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Effect of Microbial Biostimulants on Maize Growth Parameters and Yield in Northern and Central Côte D'ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Maize production in Côte d'Ivoire is constrained by declining soil fertility and the high cost of mineral fertilisers. Microbial biostimulants may provide a complementary approach for improving crop performance while reducing dependence on chemical fertiliser inputs. This study evaluated the effects of arbuscular mycorrhizal fungi (AMF) and the plant growth-promoting rhizobacterium *Pseudomonas putida* on maize growth and yield in northern and central Côte d'Ivoire. Field trials were conducted in Boundiali, Ouangolodougou and Sakassou using the maize variety GMRP 18. Five treatments were assessed: T0, absolute control without fertiliser or biostimulant; T1, 100% recommended fertiliser plus urea; T2, AMF plus 50% recommended fertiliser plus urea; T3, *Pseudomonas putida* plus 50% recommended fertiliser plus urea; and T4, AMF plus *Pseudomonas putida* plus 50% recommended fertiliser plus urea. Growth parameters, including plant height, number of leaves, stem collar diameter and leaf area, were measured at 60 days after

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sowing. Yield components, including ear length, ear diameter, ear weight, number of grains per ear, grain weight per ear and final production, were assessed at harvest. The treatments significantly influenced maize growth and yield parameters. In general, T4 produced the best, or among the best, responses across several measured variables, while T2 and T3 also improved performance compared with the control. The findings indicate that microbial biostimulants, particularly the combined application of AMF and *Pseudomonas putida* with reduced mineral fertiliser input, may support maize growth and productivity under the studied agroecological conditions.

Keywords: Zea mays L.; arbuscular mycorrhizal fungi; Pseudomonas putida; plant growth-promoting rhizobacteria; microbial biostimulants; NPKSB fertiliser; mineral fertilisation; nutrient-use efficiency; grain yield.

1. Introduction

Maize (*Zea mays L.*) is one of the most important cereal crops and constitutes a staple food for millions of people throughout West Africa. Globally, maize accounts for approximately 41% of total cereal production, exceeding wheat (40%) and rice (9%) (Droh et al., 2022). In Côte d'Ivoire, maize is the second most cultivated cereal after rice and plays a key role in food security. It is consumed in various forms, including porridge, kabato, traditional beverages and fresh ears. In addition, maize is widely used as livestock feed for poultry, pigs and cattle, and it serves as a raw material in agro-industrial sectors such as brewing, soap manufacturing and oil processing (N'da et al., 2014). According to FAOSTAT (2024), national maize production reached approximately 1.64 million tonnes in 2024 from a cultivated area of about 640,000 ha, with an average yield of 2.56 t ha^{-1}. Despite its socioeconomic importance, maize production is increasingly constrained by declining soil fertility resulting from land degradation. Soil degradation is often characterised by nutrient imbalances, particularly deficiencies in nitrogen and phosphorus, as well as deterioration of soil structural properties (Ndiaye et al., 2023). Most maize production in Côte d'Ivoire is carried out by smallholder farmers, whose yields rarely exceed 1-2 t ha^{-1} per growing season (Siene et al., 2020). In response to increasing demographic pressure and growing food demand, farmers are compelled to cultivate the same land continuously, leading to accelerated depletion of soil fertility and reduced agricultural productivity (N'Guessan et al., 2019). Consequently, improving crop yield remains a major challenge for increasing agricultural production (Kouakou et al., 2024). This challenge is further aggravated by climate change, which is reflected in shorter rainy seasons, reduced precipitation and declining soil fertility, all of which contribute to lower crop yields (Soro et al., 2024). More broadly, maize production is threatened by continuous land degradation and nutrient depletion, as well as by the high cost of mineral fertilisers, which jeopardise the long-term sustainability of agricultural production systems (Olayossimi et al., 2026). To maintain productivity, farmers increasingly rely on chemical fertilisers and pesticides. However, excessive use of these inputs can accelerate soil acidification and reduce soil biodiversity, thereby negatively affecting environmental quality (Droh et al., 2022). Therefore, ensuring both food security and environmental sustainability requires the adoption of innovative and environmentally friendly soil fertility management strategies (Kouakou et al., 2024). In this context, biological alternatives based on beneficial microorganisms have attracted considerable attention. Arbuscular mycorrhizal fungi (AMF) and plant growth-promoting rhizobacteria (PGPR) are known to enhance nutrient availability, improve soil biological activity, stimulate root development and increase plant tolerance to environmental stresses. Recent evidence also indicates that biofertiliser-based or microbial inoculation strategies can improve maize growth, nutrient uptake and productivity when mineral fertiliser availability is limited or when plants are exposed to stress (Olayossimi et al., 2026; Nassif et al., 2025; Pang et al., 2024; Santana et al., 2023; Severo et al., 2025). However, field-based evidence remains limited on the combined use of arbuscular mycorrhizal fungi and *Pseudomonas putida* with a 50% reduction in mineral fertiliser across the contrasting maize-growing environments of northern and central Côte d'Ivoire, including Boundiali, Ouangolodougou and Sakassou. The present study was conducted to evaluate the effectiveness of microbial biostimulants based on AMF and PGPR in maize production. We hypothesised that the individual application of these microorganisms would improve maize growth, whereas their combined application would generate a synergistic effect capable of enhancing crop productivity. The overall objective of this study was to contribute to the sustainable improvement of maize production in Côte d'Ivoire through the integration of microbial biostimulants into crop management practices.

2. Materials and Methods

2.1 Material

2.1.1 Description of the Study Area

This study was conducted in the Tchologo (Ouangolodougou), Bagoué (Boundiali) and Gbêkê (Sakassou) regions of Côte d'Ivoire (Fig. 1). Field trials were established on farmers' fields involving 30 producers, with 10 farmers selected in each locality (Sakassou, Boundiali and Ouangolodougou). Each experimental plot covered an area of 300 m².

The Tchologo region (Ouangolodougou) is located between latitudes 9°20′ and 10°00′ N and longitudes 4°50′ and 5°50′ W, within the sub-Sudanian savanna zone. The area is characterised by a tropical dry climate, with a distinct dry season extending from November to June and a rainy season from July to October. Average annual rainfall is approximately 1,260 mm. The natural vegetation consists predominantly of savanna formations, including wooded, tree and shrub savannas (Kouakou et al., 2026).

The Gbêkê region (Sakassou) experiences a sub-humid tropical climate. Temperatures range from 14°C to 33°C, while relative humidity varies between 60% and 70%. According to Droh et al. (2022), average annual rainfall ranges from 1,000 to 1,600 mm and is distributed across four distinct seasons, comprising two dry seasons and two rainy seasons.

The Bagoué region (Boundiali) is located in northern Côte d'Ivoire between latitudes 9°21′ and 9°43′ N and longitudes 6°21′ and 6°48′ W, within the savanna agroecological zone, which is dominated by shrub savanna vegetation. The region is characterised by a tropical climate with two distinct seasons: a long dry season extending from October to April and a rainy season from May to September. The average annual temperature is approximately 33°C (Ouattara, 2023).

