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VARIETAL AND SEEDING RATE INFLUENCE ON FORAGE PRODUCTIVITY AND NUTRITIONAL QUALITY OF PEARL MILLET IN HUMID AGROECOLOGIES: AN EXTENSION PERSPECTIVE

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ABSTRACT

In order to determine how seeding rate affected the forage yield, mineral composition, and nutrient uptake of two local pearl millet (*Pennisetum typhoides Burm. f.)* varieties Gero Bida and Gero Badeggi, a field experiment was carried out at the Teaching and Research Farm, Faculty of Agriculture, Emaudo Annex, Ambrose Alli University, Ekpoma. In a Randomized Complete Block Design (RCBD) with three replicates, the study used a 2 × 4 factorial arrangement. Two millet varieties and four seeding rates (1, 2, 3, and 4 seeds per hole) were used as treatments, which corresponded to 53,333, 106,666, 159,999, and 213,332 plants/ha. Growth parameters, dry matter and forage yield, mineral composition, and nutrient uptake were among the data gathered. There were notable variations between the treatments. One seed per hole produced the tallest plants (219.20cm), the most leaves (12.63) per plant, the largest total leaf area (10,806.50cm^2), the highest forage yield (27.63t/ha), and the highest dry matter yield (4.49t/ha) among Gero Badeggi plants. It also showed the highest concentration of minerals and the most significant uptake of nutrients. On the other hand, the highest dry matter percentage (23.15%) was found in Gero Bida that was planted with four seeds per hole. According to the study, for optimal forage productivity and nutritional quality in humid conditions, Gero Badeggi should be planted with one seed per hole. The findings have important ramifications for agricultural extension since they offer evidence-based recommendations for sustainable forage production, variety selection, and seeding rate optimization. These results can enhance livestock feed quality, improve resource efficiency, and inform extension programming.

Keywords: Planting time; Local; Productivity; Optimization; Region, Agricultural extension

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1. INTRODUCTION

Forage production is central to sustaining livestock-based systems and ensuring the profitability of dairy and meat enterprises, particularly in the face of rising human and animal populations (Nanda and Nilanjaya 2021). Pearl millet (*Pennisetum glaucum* (L.) R. Br.), a drought-tolerant C4 cereal of the Poaceae family, has gained increasing relevance as a dual-purpose crop cultivated for both grain and fodder in sub-Saharan Africa and South Asia (Serba et al. 2020; Satyavathi et al. 2021). Compared to maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench), it demonstrates superior photosynthetic efficiency, dry matter accumulation, and resilience under adverse environmental conditions, making it a strategic crop for climate-smart agriculture (Bhattacharya et al. 2021; Cicek & Yucel 2022; Erekalo & Yadda 2023; Kabato et al. 2025).

Globally, pearl millet is the second most important millet after sorghum, cultivated on over 28 million hectares, mainly in India and Africa (FAOSTAT, 2023). In Nigeria, it remains a vital crop, contributing both as a staple food and a forage source for livestock (Mawouma et al., 2022). Its adaptability to marginal environments, including sandy soils, low rainfall, and nutrient stress, underscores its potential as a reliable feed resource in humid agro-ecological zones where feed scarcity and competition for arable land pose critical challenges (Upreti et al. 2022; Nwajei, 2023; Zeng et al. 2025).

Nutritionally, pearl millet grain provides about 361 Kcal per 100g, with 11–12% protein, while its green fodder contains approximately 13–14% crude protein, 7–8% crude fat, and high starch content, making it suitable for hay, silage, and rotational grazing systems (Amarghade and Singh 2021; Mohan and Singh 2022). Recent advances in

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stress physiology and proteomics have also highlighted its resilience, with stress-responsive proteins identified under drought and heat stress, reinforcing its role as a climate-resilient forage crop (Weckwerth et al. 2020; Ghatak et al. 2021).

Genotypic variation strongly influences forage yield and nutritional composition in pearl millet. Studies have reported differences in biomass accumulation, crude protein levels, and digestibility among varieties, particularly in multi-cut forage types (Upreti et al. 2022). Nitrogen use efficiency also varies by genotype, with significant implications for productivity in humid agro-ecologies where nutrient leaching is common (Shekara et al. 2020). Varietal improvement and targeted selection, therefore, remain essential for enhancing forage potential in regions with variable rainfall and soil fertility dynamics.

