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Biofertilizers and Maize: Impacts on Growth and Productivity in Sustainable Agriculture

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Abstract

The use of biofertilizers in modern agriculture represents a sustainable alternative to the excessive use of chemical fertilizers, contributing to improved soil health, enhanced nutrient uptake efficiency, and reduced environmental impacts. This research aimed to determine the effect of combined doses of biol (*Moringa oleifera* Lam) and bitter melon (*Momordica charantia*) applied via soil and foliar routes on maize (*Zea mays* L.) cultivation. The methodology used was a cross-sectional experimental field study employing a factorial design represented by two factors (F(A) foliar and F(B) soil), for a total of 16 combinations (4 foliar applications × 4 soil applications) with 3 replicates, resulting in 48 experimental units across an area of 260 m^2. Regarding the research results obtained, it was determined that the effect of moringa and bitter melon showed significant differences among the combinations and treatments, where A2B3 (760 $L \cdot ha^{-1}$ foliar + 11,400 $L \cdot ha^{-1}$ soil) showed the highest vegetative and yield averages, reaching a cob weight of 0.37 kg, equivalent to 8700 $kg \cdot ha^{-1}$ of grain, representing a 7.27% increase compared to the control. This dose exhibited greater physiological characteristics in the corn seedlings, such as weight, stem diameter, and height. In this case, significant differences were observed between the treatments, thereby supporting the alternative hypothesis of this study.

Subject Areas

Earth & Environmental Sciences and Engineering

Keywords

Biol, Balsam Pear, Moringa, Corn, Biofertilizers, Foliar, Soil

1. Introduction

Conventional agricultural production heavily relies on inorganic fertilizers and pesticides for plant nutrition and crop protection, which have negative environmental and public health impacts. These include soil contamination, water and air pollution, and the development of antimicrobial resistance. Organic agriculture, on the other hand, is oriented towards sustainability, focusing on natural processes like biological control, soil formation, and nutrient recycling. Biofertilizers play a crucial role in maintaining soil fertility in sustainable cropping systems. According to Nedunchezhiyan *et al.* (2018) [1], there is a growing demand for bio-based organic fertilizers as an alternative to agrochemicals. Maize (*Zea mays* L.), the second-largest cereal globally, ranks second globally after wheat and has the highest grain yield per hectare. It is essential for human food, animal feed, and balanced feed for farm animals [2] [3].

The dependence on chemical inputs for agricultural production in Latin America and the Caribbean (LAC) has made countries in the region vulnerable to international market volatility. In the first six months of 2022, chemical fertilizer imports in 18 LAC countries increased by 136.6% compared to 2021, largely due to factors such as the armed conflict between Russia and Ukraine, global demand for inputs due to the pandemic, and high energy and transportation costs [4]. In the Dominican Republic, maize cultivation relies heavily on chemical fertilization, leading to a decline in beneficial soil microorganisms and a loss of productivity. However, maize's high adaptability to various ecological and edaphic conditions makes it a potential solution [2] [5].

Organic matter sources offer agronomic benefits, but global technological innovation requires finding fertilizers that preserve ecological balance and are economically viable [6]. Modernizing the agricultural sector and using land efficiently are strategic for food security, reducing rural poverty, and promoting sustainable development [7]. Bioles, liquid biofertilizers obtained from the anaerobic digestion process of organic materials, are rich in nutrients and phytohormones and have positive effects on foliar or soil [8]. They enhance the availability of macro- and micronutrients through processes like biological nitrogen fixation, phosphate solubilization, potassium mineralization, plant growth regulator release, antibiotic production, and biodegradation of organic matter [9].

Moringa (*Moringa oleifera* Lam.) and bitter melon (*Momordica Charantia*) are plant hormones with high fertilizing capacity and potential insecticidal effects [10]. *Moringa oleifera* has zeatin and cytokinins, ascorbates, phenols, and minerals, while bitter melon has saponins and is used to control pests like *Fossaria cubensis* [11]. These plants can address agricultural sector limitations in organic fertilization and sustainable phytosanitary control. This study evaluates the use of *Moringa oleifera* and *Momordica charantia* bio-digestates as a biofertilizer alternative for small-scale farmers in Dominican agriculture. This economical, ecological, and locally available solution reduces dependence on synthetic fertilizers and offers an economical, ecological, and locally available solution.

This study aims to assess the impact of combined soil- and foliar-applied bio-extracts from the moringa plant (*Moringa oleifera* Lam.) and bitter melon (*Momordica charantia*) on maize (*Zea mays* L.) cultivation.

2. Materials and Methods

The research was conducted on a farm in the Las Yayas area, La Vega Province, Dominican Republic, located at 19˚14'58.8"N, 70˚29'06.5"W, at an elevation of 90 m above sea level. The average temperature during the period was 26.6˚C, with recorded minimum and maximum temperatures of 21˚C and 32.5˚C, and an average relative humidity of 78%. The field evaluation period ran from March to May 2024.