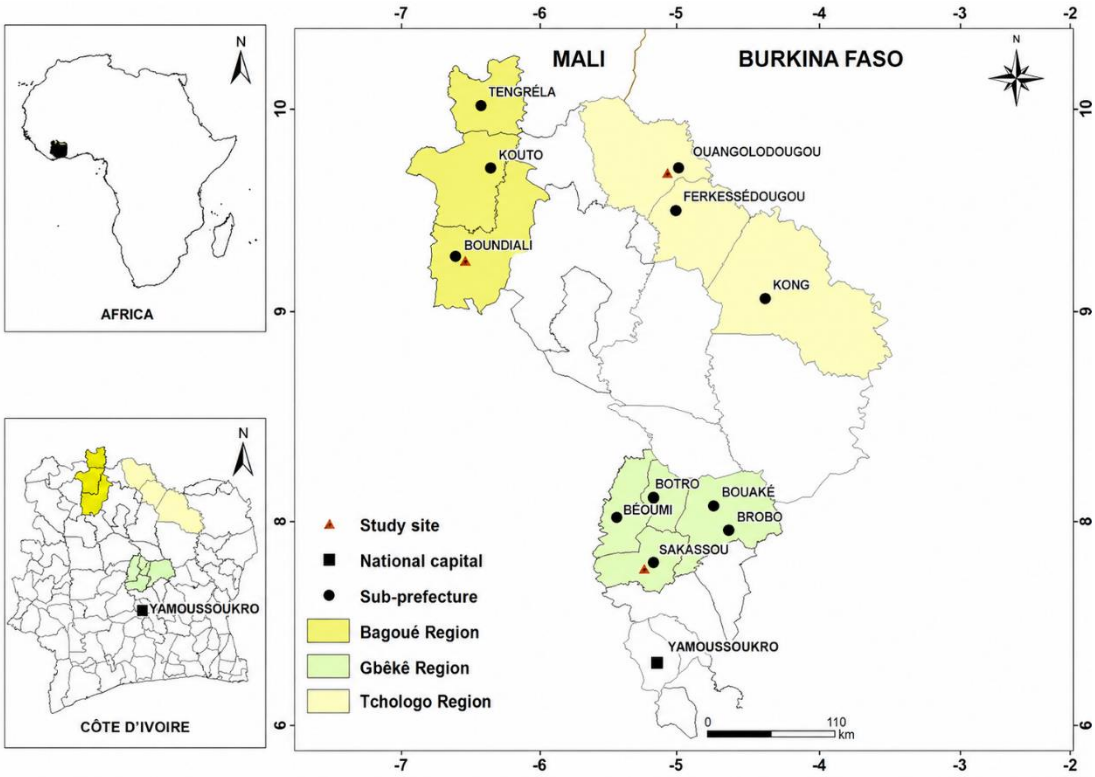

Fig. 1. Location map of the study areas

Source: Map created by the author using field GPS coordinates (Bohoussou, 2025)

2.1.2 Plant Material

The plant material consisted of seeds of the maize (*Zea mays L.*) variety GMRP 18 (Fig. 2). This maize variety has a growth cycle of approximately 90 days and a potential grain yield of 6 t ha⁻¹. The kernels are yellow and exhibit a semi-dent grain texture (Touré, 2025). This variety was selected because of its high yield potential, tolerance to maize streak disease, lodging and rust, as well as its good adaptation to intermediate-textured soils, including sandy, sandy-clay and clay-sandy soils. The seeds were supplied by the Korhogo Research Station of the National Centre for Agronomic Research (CNRA), Côte d'Ivoire.

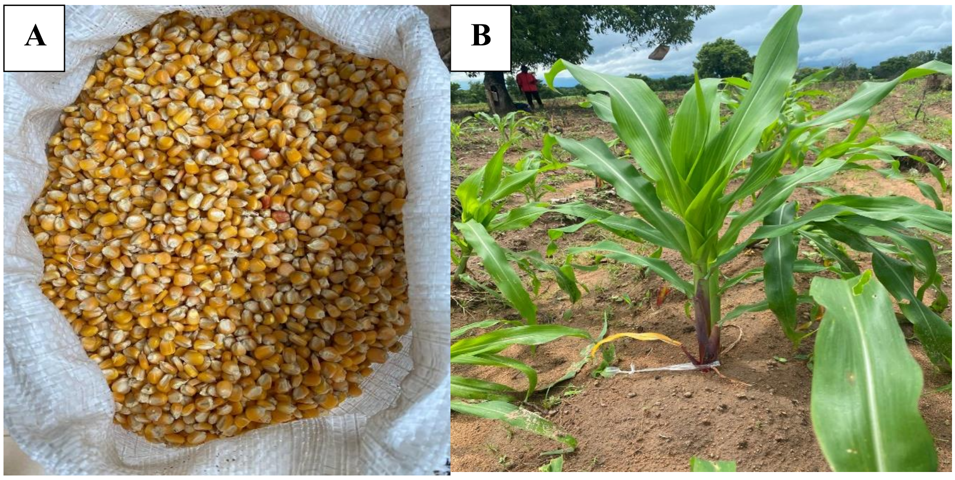

Fig. 2. Maize seeds (a) and maize plants (b). Source: Photographs by Bohoussou (2025)

2.1.3 Fungal Material

The fungal material used in this study consisted of spores of arbuscular mycorrhizal fungi (AMF) belonging to the family Glomeraceae, namely *Glomus caledonius*, *Rhizophagus intraradices* and *Funneliformis geosporum*, as well as strains of *Pseudomonas putida*, a plant growth-promoting rhizobacterium (PGPR). These microbial strains were originally isolated from the rhizosphere of maize plants in southern Benin by Aguégué (2020) and Adjanohoun et al. (2011). The microbial inocula were preserved at −20°C in Mueller-Hinton broth supplemented with 10% glycerol and were provided by the Laboratory of Biology and Molecular Typing in Microbiology (LBTMM), Benin.

2.2 Methods

2.2.1 Experimental Design and Treatments

A completely randomised block design was used, comprising five treatments with three replications. The treatments were as follows:

T0: Absolute control (no biostimulant and no fertiliser)
T1: 100% of the recommended dose of NPKSB fertiliser + urea
T2: AMF + 50% of the recommended dose of NPKSB fertiliser + urea
T3: PGPR + 50% of the recommended dose of NPKSB fertiliser + urea
T4: AMF + PGPR + 50% of the recommended dose of NPKSB fertiliser + urea

Each experimental plot covered an area of 300 m². The distance between plots was 1.5 m, while the distance between blocks was 2 m. Sowing was carried out by placing two seeds per planting hole, with a spacing of 0.5 m between planting holes and 1 m between rows. To minimise border effects, data were collected from the two central rows of the useful area of each elementary plot. NPKSB fertiliser was applied at sowing at a rate of 6 g per planting hole for treatment T1 and 3 g per planting hole for treatments T2, T3 and T4, in a neighbouring hole adjacent to the seed, except for the control treatment. Urea was used as a top-dressing fertiliser at a rate of 6 g per planting hole and was applied 45 days after sowing for all fertilised treatments, excluding the control. The recommended fertiliser rates corresponded to 200 kg ha^{-1} for NPKSB and 100 kg ha^{-1} for urea, respectively.

