeds increased the Leaf Area Index (LAI) by around 44%, the leaf chlorophyll index by about 61%, and biomass dry weight by 24%. The increase in leaf length and, consequently, LAI indicates enhanced photosynthetic activity in plants, leading to higher dry matter production and yield.

Stem girth (cm)

The results in Tables 7 and 8 show that there was a significant ($p < 0.001$) effect of treatments, seasons, maize variety, and growth period on plant stem girth. Significantly wider stem girth was observed in plants treated with DAP + urea (10.2 cm) and biofertilizer + DAP + urea (10.1 cm), compared to those treated with biofertilizer + DAP (8.6 cm), biofertilizer (8.3 cm), and the control (7.6 cm). Wider plant stem girth was most pronounced during the second season of production than the first season, with the Longe 5 maize variety showing the greatest increase, and it generally expanded during the tasseling stage of maize growth.

The findings demonstrate that the application of DAP + urea, as well as a combined application of biofertilizer + DAP + urea, increased plant stem girth. The combined fertilizer application improved nutrient availability for strong stem development and supported a rapid growth rate. Potassium, essential for strong stem development, was likely supplied through the application of *F. aurantia*,

Table 5. Leaf length (cm) under different treatments, maize varieties, 5WAS, 7WAS and 9WAS.

Season	Treatment	Maize variety	5 WAS	7 WAS	9 WAS	Mean
		Longe 10 H	65.5	75.7	86.7	76
	Biofertilizers	UH5355	65.5	75.5	87.2	76.1
		Longe 5	77	87.4	97.1	87.2
		Longe 10 H	68.3	78.3	89.4	78.7
	DAP + Urea	UH5355	68.8	79.4	92.3	80.1
		Longe 5	78.1	86.9	97.5	87.5
		Longe 10 H	67.2	77.5	88.2	77.6
Season 1	DAP + Biofertilizer	UH5355	61.3	71.3	101.1	77.9
		Longe 5	66.1	75	85.5	75.5
		Longe 10 H	71.4	81.9	93	82.1
	DAP + Biofertilizer + Urea	UH5355	66.3	76.5	86.9	76.6
		Longe 5	78.2	88.4	118.5	95
		Longe 10 H	68.3	76.1	82.3	75.6
	Control	UH5355	57.1	66.1	74.1	65.8
		Longe 5	78.1	85.6	94.3	86
		Longe 10 H	68.9	80.1	93.3	80.8
	Biofertilizers	UH5355	66.6	78	91.5	78.7
		Longe 5	82.4	94.7	106	94.4
		Longe 10 H	71.8	82.8	96.3	83.6
	DAP + Urea	UH5355	69.9	82	96.9	82.9
		Longe 5	83.5	94.1	106.5	94.7
		Longe 10 H	70.6	82	94.9	82.5
Season 2	DAP + Biofertilizer	UH5355	62.3	73.7	106.2	80.7
		Longe 5	70.8	81.2	93.3	81.8
		Longe 10 H	75.1	86.6	100.2	87.3
	DAP + Biofertilizer + Urea	UH5355	67.4	79.1	91.2	79.2
		Longe 5	83.7	95.8	129.4	102.9
		Longe 10 H	71.8	80.5	88.6	80.3
	Control	UH5355	58	68.3	77.8	68.1
		Longe 5	83.6	92.7	102.9	93.1
	p-value		<0.001	<0.001	<0.001	<0.001
	LSD		2.894	3.212	2.217	2.267
	CV (%)		32.446	28.9	32.1	23.4

V = Variety, S = Season, T = Treatment, WAS = Weeks after Sowing, LSD = Least Square Difference, CV = Coefficient of Variation, DAP = Diammonium Phosphate.

a K-mobilizing bacterium in the biofertilizer treatment. Therefore, using biofertilizers in combination with chemical fertilizers could serve as a promising technology to mobilize potassium from soil to plants, thereby enhancing crop yield (Subhashini, 2016).