2.1. Study Design

A completely randomized design (CRD) with a 4 × 4 factorial arrangement was employed, in which factor A corresponded to four levels of foliar application and factor B to four levels of soil application, generating 16 treatment combinations (4 × 4), as described in Table 1. Each treatment was replicated three times, resulting in a total of 48 experimental units and 12 plants per replicate, for a total of 576 plants in the experiment.

The experiment was established in a total area of 260 m^2, with a planting grid of 0.80 m between rows and 0.50 m between plants. Each experimental plot measured 3.20 m × 2.00 m (6.4 m^2). Moringa (*Moringa oleifera*) and bitter melon (*Momordica charantia*) bio-fertilizers, although fermented separately, were mixed in a 1:1 (v/v) ratio for combined application in the treatments, allowing evaluation of their joint effect on the crop's agronomic variables.

The combinations of the 16 treatments were the four foliar-applied doses (A0, A1, A2, A3) and the four soil-applied doses (B0, B1, B2, B3), where all applications were based on a volume/volume (water/biol) ratio (Table 1), using 15 L of water per application for the foliar factor (A) and 78 L for the soil factor (B). The planting material consisted of Dorado F1 corn seeds, sown directly into the soil.

Table 1. Combination and description of treatments.

Treatments	Factor A: Foliar	Factor B: Soil
	Biol Quantity ($l \cdot ha^{-1}$)	**Biol Quantity ($l \cdot ha^{-1}$)**
A0B0	0	0
A0B1	0	3800
A0B2	0	7600
A0B3	0	11,400
A1B0	380	0
A1B1	380	3800
A1B2	380	7600

Continued

A1B3	380	11,400
A2B0	760	0
A2B1	760	3800
A2B2	760	7600
A2B3	760	11,400
A3B0	1140	0
A3B1	1140	3800
A3B2	1140	7600
A3B3	1140	11,400

2.2. Preparation and Application of the Biofertilizer

Liquid biofertilizers (bioles) from *Moringa oleifera* and *Momordica charantia* were prepared separately in 120-liter biodigesters, using 6.82 kg of fresh foliar per tank. The plant material was mixed with water to a depth of three-quarters of the container's capacity and sealed airtight to induce anaerobic fermentation for 90 days. Once the process was completed, the biol was filtered through a sieve to separate the liquid fraction, which was then packaged, labelled, and subjected to chemical composition analysis for application at different doses during the crop's phenological stages (**Table 2**).

A soil fertility analysis was conducted by sampling the experimental area to determine nutrient availability (**Table 2**). The biofertilizer was applied every 15 days, according to the treatments defined in the experimental design. Weed control was carried out manually throughout the entire crop cycle.

Table 2. Chemical results of soil analysis and biological fertilizers.

Parameters	Soil	Biol Moringa	Biol bitter melon
pH	–	5.34	6.73
EC (μmhos/cm)	–	4340	2790
pH (1:2 H_2O)	6.67	–	–
EC (1:2 H_2O)	0.16	–	–
Organic Matter (ppm)	5.74	500	200
CEC (meq/100 g)	23.23	–	–
Organic Carbon (ppm)	–	300	100
Nitrogen (ppm)	–	300	100
C/N Ratio	–	9900	0.87
Phosphorus (ppm)	5.67	10	10
Calcium (Ca^{2+}, ppm)	19.4	700	420
Magnesium (Mg^{2+}, ppm)	2.6	120	120

Continued

Potassium (K^+, % w/w)	1.01	<200	<200
Copper (Cu^{2+}, ppm)	38.67	<6	<6
Sodium (Na^+, meq/100 g)	0.38	–	–
Al^{3+} + H^+ (meq/100 g)	–	–	–
Ca/Mg Ratio	7.41	–	–
Ca/K Ratio	19.02	–	–
Mg/K Ratio	2.58	–	–
(Ca + Mg)/K Ratio	21.7	–	–
Ca/Na Ratio	50.84	–	–
Manganese (Mn^{2+}, ppm)	24.06	<40	<40
Iron (Fe^{2+}, ppm)	69.05	<12	<12
Zinc (Zn^{2+}, ppm)	25.06	<2	<2
% Aluminum Saturation	–	–	–
% Calcium Saturation	82.84%	–	–
% Magnesium Saturation	11.18%	–	–
% Potassium Saturation	4.33%	–	–
% Sodium Saturation	1.65%	–	–

2.3. Statistical Analysis

Data analysis was performed using a two-way analysis of variance (ANOVA), considering the main effects of foliar application (factor A), soil application (factor B), and their interaction (A × B). The dependent variables of interest (cob weight (cm), cob diameter, cob length (cm), maize crop yield ($kg \cdot ha^{-1}$), plant height (cm), plant stem diameter (cm), and number of leaves per plant) were evaluated using Minitab statistical software version 19, with a 5% significance level. Means were separated using Tukey's test ($\alpha = 0.05$); significant differences among treatments are indicated by different superscripts. A generalized linear model (GLM) was fitted with a Box-Cox transformation $\lambda = 0$ (equivalent to log) for continuous, positive, and skewed variables. Parameters were estimated by maximum likelihood using iteratively reweighted least squares (IRLS).