2.2.2 Data Collection

Measurements of plant height and stem diameter were carried out on eight (8) maize plants selected from the two central rows of each plot. Data were recorded every 15 days from sowing until 60 days after sowing (DAS). Leaf area measurements were taken at 60 DAS. Plant height was measured using a measuring tape from the collar (soil surface) to the last ligule. Stem diameter was measured at the collar level using a digital calliper. The number of leaves per plant was determined by direct counting. Leaf area was estimated using the following formula:

$$\text{Leaf area} = \text{Leaf length} \times \text{Leaf width} \times 0.75$$

For yield assessment, harvesting was conducted at 100 days after sowing (DAS). Ears were weighed using a precision electronic balance. The average ear diameter was measured using a calliper (cm), while ear length (cm) was determined using a measuring tape after harvest.

2.2.3 Statistical Analysis

The collected data were entered, coded and processed using Microsoft Excel. The normality of data distributions among treatments was assessed using the Shapiro-Wilk test, while the homogeneity of variances was verified using Levene's test. When the assumptions of normality and homoscedasticity were satisfied, an analysis of variance (ANOVA) was performed to evaluate the effects of the treatments on agronomic, morphological, yield and soil physicochemical parameters. When these assumptions were not met, the Kruskal-Wallis non-parametric test was applied. The hypothesis of equality of means was tested at the 5% significance level. Whenever significant differences were detected, Dunn's multiple comparison test ($\alpha = 0.05$) was used to classify treatment means into homogeneous groups under the null hypothesis of equal means.

3. Results and Discussion

3.1 Effect of Biostimulants on Maize Growth Parameters at 60 Days after Sowing

Table 1 presents the effects of the different treatments on maize growth parameters in the localities of Boundiali, Ouangolo and Sakassou. The parameters evaluated included plant height, number of leaves, stem diameter at the collar and leaf area. The results of the Kruskal-Wallis test revealed highly significant differences among treatments for all the growth parameters assessed ($p < 0.01$).

3.1.1 Plant Height Development

The results showed that mean plant height was significantly influenced by both the applied treatments and the study locations. At Boundiali, treatments T1 (115.47 ± 36.98 cm) and T4 (117.94 ± 36.27 cm) recorded the greatest plant heights and were not significantly different from each other. Treatments T2 and T3 exhibited intermediate values, whereas the control treatment T0 (89.30 ± 46.34 cm) showed the lowest plant height. These findings indicate the positive effect of mineral fertilisation and microbial biostimulants on the vegetative growth of maize in this locality. In contrast, at Ouangolo, plant heights were generally lower than those observed in the other localities. In this area, treatment T2 (98.81 ± 35.96 cm) produced the highest value, followed by treatments T3 and T4. The control treatment T0 recorded the lowest plant height (66.11 ± 37.66 cm). At Sakassou, treatments T1 (121.77 ± 40.07 cm), T2 (116.97 ± 38.86 cm), T3 (115.05 ± 38.06 cm) and T4 (120.97 ± 38.57 cm) resulted in significantly greater plant heights than the control treatment T0 (90.47 ± 41.34 cm). Furthermore, the inoculated treatments combined with 50% of the recommended NPK dose achieved performances comparable to those obtained with T1, which received 100% of the recommended NPK dose. Overall, these results suggest that the use of arbuscular mycorrhizal fungi (AMF) and plant growth-promoting rhizobacteria (PGPR) enhances the efficiency of mineral fertiliser utilisation and promotes maize growth despite a 50% reduction in chemical fertiliser application (Table 1). The microbial treatments T2, T3 and particularly T4 produced plant heights that were comparable to, or greater than, those obtained with treatment T1, despite a 50% reduction in NPK fertiliser application. This finding indicates an improvement in nutrient-use efficiency resulting from the synergistic effects of AMF and PGPR.

3.1.2 Number of Leaves per Maize Plant

The number of leaves was also significantly influenced by the applied treatments and the different study locations. At Boundiali, treatments T1 (10.97 ± 1.42), T3 (10.72 ± 1.71) and T4 (10.99 ± 1.61) recorded the highest numbers of leaves compared with the control treatment T0 (9.06 ± 2.12), which showed the lowest value. These results highlight the beneficial effects of mineral fertilisers and microbial biostimulants on leaf development in maize plants in this locality. At Ouangolo, treatments T2 (10.54 ± 2.02), T3 (10.59 ± 2.19) and T4 (10.46 ± 2.20) exhibited the best performances compared with the control treatment T0 (8.74 ± 1.90). Furthermore, treatment T1 also enhanced leaf development relative to the control. However, despite this improvement, the values recorded in this locality remained slightly lower than those observed in Boundiali and Sakassou. Similarly, at Sakassou, treatments T1 and T4 produced the highest numbers of leaves, with 10.12 ± 1.74 and 10.24 ± 1.55 leaves per plant, respectively. In contrast, the control treatment T0 recorded the lowest value (8.87 ± 1.84 leaves per plant). These findings indicate that fertilised treatments, whether based on mineral fertilisers or microbial inoculants, promoted a greater average number of leaves compared with the unfertilised control. Overall, the results demonstrate that the combination of beneficial microorganisms with a reduced rate of mineral fertilisation enhanced leaf development in maize across the different study locations. In particular, treatment T4 generally achieved the best performance, suggesting a synergistic interaction between AMF and PGPR in improving the vegetative growth of maize (Table 1).

3.1.3 Stem Diameter of Maize Plants

Stem diameter varied significantly according to both treatments and study locations. At Boundiali, treatments T1 (1.48 ± 0.34 cm) and T4 (1.48 ± 0.33 cm) recorded the largest stem diameters, followed by treatments T3 and T2, respectively. In contrast, the control treatment T0 exhibited the lowest value (1.26 ± 0.41 cm). At Ouangolo, treatment T3 (1.45 ± 0.37 cm) produced the greatest stem diameter, followed by treatment T4 (1.39 ± 0.27 cm), whereas the control treatment T0 recorded the lowest value (1.16 ± 0.39 cm). Similarly, at Sakassou, treatments T1 (1.31 ± 0.32 cm) and T4 (1.31 ± 0.33 cm) achieved the best performances compared with the control treatment T0 (1.07 ± 0.33 cm). Overall, these results indicate that microbial treatments contributed to improving stem diameter in maize plants. In particular, treatments T3 and T4 appeared to be the most effective in enhancing stem diameter, reflecting improved physiological activity and root development. These findings suggest that the combined application of beneficial microorganisms and mineral fertilisation promotes more vigorous plant growth and enhances the structural development of maize plants (Table 1).

