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Enhancing Agronomic Efficiency of Pearl Millet through Integrated Laying Hen Manure and Mineral Fertilization in Burkina Faso's Sudano-Sahelian Zone

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Authors' contributions

This work was carried out in collaboration among all authors. Author SA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors ZRA and NR managed the analyses of the study and corrected the manuscript. Author SA managed the literature searches and data collection. All authors read and approved the final manuscript.

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Abstract

Background: The integration of organic and mineral fertilizers is increasingly recognized as a promising approach to enhance nutrient use efficiency (NUE) and improve the sustainability of cropping systems. The application of organic fertilizers, particularly poultry manure, constitutes a relevant strategy for restoring soil fertility. Such amendments simultaneously improve nutrient availability and enhance the soil's physical, chemical, and biological properties.

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Aims: The present study evaluated the combined effect of graded rates of laying hen manure (LHM) and mineral fertilizers on millet growth and yield to identify an optimal organo-mineral fertilization strategy adapted to the Sudano-Sahelian conditions of Burkina Faso.
Study Design: A field experiment was conducted using a split-plot design with 16 treatments resulting from the combination of two factors, replicated three times.
Place and Duration of Study: The experiment was carried out at the experimental station of the Rural Development Institute in Gampela, Burkina Faso during the rainy season of the 2024/2025 cropping year.
Methodology: Two factors were tested: (i) eight fertilizer rates combining LHM, NPK, and urea (R0–R7), and (ii) two millet varieties (Nafagnon and Chakti). Growth parameters, yield components, and yields were measured and analyzed. A total of 48 experimental plots (1 plot × 8 fertilizer levels × 2 variety levels × 3 replications) were used for the experiment. The replications were separated by a distance of 2m, and within the replications, the experimental plots were spaced 2m apart. Channels were constructed between the experimental plots to reduce cross-contamination between treatments due to water runoff from one plot to another.
Results: Organo-mineral fertilization significantly improved plant height, tiller number, canopy cover, number of flowering tillers, grain yield, and straw yield. In contrast, panicle length and panicle diameter were not significantly affected. The highest grain yields were consistently obtained under organo-mineral treatments. The results showed no significant differences among the different fertilizer doses (R1–R7) for the evaluated parameters, indicating a clear plateau in crop response across the tested fertilization range. This suggests that the nutrient requirements of pearl millet were already sufficiently met at the lowest organo-mineral dose (R1, laying hen manure + NPK), beyond which additional fertilizer inputs did not result in further agronomic improvement.
Conclusion: Organo-mineral fertilization is a sustainable strategy to improve millet productivity under Sudano-Sahelian conditions. Considering agronomic efficiency and fertilizer cost, R1 (2 t·ha^{-1} LHM + 60 kg·ha^{-1} NPK + 30 kg·ha^{-1} urea) is recommended as the optimal fertilization strategy for pearl millet production in Burkina Faso.

Keywords: Pearl millet; Nafagnon; Chakti; Laying hen manure; organo-mineral fertilizer.

1. Introduction

Pearl millet (Pennisetum glaucum (L.) R. Br.) is a major cereal crop in arid and semi-arid agroecosystems, widely recognized for its physiological plasticity and tolerance to water and nutrient stress (Govindaraj et al., 2010). In Burkina Faso, it ranks as the third most produced cereal after maize and sorghum, with 718,000 tonnes produced in 2021 over approximately 1.2 million hectares (FAOSTAT, 2023). Cultivated both for human consumption and for its biomass used as livestock feed, pearl millet exhibits high nutritional value, particularly in terms of protein, calcium, and iron content (Maiti & Rodríguez, 2010, Moussa et al., 2017). Despite its strategic importance for food security, pearl millet productivity remains low and highly variable. This is largely attributed to soil degradation, characterized by low organic matter content, nutrient deficiencies, and limited nutrient retention capacity. These constraints are further exacerbated by climate variability and restricted access to agricultural inputs (Traoré & Toé, 2008). In this context, sustainable soil fertility management represents a critical lever for enhancing crop productivity. The application of organic fertilizers, particularly poultry manure, constitutes a relevant strategy for restoring soil fertility. Such amendments simultaneously improve nutrient availability and enhance the soil's physical, chemical, and biological properties (Mandal et al., 2013; Enujeke, 2013, Nyembo et al., 2014; Gomgnimbou et al., 2019; Sha et al., 2023). Recent studies have demonstrated that applying 5 t. ha^{-1} of laying hen manure can achieve high pearl millet yields in low-fertility soils (Sory et al., 2022), confirming its agronomic effectiveness. However, although the efficiency of this relatively high organic rate has been established, its large-scale adoption remains constrained by limited availability of laying hen manure. Local production is insufficient to cover extensive agricultural areas, thereby restricting the widespread implementation of this practice. From a sustainable intensification perspective, there is therefore a need to identify fertilization strategies that reconcile agronomic performance, input availability, and economic feasibility. The integration of organic and mineral fertilizers is increasingly recognized as a promising approach to enhance nutrient use efficiency (NUE) and improve the sustainability of cropping systems (Vanlauwe et al., 2015; Agegnehu et al., 2016). Nevertheless, under the specific pedoclimatic conditions of Burkina Faso, the potential synergistic effects between reduced rates of laying hen manure and complementary mineral fertilization on pearl millet growth and yield remain insufficiently documented. In particular, it remains unclear whether lowering the organic manure rate can be compensated by appropriate mineral fertilization without compromising crop productivity. The present study therefore aime to evaluated the combined effect of graded rates of laying hen manure (LHM) and mineral fertilizers on millet growth and yield to identify an optimal organo-mineral fertilization strategy adapted to the Sudano-Sahelian conditions of Burkina Faso. We hypothesised that reducing LHM rate from 5 to 2 $t \cdot ha^{-1}$ with complementary NPK+urea would maintain grain yield and improve agronomic efficiency.