3. Results

The results of the variables measured in the study are presented in **Table 3** to determine the yield and vegetative development or characteristics of the corn crop, such as cob weight (kg), cob diameter (cm), cob length (cm), corn crop yield ($kg \cdot ha^{-1}$), plant height (m), plant stem diameter (cm), and number of green leaves with intact foliar structure per plant.

Table 3. Treatment results in the evaluation of the effect of biofertilizer on the development and production of corn (*Zea mayz* L.) crop.

Treatments F(A) × F(B)	Cob Weight (kg)	Cob Diameter (cm)	Cob Length (cm)	Corn Yield (Kg·ha^{-1})	Plant Height (m)	Stem Diameter (cm)	Number of Leaves per Plant
A0B0	0.24	4.56	17.40	6300.0	1.44	1.36	13.80
A0B1	0.31	5.05	16.20	7400.0	1.56	1.71	14.80
A0B2	0.32	5.21	17.67	7600.0	1.60	1.69	14.93
A0B3	0.32	5.25	18.13	7900.0	1.63	1.76	14.47
A1B0	0.28	4.98	17.69	6800.0	1.63	1.65	13.54
A1B1	0.28	4.70	17.20	8100.0	1.41	1.45	13.80
A1B2	0.29	8.67	17.15	7300.0	1.62	1.68	14.38
A1B3	0.33	5.53	18.14	8000.0	1.62	1.73	14.86
A2B0	0.36	5.55	18.00	8100.0	1.64	1.66	14.58
A2B1	0.34	5.60	17.08	8200.0	1.69	1.76	15.08
A2B2	0.28	5.09	17.93	7200.0	1.66	1.62	15.21
A2B3	0.37	5.34	18.79	8700.0	1.77	1.86	15.29
A3B0	0.31	5.26	17.25	6500.0	1.61	1.61	14.31
A3B1	0.34	5.31	18.06	7700.0	1.59	1.66	14.75
A3B2	0.35	5.56	17.14	8700.0	1.61	1.69	13.64
A3B3	0.37	5.47	17.79	8800.0	1.70	1.81	15.29

3.1. Determination of Corn Crop Yield

The study evaluated variables such as cob weight, diameter, length, and maize crop yield to determine corn crop yield. A hypothesis test was conducted to verify randomness, homogeneity of variances, and normality. Results showed that the data did not follow a normal distribution, but homogeneity of variances was confirmed. In the absence of normality, an Analysis of Variance (ANOVA) was performed using a generalised Linear Model (GLM), allowing the statistical model to be properly fitted by employing distributions other than the normal distribution. The results obtained through generalized linear models (GLM) with a Box-Cox transformation $\lambda = 0$ (equivalent to log) reveal significant differences in the response of maize morphological and productive variables to factors F(A) and F(B) (Table 4).

3.1.1. Cob Weight (kg)

The study found that treatments A2B3 and A3B3 had the highest cob weight at 0.37 kg, followed by treatment A2B0 at 0.36 kg (Table 3). Statistically significant differences ($p \leq 0.05$) for all sources of variation were observed (Table 5). The model coefficient showed a significant difference among treatments A0B0, A2B0, and A2B2 when comparing the interactions (F(A) Foliar × F(B) Soil), while no

Table 4. Estimated coefficients of the GLMs, log link, for maize morphological and productive variables as a function of factors F(A) and F(B).