Seeding rate is a critical determinant of plant population density, resource use efficiency, and forage quality. While higher seeding rates increase biomass yield, they may reduce nutritional quality due to higher stem-to-leaf ratios. Conversely, lower rates may enhance crude protein content but result in a reduced total yield (Salama 2019; Pyati 2021). Under humid conditions, Nwajei (2023) reported pearl millet forage yields ranging between 2.49 and 5.80t ha^{-1} in Edo State, Nigeria, whereas Donmez and Hatipoglu (2024) observed substantially higher yields of 7.9–20.3t ha^{-1} in Kahramanmaraş, Turkey. These contrasting results underscore the combined influence of seeding density, environment, and management practices on yield outcomes. Although pearl millet has been widely studied as a grain and forage crop in semi-arid regions (Mawouma et al. 2022), research on its productivity and nutritional quality under humid agro-ecologies remains limited. In such environments, challenges such as nutrient leaching, weed pressure, and lodging interact with varietal traits and seeding rates to influence performance. With growing demand for livestock feed and intensifying competition for arable land, identifying suitable varieties and optimal seeding rates is essential to maximize forage yield and nutritive value. This study, therefore, was designed to evaluate the influence of varietal differences and seeding rate on the forage productivity and nutritional quality of pearl millet in a humid forest savanna transition zone of Nigeria. The specific objectives were to:

1. Assess the growth performance of two pearl millet varieties under varying seeding rates.
2. Determine the forage yield and biomass accumulation across treatments.
3. Evaluate the mineral composition and nutrient uptake of the varieties as influenced by seeding rates.

2. MATERIALS AND METHODS

2.1. Experimental Site

The field experiment was conducted at the Teaching and Research Farm, Faculty of Agriculture, Ambrose Alli University, Emaudo Annex, Ekpoma (Lat. 6'45 N and Long. 6'8' E) during the 2018 cropping season. Ekpoma is situated inside Nigeria's rainforest zone's northern border. The area is 113 meters above sea level, with an average annual rainfall of roughly 1200–1500mm, a mean air temperature of 29°C, a relative humidity of 70%, and five to seven hours of sunshine per day (Ighalo and Remison 2010).

2.2. Experimental Material

The National Cereals Research Institute (NCRI) in Badeggi, Niger State, provided the two types of millet used in the study. They were Gero Badeggi and Gero Bida.

2.3. Land Preparation and Planting

The experimental site was cleared, and the debris was packed out without burning before planting. The plot was delineated, and the land was prepared by hand. On a bed that had been minimally prepared, a small amount of seeds of each of the two local millet varieties was planted. These were subsequently diluted to 1, 2, 3, and 4 plants/stand, or 53, 333, 106, 666, 159, 999, and 213,332plants/ha, respectively. The intra- and inter-row spacing was 25 x 75cm. There were twenty-four (24) 1.50 x 4.50m plots in all, with a 1m gap between plots and replicates. The land area utilized was 12 x 13.5m, or 162m (0.02ha). During the experiment, weed control was carried out by hand using a hoe at three and seven weeks after planting.

2.4. Experimental Design and Layout

The study used a Randomized Complete Block Design (RCBD) with a 2 x 4 factorial. In order to create eight treatment combinations with three (3) replicates, the two (2) millet varieties were sown at four seeding rates, resulting in twenty-four (24) plots.

2.5. Plant Analysis

Following the AOAC (1990) method, flag leaves of each variety corresponding to the treatments were harvested after flowering, placed in a paper envelope, weighed, and dried in a laboratory for mineral analysis at 70°C to a constant weight.

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2.6. Data Collection

Growth, flowering traits, and yield parameters were used to group the collected data.