2. Materials and Methods

2.1 Experimental Site

The study was conducted during the rainy season of the 2024-2025 cropping year at the experimental station of the Institute for Rural Development (IDR) located in Gampèla, in the central region of Burkina Faso. Geographically, the experimental station is situated at 12°15′ N latitude and 1°12′ W longitude. The climate was of the Sudano-Sahelian type with average annual rainfall ranging from 600 to 900 mm (Boubacar, 2012). During the rainy season of the study, the station recorded a total rainfall of 984 mm. The highest rainfall occurred in August, totaling 324 mm over 15 rainy days, whereas May was the driest month, receiving only 79 mm of rainfall across 5 rainy days (Fig. 1).

2.2 Plant Material

The plant material used consisted of the hybrid pearl millet varieties "Nafagnon" and "Chakti," provided by the Institute for Environment and Agricultural Research (INERA) in Kamboinsé, Burkina Faso. The choice of these varieties was justified by: (i) their high yield potential (Nafagnon = 4 $t \cdot ha^{-1}$ and Chakti = 3 $t \cdot ha^{-1}$); (ii) their early maturity (85 days for Nafagnon and 65 days for Chakti); and (iii) their resistance to downy mildew (*Sclerospora graminicola*).

2.3 Experimental Design

The experimental design was a two-factor split-plot with three replications. The factors studied were variety at two levels (Chakti and Nafagnon) and fertilizer treatment at eight levels: R0: Control (no fertilizer), R1: $2 t.ha^{-1}$ LHM + $60 kg.ha^{-1}$ NPK + 30 $kg.ha^{-1}$ Urea, R2: $2 t.ha^{-1}$ LHM + $80 kg.ha^{-1}$ NPK + $40 kg.ha^{-1}$ Urea, R3: $3 t.ha^{-1}$ LHM + $40 kg.ha^{-1}$ NPK + $20 kg.ha^{-1}$ Urea, R4: $3 t.ha^{-1}$ LHM + $60 kg.ha^{-1}$ NPK + $30 kg.ha^{-1}$ Urea, R5: $4 t.ha^{-1}$ LHM + $20 kg.ha^{-1}$ NPK + $10 kg.ha^{-1}$ Urea, R6: $4 t.ha^{-1}$ LHM + $40 kg.ha^{-1}$ NPK + $20 kg.ha^{-1}$ Urea and R7: $5 t.ha^{-1}$ LHM Each replication consisted of 16 experimental plots, and each plot, with an area of 4.16m2, represented one treatment (a combination of variety and fertilizer factors). A total of 48 experimental plots (1 plot × 8 fertilizer levels × 2 variety levels × 3 replications) were used for the experiment. The replications were separated by a distance of 2m, and within the replications, the experimental plots were spaced 2m apart. Channels were constructed between the experimental plots to reduce cross-contamination between treatments due to water runoff from one plot to another.

2.4 Trial Management

The experimental field was plowed, and channels were constructed to separate the experimental plots in order to limit cross-contamination by runoff water. The different rates of laying hen manure (LHM) were applied to the respective plots. Sowing was carried out with a spacing of 80cm between rows and 30cm between hills. On the 14th day after sowing (DAS), weeding was carried out, followed by thinning to two plants per hill, and a second weeding combined with earthing up was performed on the 40th DAS. NPK fertilizer (14-23-14) was applied to the plants on the 14th and 21st DAS, while urea (46% N) was applied on the 30th DAS. To control granivorous birds, the entire field was covered with nets.

2.5 Physical and Chemical Properties of the Experimental Soil and the Laying Hen Manure (LHM)

The soil of the experimental plot had a sandy loam texture, with 76.47% sand, 13.73% silt, and 9.80% clay. It is slightly acidic (pH = 6.32) and characterized by relatively low levels of organic matter (0.321%) and organic carbon (0.186%). Chemically, the soil was poor in mineral nutrients, with a total nitrogen content of 0.018%, available phosphorus of 7.72 ppm, and available potassium of 67.01 ppm (Table 1).