Response Variable	Treatments F(A) F × F(B) S	β (Coef.)	SE	95% CI	t-Value	p-Value
Cob weight (kg)	A0B0	−0.1364	0.0575	(−0.2499; −0.0229)	−2.37	0.019
	A0B1	0.0265	0.0575	(−0.0869; 0.1400)	0.46	0.645
	A0B2	0.1099	0.0575	(−0.0035; 0.2234)	1.91	0.057
	A0B3	−0.0001	0.0575	(−0.1135; 0.1134)	0	0.999
	A1B0	−0.0155	0.0575	(−0.1290; 0.0980)	−0.27	0.788
	A1B1	0.013	0.0575	(−0.1005; 0.1265)	0.23	0.821
	A1B2	0.0289	0.0575	(−0.0846; 0.1424)	0.5	0.616
	A1B3	−0.0264	0.0575	(−0.1399; 0.0870)	−0.46	0.646
	A2B0	0.1705	0.0575	(0.0571; 0.2840)	2.97	0.003
	A2B1	0.0037	0.0575	(−0.1097; 0.1172)	0.07	0.948
	A2B2	−0.1932	0.0575	(−0.3067; −0.0798)	−3.36	0.001
	A2B3	0.019	0.0575	(−0.0945; 0.1324)	0.33	0.742
	A3B0	−0.0186	0.0575	(−0.1321; 0.0948)	−0.32	0.746
	A3B1	−0.0433	0.0575	(−0.1567; 0.0702)	−0.75	0.453
	A3B2	0.0544	0.0575	(−0.0591; 0.1679)	0.95	0.345
	A3B3	0.0075	0.0575	(−0.1059; 0.1210)	0.13	0.896
Cob diameter (cm)	A0B0	−0.0619	0.0193	(−0.1000; −0.0239)	−3.21	0.002
	A0B1	0.0054	0.0193	(−0.0326; 0.0435)	0.28	0.779
	A0B2	0.0193	0.0193	(−0.0188; 0.0573)	1	0.319
	A0B3	0.0373	0.0193	(−0.0008; 0.0753)	1.93	0.055
	A1B0	−0.0032	0.0193	(−0.0412; 0.0349)	−0.16	0.87
	A1B1	−0.0245	0.0193	(−0.0625; 0.0135)	−1.27	0.205
	A1B2	0.0017	0.0193	(−0.0363; 0.0397)	0.09	0.93
	A1B3	0.026	0.0193	(−0.0121; 0.0640)	1.35	0.18
	A2B0	0.0671	0.0193	(0.0291; 0.1052)	3.48	0.001
	A2B1	0.0456	0.0193	(0.0076; 0.0836)	2.37	0.019
	A2B2	−0.0595	0.0193	(−0.0975; −0.0214)	−3.09	0.002
	A2B3	−0.0533	0.0193	(−0.0913; −0.0152)	−2.76	0.006
	A3B0	−0.0021	0.0193	(−0.0401; 0.0360)	−0.11	0.915
	A3B1	−0.0265	0.0193	(−0.0645; 0.0115)	−1.38	0.171
	A3B2	0.0385	0.0193	(0.0005; 0.0765)	2	0.047
	A3B3	−0.0099	0.0193	(−0.0480; 0.0281)	−0.52	0.606
Cob length (cm)	A0B0	0.0024	0.0232	(−0.0435; 0.0482)	0.1	0.919
	A0B1	−0.0551	0.0232	(−0.1010; −0.0093)	−2.37	0.019
	A0B2	0.0254	0.0232	(−0.0205; 0.0712)	1.09	0.276

Continued

	A0B3	0.0274	0.0232	(−0.0185; 0.0732)	1.18	0.24
	A1B0	−0.0002	0.0232	(−0.0460; 0.0457)	−0.01	0.994
	A1B1	0.0369	0.0232	(−0.0090; 0.0827)	1.59	0.114
	A1B2	−0.0169	0.0232	(−0.0627; 0.0290)	−0.73	0.468
	A1B3	−0.0198	0.0232	(−0.0656; 0.0260)	−0.85	0.395
	A2B0	0.0114	0.0232	(−0.0344; 0.0573)	0.49	0.624
	A2B1	−0.0175	0.0232	(−0.0634; 0.0283)	−0.76	0.451
	A2B2	0.0017	0.0232	(−0.0441; 0.0475)	0.07	0.942
	A2B3	0.0044	0.0232	(−0.0414; 0.0503)	0.19	0.849
	A3B0	−0.0136	0.0232	(−0.0594; 0.0322)	−0.59	0.559
	A3B1	0.0358	0.0232	(−0.0100; 0.0817)	1.54	0.125
	A3B2	−0.0102	0.0232	(−0.0560; 0.0356)	−0.44	0.661
	A3B3	−0.012	0.0232	(−0.0579; 0.0338)	−0.52	0.605
Corn yield ($Kg\cdot ha^{-1}$)	A0B0	−0.0752	0.0709	(−0.2151; 0.0648)	−1.06	0.291
	A0B1	0.0033	0.0709	(−0.1367; 0.1433)	0.05	0.963
	A0B2	0.0783	0.0709	(−0.0617; 0.2183)	1.1	0.271
	A0B3	−0.0064	0.0709	(−0.1464; 0.1336)	−0.09	0.928
	A1B0	0.0035	0.0709	(−0.1365; 0.1435)	0.05	0.961
	A1B1	0.0489	0.0709	(−0.0911; 0.1889)	0.69	0.491
	A1B2	−0.0112	0.0709	(−0.1512; 0.1288)	−0.16	0.874
	A1B3	−0.0412	0.0709	(−0.1812; 0.0988)	−0.58	0.562
	A2B0	0.1304	0.0709	(−0.0096; 0.2704)	1.84	0.068
	A2B1	0.0143	0.0709	(−0.1257; 0.1543)	0.2	0.84
	A2B2	−0.1573	0.0709	(−0.2973; −0.0173)	−2.22	0.028
	A2B3	0.0126	0.0709	(−0.1274; 0.1526)	0.18	0.859
	A3B0	−0.0588	0.0709	(−0.1987; 0.0812)	−0.83	0.409
	A3B1	−0.0665	0.0709	(−0.2065; 0.0735)	−0.94	0.35
	A3B2	0.0903	0.0709	(−0.0497; 0.2303)	1.27	0.205
	A3B3	0.035	0.0709	(−0.1050; 0.1750)	0.49	0.623
Plant height (m)	A0B0	−0.04716	0.00821	(−0.06335; −0.03096)	−5.75	0
	A0B1	0.02778	0.00821	(0.01158; 0.04397)	3.39	0.001
	A0B2	0.00847	0.00821	(−0.00772; 0.02467)	1.03	0.303
	A0B3	0.01091	0.00821	(−0.00528; 0.02710)	1.33	0.185
	A1B0	0.04928	0.00821	(0.03309; 0.06547)	6.01	0
	A1B1	−0.0292	0.00821	(−0.04539; −0.01300)	−3.56	0
	A1B2	−0.00453	0.00821	(−0.02073; 0.01166)	−0.55	0.581
	A1B3	−0.01555	0.00821	(−0.03175; 0.00064)	−1.9	0.06