3.1.4 Leaf Area of Maize Plants

Leaf area was strongly influenced by both the treatments and the study locations. At Boundiali, treatments T1 (283.10 ± 104.20 cm²) and T4 (282.28 ± 103.20 cm²) recorded the largest leaf areas, followed by treatment T3. In contrast, the control treatment T0 exhibited the smallest leaf area (233.45 ± 108.85 cm²). At Ouangolo, treatments T3 (285.30 ± 118.31 cm²) and T4 (287.43 ± 110.70 cm²) achieved the best performances, whereas the control treatment T0 recorded the lowest value (155.75 ± 64.05 cm²). Similarly, at Sakassou, treatment T1 (316.60 ± 87.63 cm²) produced the largest leaf area, followed by T4 (310.21 ± 97.12 cm²) and T2 (300.10 ± 90.10 cm²). The control treatment T0 again recorded the lowest value. Overall, the microbial treatments combined with a reduced rate of mineral fertilisation resulted in leaf areas that were comparable to, or even greater than, those obtained with treatment T1, which received the full recommended fertiliser dose. Treatment T4 consistently exhibited high performance across all study locations, indicating an enhancement of the photosynthetic capacity of maize plants through the synergistic action of AMF and PGPR.

Furthermore, the differences observed among locations may be attributed to variations in agroecological conditions, including soil characteristics, climatic factors and nutrient availability (Table 1).

Table 1. Variation in plant height, leaf number, stem collar diameter, and leaf area as affected by treatment

Site	Treatment	Height (cm)			Number of leaves			Root collar diameter (cm)			Leaf area (cm²)		
		Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max
Boundiali	T0	9	89,30±46,34d	224	2	9,06±2,12f	13	0,43	1,26±0,41cde	2,8	39	233,45 ± 108,85c	498
	T1	1,22	115,47±36,98a	200	7	10,97±1,42a	15	0,5	1,48±0,34a	2,83	73,22	283,10 ± 104,2a	602,55
	T2	10	111,65±36,85ab	190	4	10,74±1,53ab	15	0,3	1,37±0,32ab	2,36	51,35	251,38 ± 98,85b	520,97
	T3	1,69	107,54±40,98abc	206	5	10,72±1,71ab	14	0,52	1,41±0,36ab	2,43	24,3	264,42 ± 100,3ab	529,12
	T4	18,5	117,94±36,27a	197,5	5	10,99±1,61a	15	0,29	1,48±0,33a	2,62	56,55	282,28 ± 103,20a	565,45
	T0	3	66,11±37,66e	198	4	8,74±1,90f	14	0,52	1,16±0,39fg	100	14,625	155,75 ± 64,05d	399,75
	T1	1,26	95,85±40,85cd	204	4	10,37±2,09abcde	14	0,55	1,33±0,46bc	155	57,2	254,1 ± 102,17c	597,5
	T2	11	98,81±35,96bcd	183	3	10,54±2,02abcd	15	0,66	1,30±0,27bcd	2,26	61,1	261,32 ± 104,9bc	554,31
	T3	11,5	97,98±38,33cd	226	4	10,59±2,19abc	16	0,65	1,45±0,37bcd	128	54,6	285,3 ± 118,31ab	646,4
	T4	14,5	96,02±40,12cd	201	2	10,46±2,20abcd	16	0,62	1,39±0,27bcd	15,7	61,87	287,43 ± 110,70a	644,4
	T0	19	90,47±41,34d	201	5	8,87±1,84f	14	0,3	1,07±0,33g	2,09	65,25	262,34 ± 98,68c	547,4
	T1	1,21	121,77±40,07a	205	5	10,12±1,74cde	14	0,51	1,31±0,32bcd	2,19	88,2	316,60 ± 87,63a	575
	T2	30	116,97±38,86a	195	6	10,08±1,71de	14	0,5	1,23±0,30ef	2,47	119,25	300,10 ± 90,10ab	547,92
	T3	34	115,05±38,06a	219	5	10,01±1,64e	14	0,44	1,24±0,32de	2,25	73,5	293,98 ± 93,61b	548,25
	T4	33	120,97±38,57a	225,5	6	10,24±1,55bcde	14	0,66	1,31±0,33bcd	2,38	90	310,21 ± 97,12a	519,4
Test Kruskal-Wallis		H = 242,761** P < 0,01			H = 377,576** P < 0,01			H = 226,326** P < 0,01			H = 240,774** P < 0,01		

Means followed by different letters are significantly different according to the Kruskal-Wallis test at the 5% significance level. Moy: Mean; Min: Minimum; Max: Maximum. T0: Absolute control (without biostimulants and without fertilizer); T1: 100% recommended dose of NPKSB + urea; T2: AMF + 50% of the recommended dose of NPKSB + urea; T3: PGPR + 50% of the recommended dose of NPKSB + urea; T4: AMF + PGPR + 50% of the recommended dose of NPKSB + urea

Table 2. Variation in yield parameters and total productivity

Site	Agronomic parameter of productive performance		Treatments					Associated statistical test
			T0	T1	T2	T3	T4	
Boundiali	Ear length (cm)	Mini	5	4	0,5	5	5	**Kruskal-Wallis test; H = 260.051**; Theoretical P < 0.01**
		Average	10,60 ± 2,48^{cd}	12,87±2,58^{a}	12,43±2,86^{ab}	12,28±2,77^{bcd}	12,38±2,71^{abc}	
		Maxi	18	19	20	20	20	
Ouangolo		Mini	4,2	6,4	6,5	6,5	5,8	
		Average	8,82 ± 2,67^{cd}	11,99±2,38^{a}	11,29±2,06^{bcd}	11,99±2,06^{ab}	11,90±2,52^{abc}	
		Maxi	17,4	18,5	21	21	19,5	
Sakassou		Mini	5	7	6,5	6	7	
		Average	10,27 ± 2,42^{cd}	11,53±2,21^{ab}	11,01±2,20^{bcd}	11,39±2,04^{abc}	11,82±1,87^{a}	
		Maxi	18	17	17	16	16	
Boundiali	Ear diameter (cm)	Mini	2,14	2,59	2,33	1,73	2,33	**Kruskal-Wallis test; H = 173.139**; Theoretical P < 0.01**
		Average	3,63±0,53^{cd}	3,92±0,44^{abc}	3,87±0,67^{bcd}	3,88±0,49^{ab}	3,88±0,46^{a}	
		Maxi	4,74	5,04	9,94	5	5	
Ouangolo		Mini	1,5	1,5	2,4	2,86	2,44	
		Average	3,30±0,57^{cd}	3,77±0,42^{abc}	3,72±0,41^{bcd}	3,86±0,35^{a}	3,78±0,43^{ab}	
		Maxi	6,32	4,91	5,08	5	4,43	
Sakassou		Mini	2,2	2,88	2,76	2,11	2,61	
		Average	3,58±0,45^{cd}	3,81±0,39^{abc}	3,82±0,39^{ab}	3,77±0,44^{bcd}	3,84±0,39^{a}	
		Maxi	4,78	4,81	4,74	5,11	4,87	
Boundiali	Ear weight (g)	Mini	10,5	9	20	10	11,00	**Kruskal-Wallis test; H = 243.248**; Theoretical P < 0.01**
		Average	65,73±30,78^{bcd}	92,51±34,40^{a}	88,30±35,81^{ab}	87,13±36,59^{abc}	87,87±37,63^{cd}	
		Maxi	165	185	191	185	195	
Ouangolo		Mini	9	24	20	27	24	
		Average	42,19±28,95^{cd}	79,33±27,29^{a}	70,20±26,62^{bcd}	76,61±25,23^{abc}	77,38±32,55^{ab}	
		Maxi	155	165	183	154	190	
Sakassou		Mini	23	38	29	31	29	
		Average	68,18±26,53^{cd}	80,76±30,99^{ab}	74,63±24,58^{bcd}	77,91±27,31^{abc}	85,02±27,80^{a}	
		Maxi	178	166	152	170	170	
Boundiali	Number of grains per ear	Mini	69	116	120	54	136	**Kruskal-Wallis test; H = 220.562**; Theoretical P < 0.01**
		Average	283,63±102,64^{cd}	362,93±110,76^{a}	341,91±104,97^{bcd}	350,27±113,61^{abc}	352,57±105,49^{ab}	
		Maxi	635	798	618	696	712	