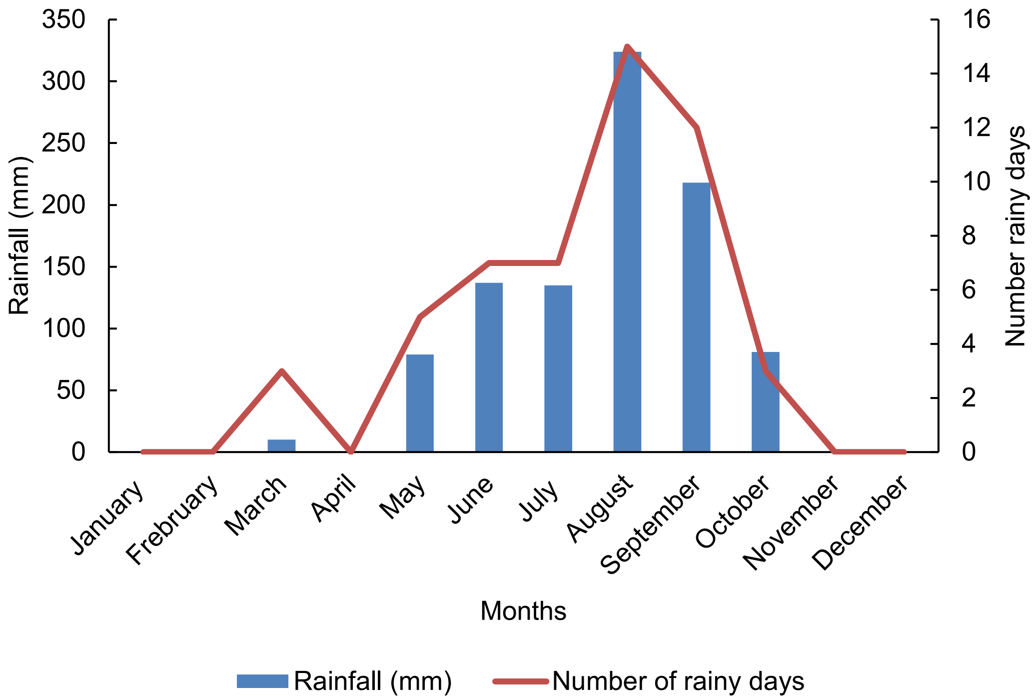

Fig. 1. Monthly rainfall distribution at the experimental site in 2025

The laying hen manure used in this study exhibited a slightly alkaline pH of 8.02. It was characterized by a high organic matter content (63.84%), with a carbon content of 37.03% and a C/N ratio of 9, indicating a high mineralization potential and relatively rapid decomposition (Table 1). Nutritionally, the manure contained high concentrations of major nutrients, including total nitrogen (39.6 $g.kg^{-1}$), available phosphorus (18.85 $g.kg^{-1}$), and available potassium (12.89 $g.kg^{-1}$). It was also rich in calcium (39.76 $g.kg^{-1}$) and magnesium (9.79 $g.kg^{-1}$) (Table 1).

Table 1. Physical and chemical properties of experimental soil and laying hen manure (LHM)

Particulars	Soil	LHM	Methods
Soil texture	Sandy loam	-	Pipette method
Clay (%)	9.80	-	
Silt (%)	13.73	-	
Sand (%)	76.47	-	
Organic matter (%)	0.321	63.84	Walkley-Black method (Nelson & Sommers,
Organic carbon ($g.kg^{-1}$)	0.186	37.03	1982).
Total nitrogen ($g.kg^{-1}$)	0.018	39.6	Kjeldahl method (Cottenie et al.,1982).
C/N ratio	10	9	-
Available phosphorus (ppm)	7.72	18.85	Bray n°1 method (Olsen & Sommers, 1982).
Available potassium (ppm)	67.01	12.89	Flame photometric method (APHA, 1989)
Total calcium (ppm)	278.61	39.76	Method proposed by Pinta (1973)
Total magnesium(ppm)	102.10	9.79	
Sum of bases (cmol(+)/kg)	3.25	-	Metson et al. (1956) method
CEC (cmol(+)/kg)	4.92	-	
pH (H_2O)	6.32	8.02	pH digital meter

2.6 Data Collection

Data were collected during two growth stages: flowering and maturity. At the flowering stage, plant height was measured using a tape measure, and the canopy cover was estimated using Canopeo version 1.1.7 software. The number of tillers produced and flowering tillers were determined by direct counting. At maturity, the length of the ear was measured using a tape measure, and the ear diameter was measured with a caliper. Grain, straw yields, and agronomic efficiency were calculated using the following formulas:

$$Grain\ yield\ (kg/ha) = \frac{\text{Grain weight of the sampling square} \times 10{,}000}{4.16\ \text{m}^2}$$

$$\text{Straw yield (kg/ha)} = \frac{\text{Straw weight of the sampling square} \times 10{,}000}{4.16\ \text{m}^2}$$

$$\text{Agronomic efficiency} = \frac{\text{Yf} - \text{Y0}}{\text{Qf}}$$

with Yf = yield ($kg \cdot ha^{-1}$) of the fertilized plot; Y0 = yield (kg. ha^{-1}) of the control plot (unfertilized); Qf = quantity of nutrient ($N + P_2O_5 + K_2O$) applied (kg. ha^{-1}).

Where 4.16 m^2 represents the area of the sampling square used for yield determination.

2.7 Data Analysis

The data were entered using Microsoft Excel 2019, which was also used to calculate means and generate graphs. XLSTAT 2016 software was employed to perform a two-way analysis of variance (ANOVA) to assess the variability among treatments. Mean comparisons for the studied parameters were conducted using the Newman–Keuls test at a 5% significance level.