Continued

	A2B0	−0.00593	0.00821	(−0.02213; 0.01026)	−0.72	0.47
	A2B1	0.02379	0.00821	(0.00759; 0.03998)	2.9	0.004
	A2B2	−0.03468	0.00821	(−0.05087; −0.01849)	−4.23	0
	A2B3	0.01683	0.00821	(0.00063; 0.03302)	2.05	0.042
	A3B0	0.00381	0.00821	(−0.01238; 0.02001)	0.46	0.643
	A3B1	−0.02237	0.00821	(−0.03856; −0.00617)	−2.73	0.007
	A3B2	0.03074	0.00821	(0.01455; 0.04693)	3.75	0
	A3B3	−0.01218	0.00821	(−0.02838; 0.00401)	−1.48	0.139
Stem diameter (cm)	A0B0	−0.1184	0.0209	(−0.1596; −0.0772)	−5.67	0
	A0B1	0.0578	0.0209	(0.0165; 0.0990)	2.77	0.006
	A0B2	0.0248	0.0209	(−0.0165; 0.0660)	1.19	0.238
	A0B3	0.0359	0.0209	(−0.0053; 0.0771)	1.72	0.088
	A1B0	0.0751	0.0209	(0.0339; 0.1163)	3.6	0
	A1B1	−0.062	0.0209	(−0.1032; −0.0208)	−2.97	0.003
	A1B2	0.0115	0.0209	(−0.0297; 0.0527)	0.55	0.583
	A1B3	−0.0246	0.0209	(−0.0658; 0.0166)	−1.18	0.241
	A2B0	0.042	0.0209	(0.0008; 0.0833)	2.01	0.046
	A2B1	0.0309	0.0209	(−0.0104; 0.0721)	1.48	0.141
	A2B2	−0.0809	0.0209	(−0.1221; −0.0397)	−3.87	0
	A2B3	0.008	0.0209	(−0.0332; 0.0492)	0.38	0.702
	A3B0	0.0013	0.0209	(−0.0399; 0.0425)	0.06	0.951
	A3B1	−0.0266	0.0209	(−0.0678; 0.0146)	−1.27	0.204
	A3B2	0.0447	0.0209	(0.0034; 0.0859)	2.14	0.034
	A3B3	−0.0193	0.0209	(−0.0605; 0.0219)	−0.92	0.356
Number of leaves per plant	A0B0	−0.0164	0.0138	(−0.0437; 0.0109)	−1.19	0.237
	A0B1	0.0117	0.0138	(−0.0156; 0.0389)	0.84	0.4
	A0B2	0.0223	0.0138	(−0.0049; 0.0496)	1.62	0.108
	A0B3	−0.0176	0.0138	(−0.0449; 0.0097)	−1.27	0.205
	A1B0	−0.0027	0.0138	(−0.0299; 0.0246)	−0.19	0.847
	A1B1	0.0138	0.0138	(−0.0135; 0.0411)	1	0.318
	A1B2	−0.011	0.0138	(−0.0382; 0.0163)	−0.79	0.429
	A1B3	−0.0002	0.0138	(−0.0275; 0.0271)	−0.02	0.988
	A2B0	0.0147	0.0138	(−0.0126; 0.0420)	1.07	0.288
	A2B1	−0.0141	0.0138	(−0.0414; 0.0132)	−1.02	0.309
	A2B2	0.0024	0.0138	(−0.0249; 0.0297)	0.17	0.863
	A2B3	−0.003	0.0138	(−0.0303; 0.0243)	−0.22	0.828
	A3B0	0.0043	0.0138	(−0.0229; 0.0316)	0.31	0.754

Continued

	A3B1	−0.0114	0.0138	(−0.0387; 0.0159)	−0.82	0.412
	A3B2	−0.0138	0.0138	(−0.0411; 0.0135)	−1	0.32
	A3B3	0.0208	0.0138	(−0.0065; 0.0481)	1.51	0.134

Regression analysis (GLM-type with Box-Cox transformation $\lambda = 0$, equivalent to log).

significant differences were found for the remaining combined treatments (Table 4). The multiple comparison test of Tukey is shown in Table 6. The R^2 values obtained (<30%) indicate that, although the model partially explains the variability, unmeasured environmental and management factors also contributed to yield, which is common in field trials.

Table 5. ANOVA test for the variables determining corn crop yield by treatments.

