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Biofertilizers and Agronomic Advantages in a Soybean-Millet System on Ferralsol in Katanda Territory, Kasaï Oriental, DRC

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Abstract: The low fertility of tropical ferralsols is a major constraint for soybean (*Glycine max* L.) and pearl millet (*Pennisetum glaucum* L.) production in the Democratic Republic of Congo. This study, conducted in the Katanda territory (Kasaï Oriental), aimed to evaluate the effect of commercial biofertilizers (Super Gro, Fertiplus, D.I. Grow Vert) and local organic amendments (bat guano and poultry manure) on the productivity of soybean and millet in monoculture and intercropping. A split-plot experimental design with three replications was used to measure production parameters and agronomic advantages (RYEM, RYIS, AAY). Results show that bat guano (0.93 t/ha) and Super Gro (0.89 t/ha) significantly improved soybean yield compared to the control (0.29 t/ha). In the soybean-millet intercrop, the actual soybean yield reached 1.1 t/ha with Super Gro and bat guano, confirming the agronomic advantage of intercropping. These findings demonstrate that integrating liquid and solid biofertilizers into a soybean-millet system constitutes a sustainable alternative to improve productivity and resilience of agricultural systems on ferralsols.

Keywords*: Soybean, Millet, Biofertilizers, Ferralsol, Katanda, Agronomic Advantage.*

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I. INTRODUCTION

Soybean (*Glycine max* L.) is a strategic legume for global food security, providing nearly 40% protein and 20% oil in its seeds (Ayew et al., 2026). In the Democratic Republic of Congo (DRC), its cultivation is gradually intensifying but remains constrained by major issues related to tropical soil fertility. Ferralsols, which cover a large part of Kasaï Oriental, are characterized by high acidity (pH < 5), low nitrogen content (< 0.05%), and limited phosphorus availability (6–25 ppm) (Yalombe et *al*., 2025; Tshibangu et *al*., 2023). These unfavorable conditions reduce nodulation and symbiotic nitrogen fixation, thus compromising soybean productivity.

Pearl millet (*Pennisetum glaucum* L.), on the other hand, is a resilient cereal capable of adapting to poor soils and erratic climates (Pale et *al*., 2021). Its integration into intercropping systems with soybean is an agroecological strategy aimed at optimizing resource use and improving overall productivity (Muyayabantu et *al*., 2013). Previous studies have shown that maize-legume intercropping can achieve an agronomic advantage greater than 1, confirming the relevance of such systems for smallholder farmers (Ngoyi et *al*., 2025). Recent research in China has shown that crop diversification (peanut intercropped with maize and rapeseed) stimulates the production of root metabolites such as flavonoids and coumarins, which modulate the microbiome composition and promote biological nitrogen fixation (Qiao et *al*., 2024). This plant-microbiome interaction illustrates how intercropping can improve soil fertility and agricultural sustainability.

In the Katanda territory, soybean and millet farmers face low ferralsol fertility, high acidity, and scarcity of mineral inputs. This situation limits productivity and compromises the sustainability of agricultural systems. The central question is therefore whether the use of commercial biofertilizers (Super Gro, Fertiplus, D.I. Grow Vert) and local amendments (bat guano, poultry manure) can improve the agronomic performance of soybean and millet, in

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monoculture and intercropping, while generating a measurable agronomic advantage.

II. MATERIALS AND METHODS

➢ *Study Site*

The experiment was conducted within the concession of the Dibula Agropastoral Domain (DADI) located in Bena Ntonko village, Bakua Ndaba chiefdom, Katanda territory, one of five territories comprising the Kasaï Oriental province in the Democratic Republic of Congo. The corresponding geographic coordinates of the experimental site are: latitude (-6.17153), longitude (23.74023).

The climate of this region is tropical humid, type AW3 according to the Köppen classification, characterized by two dominant seasons: the rainy season and the dry season. The rainy season is subdivided into two phases: the long rainy season from August 15 to December 31 and the short rainy season from January 15 to May 15. The dry season lasts 3 months, from May 15 to August 15. Annual rainfall is approximately 1500 mm, with a precipitation peak observed in March with 224.7 mm for growing season B and in November with 230.4 mm for growing season A. Relative humidity is 77.7%. The soil on the site is sandy, light, and well-drained, belonging to the ferralsol group according to the World Reference Base for soil classification (Muyayabantu, 2017; Ngoyi et *al*., 2025).