The Longe 5 variety was the most optimal maize variety, achieving greater stem girth compared to other varieties. This maize variety is noted for its high tolerance

Table 6. Source of variation of leaf length (cm) under different treatments, maize varieties, seasons and weeks after sowing.

Source of variation	df	MS	p-value
Treatment	4	11213.6	<0.001
Season	1	24285.2	<.0001
Maize variety	2	62239.7	<0.001
Weeks after planting	2	198799.2	<0.001
Treatment × season	4	11.8	1
Treatment × maize variety	8	6821	<0.001
Season × maize variety	2	1695.1	0.153
Treatment x weeks	8	1996.3	0.024
Season × weeks	2	1029.6	0.32
Maize variety × weeks	4	908.2	0.403
Treatment × season × maize variety	8	8.5	1
Treatment × season × weeks	8	3.2	1
Treatment × maize × variety × weeks	16	1820	0.009
Season × maize variety × weeks	4	4.1	1
Treatment × season maize variety × weeks	16	2.4	1
Residual	3958	902.5	

***Significant at 0.1%, **Significant at 1%, *Significant at 5%, ns = non-significant, MS = mean square, df = degrees of freedom.

to dry conditions, pests, and diseases, which contributed to its enhanced growth and broader stem girth. Plant growth was particularly pronounced during the wet season (season 2), likely due to increased rainfall, which improved soil nutrient breakdown and allowed maize plants to access essential nutrients such as N, P, and K. These findings align with Cadot et al. (2018), who found that integrating biofertilizers and chemical fertilizers is crucial for sustained nutrient uptake, as variations in weather patterns can affect nutrient availability in biofertilizers. The combined application of biofertilizers and DAP increases the availability of phosphorus necessary for overall plant growth, root formation, and stronger stem development. P deficiency during early maize growth can lead to stunted development (Bélanger et al., 2017). K, like N, promotes plant growth and is required in large quantities; thus, an adequate supply from both NPK and biofertilizers helps mitigate the effects of frostbite and protects plants from pest infestations (Razaq et al., 2017).

Effect of biofertilizer, DAP and urea on maize yield

Results show that the treatments had a significant ($p < 0.001$) effect on maize yield per hectare (Figure 1). Plants treated with biofertilizers + DAP + urea produced the highest yield per hectare compared to those receiving DAP + urea, biofertilizer + DAP, biofertilizers alone, and the control. The yield potential per hectare differed significantly ($p < 0.001$) among the maize varieties. The Longe 10H hybrid attained the highest yield per hectare compared to UH5355 and Longe 5. For example, in the biofertilizers + DAP + urea treatment during the second season, Longe 10H produced the highest yield (1.67 t/ha) compared to UH5355 (1.63 t/ha) and Longe 5 (1.54 t/ha) for the same treatment. This effect was significantly ($p < 0.001$) higher during the second season than the first, likely due to better rainfall conditions in the second season. Furthermore, Longe 10H and UH5355 are hybrids, while Longe 5 is an open-pollinated variety (OPV). Hybrids, particularly Longe 10H, generally yield higher under good management due to the effects of heterosis, compared to OPVs (Heerwaarden et al., 2009).

The results above show that the biofertilizers + DAP + urea treatment had the most significant effect on maize yield. This finding aligns with Pangaribuan and Hendarto (2018), who reported that the integrated application of biofertilizers with organic manure at various rates significantly improved sweet corn yield and soil health. Research suggests that using biofertilizers in combination with small amounts of chemical fertilizers is more effective for achieving optimal yield than using biofertilizers alone (Mekki, 2016). Therefore, the co-application of biofertilizers and chemical fertilizers is crucial for enhancing soil health, plant growth, and agricultural sustainability.