Source of Variation	[1]Weight of the Cob (kg)		[2]Diameter of the Cob (cm)		[3]Cob Length (cm)		[4]Corn Crop Yield (Kg·ha^{-1})	
	F-Value	p-Value	F-Value	p-Value	F-Value	p-Value	F-Value	p-Value
F(A) F	3.92	0.010	6.68	0.000	0.88	0.452*	1.09	0.354*
F(B) S	4.21	0.007	4.72	0.003	1.73	0.162*	3.21	0.024
F(A) F × F(B) S	1.98	0.044	3.80	0.000	1.16	0.325*	0.79	0.627*

Note: *Significant at the $\alpha = 0.05$. F(A) F: Factor (A) Foliar, F(B) F: Factor (B) soil. [1]S = 0.153911. R^2 = 19.34%; [2]S = 0.461521. R^2 = 27.98%; [3]S = 1.78827. R^2 = 9.40%; [4]S = 2296.58. R^2 = 10.21%.

Table 6. Multiple mean comparison of treatments.

Treatments F(A) F × F(B) S	Weight of the Cob (kg)	Diameter of the Cob (cm)	Cob Length (cm)	Corn Crop Yield (Kg·ha^{-1})	Plant Height (m)	Plant Stem Diameter (cm)	Number of Leaves per Plant
				Means			
A0B0	0.525000^{b}	45.5000^{c}	17.6667^{a}	6250.00^{a}	1.44500^{g}	13.3333^{d}	13.5^{c}
A0B1	0.666667^{ab}	50.5000^{abc}	16.3333^{a}	7424.24^{a}	1.56833^{ed}	17.0000^{abc}	14.75^{abc}
A0B2	0.683333^{ab}	51.2500^{abc}	17.7500^{a}	7613.64^{a}	1.59583^{def}	16.7500^{abc}	14.9167^{ab}
A0B3	0.716667^{ab}	54.0000^{ab}	18.5833^{a}	7878.79^{a}	1.63000^{cde}	17.6667^{abc}	14.4167^{abc}
A1B0	0.616667^{ab}	49.7500^{bc}	17.9167^{a}	6780.30^{a}	1.62833^{cde}	16.4167^{abc}	13.75^{bc}
A1B1	0.683333^{ab}	50.4167^{abc}	18.3333^{a}	8143.94^{a}	1.51750^{fg}	15.5000^{cd}	14.8333^{ab}
A1B2	0.666667^{ab}	52.0000^{abc}	17.3333^{a}	7348.48^{a}	1.61250^{cde}	16.9167^{abc}	14.5^{abc}
A1B3	0.725000^{ab}	55.0000^{ab}	18.0833^{a}	7992.42^{a}	1.62500^{cde}	17.0000^{abc}	14.75^{abc}
A2B0	0.791667^{a}	55.5000^{ab}	18.0000^{a}	8106.06^{a}	1.63583^{cde}	16.5833^{abc}	14.5833^{abc}
A2B1	0.733333^{ab}	56.3333^{a}	17.2500^{a}	8219.70^{a}	1.69667^{abc}	17.6667^{abc}	15.0833^{a}
A2B2	0.608333^{ab}	50.9167^{abc}	17.8333^{a}	7196.97^{a}	1.66167^{bcd}	16.1667^{abc}	15.3333^{a}
A2B3	0.791667^{a}	52.6667^{ab}	18.3333^{a}	8712.12^{a}	1.78333^{a}	18.3333^{a}	15.3333^{a}
A3B0	0.666667^{ab}	51.8333^{abc}	17.1667^{a}	6515.15^{a}	1.61583^{cde}	15.9167^{bc}	14.0833^{abc}

Continued

A3B1	0.716667[ab]	52.3333[ab]	17.7500[a]	7651.52[a]	1.58500[def]	16.6667[abc]	14.6667[abc]
A3B2	0.766667[a]	56.0833[ab]	17.0000[a]	8712.12[a]	1.73500[ab]	18.2500[a]	14.6667[abc]
A3B3	0.800000[a]	55.0833[ab]	17.6667[a]	8787.88[a]	1.69583[abc]	17.8333[ab]	15.25[a]

Means not sharing a letter are significantly different according to Tukey's test ($\alpha = 0.05$).

3.1.2. Cob Diameter (cm)

Treatment A1B2 produced an average cob diameter of 8.67 cm, while treatments A2B1 and A3B2 had averages of 5.60 cm and 5.56 cm, respectively. The other treatments exhibited reduced mean diameters (Table 3). Significant differences were observed between treatments for variables and interactions of foliar and soil application (Table 5), whereas no statistically significant differences were observed for the other interaction treatments.

3.1.3. Cob Length (cm)

The study measured cob length in various treatments, with the A2B3 treatment having the highest mean of 18.79 cm. The A1B3 and A0B3 treatments had the lowest means of 18.14 cm and 18.13 cm, respectively. The A0B1 combination had the lowest means of 16.20 cm (Table 3). The ANOVA fit of GLM showed no significant differences among the treatments or in the interactions of factors A and B (Table 5). However, the A0B1 combination had the highest mean difference ($p < \alpha < 0.05$) for foliar F(A) and soil F(B), indicating a significant difference. No significant differences were found for the remaining interaction (Tables 4-6).