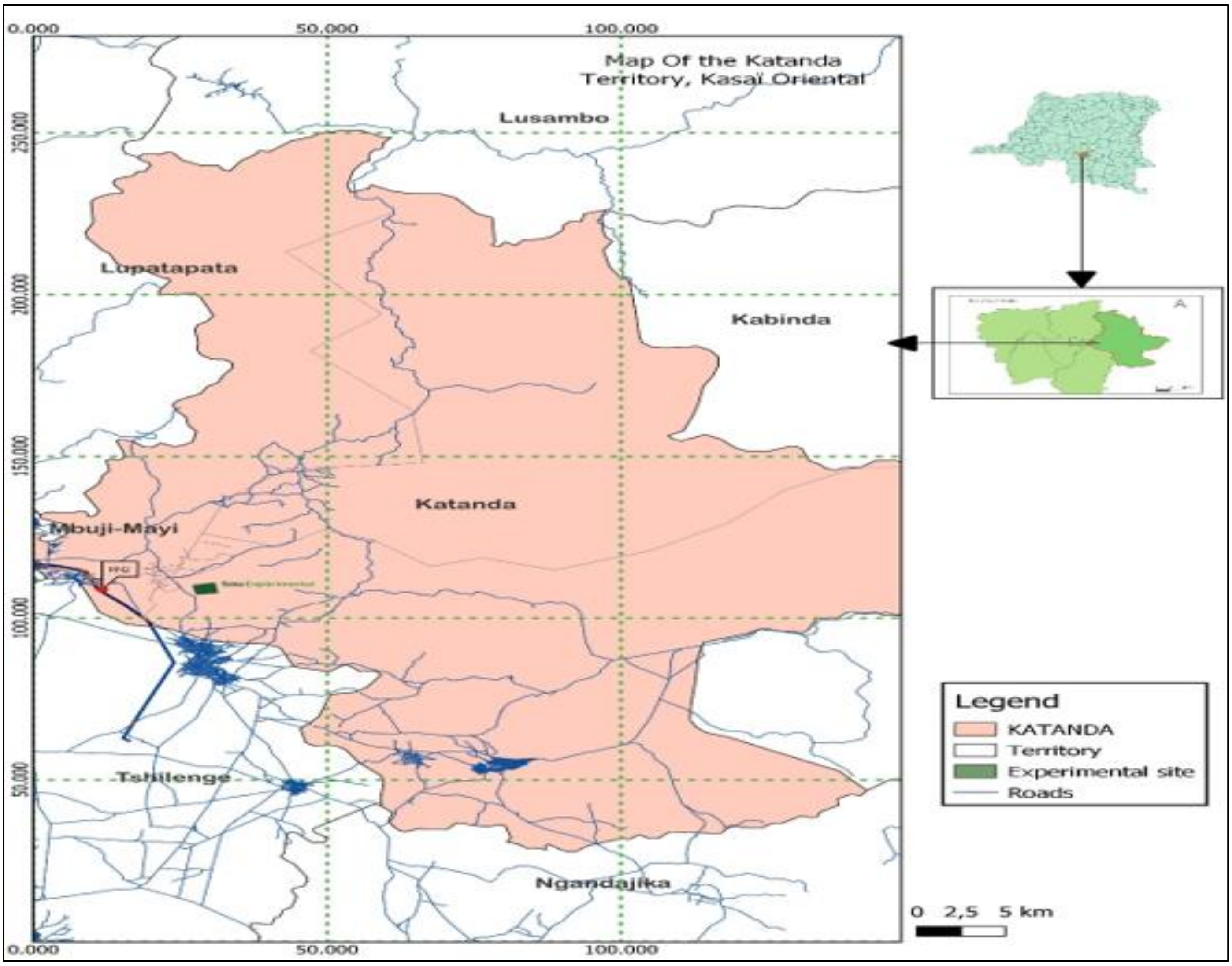

Fig 1 Map of Katanda Territory

➢ *Materials*

• *Biological Material*

For this research, the soybean variety 'AFYA' and the local millet variety LC005 from the National Institute for Agronomic Studies and Research (INERA)/Ngandajika in Lomami province were used.

• *Fertilizer Material*

The biofertilizers tested in this study included poultry manure, Super Gro, bat guano, Fertiplus, and D.I. Grow Vert.

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➢ *Methods*

- *Experimental Design*

A factorial split-plot experimental design was used to test the hypotheses, with cropping systems as the main factor at two levels: monoculture and intercropping, and fertilizers as the secondary factor at six levels: Super Gro (2 L/ha), Fertiplus (5-2-4, at 3 L/ha), D.I. Grow Vert (4 L/ha), poultry manure (at 10 t/ha), bat guano (at 10 t/ha), and Control (no fertilizer). This design consisted of three replications, each containing 12 subplots with an area of 9 m² (3 m x 3 m). Plots were spaced 1 meter apart. Soybeans were sown at spacing of 40 cm x 20 cm in monoculture and 50 cm x 25 cm in intercropping with millet.