2.6.1. Growth Parameters**:** After planting, growth parameters were measured every two weeks until flowering. Four plants per plot, two from each of the two middle rows, were tagged in order to collect data. These were the parameters:

a. Plant Height (cm)*:* Four plants per plot were measured for height using a measuring tape from the soil's surface to the crop's tip, where the youngest leaves branch, and the average height was noted.

b. Number of Leaves per Plants: Four plants per plot had their leaf counts visually counted, and the average was noted.

c. Number of Synchronous Tillers (Branches) Per Plant: Four plants per plot were visually counted for the number of synchronous tillers (branches) (Omoregie and Nwajei 2015), and the average number was noted.

d. Total Leaf Area (cm) Per Plant: The length and width of the leaves on four plants per plot were measured with a measuring tape, then multiplied by a constant of 0.75. The results were then multiplied by the total number of leaves on each plant, and the average value was noted.

e. Stem Girth (cm): Four plants per plot had their stem girth measured at the first node above ground level using a digital venier caliper, and the average was noted.

f. Number of Tillers per Plant: Each plot's four tillers were visually counted, and the average number was noted.

2.6.2. Flowering Trait

a. Days to 50% flowering: A sample of 50% of the plant population per plot was taken, and the average number of days from the date of sowing to the opening of the first floral bud was noted.

2.6.3. Forage Yield**:** Harvesting the entire plant at a height of 2cm above the ground allowed for the determination of the fresh weight of four (4) plants per plot, and the mean value was noted.

2.6.4. Dry Matter Yield: By oven-drying the four harvested plants per plot to a constant weight at 70°C, the dry matter weight of each plant was calculated, and the mean value was noted.

2.6.5. Mineral Composition: The AOAC (1990) method was used to determine the mineral composition (N, P, K, Mg, Ca, Na, Fe, Mn, Zn, and Cu) of the flag leaf. According to AOAC (1990), crude protein (CP) was calculated by multiplying the mineral contents by 6.25.

2.6.6. Nutrient uptake: The nutrient uptake was calculated by multiplying the dry matter weight by nutrient contents, and the mean values were recorded. The values in kg/ha were extrapolated.

2.7. Data Analysis

Data collected were analyzed using analysis of variance (ANOVA) at 5% level of probability, and the means were compared using Duncan's multiple range test (DMRT) depending on when the F-ratio shows significance. Following the process by AOAC (1990), the mineral composition of the flag leaf (N, P, K, Mg, Ca, Na, Fe, Mn, Zn, and Cu) was ascertained. In accordance with AOAC (1990), crude protein (CP) was calculated by multiplying the mineral contents by 6.25.

3. RESULTS

3.1. Growth Parameters

3.1.1. Plant Height: With the exception of 6 and 10 WAP, Table 1 shows that the impact of seeding rate on two millet varieties was significant. Different seeding rates resulted in a notable variation in plant height. At 2, 4, and 10 WAP, there was a significant interaction between plant density and variety. In both varieties, plant height increased from 2 to 10 WAP. The average plant height at 10 WAP varied between 155.6-219.20cm in Gero Badeggi and 74.10-195.60cm in Gero Bida. Overall, Gero Bida (183.26cm) was shorter than Gero Badeggi (200.3cm). Crops sown at one seed per hole produced the tallest plants, while crops sown at two seeds per hole produced the smallest plants.

3.1.2. Number of Leaves/Plant: Table 2 shows how seeding rates affect the number of leaves per plant. At 2 and 10 WAP, the number of leaves/plant was not significantly impacted by seeding rate or the variety x seeding rate interaction; however, variety's effects were significant ($P<0.05$) over the course of the study. In both types, the

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number of leaves per plant increased from two to ten WAP. In terms of overall performance, Gero Badeggi outperformed Gero Bida in terms of leaves per plant. The mean at 10 WAP varied between 9.43 and 10.47 in Gero Bida and 10.76 and 12.63 in Gero Badeggi. Gero Bida had 9.70 leaves on average, compared to 1.32 for Gero Badeggi. Crops planted at one seed per hole produced the most leaves per plant, while crops planted at three seeds per hole produced the fewest leaves per plant.