3.1.4. Corn Crop Yield in kg

The study analyzed the effects of biofertilizer application factors on crop yield. The combined treatment A3B3 (F(A) 1140 $L \cdot ha^{-1}$ of biofertilizer + F(B) 11,400 $L \cdot ha^{-1}$ of biofertilizer) had a mean of 8800 $kg \cdot ha^{-1}$, compared to treatments A2B3 and A3B2, which had the same weight (8700 $kg \cdot ha^{-1}$) (Table 3). The ANOVA test showed no significant differences between the foliar factor F(A) and the interactions, but the soil factor F(B) did show a significant difference (Table 5). The coefficient for the treatment combinations in crop yield showed no significant difference (Table 4).

3.2. Determination of the Vegetative Development or Characteristics of the Maize Crop

The study evaluated the vegetative development of maize crops by considering variables like plant height, stem diameter, and leaf count. The hypothesis of equality or difference between treatments was tested, verifying randomness, homogeneity of variances, and normality. If the data did not meet normality assumptions, an Analysis of Variance (ANOVA) was performed using a generalised Linear Model (GLM) framework. The normality test showed that the data for the treatments were not normally distributed, while the homogeneity test indicated that the data were homogeneous. A statistical analysis of variance was performed to fit the statistical model. Table 6 presents the results of Tukey's multiple comparison test for the different variables.

3.2.1. Plant Height (m)

Plant height was measured 25 days before crop harvest, from the base of the stem to the anthers or spikes. Treatment A2B3 (F(A) 760 $L \cdot ha^{-1}$ of biofertilizer + F(B) 11,400 $L \cdot ha^{-1}$ of biofertilizer) reached the greatest height at 1.77 m, followed by treatment A3B3 at 1.70 m. The control A0B0 (control: 0 $L \cdot ha^{-1}$ of biofertilizer on foliar and soil) exhibited the lowest height at 1.44 m (Table 3). The ANOVA for the Generalised Linear Model (GLM) showed a statistically significant difference among treatments, factors, and the foliar F(A) × soil F(B) interaction (Table 7).

Table 7. ANOVA test for variables determining the development or vegetative characteristics of corn crops by Treatments.

Source of Variation	[1]Plant Height (m)		[2]Plant Stem Diameter (cm)		[3]Number of Leaves per Plant	
	F-Value	p-Value	F-Value	p-Value	F-Value	p-Value
F(A) F	44.22	0.000	5.17	0.002	5.91	0.001
F(B) S	28.63	0.000	16.20	0.000	12.41	0.000
F(A) F × F(B) S	8.80	0.000	5.34	0.000	0.94	0.492*

Note: *Significant at the $\alpha = 0.05$. F(A) F: Factor (A) Foliar, F(B) F: Factor (B) soil. [1]S = 0.0630408. $R^2 = 62.85\%$. [2]S = 0.154080. $R^2 = 38.91\%$. [3]S = 0.885222. $R^2 = 26.49\ \%$.

3.2.2. Plant Stem Diameter (cm)

The study found that treatments A2B3 and A3B3 had the highest average cob diameter, with no significant differences between them (Table 3). ANOVA showed significant differences among treatments and in the interaction between foliar and soil biofertilizer application factors (Table 7). The model's adjustment coefficients showed significant differences in treatment combinations A0B0, A0B1, A1B0, A1B1, and A3B2, but no significant differences were observed in the remaining combinations due to the interaction effect between the factors.

3.2.3. Number of Leaves per Plant

The number of leaves per plant at 60 days, considering true green leaves, was evaluated. The treatments A2B3 and A3B3 had an average of 15.29 leaves per plant, followed by A2B1 with 15.08 leaves and A1B0 with 13.54 leaves (Table 3). The ANOVA showed significant differences among the treatments, but the interaction between factors F(A) foliar × F(B) soil was not statistically significant (Table 7). The model's data-fitting coefficients also showed no statistically significant differences among the treatment interactions.

4. Discussion

The study evaluated maize's vegetative development and productivity using organic biofertilizers from *Moringa oleifera* and *Momordica charantia*. The A2B3 combination, which included foliar spray and soil application, achieved the highest averages for cob weight, cob length, and fresh-weight yield. However, it did not show superiority in cob diameter or cob length. The findings suggest that the impact of biofertilizers is not consistent across all indicators, highlighting the need to consider crop responses to biofertilizer doses and application methods. The ANOVA test showed significant differences in factors and treatment interactions for cob weight and cob diameter in foliar F(A) and interaction treatments, but no significant differences for cob length and crop yield. Liquid biofertilizers in maize have been shown to improve yield and fertilizer use efficiency, while also representing a cost-effective option for farmers [12] [13]. Although the application volumes reported in other trials were lower than the 11,400 $L \cdot ha^{-1}$ used in this study, the literature supports the feasibility of high doses when adequate irrigation and low-cost *bioles* are available, confirming their technical and economic viability in tropical contexts.