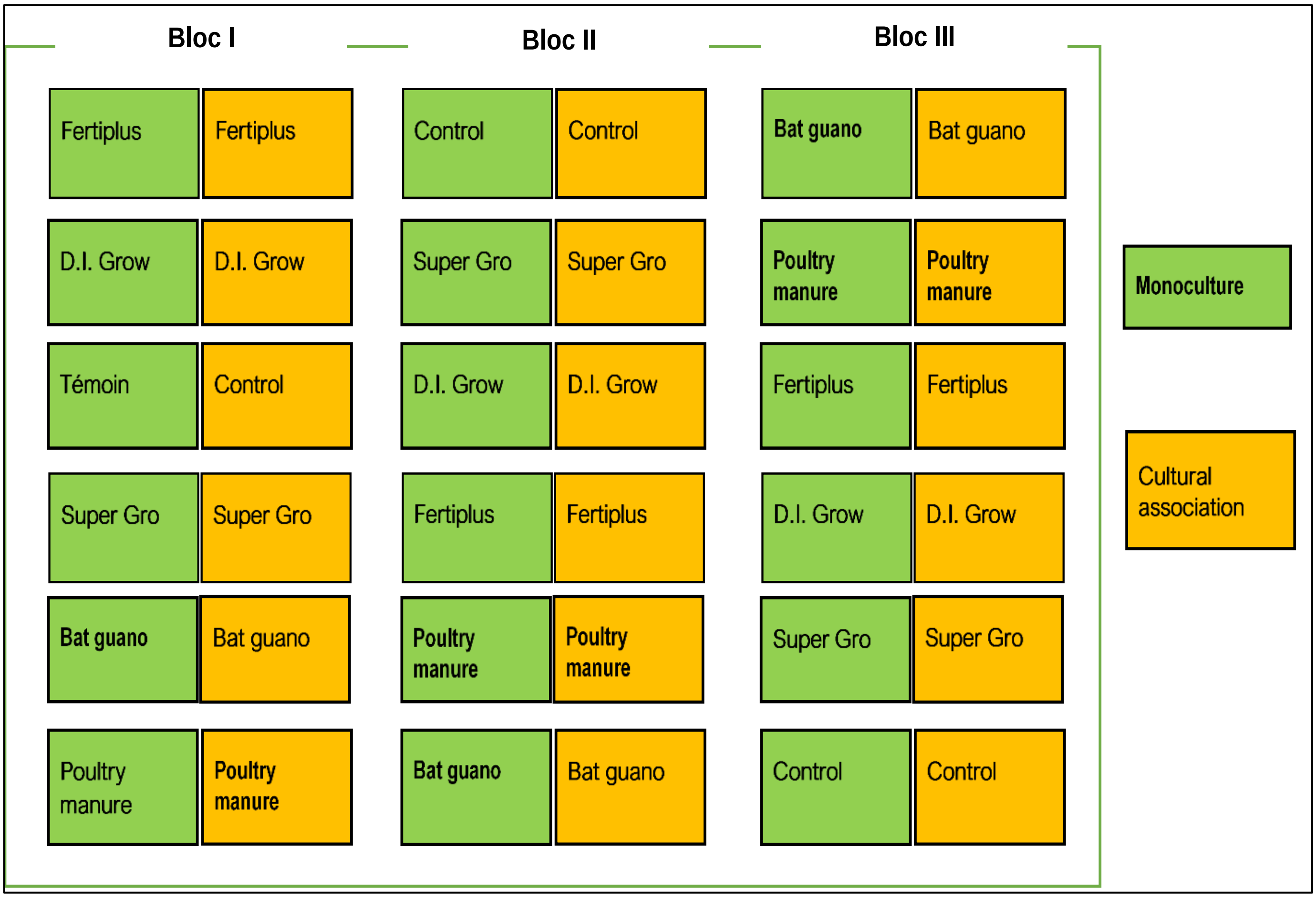

Fig 2 Experimental Design

✓ Legend: Super Gro (2 L/ha), Fertiplus (5-2-4, 3 L/ha), D.I. Grow Vert (4 L/ha), poultry manure (10 t/ha), bat guano (10 t/ha), and Control (no fertilizer).