Table 1: Effects of seeding rate on the plant height (cm) of two varieties of millet

Crop variety	Seeding rates (seeds/hole)	Weeks after planting				
		2	4	6	8	10
Gero Bida	1	2.34abc	6.98bcd	17.10	140.05c	195.6ab
	2	2.92a	6.23d	15.16	127.83d	182.7ab
	3	2.87ab	7.58bcd	16.35	131.67cd	181.6ab
	4	2.87ab	7.90bcd	30.78	150.97b	174.1ab
	Mean	2.50	7.39	19.85	137.63	183.5
Gero Badeggi	1	2.42abc	7.80bcd	28.40	167.83	219.2a
	2	2.47abc	9.93abc	31.83	139.37c	155.60b
	3	2.15abc	10.43ab	31.38	160.68ab	210.2a
	4	2.07bc	11.60a	27.65	153.90b	216.1a
	Mean	2.28	9.94	29.85	155.45	200.3
	SL					
	Variety	ns	*	*	*	*
	Seeding rate	*	*	ns	ns	Ns
	Interaction (V x D)	*	*	ns	*	*

Values with same letters superscript in columns are not significantly different using DMRT at 5% level of Probability. SL: significant level, *: Significant, Ns: not significant, V: variety, D: seeding rates, MDRT: Duncan's Multiple Range Test;

Table 2: Effects of seeding rate on the number of leaves/plant of two varieties of millet

Crop Variety	Seeding rates (seeds/hole)	Weeks after planting				
		2	4	6	8	10
Gero Bida	1	3.00ns	5.33b	5.83bc	8.50b	9.43b
	2	3.67	4.67b	5.67c	10.17cb	10.47ab
	3	3.67	5.67ab	7.50abc	8.67c	9.44b
	4	3.00	7.00ab	9.30a	9.47abcd	9.47b
	Mean	3.33	5.67	7.08	9.20	9.70
Gero Badeggi	1	3.00	6.50ab	8.67abc	11.67abcd	12.63a
	2	3.00	6.83ab	10.50a	10.83bc	12.63a
	3	2.67	8.00a	9.17ab	10.00abcd	11.10ab
	4	3.33	7.00a	10.83a	10.83abcd	10.76ab
	Mean	3.00	7.08	9.79	10.83	11.34
	SL					
	Variety	*	*	*	*	*
	Seeding rate	Ns	*	*	*	Ns
	Interaction V x D	Ns	*	*	*	*

Values with same letters superscript in columns are not significantly different using DMRT at 5% level of Probability. SL: significant level, *: Significant, Ns: not significant, V: variety, D: seeding rates MDRT: Duncan's Multiple Range Test

***3.1.3. Number of synchronous tillers (branches) per plant*:** Table 3 shows the number of branches per plant for the two millet varieties. In both types, branching (synchronous tillers) began at 6 WAP. The number of branches at 10 WAP ranged between 1.80 and 2.97 in Gero Bida and 1.23-2.16 in Gero Badeggi. In general, Gero Bida produced more branches per plant than Gero Badeggi. In both types, there were roughly two branches per plant. Crops planted with one or four seeds per hole produced the most and the fewest branches per plant, respectively; these results were substantially different from those of other treatments.

***3.1.4. Total leaf area/plant*:** At every stage of growth, the total leaf area per plant was greatly impacted by the combination of variety and seeding rate. However, at 2 and 6 WAP, this parameter was not significantly impacted by variety or seeding rate (Table 4). From 2 WAP to 10 WAP, the total leaf area per plant increased. Gero Bida and Gero Badeggi had mean values between 6771.00 and 8731.00cm and 10055.00 and 10553.00cm at 10 WAP, respectively. Compared to Gero Bida, Gero Badeggi had more leaf area per plant. One seed per hole produced the largest total leaf area per plant, whereas two seeds per hole produced the smallest.

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Table 3: Effects of seeding rate on number of synchronous tillers (branches)/plant of two varieties of millet

Crop variety	Seeding rates (seeds/hole)	Weeks after planting				
		2	4	6	8	10
Gero Bida	1	0.00	0.00	1.33ns	1.33ab	2.97a
	2	0.00	0.00	1.33	1.76a	2.00b
	3	0.00	0.00	1.33	1.60b	1.90b
	4	0.00	0.00	1.33	1.50b	1.80b
	Mean	0.00	0.00	1.33	1.55	2.16
Gero Badeggi	1	0.00	0.00	1.00	1.00b	2.00b
	2	0.00	0.00	1.00	1.00b1	2.00b
	3	0.00	0.00	1.00	1.33ab	1.43b
	4	0.00	0.00	1.00	1.10b	1.23b
	Mean	0.00	0.00	1.00	1.11	1.67
	SL					
	Variety	-	-	ns	ns	*
	Seeding rate	-	-	ns	ns	*
	Interaction V x D	-	-	ns	*	*