Site	**Agronomic parameter of productive performance**		**Treatments**					**Associated statistical test**
			T0	**T1**	**T2**	**T3**	**T4**	
Ouangolo		Mini	10	110	69	102	121	
		Average	198,04±97,70^{cd}	311,11±97,11^{a}	285,48±87,13^{bcd}	307,08±83,12^{ab}	305,04±116,34^{abc}	
		Maxi	541	660	576	560	910	
Sakassou		Mini	103	105	76	158	120	
		Average	246,95±81,71^{cd}	279,58±94,92^{bcd}	296,14±95,38^{abc}	299,86±86,08^{ab}	302,45±93,26^{a}	
		Maxi	480	510	603	525	770	
Boundiali	Grain weight per ear	Mini	12	9	13	13	7	**Kruskal-Wallis test; H = 248.651**; Theoretical P < 0.01**
		Average	55,17±26,10^{cd}	87,74±57,234^{a}	73,84±30,29^{ab}	72,85±30,51^{bcd}	73,67±31,59^{abc}	
		Maxi	151	378	161	157	165	
Ouangolo		Mini	4	18	15	16	16	
		Average	34,72±24,37^{cd}	66,03±63^{a}	58,73±23,06^{bcd}	64,31±20,98^{ab}	64,13±27,53^{abc}	
		Maxi	129	138	153	144	161	
Sakassou		Mini	11	28	23	22	25	
		Average	55,47±23,59^{cd}	65,77±26,49^{ab}	61,60±21,34^{bcd}	64,61±24,00^{abc}	71,03±24,15^{a}	
		Maxi	149	148	130	138	137	
Boundiali	Grain yield (t/ha)	Mini	0,03	0,03	0,05	0,03	0,06	**Kruskal-Wallis test; H = 45.147**; Theoretical P < 0.01**
		Average	0,08±0,04^{cd}	0,16±0,09^{bcd}	0,23±0,13^{abc}	0,24±0,16^{ab}	0,30±0,18^{a}	
		Maxi	0,14	0,29	0,39	0,44	0,50	
Ouangolo		Mini	0,02	0,07	0,10	0,08	0,07	
		Average	0,05±0,05^{cd}	0,15±0,05^{bcd}	0,25±0,11^{abc}	0,28±0,15^{ab}	0,35±0,20^{a}	
		Maxi	0,16	0,23	0,36	0,40	0,54	
Sakassou		Mini	0,06	0,11	0,32	0,43	0,52	
		Average	0,07±0,01^{cd}	0,13±0,03^{bcd}	0,37±0,05^{abc}	0,46±0,03^{ab}	0,53±0,02^{a}	
		Maxi	0,09	0,19	0,44	0,51	0,55	

Means followed by different letters are significantly different according to the Kruskal-Wallis test at the 5% significance level. Moy: Mean; Min: Minimum; Max: Maximum. T0: Absolute control (without biostimulants and without fertilizer); T1: 100% recommended dose of NPKSB + urea; T2: AMF + 50% of the recommended dose of NPKSB + urea; T3: PGPR + 50% of the recommended dose of NPKSB + urea; T4: AMF + PGPR + 50% of the recommended dose of NPKSB + urea

3.2 Effect of Biostimulants on Yield Components and Final Productivity

Table 2 presents the effects of the different treatments (T0 to T4) on agronomic parameters and maize yield components at the study sites of Boundiali, Ouangolodougou and Sakassou. The results of the Kruskal-Wallis test revealed highly significant differences among treatments for all the parameters evaluated ($p < 0.01$), indicating that both microbial biostimulants and mineral fertilisation significantly influenced maize yield performance and productivity across the different agroecological conditions.

3.2.1 Ear Length

Mean ear length varied significantly among treatments and study sites. Overall, treatments T1, T3 and T4 produced the longest ears compared with the control treatment T0. At Ouangolodougou, the highest values were obtained with T1 (11.99 cm) and T3 (11.99 cm), whereas at Sakassou, treatment T1 recorded the highest mean ear length (11.53 cm). The control treatment T0 consistently exhibited the shortest ear lengths across all study sites. This improvement demonstrates the positive effect of the treatments on the development of maize reproductive organs (Table 2).

3.2.2 Ear Diameter

Ear diameter was also significantly influenced by the treatments. Treatments T1, T3 and T4 generally recorded the highest mean values across the three study sites. At Boundiali, treatment T3 produced the largest mean ear diameter (3.92 cm), while at Ouangolodougou, treatments T3 and T4 achieved similar values that were higher than those of the control. At Sakassou, treatments T1 and T4 resulted in the greatest ear diameters. The lower values observed in the control treatment T0 reflect the poor performance of untreated plants (Table 2).

3.2.3 Ear Weight

Mean ear weight increased under the different treatments, although the magnitude of the increase varied among sites. Treatments T1 and T3 were generally the most effective across the study locations. At Boundiali, the highest mean ear weight was recorded with T1 (92.51 g), whereas at Ouangolodougou and Sakassou, treatments T1 and T4 produced the best performances. These results indicate that seed coating with microbial biostimulants significantly enhanced ear filling and ear development in maize (Table 2).

3.2.4 Number of Grains per Ear

The number of grains per ear varied significantly according to the applied treatments. Treatments T1, T3 and T4 consistently recorded the highest mean numbers of grains per ear across the different study sites. At Boundiali, treatment T1 produced approximately 362 grains per ear, compared with 283 grains per ear for the control treatment. At Ouangolodougou and Sakassou, treatments T3 and T4 achieved the best performances. The increase in the number of grains per ear reflects an improvement in ear fertility and grain filling, highlighting the beneficial effects of microbial biostimulants and mineral fertilisation on maize reproductive performance (Table 2).