- *Crop Management*

Medium plowing (20 cm depth) was performed using a tractor. In pure culture, soybeans were sown in single rows at spacing of 40 cm x 20 cm with two (2) seeds per hole, making 8 sowing rows per plot, equivalent to a density of 250,000 plants/ha. In intercropping, they were sown at spacing of 50 cm x 25 cm. The secondary crop (millet) was sown in the inter-row two weeks after soybean sowing, at spacing of 80 cm x 80 cm. Local amendments (poultry manure and bat guano) were incorporated 10 days before sowing as base fertilizer at a rate of 1 kg/m². Foliar spraying of liquid fertilizers was carried out 30 days after sowing (DAS) and 15 days after the first spraying, at a dilution rate of 2 ml/L water for Super Gro, 3 ml/L water for Fertiplus, and 4 ml/L water for D.I. Grow Vert. Three weedings and hoeings were performed at 15, 30, and 45 DAS. Soybean harvest took place 100 days after crop establishment, and the first millet harvest occurred at 93 DAS, with the second harvest 10 days after the first pass. Soybeans and millet were sun-dried, threshed, and winnowed to obtain well-dried seeds and grains, which were then weighed to obtain the exact production weight. Soil samples were taken before crop establishment and analyzed to determine baseline elements (pH water, nitrogen, phosphorus, and potassium content). The results of these analyses are presented in Table 1.

Table 1. Baseline Soil Analysis Results

Conductivity (us/cm)	pH	Nitrogen (mg/kg)	Phosphorus (mg/kg)	Potassium (mg/kg)
20	6,7	1	1	3

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- Variables Measured

To evaluate biofertilizers and agronomic advantages, observations focused on production parameters: for soybean (number of pods per plant, number of seeds per pod, number of empty pods per plant, weight of 1000 seeds, plot production, yield) and for millet (plant height, number of tillers, number of harvested ears, plot production, and yield), and agroecological parameters (RYEM: soybean yield equivalent to millet yield obtained in intercrop with soybean; RYIS: soybean yield obtained in intercrop with millet; AAY: agronomic advantage based on yield; AYI: actual yield obtained in intercrop).

✓ RYEM: this index allows for a comparison of agronomic performance in monoculture and in intercropping. It was calculated using the following formula:

$$RYEM = \frac{\text{millet yield} \times \text{unit price of millet on market}}{\text{unit price of soybean on market}}$$

✓ AYI: actual soybean yield obtained in intercrop was obtained from the formula:

$$AYI = RYIS + RYEM$$

with RYIS: soybean yield in intercrop with millet.

✓ AAY: this index helps confirm whether crop association is more productive than monoculture. It was calculated using the following formula:

$$AAY = AYI - YSM$$

with YSM: soybean yield obtained in monoculture.

When AAY=0, the association has produced similarly to the monoculture, when it is less than 0, the association is not productive compared to the monoculture and when it is greater than 0, the association has produced more than the monoculture, there is an advantage.

- *Statistical Analysis*

Collected data were analysed using R software version 4.2.1. Analysis of variance (ANOVA) with DMRT at the 5% threshold was used to evaluate differences between treatment means.

III. RESULTS AND DISCUSSION

➢ *Effects of Biofertilizers on Soybean Performance in a Soybean-Millet Cropping System*

- *Effect of Cropping Systems on Soybean Production*

Results presented in Table 2 reveal that the cropping system did not significantly improve the number of pods per plant, number of seeds per pod, 1000-seed weight, or soybean grain yield (p-value > 0.05). However, ANOVA showed a significant improvement (p=0.05) in plot production (471.21 g) in monoculture compared to intercropping (428.65 g), with p-value < 0.05.

Table 2 Effect of Cropping Systems on Soybean Production

Cropping System	Pods per plant	Seeds per pod	1000-seed weight (g)	Plot production (g)	Yield (t/ha)
Monoculture	42.72	2.00	104.61	471.21 [a]	0.65
Intercrop	40.06	1.94	103.1	428.65 [b]	0.63
CV	8.8	1.6	3	9.5	9.1
P-value	0.09 [ns]	0.328 [ns]	0.224 [ns]	0.04*	0.63 [ns]

Within columns, means followed by the same letter do not differ significantly at the 5% threshold according to LSD. ns: not significant; *: *significant.*

- *Effects of Biofertilizers on Soybean Production*

Statistical analysis in Table 3 shows that fertilizers significantly improved (p=0.05) the number of pods per plant, 1000-seed weight, plot production, and soybean grain yield (p-value < 0.05). For pods per plant, soybean under bat guano (58.16 pods) and Super Gro (56.17 pods) ranked highest, followed by soybean under Fertiplus (44.33 pods), poultry manure (38.66 pods), and D.I. Grow Vert (33.33 pods), compared to the control (17.67 pods).

The number of seeds per pod remained stable across all fertilizers (≈2 seeds). ANOVA showed no improvement under the influence of different fertilizers (p-value > 0.05).