Values with same letters superscript in columns are not significantly different using DMRT at 5% level of Probability. SL: significant level *: Significant, Ns: not significant, V: variety, D: seeding rates, MDRT: Duncan's Multiple Range Test

Table 4: Effects of seeding rate on the total leaf area/plant (cm^2) of two varieties of millet

Crop variety	Seeding rates (seeds/hole)	Weeks after planting				
		2	4	6	8	10
Gero Bida	1	149.00b	1257.00abc	5772.00abc	7731.00abc	8731.00abc
	2	120.90ab	562.00c	5165.00ab	5842.00c	6842.00c
	3	150.50a	1892.00a	4838.00b	5771.00c	6771.00c
	4	68.00b	1258.00abc	6072.00ab	6380.00bc	7380.00bc
	Mean	122.10	1242.00	517.00	6431.00	7431.00
Gero Badeggi	1	104.20ab	1032.00bc	4829.00	9806.00a	10806.50a
	2	88.90ab	1396.00ab	4261.00b	9553.00a	10553.00a
	3	93.10ab	1283.00abc	7356.00ab	8133.00abc	9133.00ab
	4	107.80abc	1711.00ab	6144.00ab	8722.00ab	10055.00a
	Mean	98.50b	1356.00	5647.00	9053.00	10137.00
	SL					
	Variety	Ns	ns	ns	*	*
	Seeding rate	Ns	*	ns	*	*
	Interaction V x D	*	*	*	*	*

Values with same letters superscript in columns are not significantly different using DMRT at 5% level of Probability. SL: significant level, *: Significant, Ns: not significant, V: variety, D: seeding rates, MDRT: Duncan's Multiple Range Test

***3.1.5. Stem Girth*:** Table 5 shows the stem girth of two millet varieties as influenced by seeding rates. Variety and seeding rate x variety interaction with plant age is not significant (P>0.05), with the exception of 4 WAP. At 6 WAP, however, the seeding rate effect was significant (P<0.05). The millet's stem girth grew from 2 WAP to 10 WAP. Stem girth varied between 1.44 and 1.86cm in Gero Bida and 1.70 and 2.10cm in Gero Badeggi at 10 WAP. Overall, the culm size of the Gero Bida and Gero Badeggi varieties was about 2cm. The plantings at one and four seeds/hole had the highest and lowest stem girth values at 8–10 WAP, respectively.

***3.1.6. Number of Tillers per Plant*:** The millet's estimated number of tillers per plant is shown in Table 6. The number increased from 4 WAP to 10 WAP in both varieties. At 10 WAP, Gero Bida's mean value varied from 3.64 to 4.02, while Gero Badeggi's ranged from 3.33 to 3.56. Gero Badeggi produced more tillers per plant (3.81) than Gero Bida (3.39). Tillers were greatest in crops sown at one seed per hole and least in crops sown at four seeds per hole.

3.2. Days to 50% Flowering

Results for the two millet varieties' days to 50% flowering revealed significant differences (P<0.05) for seeding rate, varieties, and interactions (Table 7). Gero Bida took an average of 52–54.61 days to reach 50% flowering, while Gero Badeggi took an average of 54.67–59.33 days. Overall, Gero Bida had more flowers than Gero Badeggi. Gero Badeggi had an average of 58 days to S0% flowering, whereas Gero Bida had an average of 53 days. Four seed and one seed/hole plantings yielded the highest and lowest number of days to 50% flowering, respectively.

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Table 5: Effects of seeding rate on the stem girth (cm) of two varieties of millet

Crop variety	Seeding rate (seeds/hole)	Weeks after planting				
		2	4	6	8	10
Gero Bida	1	0.46ns	0.97abc	1.10ns	1.49ns	1.86
	2	0.43	0.98abc	1.40	1.49	1.80
	3	0.40	1.01a	1.05	1.46	1.49
	4	0.36	0.97abc	1.29	1.39	1.44
	Mean	0.40	0.98	1.21	1.46	1.65
Gero Badeggi	1	0.40	0.97abc	1.39	1.74	2.10
	2	0.40	0.88bc	1.24	1.50	1.70
	3	0.43	0.85c	1.06	1.60	2.00
	4	0.43	0.99ab	1.35	1.65	2.00
	Mean	0.41	0.92	1.26	1.62	1.88
	SL					
	Variety	ns	*	ns	ns	Ns
	Seeding rate	ns	ns	*	ns	Ns
	Interaction V x D	ns	*	ns	ns	Ns