4. Discussion

4.1 Effect of Biostimulants on Maize Growth Parameters at 60 Days After Sowing

The results obtained showed that the application of microbial biostimulants based on arbuscular mycorrhizal fungi (AMF) (*Glomus caledonius*, *Rhizophagus intraradices* and *Funneliformis geosporum*) and the plant growth-promoting rhizobacterium (PGPR) *Pseudomonas putida*, combined with a 50% reduction in mineral fertiliser application, significantly influenced maize growth parameters across the different study sites. The differences observed among treatments for plant height, number of leaves, stem diameter and leaf area were statistically significant ($p < 0.01$), indicating that the use of microbial biostimulants enhanced the vegetative development of maize plants compared with the unfertilised control under the agroecological conditions of Boundiali, Ouangolo and Sakassou. Plant height is an important indicator of vegetative vigour and nutrient acquisition efficiency. In the present study, treatments T1 (100% NPK), T2 (AMF + 50% NPK + urea), T3

(PGPR + 50% NPK + urea) and T4 (AMF + PGPR + 50% NPK + urea) resulted in significantly greater plant heights than the control treatment (T0). The best performances were recorded with treatments T1 and T4, demonstrating that the combination of microbial biostimulants with reduced mineral fertilisation can maintain growth levels comparable to those achieved with full mineral fertilisation. These findings are consistent with those reported by Aguégué et al. (2021), who demonstrated in Benin that maize inoculation with *Rhizophagus intraradices* significantly improves vegetative growth through enhanced uptake of phosphorus and other poorly mobile nutrients, including zinc and water, from the soil. According to these authors, the extensive mycelial network developed by AMF increases the volume of soil explored by the root system, thereby improving water and nutrient acquisition. Similarly, Adoko et al. (2022) reported that the use of PGPR-based biostimulants significantly increased maize plant height compared with uninoculated controls. This improvement was attributed to the ability of rhizobacteria to produce plant growth-promoting substances such as auxins, cytokinins and gibberellins, which stimulate cell elongation and root development. The superior performance observed under treatment T4 suggests a synergistic interaction between AMF and PGPR. This synergy simultaneously enhances mineral nutrition and hormonal stimulation, thereby promoting better expression of maize vegetative potential. The number of leaves was also significantly affected by the treatments. Inoculated plants generally produced more leaves than the control. This improvement may be explained by increased nutrient availability, particularly nitrogen and phosphorus, which are essential for the formation and development of vegetative organs. AMF enhance phosphorus uptake, while PGPR improve nutrient availability in the rhizosphere through the production of enzymes and organic acids. The present results agree with those reported by Agbodjato et al. (2021), who observed a significant increase in leaf number in maize plants inoculated with *Pseudomonas putida* and grown under reduced mineral fertiliser rates in Benin. According to these authors, the enhanced nutrient availability induced by *Pseudomonas putida* stimulates cell division in apical meristems, thereby promoting the differentiation and development of vegetative organs, particularly leaves. Stem diameter is an important indicator of plant robustness and its capacity to transport water and assimilates efficiently to different organs. The results showed that inoculated treatments generally produced greater stem diameters than the control plants. This improvement may result from enhanced nutrient uptake, particularly phosphorus and potassium through AMF activity, combined with the beneficial effects of PGPR on root development. More balanced mineral nutrition promotes the formation of conductive tissues and strengthens stem structure. The observations made in this study are in agreement with those of Akpodé et al. (2025), who reported that the combination of AMF with reduced mineral fertilisation significantly improves maize growth parameters, including stem diameter. Mycorrhizal fungi enhance the efficiency of nutrient utilisation from fertilisers, thereby improving plant vigour. The results obtained with T4 indicate that the AMF-PGPR combination can produce stem diameters comparable to, or even greater than, those achieved under full mineral fertilisation (T1), despite a 50% reduction in fertiliser application. Leaf area was one of the growth parameters most strongly influenced by the treatments. The highest values were recorded under T4, followed by T1, whereas the control treatment (T0) consistently exhibited the lowest values. This response is particularly important because leaf area directly determines the photosynthetic capacity of the plant. The improvement observed under T2 and T4 may be attributed to the ability of AMF to enhance phosphorus uptake, a key nutrient involved in photosynthetic metabolism. Several studies conducted in West Africa have shown that mycorrhizal inoculation significantly increases maize leaf area on phosphorus-deficient soils. Regarding *Pseudomonas putida*, its effect on leaf area is often associated with phytohormone production and improved mineral nutrition. These findings are consistent with those of Agbodjato et al. (2022), who observed that maize plants inoculated with this bacterium exhibited leaf areas more than 20% greater than those of uninoculated controls. Furthermore, Alao et al. (2024) demonstrated that AMF consortia significantly increase maize leaf area and biomass through improved root colonisation and nutrient uptake. The authors emphasised that the use of multiple mycorrhizal species often produces greater responses than single-species inoculation due to functional complementarity among fungal species. Therefore, the high performance observed under T4 may result from the combined action of the mycorrhizal consortium (*Glomus caledonius*, *Rhizophagus intraradices* and *Funneliformis geosporum*) and *Pseudomonas putida*, which simultaneously improves mineral nutrition, root development and physiological stimulation of maize plants. Overall, the results demonstrate that microbial biostimulants based on *Glomus caledonius*, *Rhizophagus intraradices*, *Funneliformis geosporum* and *Pseudomonas putida* significantly improve the agro-morphological performance of maize. Treatments T2, T3 and particularly T4 produced performances comparable to, or greater than, those achieved with T1, which received 100% of the recommended mineral fertiliser rate. These findings confirm that AMF and PGPR represent promising alternatives for reducing chemical fertiliser inputs while maintaining optimal maize growth. The AMF-PGPR association therefore appears to be a sustainable strategy capable of contributing to the ecological intensification of maize production in Côte d'Ivoire.