3. Results and Discussion

3.1 Results

3.1.1 Growth Parameters

The application of organic fertilizer (R1) and organo-mineral fertilizers (R2–R7) resulted in a significant increase in plant height in the Nafagnon and Chakti varieties compared with the unfertilized control (R0) (Table 2). However, no significant difference was observed between plants subjected to organic fertilization (R1) and those receiving the different rates of organo-mineral fertilization (R2–R7) (Table 2). Furthermore, the Nafagnon variety exhibited a higher mean plant height (200.56 cm) than the Chakti variety (173.88 cm). Analysis of variance (ANOVA) revealed a significant effect of fertilizer rates on plant height in the Nafagnon variety (P = .01) and in the Chakti variety (P = .00). Similarly, the variety effect was highly significant on plant height (P = .000). In contrast, the interaction between variety and fertilizer rate did not show a significant effect on plant height (P = .98).

Applications of organic (R1) and organo-mineral fertilizers (R2–R7) resulted in an increase in the number of tillers com-pared with the control plots of the Nafagnon variety (Table 2). In contrast, for the Chakti variety, the number of tillers observed in plots fertilized with organic (R1) and organo-mineral fertilizers (R2–R7) was comparable to that recorded in the control plots (R0). Overall, plots treated with organic (R1) and organo-mineral fertilizers (R2–R7) exhibited statistically similar tiller numbers. The Nafagnon variety showed a significantly higher mean number of tillers (7.52) than the Chakti variety (6.52). Statistical analysis revealed a significant effect of fertilizer rates on tiller number in the Nafagnon variety (P = .03), whereas no significant effect was observed in the Chakti variety (P = .12). Furthermore, both the variety effect (P = .00) and the variety × fertilizer rate interaction (P = .01) were significant with respect to tiller production.

Similar to plant height, the application of organic fertilizer (R1) and organo-mineral fertilizers (R2–R7) resulted in a significant increase in canopy cover of both Nafagnon and Chakti varieties compared to the unfertilized control (Table 2). However, the canopy cover observed in Nafagnon plots (52.26%) was similar to that in Chakti plots (45.78%). Plots treated with organic (R1) and organo-mineral (R2–R7) fertilizers exhibited statistically similar canopy cover values. Analysis of variance (ANOVA) revealed a significant effect of fertilizer rates on canopy cover for both Nafagnon (P = .00) and Chakti (P = .04). In contrast, the variety effect (P = .21) and the interaction between variety and fertilizer rate (P = .82) was not significant.

Table 2. Effect of organic and organo-mineral fertilization on plant height, tillering, and canopy cover

Rate	Plant height (cm)		Number of tillers		Canopy cover (%)	
	Nafagnon	**Chakti**	**Nafagnon**	**Chakti**	**Nafagnon**	**Chakti**
R0	124.75 ±48.44b	91.94 ± 33.32b	4.13 ± 0.18b	5.50 ± 1.06a	15.61 ± 8.97b	15.84 ± 9.94b
R1	210.04 ± 15.30a	184.50 ±0.35a	9.22 ±0.20a	5.88 ± 0.53a	58.24 ± 4.17a	52.36 ±4.15a
R2	200.75 ± 23.49a	174.29±11.25a	8.33 ±1.26a	7.00 ± 0.25a	54.83 ±13.18a	50.91±25.15a
R3	203.75 ± 7.63a	188.38±26.34a	6.17±1.70ab	6.00 ± 1.50a	56.41 ±18.60a	53.86±22.01a
R4	207.83 ± 7.50a	179.25±6.01a	7.25±1.15ab	7.38 ± 0.18a	58.96 ±10.13a	51.94±9.90a
R5	216.00 ± 4.60a	200.44±0.97a	7.42±1.63ab	7.00 ± 0.35a	59.87 ±2.04a	54.68±6.48a
R6	212.04 ± 13.73a	179.38±11.14a	7.67±1.38ab	7.13 ± 0.18a	51.85 ±10.70a	47.90±3.55a
R7	204.75 ± 17.32a	180.75 ±0.71a	9.00±0.35a	5.88 ±0.88a	62.32 ±12.28a	38.81±5.62a
Varietal mean	200.56±30.21^{a}	173.88±34.40^{b}	7.52±1.75^{a}	6.52±0.93^{b}	52.26±16.73^{a}	45.78±15.95^{a}
***P*-values**						
Rate	.01	.00	.03	.12	.00	.04
Variety	.000		.00		.21	
R≠V	.98		.01		.82	

Legend: Means sharing the same letters do not differ significantly at the 5% level. V = variety; R = rate; R0 = absolute control without fertilizer; R1 = 2 t ha^{-1} of laying hen manure (LHM) + 60 kg ha^{-1} NPK + 30 kg ha^{-1} urea; R2 = 2 t ha^{-1} LHM + 80 kg ha^{-1} NPK + 40 kg ha^{-1} urea; R3 = 3 t ha^{-1} LHM + 40 kg ha^{-1} NPK + 20 kg ha^{-1} urea; R4 = 3 t ha^{-1} LHM + 60 kg ha^{-1} NPK + 30 kg ha^{-1} urea; R5 = 4 t ha^{-1} LHM + 20 kg ha^{-1} NPK + 10 kg ha^{-1} urea; R6 = 4 t ha^{-1} LHM + 40 kg ha^{-1} NPK + 20 kg ha^{-1} urea; R7 = 5 t ha^{-1} LHM

Table 3. Effect of organic and organo-mineral fertilization on length and diameter of millet panicle