Values with same letters superscript in columns are not significantly different using DMRT at 5% level of Probability. SL: significant level, *: Significant, Ns: not significant, V: variety, D: seeding rates, MDRT: Duncan's Multiple Range Test

Table 6: Effects of seeding rate on number of tillers/plant of two varieties of millet

Crop variety	Seeding rate (seeds/hole)	Weeks after planting				
		2	4	6	8	10
Gero Bida	1	0.00	2.00ns	3.67ns	3.33ns	3.22na
	2	0.00	1.66	3.67	3.33	3.22
	3	0.00	2.00	3.00	3.56	3.35
	4	0.00	1.66	3.00	3.44	3.52
	Mean	0.00	1.83	3.33	3.42	3.33
Gero Badeggi	1	0.00	1.66	3.67	4.11	4.02
	2	0.00	2.33	3.67	3.33	3.80
	3	0.00	2.00	3.33	3.89	3.78
	4	0.00	2.33	3.33	3.89	3.64
	Mean	0.00	2.08	3.50	3.72	3.81
	SL					
	Variety	-	Ns	ns	ns	Ns
	Seeding rate	-	Ns	ns	ns	Ns
	Interaction V x D	-	Ns	ns	ns	Ns

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Table 7: Effects of seeding rate on dry matter % days to 50% flowering, dry matter yield and forage yield on two varieties of millet

Crop variety	Seeding rates (seeds/hole)	Days to 50% flowering	Dry matter %	Dry matter yield	Forage yield
			→ t/ha ←		
Gero Bida	1	52.00d	21.76ba	3.34bc	15.26b
	2	54.61bcd	18.24ba	2.49c	14.42b
	3	53.33cd	18.84ba	2.78c	14.6cb
	4	53.00d	23.15a	2.84c	12.21b
	Mean	53.25	20.50	2.86	14.14
Gero Badeggi	1	54.67bcd	16.31b	4.49a	27.62a
	2	59.33a	18.95ba	4.39a	23.22a
	3	57.67abc	19.33ba	4.39a	23.37a
	4	59.00ab	17.86ba	4.24ab	24.09a
	Mean	57.67	18.11	4.38	24.57
	SL				
	Variety	*	ns	*	*
	Seeding rate	*	ns	*	Ns
	Interaction V x D	*	*	Ns	*

Values with same letters superscript in columns are not significantly different using DMRT at 5% level of Probability. SL: significant level, *: Significant, Ns: not significant, V: variety, D: seeding rates, MDRT: Duncan's Multiple Range Test

3.3. Forage Yield

Table 7 displays the forage yield of the two millet varieties under investigation. The ranges for Gero Badeggi and Gero Bida were 23.22–27.62t/ha and 12.21–15.26t/ha, respectively. The forage yield of Gero Badeggi was

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substantially higher than that of Gero Bida. The mean forage yields of Gero Bida and Gero Badeggi were 12.21 and 24.57t/ha, respectively. Thus, crops planted at one seed/hole had the highest forage yield while those at four seeds/ha had the least.

3.4. Dry Matter Yield

Table 7 displays the dry matter yield of the two millet varieties. In Gero Bida and Gero Badeggi, the means varied from 2.49 to 3.34t/ha and 4.24 to 4.49t/ha, respectively. Gero Badeggi outperformed Gero Bida in terms of dry matter yield, according to the overall performance. The mean for Gero Bida was 2.86t/ha, whereas the mean for Gero Badeggi was 4.38t/ha. Crops planted in one-seed/hole plots produced the highest dry matter yield, while crops planted in two-seed/hole plots produced the lowest.

3.5. Dry Matter %

Table 7 shows the dry matter percentage of two millet varieties. Dry matter yield was generally not significantly impacted by seeding rate or variety. Crops with four seeds per hole had the highest dry matter percentage, while those with one seed per hole had the lowest. Generally speaking, Gero Bida had a higher dry matter percentage (20.50) than Gero Badeggi (18.11).