In this study, the yield improvement is attributed to enhanced plant growth, as evidenced by increases in plant height, leaf length, and stem girth. This growth improvement is likely due to the availability of essential plant nutrients throughout the maize growth cycle. Biofertilizers, such as those containing *Azotobacter, Azospirillum*, *Phosphobacter*, and *Rhizobacter*

Table 7. Stem girth (cm) under different treatments, maize varieties, 5WAS, 7WAS and 9WAS.

Season	Treatment	Maize variety	5 WAS	7 WAS	9 WAS	Mean
		Longe 10 H	6.2	7.7	9.6	7.8
	Biofertilizer	UH5355	5.9	7.3	9.1	7.4
		Longe 5	6.5	8.2	11.9	8.9
		Longe 10 H	9.3	10.2	12.1	10.5
	DAP + Urea	UH5355	7.5	9.2	10.7	9.1
		Longe 5	8.3	10.1	11.7	10
		Longe 10 H	8.2	10.3	11.6	10
Season 1	DAP + Biofertilizer	UH5355	6.6	7.8	9.5	8
		Longe 5	5.7	7	8.7	7.1
		Longe 10 H	9.4	11.2	12.8	11.2
	DAP + Biofertilizer + Urea	UH5355	7	8.6	9.3	8.3
		Longe 5	8.4	10.1	11.6	10.1
		Longe 10 H	6.7	7.7	8.8	7.7
	Control	UH5355	5.5	7.6	7.8	7
		Longe 5	6.5	7.4	8.3	7.4
		Longe 10 H	6.5	8.1	10.3	8.3
	Biofertilizer	UH5355	6	7.5	9.6	7.7
		Longe 5	7	8.9	12.9	9.6
		Longe 10 H	9.8	10.8	13.1	11.2
	DAP + Urea	UH5355	7.6	9.5	11.2	9.4
		Longe 5	8.9	11	12.8	10.9
		Longe 10 H	8.6	10.9	12.5	10.7
Season 2	DAP + Biofertilizer	UH5355	6.7	8.1	10	8.2
		Longe 5	6	7.6	9.6	7.7
		Longe 10 H	9.9	11.9	13.8	11.9
	DAP + Biofertilizer + Urea	UH5355	7.1	8.9	9.8	8.6
		Longe 5	9	11	12.7	10.9
		Longe 10 H	7.1	8.1	9.4	8.2
	Control	UH5355	5.6	7.8	8.2	7.2
		Longe 5	6.9	8.1	9.1	8
P-value			<.001	<.001	<.001	<.001
LSD			0.2273	0.3754	0.643	0.2188
CV (%)			29.3	33.7	28.3	25.4

V = Variety, S = Season, T = Treatment, WAS = Weeks after Sowing, LSD = Least Square Difference, CV = Coefficient of Variation, DAP = Diammonium Phosphate.

(Muthusamy et al., 2023), play a significant role in improving soil fertility through natural processes like nitrogen fixation and phosphorus solubilization. While biofertilizers recycle nutrients in the soil, chemical fertilizers directly supply readily available nutrients.

In this study, the chemical fertilizers DAP and urea, along with biofertilizers containing nitrogen fixers (*Azotobacter* spp.), phosphorus solubilizers (*B. megaterium var*

Table 8. Source of variation of stem girth (cm) under different treatments, maize varieties, seasons and weeks after planting.

Source of variation	df	MS	P-value
Treatment	4	1090.797	<0.001
Season	1	289.037	<0.001
Maize variety	2	934.026	<0.001
Weeks after planting	2	3598.193	<0.001
Treatment × season	4	1.027	0.975
Treatment × maize variety	8	194.806	<0.001
Season × maize variety	2	17.556	0.124
Treatment × weeks	8	44.442	<0.001
Season × weeks	2	15.006	0.168
Maize variety × weeks	4	17.576	0.079
Treatment × season × maize variety	8	0.297	1
Treatment × season × weeks	8	0.077	1
Treatment × maize × variety × weeks	16	13.675	0.054
Season × maize variety × weeks	4	0.144	0.999
Treatment × season maize variety × weeks	16	0.029	1
Residual	3958	8.406	

***Significant at 0.1%, **Significant at 1%, *Significant at 5%, ns = non-significant, MS = mean square, df = degrees of freedom.