Rate	Number of flowering tillers		Panicle length (cm)		Diameter of Panicle (mm)	
	Nafagnon	**Chakti**	**Nafagnon**	**Chakti**	**Nafagnon**	**Chakti**
R0	0.67 ± 1.15b	1.50 ± 0.50c	34.2 ± 2.56a	20.17 ± 3.53a	23.40 ± 0.50a	26.31 ± 3.22a
R1	2.67 ± 0.58a	3.08 ± 0.14ab	32.83 ± 3.73a	23.79 ± 3.21a	29.52 ± 1.40a	27.51 ± 2.84a
R2	3.00 ± 1.00a	4.22 ± 0.38a	35.38 ± 2.69a	21.25 ±.1.32a	30.45 ± 2.92a	28.43 ± 1.29a
R3	2.67 ± 0.58a	3.22 ± 0.38ab	34.29 ± 1.28a	21.67 ± 0.51a	28.35 ± 3.02a	27.25 ± 1.84a
R4	3.67 ± 1.53a	2.78 ± 0.38b	32.69 ± 0.44a	20.29 ± 0.31a	30.28 ± 2.14a	30.95 ± 0.45a
R5	3.67 ± 0.58a	4.00 ± 0.25ab	32.04 ± 0.89a	24.63 ± 4.07a	28.57 ± 4.36a	30.09 ± 2.87a
R6	3.00 ± 0.00a	3.81 ± 0.97ab	34.19 ± 0.97a	21.58 ± 1.82a	29.35 ± 2.03a	25.35 ± 2.96a
R7	3.00 ± 0.00a	2.83 ± 0.52b	33.07 ± 1.69a	21.50 ± 1.64a	30.76 ± 5.50a	25.13 ± 1.65a
Varietal mean	2.79±1.14[a]	3.18±0.92[a]	33.60±2.08[a]	21.86±2.35[b]	28.83±3.15[a]	27.63+2.69[a]
P-values						
Rate	.01	.000	.76	.39	.33	.07
Variety	.20		.000		.09	
R≠V	.25		.04		.09	

Legend: Means sharing the same letters do not differ significantly at the 5% level. V = variety; R = rate; R0 = absolute control without fertilizer; R1 = 2 t ha⁻¹ of laying hen manure (LHM) + 60 kg ha⁻¹ NPK + 30 kg ha⁻¹ urea; R2 = 2 t ha⁻¹ LHM + 80 kg ha⁻¹ NPK + 40 kg ha⁻¹ urea; R3 = 3 t ha⁻¹ LHM + 40 kg ha⁻¹ NPK + 20 kg ha⁻¹ urea; R4 = 3 t ha⁻¹ LHM + 60 kg ha⁻¹ NPK + 30 kg ha⁻¹ urea; R5 = 4 t ha⁻¹ LHM + 20 kg ha⁻¹ NPK + 10 kg ha⁻¹ urea; R6 = 4 t ha⁻¹ LHM + 40 kg ha⁻¹ NPK + 20 kg ha⁻¹ urea; R7 = 5 t ha⁻¹ LHM

3.1.2 Number of Flowering Tillers, Length and Diameter of Millet Panicle

The number of flowering tillers in plots treated with organic fertilizer (R7) and organo-mineral fertilizers (R1–R6) was higher than in the control plot (R0) for both varieties (Table 3). Plots receiving organic (R7) and organo-mineral (R1–R6) fertilizers showed similar numbers of flowering tillers across both varieties. The two varieties also exhibited a comparable number of flowering tillers. Analysis of variance (ANOVA) indicated a significant effect of fertilization on the number of flowering tillers for Nafagnon (P = .01) and Chakti (P = .000). However, the variety effect on flowering tiller number was not significant (P = .20), and the interaction between variety and fertilization was also not significant (P = .25).

The panicle length and diameter of the panicle from both varieties subjected to fertilizer rates R1–R7 were comparable to those of the unfertilized control (R0) (Table 3). Furthermore, for each variety, no significant differences were observed between plots fertilized with organo-mineral fertilizers (R1–R6) and those receiving organic fertilizer alone (R7). However, the Nafagnon variety exhibited significantly longer panicles than the Chakti variety, while panicle diameter was similar between the two varieties. Analysis of variance indicated that fertilization had no significant effect on panicle length in Nafagnon (P = .76) or Chakti (P = .39), nor on panicle diameter in Nafagnon (P = .33) and Chakti (P = .07). The effect of variety on panicle diameter was also not significant (P = .09). In contrast, the variety effect was significant for both mean panicle length (P = .000). Moreover, the variety × fertilization interaction had a significant effect on panicle length (P = .04), whereas no significant effect was observed on panicle diameter (P = .09).

3.1.3 Grain and Straw Yields

Grain and straw yields of plants from plots fertilized with the different rates (R1–R7) were significantly higher than those of the unfertilized control (R0) for both Nafagnon and Chakti varieties (Table 4). However, the effects of organo-mineral fertilizer rates (R1–R6) were comparable to those obtained with organic fertilization alone (R7). Between the two varieties, Nafagnon exhibited higher yields, both in grain (4.73 t·ha^{-1}) and straw (15.05 t·ha^{-1}), compared with Chakti, which recorded 3.48 t·ha^{-1} and 13.10 t·ha^{-1}, respectively. Analysis of variance showed that treatments based on laying hen manure, applied alone or in combination with NPK and urea, significantly improved grain yields in both varieties (P = .000), as well as straw yields in Nafagnon (P = .00) and Chakti (P = .000). Moreover, the variety effect was highly significant for both mean grain and straw yields (P = .000). Finally, the variety × fertilization interaction had a significant effect on grain yield (P = .01) and straw yield (P = .00) (Table 4).