Regarding 1000-seed weight, ANOVA revealed a significant difference (p=0.05) among biofertilizers (p-value < 0.05). Soybean with bat guano (108 g) and Super Gro (107.8 g) significantly improved seed weight, followed by D.I. Grow Vert (103.0 g), poultry manure (102.67 g), and Fertiplus (101.3 g), compared to the control (100.5 g).

For plot production and grain yield, soybean with bat guano (650.69 g plot production; 0.93 t/ha yield) and Super Gro (626.77 g; 0.89 t/ha) ranked highest. Soybean with Fertiplus produced 465.2 g/plot (0.66 t/ha), higher than poultry manure (405.17 g; 0.57 t/ha). Soybean with D.I. Grow Vert recorded lower production (350.41 g/plot; 0.50 t/ha), though still higher than the control (201.2 g; 0.29 t/ha).

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Table 3 Effect of Biofertilizers on Soybean Production

Biofertilizer	Pods per plant	Seeds per pod	1000-seed weight (g)	Plot production (g)	Yield (t/ha)
Control	17.67 d	1.83 a	100.5 b	201.2 d	0.29 d
Bat-guano	58.16 a	2.00 a	108.0 a	650.69 a	0.93 a
Poultry manure	38.66 bc	2.00 a	102.6 ab	405.17 bc	0.57 bc
Super Gro	56.17 a	2.00 a	107.8 a	626.77 a	0.89 a
Fertiplus	44.33 b	2.00 a	101.3 b	465.2 b	0.66 b
D.I. Grow Vert	33.33 c	2.00 a	103.0 ab	350.41 c	0.50 c
CV	8.8	1.6	3	9.5	9.1
P-value	<0.001	0.441	0.002	<0.001	<0.001

Within columns, means followed by the same letter do not differ significantly at the 5% threshold according to LSD

- *Effects of Cropping System × Fertilizer Interaction on Soybean Production*

Table 4 highlights the combined effect of cropping system and biofertilizers on soybean production parameters. For pods per plant in monoculture, soybean under bat guano (60.66 pods) and Super Gro (58.33 pods) ranked highest, followed by Fertiplus (47.33 pods), poultry manure (39.6 pods), and D.I. Grow Vert (34.0 pods), compared to the control (19.0 pods) (p-value<0.05). In intercropping, the trend remained the same, with bat guano (55.66 pods) and Super Gro (54.0 pods) ranking highest (p-value<0.05).

No significant differences were found for seeds per pod (≈2 seeds/pod) across all treatments (p>0.05). For 1000-seed weight, values ranged from 100 g to 109 g, with no significant differences (p-value > 0.05).

For plot production in monoculture, bat guano significantly improved production (686.77 g), followed by Super Gro (647.02 g), Fertiplus (506.84 g), poultry manure (421.88 g), and D.I. Grow Vert (357.8 g), compared to the control (206.96 g) (p-value<0.05). In intercropping, bat guano again ranked highest (614.6 g), followed by Super Gro (606.5 g), Fertiplus (423.66 g), poultry manure (388.47 g), and D.I. Grow Vert (342.9 g), compared to the control (195.6 g).

Table 4 Effect of Cropping System × Fertilizer Interaction on Soybean Production

Biofertilisants	Pods per plant		Seeds per pod		1000-seed weight (g)		Plot production (g)	
	Mono.	Inter.	Mono.	Inter.	Mono.	Inter.	Mono.	Inter.
Control	19.0 ex	16.3ex	1.66 ax	2.00ax	100.3ax	100.6ax	206.9d	195.62d
Bat-guano	60.6aw	55.6ax	2.0 ax	2.0ax	109.66 ax	106.3ax	686.7a	614.6ab
Poultry manure	39.6 cdx	37.6 cdx	2.00 ax	2.00ax	104.00 ax	101.3ax	421.8c	388.47c
Super Gro	58.33aw	54.0abx	2.0ax	2.0ax	108.33 ax	107.3ax	647.02ab	606.5ab
Fertiplus	47.33abcw	41.3bcdx	2.0ax	2.00ax	102.33 ax	100.3ax	506.84bc	423.66c
D.I. Grow Vert	34.00 cdx	32.6dx	2.0ax	2.0ax	103.0ax	103.0ax	357.8cd	342.9cd
CV	8.8		1.6		3		9.5	

Means followed by the same letter do not differ significantly at the 5% threshold according to LSD. First letter series (a, b, c, d) for column comparisons; second series (w, x) for row comparisons between soybean monoculture and soybean-millet intercrop.

✓ Legend:

- Mono: Monoculture;
- Inter: Intercropping.