These results are consistent with multiple studies reporting varying but generally positive effects of biofertilizers on maize. Related studies found significant differences among doses, with treatment T3 (1500 mL biol in 20 L water) yielding 2.5 $t \cdot ha^{-1}$ of dry grain [6]. Other authors observed improvements in cob diameter and plant height in one plot, but cob weight and overall yield showed no statistical differences; treatment T3 averaged 5501 $kg \cdot ha^{-1}$ [14]. It also reported a yield of 8310 $kg \cdot ha^{-1}$ with biofertilizers, comparable to the best treatments in the current study [15]. Similar findings were reported by Gao *et al.* [16], who found that the combined application of organic and biofertilizers significantly improved maize yield parameters compared to control treatments. The study showed that the highest cob weight was obtained when biogas slurry, humic acid, and biofertilizer mixtures were applied together, demonstrating that integrated foliar and soil applications of organic inputs can enhance nutrient availability and overall crop productivity.

This study shows that biofertilizer applications significantly influenced vegetative growth in maize, with both foliar and soil treatments and their interactions affecting plant height, stem diameter, and leaf number. The A2B3 treatment (F(A) 760 $L \cdot ha^{-1}$ + F(B) 11,400 $L \cdot ha^{-1}$) produced a mean plant height of 1.77 m, an average stem diameter of 1.83 cm, and 15.29 leaves per plant. Literature comparisons support these findings: Ruiz (2015) [17] reported stronger effects of biofertilizers on plant height than on stem diameter or leaf number, while [18] found 800 $L \cdot ha^{-1}$ optimal for plant height. Duran, Plasencia, and Marte (2017) observed the greatest height (2.15 m) with a combined foliar and soil regime (F2S4). Also found that regular foliar sprays (moringa extract) after emergence enhanced leaf number, plant height, and biomass compared with controls [19].

The observed efficacy likely reflects the dual action of the bioles on root systems and enhanced nutrient uptake in the A2B3 treatment. Recent studies report that liquid biofertilizers—formulated with *Moringa, Trichoderma*, and bacteria such as *Bacillus subtilis*—can increase root development by up to 80% and improve phosphorus and nitrogen availability in maize [20]. Rhizospheric microorganisms also enhance P and K solubilisation and water uptake, aligning with the increases in cob weight and length observed here. Moreover, liquid biofertilizers and inoculation with plant growth–promoting bacteria (e.g. *Azotobacter, Bacillus*) boost chlorophyll content, photosynthetic efficiency, and antioxidant enzyme activity, reducing oxidative stress. These physiological improvements likely underlie the higher yields seen in the A2B3 treatment by enhancing metabolic capacity and stress resistance [21] [22].

The combined foliar and soil application of *Moringa oleifera* and *Momordica charantia* bio-extracts (A2B3) likely increased maize yield by stimulating endogenous phytohormones (auxins, gibberellins) and improving phosphorus and nitrogen uptake through enhanced rhizosphere microbial activity. This effect is consistent with reports that liquid biofertilizers boost photosynthesis, root growth, plant height, and dry weight. Evidence from Zakari and Belel (2024) [23] shows that moringa leaf extract plus organic matter increases leaf number, height, and grain yield. Although antioxidant enzymes (SOD, POD, CAT) were not measured here, A2B3 may also have enhanced stress resistance via similar biochemical responses, as seen in integrated systems combining biofertilizers and ZnO nanoparticles [24].

The control (A0B0), which received no foliar or soil biofertilizer, showed a significant GLM coefficient ($p < 0.05$). The absence of additional nutrient inputs produced the lowest mean values for most yield and morphological traits. These findings align with Ziau *et al.* (2021) [25], who reported the lowest grain yield per cob (127.33 g) in treatments T0 and T1 without Moringa oleifera foliar extract, confirming that the lack of plant-derived biostimulant compounds adversely affects maize development and productivity.

Overall, the results support using combined *Moringa oleifera* and *Momordica charantia* bioles as biofertilizers. Further research should include multi-year trials, nutritional and microbiological analyses of the bioles, and comparisons with conventional synthetic fertilizers to develop integrated agronomic recommendations for sustainable, profitable, and environmentally friendly production.

5. Conclusion and Implications

This study demonstrates that a liquid biofertilizer prepared from fresh leaves of *Moringa oleifera* and *Momordica charantia* confers agronomic benefits in maize grown for fresh consumption. The combined foliar and soil application (treatment A2B3) produced improvements in cob weight and diameter and enhanced vegetative characteristics, including plant height, stem diameter, and number of leaves, indicating a favorable vegetative response to this bio-input.

No significant differences were observed in cob length or total yield across the foliar and soil application interactions, suggesting that the biofertilizer's efficacy is contingent on application method and level, as well as the crop's specific physiological response. Practically, these results are relevant for sustainable agriculture, particularly for smallholder farmers with limited access to synthetic fertilizers. Biofertilizers formulated from locally available plant material represent a viable, cost-effective, and environmentally responsible strategy to reduce dependence on chemical inputs, improve soil health, and enhance the resilience of production systems.

Conflicts of Interest

The authors declare no conflicts of interest.

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