Table 4. Effect of organic and organo-mineral fertilization on grain and straw yields

Rate	Grain yield (kg/ha)		Straw yields (kg/ha)	
	Nafagnon	**Chakti**	**Nafagnon**	**Chakti**
R0	1993.83 ± 407.03c	1716.90 ± 391.12c	8298.33 ± 254.94c	2103.37 ± 901.44c
R1	3861.91 ± 161.21ab	3365.50 ± 184.22ab	10691.62 ± 793.43bc	7572.12±2043.27b
R2	3676.82 ± 268.66b	2948.71 ± 143.23ab	11561.34 ± 857.50abc	6730.77 ± 721.15b
R3	3504.02 ± 240.62b	2728.57 ± 103.05b	10603.63 ± 1949.79bc	7211.54 ± 2403.85b
R4	3853.25 ± 726.70ab	3181.75 ± 258.49ab	13880.67 ± 2021.70ab	9615.38 ± 2403.85ab
R5	4390.37 ± 429.19ab	3014.01 ± 228.75ab	12746.71 ± 1929.40ab	13100.96 ± 2524.04a
R6	4024.38 ± 358.88ab	2869.42 ± 454.70ab	11877.83 ± 2262.4abc	9855.77 ± 961.54ab
R7	4428.80 ± 156.38ab	3078.22 ± 235.97ab	15052.66 ± 972.99a	6971.15 ± 240.38b
Varietal mean	3754.17±839.87[a]	2900.39±563.22[b]	11839.09±2382.41[a]	7895.13±3359.11[b]
P-values				
Rate	.000	.000	.00	.000
Variety	.000		.000	
R≠V	.01		.00	

Legend: Means sharing the same letters do not differ significantly at the 5% level. V = variety; R = rate; R0 = absolute control without fertilizer; R1 = 2 t ha⁻¹ of laying hen manure (LHM) + 60 kg ha⁻¹ NPK + 30 kg ha⁻¹ urea; R2 = 2 t ha⁻¹ LHM + 80 kg ha⁻¹ NPK + 40 kg ha⁻¹ urea; R3 = 3 t ha⁻¹ LHM + 40 kg ha⁻¹ NPK + 20 kg ha⁻¹ urea; R4 = 3 t ha⁻¹ LHM + 60 kg ha⁻¹ NPK + 30 kg ha⁻¹ urea; R5 = 4 t ha⁻¹ LHM + 20 kg ha⁻¹ NPK + 10 kg ha⁻¹ urea; R6 = 4 t ha⁻¹ LHM + 40 kg ha⁻¹ NPK + 20 kg ha⁻¹ urea; R7 = 5 t ha⁻¹ LHM

3.1.4 Agronomic Efficiency

Agronomic efficiency did not differ significantly among the different organo-mineral and organic fertilizer rates (R1–R7) in the Nafagnon variety ($P = .20$) (Fig. 2). In contrast, in the Chakti variety, the agronomic efficiency of rate R1 was significantly higher than those of rates R3, R5, R6, and R7, with respective differences of 2.85, 2.51, 3.15, and 2.74 ($P = .00$).

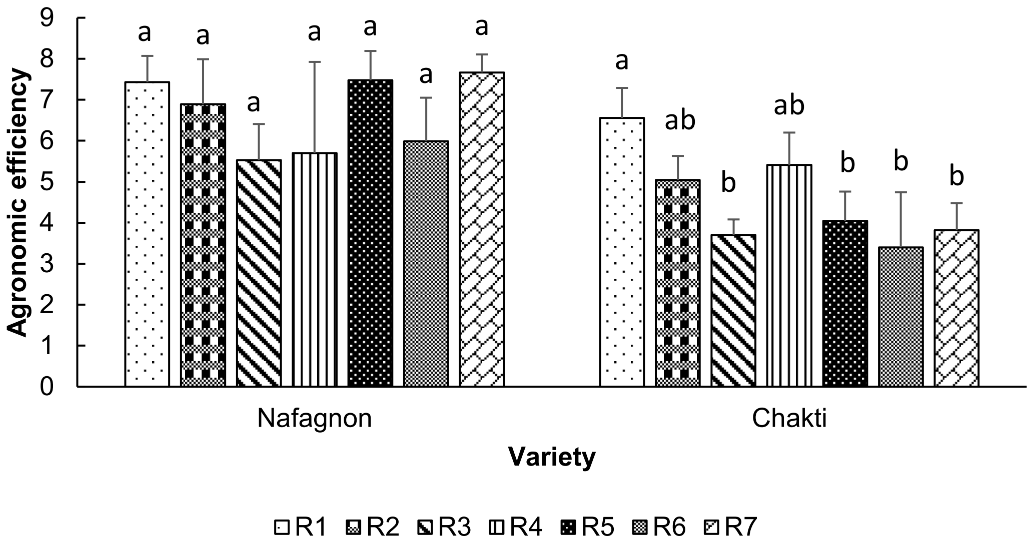

Fig. 2. Effect of organic and organo-mineral fertilization on agronomic efficiency