- *Figure*

Figure 2 reveals that the studied biofertilizers improved soybean grain yield in both monoculture and intercropping (p-value < 0.05). Soybean under bat guano dominated with 0.94 t/ha in monoculture and 0.91 t/ha in intercrop, followed by Super Gro (0.90 t/ha in monoculture and 0.88 t/ha in intercrop). Fertiplus produced 0.69 t/ha in monoculture and 0.63 t/ha in intercrop, poultry manure 0.57 t/ha in both systems, and D.I. Grow Vert showed lower yields (0.51 in monoculture and 0.49 t/ha in intercrop), though still higher than the control (0.32 t/ha in monoculture and 0.29 t/ha in intercrop).

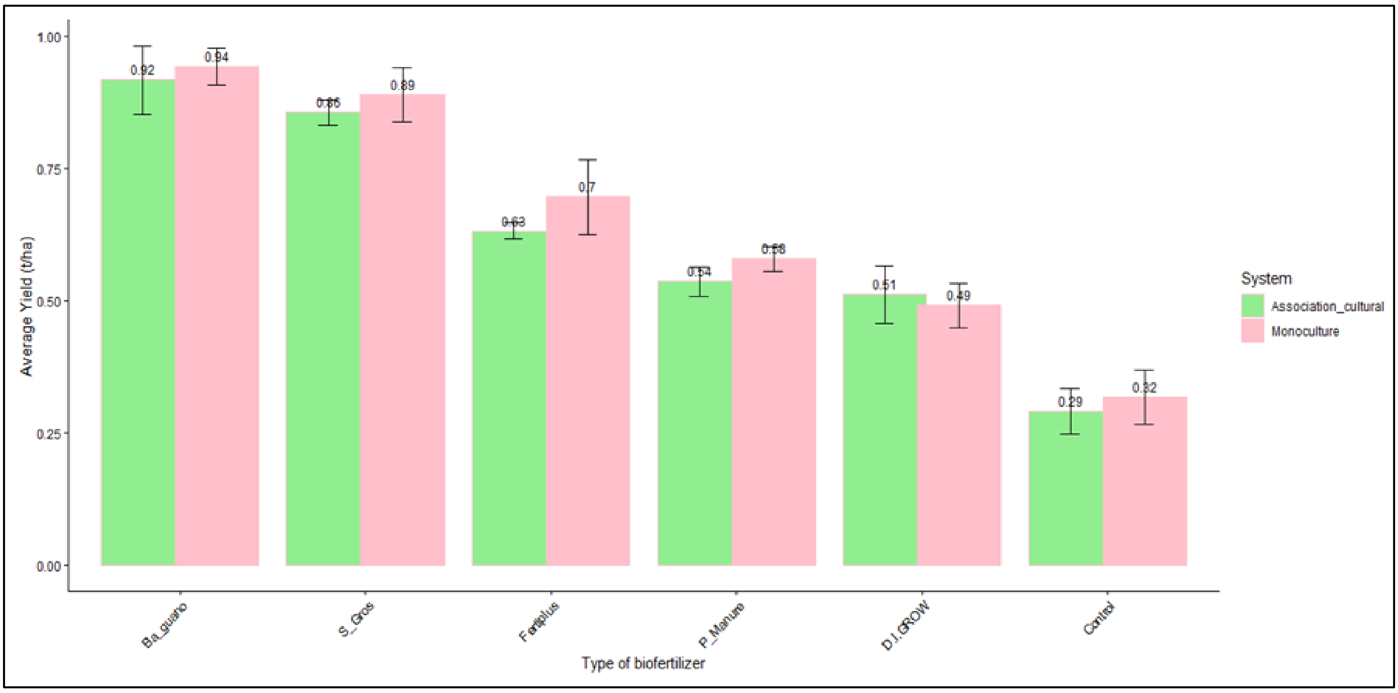

Fig 2 Interaction effect of cropping system and biofertilizers on soybean grain yield

➤ *Effects of Fertilizers on Millet Production in the Intercropping System and Comparison of Agronomic Advantages in Intercropping*

Table 5 shows that after ANOVA, no significant differences (p=0.05) were found among fertilizers for all observed variables (p-value > 0.05). Plant height ranged from 1 to 1.4 m, number of tillers from 2 to 4, number of harvested ears from 2 to 4, and yield fluctuated between 0.3 and 0.5 t/ha.