4.2 Effect of Biostimulants on Yield Components and Final Productivity

The results obtained showed that the applied treatments significantly improved maize yield components, including ear length, ear diameter, ear weight, number of grains per ear, grain weight per ear and final grain yield. The highly significant differences observed among treatments indicate that the microbial biostimulants used had a positive effect on maize productivity across the three study locations. Treatments T2, T3 and particularly T4 produced superior performances compared with the control treatment (T0). This improvement demonstrates that the combination of arbuscular mycorrhizal fungi (AMF) (*Glomus caledonius*, *Rhizophagus intraradices* and *Funneliformis geosporum*) with *Pseudomonas putida* and half the recommended mineral fertiliser dose promoted better expression of maize yield potential. Treatment T4, which combined AMF, PGPR and 50% NPK + urea, was particularly outstanding, suggesting a synergistic interaction between the fungal and bacterial microorganisms. The improvement in ear length and ear diameter observed under inoculated treatments may be attributed to enhanced mineral nutrition, particularly phosphorus availability. AMF develop an extensive extraradical mycelial network that increases the volume of soil explored by roots and facilitates the uptake of relatively immobile nutrients such as phosphorus. These findings are consistent with those reported by Droh et al. (2022) in Côte d'Ivoire, who demonstrated that the combined application of biocompost and AMF improves soil properties, increases the availability of assimilable phosphorus and enhances maize yield in the Gbêkê and Tchologo regions. Similarly, Aguégué et al. (2021) reported in Benin that the use of *Rhizophagus intraradices* significantly improves maize growth and productivity. The increase in ear weight observed under treatment T4 may be explained by improved production and translocation of photoassimilates to reproductive organs. Photoassimilates, mainly sugars produced through photosynthesis, are transported from leaves to developing ears and grains. Improved water and nutrient availability therefore promotes ear development and grain filling. These observations are in agreement with those of Siene et al. (2020), who demonstrated in Korhogo that improved soil fertility through fertiliser application enhances maize growth and productivity, even under water-limited conditions. The number of grains per ear was also improved by the treatments, particularly under T1 and T4. This response may be related to better plant nutrition during the flowering, fertilisation and grain formation stages. Adequate availability of nitrogen and phosphorus promotes pollen viability, ovule fertilisation and grain set. The results obtained confirm those reported by Adjanohoun et al. (2017), who showed that AMF consortia improve maize yield components through enhanced nutrient uptake and improved physiological activity of plants. Grain weight per ear followed the same trend, with higher values recorded in fertilised and inoculated treatments. This improvement reflects better grain filling, probably resulting from increased leaf area, enhanced photosynthetic activity and improved nutrient availability. The results obtained with treatment T3 confirm the beneficial effect of *Pseudomonas putida*. Agbodjato et al. (2015) demonstrated that biostimulants formulated with *Pseudomonas putida* improve maize growth, yield and nutrient-use efficiency. Likewise, Adoko et al. (2022) reported that the application or seed coating of PGPR-based biostimulants significantly improves maize growth, yield and nutritional status. Final maize yield is the cumulative result of the previously mentioned yield components. The highest yields recorded under T4 indicate that the combination of AMF + PGPR + 50% NPK + urea can reduce mineral fertiliser inputs while maintaining high productivity. This finding is particularly important in the Ivorian context, especially in the northern and central regions, where cultivated soils are often affected by declining fertility, soil acidification and reduced organic matter content. Droh et al. (2022) also emphasised that AMF associated with organic amendments can provide a sustainable alternative for improving soil fertility and maize yield in Côte d'Ivoire. Overall, the results of this study confirm that microbial biofertilisers represent a promising option for the sustainable intensification of maize cultivation. The superior performance of treatment T4 demonstrates that AMF and *Pseudomonas putida* act in a complementary manner: AMF improve water and nutrient uptake, whereas *Pseudomonas putida* stimulates root growth, solubilises certain mineral elements and enhances plant physiological activity. This combination therefore improves yield components while reducing chemical fertiliser inputs by half. Consequently, the combined use of AMF and PGPR appears to be an effective strategy for sustainably increasing maize productivity, reducing dependence on mineral fertilisers and contributing to the restoration of soil biological fertility.

5. Conclusion

This study assessed the effect of microbial biostimulants on maize growth and yield in Boundiali, Ouangolodougou and Sakassou. The results showed that treatments combining microbial inoculants with mineral fertilisation improved maize growth and yield components compared with the unfertilised control. The combination of arbuscular mycorrhizal fungi and *Pseudomonas putida* with 50% of the recommended mineral fertiliser dose generally produced the most favourable responses for several growth and yield parameters. Treatments involving either arbuscular mycorrhizal fungi or *Pseudomonas putida* alone, together with reduced mineral fertiliser, also improved maize performance compared with the control. These findings suggest that microbial biostimulants may enhance nutrient-use efficiency and contribute to improved crop productivity under the conditions of the study. The results further indicate that combining beneficial microorganisms with reduced fertiliser application may represent a promising approach for sustainable maize production in Côte d'Ivoire. However, the interpretation of yield performance should be made carefully after verification of yield units, calculations and table values.

6. Limitation

This study was limited to three maize-growing localities in northern and central Côte d'Ivoire and one maize variety. Yield interpretation should be made cautiously because the reported yield units, calculations and table values require author verification. Further multi-season trials across additional agroecological zones are needed to confirm the consistency of the responses.

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Declaration of AI Use

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Competing Interests

Authors have declared that no competing interests exist.

References

Adjanohoun, A., Baba-Moussa, L. S., Dagbénonbakin, G., Saïdou, A., & Toukourou, F. (2017). *Utilisation des microorganismes du sol pour accroître la productivité agricole: Manuel de l'apprenant*. CNSMaïs/INRAB/SNRA.

Adjanohoun, A., Baba-Moussa, L., Glèlè Kakaï, R., Allagbé, M., Yèhouénou, B., Gotoéchan-Hodonou, H., Sikirou, R., Sessou, P., & Sohounhloué, D. (2011). Caractérisation des rhizobactéries potentiellement promotrices de la croissance végétative du maïs dans différents agroécosystèmes du Sud-Bénin. *International Journal of Biological and Chemical Sciences, 5*(2), 433–444. https://doi.org/10.4314/ijbcs.v5i2.72073

Adoko, M. Y., Noumavo, P. A., Agbodjato, N. A., Amogou, O., Salami, H. A., Aguégué, R. M., Adjovi, N. A., Adjanohoun, A., & Baba-Moussa, L. (2022). Effect of the application or coating of PGPR-based biostimulant on the growth, yield and nutritional status of maize in Benin. *Frontiers in Plant Science, 13*, 1064710. https://doi.org/10.3389/fpls.2022.1064710

Agbodjato, N. A., Adoko, M. Y., Babalola, O. O., Amogou, O., Badé, F. T., Noumavo, P. A., Adjanohoun, A., & Baba-Moussa, L. (2021). Efficacy of biostimulants formulated with *Pseudomonas putida* and clay, peat, clay-peat binders on maize productivity in a farming environment in Southern Benin. *Frontiers in Sustainable Food Systems, 5*, 666718. https://doi.org/10.3389/fsufs.2021.666718

Agbodjato, N. A., Assogba, S. A., Babalola, O. O., Koda, A. D., Aguégué, R. M., Sina, H., Dagbénonbakin, G. D., Adjanohoun, A., & Baba-Moussa, L. (2022). Formulation of biostimulants based on arbuscular mycorrhizal fungi for maize growth and yield. *Frontiers in Agronomy, 4*, 894489. https://doi.org/10.3389/fagro.2022.894489

Agbodjato, N. A., Noumavo, P. A., Baba-Moussa, F., Salami, H. A., Sina, H., Sèzan, A., Bankolé, H., Adjanohoun, A., & Baba-Moussa, L. (2015). Characterisation of potential plant growth-promoting rhizobacteria isolated from maize (*Zea mays* L.) in central and northern Benin (West Africa). *Applied and Environmental Soil Science, 2015*, Article 901656. https://doi.org/10.1155/2015/901656

Aguégué, R. M., Adjanohoun, A., Agbodjato, N. A., Noumavo, P., & Baba-Moussa, L. (2020). Greenhouse evaluation of the growth of *Zea mays* L. inoculated by arbuscular mycorrhizal fungi strains in native arbuscules on ferrous soil. *Journal of Agricultural and Crop Research, 8*(3), 55–63. https://doi.org/10.33495/jacr_v8i3.20.106

Aguégué, R. M., Assogba, S. A., Salami, H. A., Koda, A. D., Agbodjato, N. A., Amogou, O., Salako, H. K. V., Adjovi, N. R., Dagbénonbakin, G., Glèlè Kakaï, R., Adjanohoun, A., & Baba-Moussa, L. (2021). Organic fertilizer based on *Rhizophagus intraradices*: Valorization in a farming environment for maize in the south, center and north of Benin. *Frontiers in Sustainable Food Systems, 5*, 605610. https://doi.org/10.3389/fsufs.2021.605610

Akpodé, C., Assogba, S. A., Hoteyi, S. M. I., Aguégué, R. M., Adoko, M. Y., Alao, L. T., Sina, H., Noumavo, P. A., Houssou, A. P., Adjanohoun, A., Babalola, O. O., & Baba-Moussa, L. (2025). Impact of combinations of native arbuscular mycorrhizal fungi and mineral fertilizers on the production and nutrition of maize plants on ferruginous soil. *Agricultural Research, 14*, 782–793. https://doi.org/10.1007/s40003-024-00808-5

Alao, L. T., Ouikoun, C. G., Hoteyi, S. M. I., Aguégué, R. M., Koda, A. D., Assogba, S. A., Amogou, O., Akpodé, C., Adoko, M. Y., Agbodjato, N. A., Adjovi, N. A., Moussanohoun, O., & Moussanohoun, A. (2024). Response of biostimulants based on native arbuscular mycorrhizal fungi of the Glomeraceae on maize yield in a farming environment. *Agriculture, 14*(6), 906. https://doi.org/10.3390/agriculture14060906

Bohoussou. (2025). *Field GPS coordinates and photographs of the maize study areas and plant material* [Unpublished field material].