Legend: Error bars followed by the same letter are not significantly different at the 5% level.R0 = absolute control without fertilizer; R1 = 2 t ha ⁻¹ of laying hen manure (LHM) + 60 kg ha ⁻¹ NPK + 30 kg ha ⁻¹ urea; R2 = 2 t ha ⁻¹ LHM + 80 kg ha ⁻¹ NPK + 40 kg ha ⁻¹ urea; R3 = 3 t ha ⁻¹ LHM + 40 kg ha ⁻¹ NPK + 20 kg ha ⁻¹ urea; R4 = 3 t ha ⁻¹ LHM + 60 kg ha ⁻¹ NPK + 30 kg ha ⁻¹ urea; R5 = 4 t ha ⁻¹ LHM + 20 kg ha ⁻¹ NPK + 10 kg ha ⁻¹ urea; R6 = 4 t ha ⁻¹ LHM + 40 kg ha ⁻¹ NPK + 20 kg ha ⁻¹ urea; R7 = 5 t ha ⁻¹ LHM

3.2 Discussion

The results highlight the agronomic value of organo-mineral fertilization. Treatments combining laying hen manure (LHM) with mineral fertilizers significantly enhanced plant height, tillering, and canopy cover compared to the unfertilized control. These observations support the principle of complementarity underlying organo-mineral fertilization: mineral fertilizers supply immediately available nutrients (N, P, K), which are particularly critical during the early stages of crop establishment, while organic amendments provide a gradual nutrient release and simultaneously improve the soil's physical, chemical, and biological properties. The mineralization of LHM ensures a continuous supply of nitrogen and phosphorus, thereby maintaining prolonged nutrient availability for the plant (Palm et al., 2001). Nitrogen promotes cell division and elongation, directly stimulating vegetative growth, whereas phosphorus plays a key role in root development and cellular energy metabolism (Marschner, 2012; Taiz et al., 2015). Their combined availability thus contributes to increased plant height (Harper, 1994) and enhanced tillering (Dutordoir, 2006). Beyond mineral nutrition, the organic fraction improves soil structure, increases water-holding capacity, stimulates microbial activity, and promotes more extensive root exploration effects that are particularly critical in tropical soils low in organic matter (Bationo et al., 2007). Similar results were reported by Somda et al. (2017) on sorghum. These authors showed that organo-mineral fertilization (10 t·ha⁻¹ of organic manure + 3 g per hill of NPK) led to a 219% increase in plant height compared to the control, whereas the increase was 70% in the present study. This difference can be mainly explained by the levels of organic fertilization applied. Indeed, the rate of organic manure used by Somda et al. (2017) (10 t·ha⁻¹) was considerably higher than that applied in our experiment (maximum of 4 t·ha⁻¹). Such a difference in organic input may have enhanced the gradual nutrient availability as well as improved the soil's physico-chemical properties, thereby contributing to a more pronounced crop response. Similar outcomes have been reported by by Oliveira et al. (2017) in sorghum confirming the beneficial impact of organo-mineral fertilization on vegetative growth. Coly et al. (2021) also reported an increase in tiller number under organo-mineral fertilization. However, the application of 7.5 $t \cdot ha^{-1}$ of organic manure combined with 150 kg of NPK resulted in a 54% increase in tiller number compared to the control, whereas a 45% increase was observed in the present study. This difference is likely attributable to the higher nitrogen content in the treatment used by these authors compared to that applied in our study.

Moreover, organic and organo-mineral treatments significantly increased the number of flowering tillers, reflecting improved nutritional conditions during the transition to the reproductive phase. Nitrogen is recognized as the primary nutritional factor controlling tiller initiation, growth, and survival in cereals, due to its central role in the synthesis of proteins, enzymes, and chlorophyll, as well as in maintaining high photosynthetic activity (Marschner, 2012). Adequate nitrogen supply reduces tiller abortion by ensuring sufficient assimilate availability during the critical phase of floral differentiation. Phosphorus, on the other hand, is involved in energy transfer (ATP), cellular signaling, and meristematic tissue development processes essential for floral induction and reproductive organ formation (Taiz et al., 2015). Sufficient phosphorus availability therefore promotes better synchronization between vegetative growth and reproductive transition. In this context, the gradual mineralization of manure allows sustained release of nitrogen and phosphorus throughout the crop cycle, while mineral fertilizers provide immediately available forms. This complementarity ensures continuous and balanced nutrition, minimizing transient deficiencies that could compromise tiller survival until flowering. Recent studies confirm that integrating organic amendments with mineral fertilizers enhances nitrogen-use efficiency and promotes the formation of fertile tillers in tropical cereal systems (Vanlauwe et al., 2015; Agegnehu et al., 2016).

Similarly, fertilization organic or organo-mineral did not significantly affect the length or diameter of the panicles in either variety. This lack of effect suggests that these morphological traits are relatively stable and strongly determined by genetic potential rather than by moderate variations in nutrient availability when basic requirements are satisfied. The significant varietal effect observed for panicle length and diameter supports this hypothesis. Nafagnon, which exhibits longer and thicker panicles than Chakti, likely expresses a higher genetic potential for these traits.