Table 5 Effects of Fertilizers on Millet Production in the Intercropping System

Biofertilizer	Plant Height(cm)	Number of Tillers	Number of Harvested Ears	Plot Production(g)	Yield (t/ha)
Control	1,03	2,66	2,33	189,33	0,37
Bat-guano	1,33	3,33	2,66	197,33	0,39
Poultry manure	1,31	3,33	2,66	191,17	0,38
Super Gro	1,31	3,66	3,33	242,67	0,48
Fertiplus	1,18	3,33	2,66	184,0	0,36
D.I. Grow Vert	1,34	3,66	2,66	176,0	0,35
CV	12,76	7,32	2,21	2,65	2,65
P-value	$0{,}196^{ns}$	$0{,}36^{ns}$	$0{,}475^{ns}$	$0{,}451^{ns}$	$0{,}451^{ns}$

ns: not significant at the 5% threshold.

➤ *Comparison of Agronomic Advantages in Intercropping and Actual Yields Under Different Fertilizers*

Information in Table 6 shows that millet yield ranged from 0.3 to 0.5 t/ha. RYEM ranged from 0.18 to 0.24 t/ha, with no significant differences among fertilizers. For RYIS, soybean under bat guano ranked highest (0.92 t/ha), followed by Super Gro (0.86 t/ha), Fertiplus (0.63 t/ha), poultry manure (0.54 t/ha), and D.I. Grow Vert (0.51 t/ha), compared to the control (0.27 t/ha). Regarding agronomic advantages, results show that intercropping was more productive than monoculture.

Table 6 Comparison of Agronomic Advantages in Intercropping and Actual Yields Under Different Fertilizers

Biofertilizer	Millet yield (t/ha)	RYEM (t/ha)	RYIS (t/ha)	AAY (t/ha)
Control	0.37	0.19	0.27^{b}	0.14
Bat guano	0.39	0.19	0.92^{a}	0.17
Poultry manure	0.38	0.19	0.54^{ab}	0.15
Super Gro	0.48	0.24	0.86^{a}	0.21
Fertiplus	0.36	0.18	0.63^{ab}	0.11
D.I. Grow Vert	0.35	0.18	0.51^{ab}	0.20
CV	2.65	3.2	9.4	0.84
p-value	0.22^{ns}	0.18^{ns}	0.02 *	0.14^{ns}

ns: not significant at 5%; *: significant at 5%.

- RYEM: soybean yield equivalent to millet yield in intercrop; RYIS: soybean yield in intercrop with millet; AAY: agronomic advantage based on yield; AYI: actual yield in intercrop.

➢ *Figure*

Figure 3 shows that the actual soybean yield in intercrop was significantly (p=5%) higher with Super Gro and bat guano (1.1 t/ha), followed by Fertiplus (0.81 t/ha), poultry manure (0.73 t/ha), and D.I. Grow Vert (0.69 t/ha), compared to the control (0.46 t/ha) (p-value < 0.05). For actual soybean yield in monoculture, bat guano (0.94 t/ha) ranked highest, followed by Super Gro (0.89 t/ha), Fertiplus (0.7 t/ha), poultry manure (0.58 t/ha), and D.I. Grow Vert (0.49 t/ha), compared to the control (0.32 t/ha) (p-value < 0.05).