Droh, G., Djezou, K. M., Touré, M., Tuo, S., Zei, P., & N'Guetta, A. S.-P. (2022). Effet du biocompost associé aux champignons mycorhiziens sur le rendement du maïs (*Zea mays* L.) en Côte d'Ivoire. *Afrique Science, 21*(4), 70–81.

FAOSTAT. (2024). *Food and agriculture data*. Food and Agriculture Organization of the United Nations. https://www.fao.org/faostat/en/#data

Kouakou, K. R., N'da, A. H., & N'cho, A. L. (2024). Revue de littérature des céréales cultivées et produites dans le Nord de la Côte d'Ivoire: Cas des spéculations maïs (*Zea mays* L.), mil (*Pennisetum glaucum* (L.) R. Br.) et sorgho (*Sorghum bicolor* L. Moench). *Journal of Animal & Plant Sciences, 60*(2), 11015–11034. https://doi.org/10.35759/JAnmPlSci.v60-2.2

Kouakou, K. R., N'da, A. H., Yeo, G., & Anguiby, B. L. A. (2026). Amélioration de la productivité du maïs par la mycorhization dans le Nord de la Côte d'Ivoire. *African Crop Science Journal, 34*(1), 1–12. https://doi.org/10.4314/acsj.v34i1.1

N'da, A. H., Akanvou, L., Akanvou, R., & Zoro Bi, I. A. (2014). Évaluation de la diversité agro-morphologique des accessions de maïs (*Zea mays* L.) collectées en Côte d'Ivoire. *Journal of Animal & Plant Sciences, 20*(3), 3144–3158. https://www.m.elewa.org/JAPS/2014/20.3/Abstract2-akanvou.html

N'Guessan, K. A., Kouakou, K. E., Alui, K. A., & Yao-Kouamé, A. (2019). Stratégies et pratiques paysannes de gestion durable de la fertilité des sols dans le département de Korhogo au Nord de la Côte d'Ivoire. *Afrique Science, 15*(4), 245–258. https://www.afriquescience.net/article.php?code=Vol.15%2C+N%C2%B04+%282019%29&id=19&nid=872

Nassif, A., Hammad, Y., Ibrahim, J., & Darwish, M. (2025). Comparing the role of mineral fertilizer, organic fertilizer and rhizobacteria as bio-fertilizers in increasing the tolerance of maize plants (*Zea mays* L.) to water stress. *Asian Journal of Advances in Research, 8*(1), 86–96. https://doi.org/10.56557/ajoair/2025/v8i1508

Ndiaye, S., Goudiaby, A. O. K., Dieme, I., Diagne, O. N., Ba, M., & Makanera, K. (2023). Effets de la combinaison des biostimulants foliaires et racinaires sur la croissance et la production du poivron (*Capsicum annuum* L.) en Basse Casamance, Sénégal. *International Journal of Biological and Chemical Sciences, 17*(5), 1960–1970. https://doi.org/10.4314/ijbcs.v17i5.15

Olayossimi, A., Lopez, E. J., Ella, N. K., & Séverin, K. K. (2026). Effects of BK fertiliser-based organic-mineral fertilisation on the growth and yield of maize (*Zea mays* L.) in the Sudano-Guinean Zone of Bouaké, Côte d'Ivoire. *Journal of Experimental Agriculture International, 48*(5), 281–290. https://doi.org/10.9734/jeai/2026/v48i54223

Ouattara, O., & Kambiré, B. (2023). Stratégies de lutte contre l'orpaillage illégal en Côte d'Ivoire: Cas du département de Boundiali. *Revue de Géographie Tropicale et d'Environnement*. https://www.revuegeotrope.com/wp-content/uploads/2023/12/15-Article-OUATTARA-KAMBIRE.pdf

Pang, F., Li, Q., Solanki, M. K., Wang, Z., Xing, Y.-X., & Dong, D.-F. (2024). Soil phosphorus transformation and plant uptake driven by phosphate-solubilizing microorganisms. *Frontiers in Microbiology, 15*, 1383813. https://doi.org/10.3389/fmicb.2024.1383813

Santana, L. R., da Silva, L. N., Tavares, G. G., Batista, P. F., Cabral, J. S. R., & Souchie, E. L. (2023). Arbuscular mycorrhizal fungi associated with maize plants during hydric deficit. *Scientific Reports, 13*, 1519. https://doi.org/10.1038/s41598-023-28744-4

Severo, H. C. de A. R., Arauco, A. M. de S., Nunes, R. W. F., Monteiro, G. N., Duarte, M. H. F., Silva, A. P. M. da, Ferreira, A. de C., Luz, M. R., Miranda, R. de S., Araújo, A. S. F. de, & Costa, E. M. da. (2025). Co-inoculation of arbuscular mycorrhizal fungi and *Bacillus subtilis* enhances morphological traits, growth and nutrient uptake in maize under limited phosphorus availability. *Scientific Reports, 15*, 25448. https://doi.org/10.1038/s41598-025-10038-6

Siene, L. A. C., Doumbouya, M., Traore, M. S., Conde, M., N'Guettia, T. V. F., & Kone, M. (2020). Effets de quatre types de fertilisants sur la croissance et la productivité de deux génotypes de maïs (*Zea mays* L.) en cas de semis tardifs à Korhogo au Centre-Nord de la Côte d'Ivoire. *International Journal of Biological and Chemical Sciences, 14*(1), 55–68. https://doi.org/10.4314/ijbcs.v14i1.6

Soro, C. L., Yapo, S. E.-S., Ouattara, T. V., Kouadio, O. K. S., & Kouadio, Y. J. (2024). Étude des paramètres de production de six nouvelles lignées de maïs (*Zea mays* L.) blanc sélectionnées pour la sécurité alimentaire en Côte d'Ivoire. *Afrique Science, 24*(4), 1–13. https://www.afriquescience.net/admin/postpdfs/df29519fcfeb3fbe844635d7da940c071715612681.pdf

Touré, A. (2025). *Utilization of agro-industrial residues in the restoration of soil fertility in the Upper Sassandra region (Ivory Coast)* [PhD thesis].

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