In contrast, both grain and straw yields were significantly enhanced by organic and organo-mineral fertilization compared to the unfertilized control in both varieties. These results reflect the structuring and synergistic effects of these fertilization strategies on the soil plant system. The positive response observed in both varieties indicates that nutrient availability was likely a limiting factor in the non-fertilized plots. The combination of organic manure and mineral fertilizers appears to provide both an immediate supply of readily available nutrients (notably nitrogen and phosphorus from mineral fertilizers) and a gradual nutrient release through the mineralization of organic matter. This dual mechanism ensures a more consistent nutrient supply throughout the crop cycle, optimizing photosynthetic activity, vegetative growth, and grain filling. These observations are consistent with those of Somda (2017), who demonstrated that organo-mineral fertilization enhances yields by improving nutrient availability and soil structure. According to Marschner (2012) and Taiz et al. (2015), adequate nitrogen and phosphorus nutrition improves photosynthetic efficiency, protein synthesis, and assimilate translocation to storage organs, thereby directly contributing to higher grain yield. Moreover, the addition of organic matter enhances soil physical, chemical, and biological properties. Increased organic matter content promotes structural stability, water-holding capacity, and cation exchange capacity, which are critical under rainfall conditions characterized by hydric variability. It also stimulates microbial activity, intensifying nutrient mineralization and solubilization processes. This biological dynamic contributes to better synchronization between nutrient supply and crop demand, thereby improving fertilizer-use efficiency. These findings corroborate those of Dasgan et al. (2022), who showed that integrating organic and mineral fertilizers enhances nutrient-use efficiency while maintaining high yields with reduced mineral input rates. Similar trends have been reported in maize (Abrol et al., 2024), rice and sorghum (Oliveira et al., 2017), where organo-mineral fertilization optimized productivity. Somda et al. (2017) observed a 45% yield increase with organo-mineral fertilizer, comparable to the 48% increase in our study for Nafagnon. In the present study, the relatively high efficiency could be attributed to the use of laying hen manure, which is typically rich in readily available nutrients, particularly nitrogen and phosphorus, thereby enhancing nutrient uptake and crop performance. In contrast, the compost used by Somda et al. (2017), although beneficial for soil structure and long-term fertility, may have exhibited slower nutrient mineralization rates. However, Coly et al. (2021) reported that organo-mineral fertilization had no significant effect on grain yield of millet. This lack of response may be explained by the timing of compost application. Indeed, the compost was applied 31 days after sowing, which likely limited the synchronization between nutrient release and crop demand, particularly during the critical grain-filling stage. This temporal mismatch may have prevented the compost from releasing sufficient mineral nutrients to effectively support yield formation.

The results showed no significant differences among the different fertilizer doses (R1–R7) for the evaluated parameters, indicating a clear plateau in crop response across the tested fertilization range. This suggests that the nutrient requirements of pearl millet were already sufficiently met at the lowest organo-mineral dose (R1, laying hen manure + NPK), beyond which additional fertilizer inputs did not result in further agronomic improvement. This response pattern reflects nutrient saturation beyond a threshold, where the soil–plant system reaches a level of adequate nutrient supply, and further additions do not translate into increased growth or yield. Such a plateau may be explained by the relatively high nutrient availability and rapid mineralization of laying hen manure combined with mineral fertilizers, which could have ensured early and sufficient nutrient uptake during critical growth stages. Once the crop demand was satisfied, other factors such as genetic yield potential, water availability, or internal physiological regulation likely became more limiting than nutrient supply. This observation is consistent with Liebig's law of the minimum and the principle of diminishing returns (Brady and Weil, 2016).

The superior growth and yield performance of the Nafagnon variety compared to Chakti suggests a genetic advantage associated with higher intrinsic productive potential. This performance may be attributed to a more developed root architecture and greater nutrient-use efficiency, as highlighted by Marschner (2012). It may also reflect higher photosynthetic capacity and more effective assimilate allocation to reproductive organs, thereby promoting grain filling (Taiz et al., 2015).

Although this study demonstrated the immediate effectiveness of organo-mineral fertilization, it would be relevant to extend these trials to other agro-ecological zones of Burkina Faso with contrasting soil and climatic characteristics. Such an approach would not only help to verify the stability of the performance of the Nafagnon and Chakti varieties, but also to refine technical recommendations for wider dissemination among farmers.

4. Conclusion

This study aimed to evaluate the combined effect of graded rates of laying hen manure (LHM) and mineral fertilizers on millet growth and yield to identify an optimal organo-mineral fertilization strategy adapted to the Sudano-Sahelian conditions of Burkina Faso. The results showed that both organic and organo-mineral fertilization significantly improved growth and yield parameters of the Nafagnon and Chakti varieties. Organic fertilization based on laying hen manure (R7) exhibited performances comparable to those obtained with organo-mineral fertilization treatments (R1–R6), thereby highlighting its potential as an effective alternative for pearl millet production. The highest grain yields were consistently recorded under organo-mineral fertilization treatments. Considering both agronomic efficiency and fertilizer cost, the organo-mineral dose R1 combining 2 $t \cdot ha^{-1}$ of laying hen manure with 60 $kg \cdot ha^{-1}$ NPK and 30 $kg \cdot ha^{-1}$ urea can be recommended as an optimal fertilization strategy for pearl millet production in the Sudano-Sahelian zone of Burkina Faso.

Disclaimer (Artificial Intelligence)

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Competing Interests

Authors have declared that no competing interests exist.

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