Table 9. The total cost, revenue, net income and decision rank for the use of biofertilizers and chemical fertilizers.

Treatment	Total Costs/ha (USD[1])	Total revenue (USD)	Net income/ ha (USD)	Decision rank
Biofertilizers	44	408	364	1st
DAP + Urea	308	459	151	3rd
Biofertilizers + DAP	198	451	253	2nd
Biofertilizers DAP + Urea	352	499	147	4th
p-value	< 0.001	< 0.001	< 0.001	

phosphaticum), and potassium mobilizers (*F. aurantia*), stimulated the release of these nutrients, promoting maize growth (Bargaz et al., 2018). Although this study did not measure soil nutrients and their uptake by maize plants, it can be hypothesized that combining chemical fertilizers with biofertilizers enhanced the availability and uptake of N, P, and K in the soil. These nutrients are essential for maize growth and yield. For instance, nitrogen is a key structural component of plants, involved in amino acids, chlorophyll, nucleic acids, ATP, and phytohormones, and is crucial for carbon and nitrogen metabolism, photosynthesis, and protein production (Leghari et al., 2016; Weil and Brady, 2016). Phosphorus, another essential nutrient, is a structural component of nucleic acids, sugars, and lipids, and plays a crucial role in seed germination, root and shoot development, and photosynthesis (Malhotra et al., 2018). Potassium enhances plant physiological features related to disease and drought resistance (Hasanuzzaman et al., 2018). Therefore, satisfying the N, P, and K demands of maize plants through the application of chemical fertilizers and biofertilizers can improve physiological processes and enhance maize growth and yield.

Economic benefits of biofertilizers, DAP and urea application on maize production

In this study, the unit costs for the application of biofertilizers, DAP + urea, biofertilizer + DAP, and biofertilizer + DAP + urea were 44, 308, 198, and 352 USD, respectively (Table 2). These findings demonstrate that the integrated application of biofertilizers, DAP, and urea varies in terms of cost. It was determined that the sole application of biofertilizers is less costly, while the application of chemical fertilizers is more expensive. These results align with Mofunanya et al. (2015) and Nielsen (2017), who noted that biofertilizers are relatively cheaper and more cost-effective compared to chemical fertilizers. Conversely, Fadare et al. (2010) found that integrating biofertilizers with a minimal amount of chemical fertilizers is relatively cost-effective and profitable, achieving higher yield goals (Table 9).