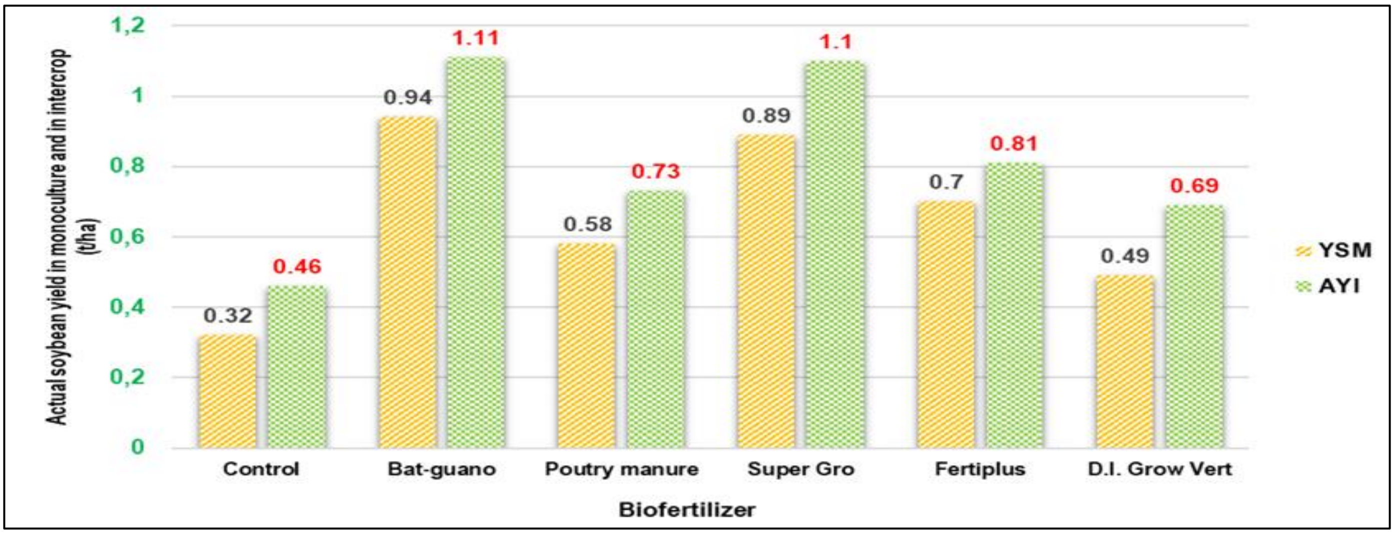

Fig 3 Effect of Intercropping on Soybean Yield (Comparison between Yield Obtained in Pure Soybean Culture and Actual Yield Obtained in Intercrop with Millet)

- *Legend:*

✓ YSM: Soybean yield in monoculture;
✓ AYI: Actual soybean yield in intercrop.

IV. DISCUSSION

The results show that the studied fertilizers significantly improved soybean growth and productivity in both monoculture and intercropping compared to the control.

The soybean-millet intercrop significantly improved grain yield compared to monoculture. Regarding commercial biofertilizers, soybean under Super Gro (0.90 t/ha in monoculture and 0.88 t/ha in intercrop) was the most performant. These results confirm its role as a water and nutrient adjuvant, already reported by Nsimba et *al.* (2023) and Ngoyi et *al.* (2025), who observed significant improvement in the productivity of biofortified maize UPN1 and MUS1 through Super Gro application. Soybean under Fertiplus (0.69 t/ha in monoculture and 0.63 t/ha in intercrop) ranked second. This performance is justified by its richness in amino acids and trace elements, confirmed by Landor (2024), promoting photosynthesis and cellular metabolism. Soybean under D.I. Grow Vert showed limitations with yields of 0.49 t/ha in monoculture and 0.51 t/ha in intercrop, which aligns with criticisms raised in Senegalese studies on foliar fertilizers rich in growth hormones that favor vegetation at the expense of fruiting (Loumatek, 2022).

Local amendments, particularly bat guano, showed positive effects with yields of 0.94 t/ha in monoculture and 0.91 t/ha in intercrop, confirming the study by Dimande et *al.* (2023), who demonstrated that guano mineralizes rapidly and acts as a mineral fertilizer. Poultry manure yielded 0.57 t/ha in monoculture and 0.63 t/ha in intercrop, compared to 0.31 t/ha and 0.29 t/ha recorded for the control soybean.

Regarding the agronomic advantage in intercropping, ANOVA showed no significant differences among biofertilizer means, ranging from 0.14 to 0.21. The results confirm that a significant agronomic advantage is recorded in intercropping, corroborating findings by Ngoyi et *al.* (2025).

For actual soybean yield in intercrop, soybean under Super Gro and bat guano ranked highest with 1.1 t/ha, followed by Fertiplus (0.81 t/ha), poultry manure (0.73 t/ha), and D.I. Grow Vert (0.69 t/ha), compared to the control (0.46 t/ha). Compared to actual soybean yield in monoculture, bat guano ranked highest (0.94 t/ha), followed by Super Gro (0.89 t/ha), Fertiplus (0.7 t/ha), poultry manure (0.58 t/ha), and D.I. Grow Vert (0.49 t/ha), compared to 0.32 t/ha for the control. These results demonstrate that combining commercial biofertilizers and local amendments in an intercropping system can optimize both productivity and sustainability by enhancing nodulation, seed quality, and resilience to agroecological constraints.

V. CONCLUSION

This research showed that the application of commercial biofertilizers and local organic amendments significantly improves soybean production in both monoculture and intercropping with millet. Bat guano and Super Gro proved most effective, with yields of 0.9 t/ha in monoculture and 1.1 t/ha in intercrop, compared to only 0.29 t/ha for the control soybean. The soybean-millet intercrop confirmed its agronomic advantage, reinforcing the relevance of intercropping systems for smallholder farmers facing low ferralsol fertility. However, the response of millet to biofertilizers remained limited, suggesting the need for further research on the growth conditions of this cereal.

In perspective, similar studies could be initiated to evaluate the effects of biofertilizers on different soil types on the productivity and biological activity of soybean and other legumes. Economic analyses would be necessary to validate the sustainability and profitability of these practices. The integration of biofertilizers into tropical agricultural systems thus appears as a promising agroecological strategy to improve the productivity and resilience of family farms.

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