The findings indicate that the application of biofertilizers

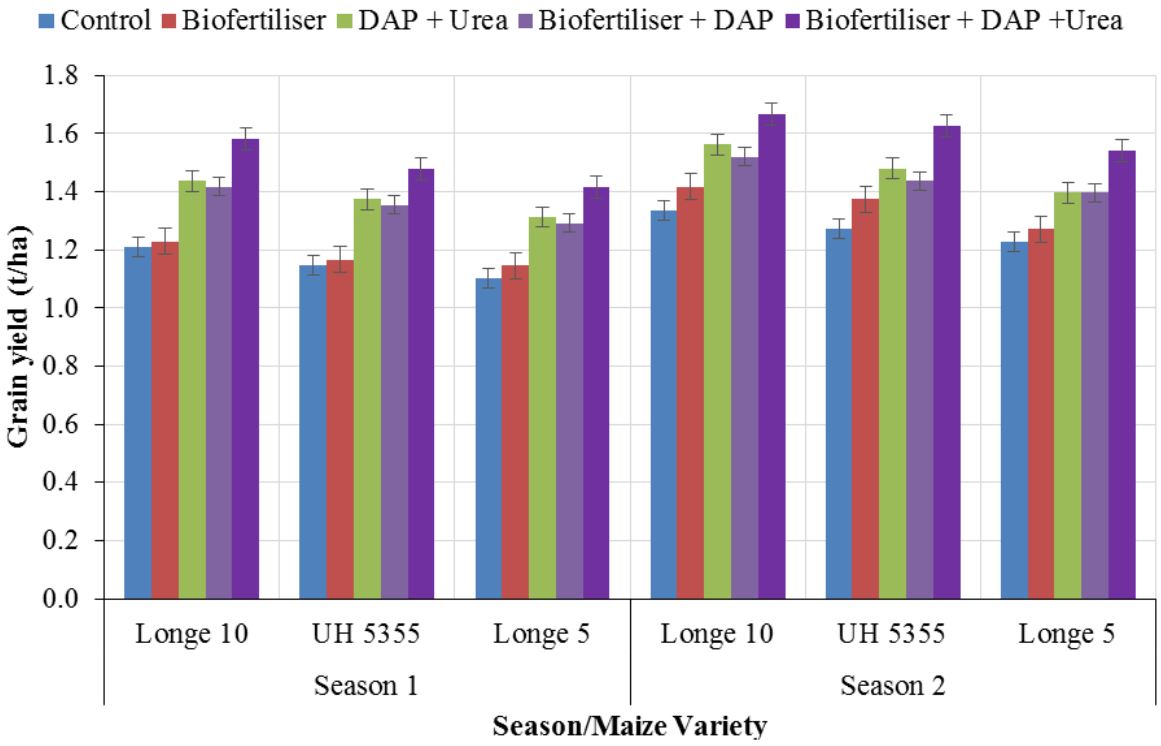


Figure 1. Grain yield of maize varieties under different treatment. Columns represent mean ± Standard Errors.

is significantly cheaper than using chemical fertilizers (DAP and urea). A sole application of biofertilizers is more cost-effective than their combined application with DAP, urea, or both.

Although the results show that the yield potential was higher when both biofertilizers and inorganic fertilizers were used, the yield margin was relatively small. This supports the importance of biofertilizers as both cost-effective and beneficial for improving soil fertility and maize yield. Biofertilizers are natural fertilizers containing living microorganisms (live biomass or dormant cells of effective microbial strains) that, when applied to seed, plant surfaces, or soil, colonize the rhizosphere and enhance growth by increasing the supply or availability of primary nutrients to the host plant. These findings are consistent with Suhag (2016), Carswell et al. (2019), and Sammauria et al. (2020), who observed that the cost of applying biofertilizers alone is low, whereas chemical fertilizers are more expensive. For optimal production, the integrated application of biofertilizers is relatively cost-effective, particularly for large-scale producers. However, smallholder farmers often rely solely on biofertilizers due to their lower cost or on chemical fertilizers based on their knowledge and availability.

Conclusion

The application of biofertilizers in maize production had a positive effect on both growth and yield. While sole application of biofertilizers had a lower impact on maize growth and yield potential, a combined application of biofertilizers + DAP + urea produced the most optimal maize growth and yield. However, biofertilizers were found to be cost-effective compared to DAP + urea fertilizers. Biofertilizers cost a fraction of what is required for DAP + urea or the combined application of biofertilizers + DAP + urea, yet the yield potential achieved with biofertilizers was comparable to that of DAP + urea or the combined application. Additionally, the Longe 10H maize variety achieved higher yield potential compared to UH5355 and Longe 5. Although biofertilizers significantly improved maize growth and yield, further studies are needed to investigate their long-term effects on soil chemical properties and nutrient uptake to better understand the mechanisms behind these improvements. Additionally, research should explore the interactive effects of biofertilizers with other chemical fertilizers beyond urea and diammonium phosphate, as well as organic amendments, to assess their potential influence on maize yield.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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