3.6. Mineral Composition

The results of the mineral composition of two varieties of millet are presented in Table 8. Nitrogen content of the millet ranged from 3.92 – 4.76% in Gero Badeggi and 3.36 –3.87% in Gero Bida. The N-content was higher in Gero Badeggi than in Gero Bida, both had similar N concentration. The highest and the least N concentrations were obtained in the plantings at two seeds/hole and four seeds/hole, respectively.

Table 8: Effects of seeding rate on the mineral composition of two varieties of pearl millet

Crop variety	Seeding rates	CP	N	P	K	Na	Ca	Mg	Fe	Mn	Zn	Cu
	(seeds/hole)	→ % ←						→ mg/kg ←				
Gero Bida	1	22.5	3.60	0.30	0.93	0.59	0.12	0.10	220	6.18	67	0.84
	2	21.94	3.51	0.25	0.59	0.38	0.11	0.08	154	5.07	62	0.82
	3	20.94	3.35	0.27	0.68	0.36	0.11	0.07	112	5.74	53	0.71
	4	20.5	3.28	0.22	0.58	0.45	0.09	0.08	118	3.02	52	0.61
Gero Badeggi	Mean	21.47	3.44	0.26	0.69	0.44	0.11	0.08	151	3.57	58.05	0.75
	1	19.38	3.10	0.30	1.00	0.76	0.15	0.12	245	3.42	74	1.45
	2	24.25	3.88	0.26	0.93	0.61	0.14	0.09	154	3.00	60	1.23
	3	21.06	3.37	0.25	0.69	0.52	0.12	0.08	143	2.89	53	0.73
	4	23.33	3.57	0.28	0.89	0.59	0.14	0.09	179.25	3.16	64.5	1.39
	Mean	0.65	0.10	0.01	0.06	0.04	0.01	0.01	16.51	0.48	3.03	0.19
	SE											

SE: Standard error

In Gero Bida and Gero Badeggi, the P content of the millet flag leaves ranged from 0.22 to 0.30% and 0.25 to 0.30%, respectively. As seeding rates increased, so did the P content. However, compared to Gero Bida (0.26%), Gero Badeggi had a higher average P content (0.28%). P content was lowest in crops sown at four seeds per hole and highest in crops sown at one seed per hole.

In Gero Bida, the millet flag leaves had potassium (K) levels ranging from 0.58 to 0.93%, while in Gero Badeggi, they ranged from 0.69 to 1.00%. As a result, the Gero Badeggi variety had a higher K level than the Gero Bida. On the other hand, Gero Bida gave 0.69% and Gero Badeggi had a mean of 0.89%. With one seed per hole having the highest K level and four seeds per hole having the lowest, the K level rose as the seeding rate increased.

Potassium and seeding rate showed similar trends in both Gero Badeggi and Gero Bida. For the contents of sodium (Na), calcium (Ca), and magnesium (Mg), that is one seed per hole and 333.333 per hole, respectively.

The concentrations of iron (Fe) in Gero Badeggi and Gero Bida ranged from 154 to 245mg/kg and 112-220 mg/ha, respectively. Overall, the Fe content of Gero Badeggi was higher than that of Gero Bida (179.25mg/kg) (151mg/kg). The highest and lowest Fe contents were found in crops grown at one and two seeds/hole, respectively, and increased with seeding rate.

The levels of manganese (Mn) in Gero Bida ranged from 2.89 to 3.42mg/kg and 3.02 to 8.18mg/kg. Overall, the concentration of Mn in Gero Bida was higher than that in Gero Badeggi. The mean for Gero Badegi was 3.16mg/kg, whereas the mean for Gero Bida was 5.50mg/kg. The highest Mn content was found in plantings at one seed per hole, while the lowest was found at four seeds per hole.

The zinc content of the millet under study varied between 52 and 67mg/kg in Gero Bida and 53 and 74mg/kg in

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Gero Badeggi. The zinc content of the flag leaves rose as the seeding rate decreased, and Gero Badeggi had a higher overall zinc concentration (64.50mg/kg) than Gero Bida (58.50mg/kg). On the other hand, plantings with one seed per hole had the highest zinc contents, while those with four seeds per hole had the lowest.

In Gero Bida and Gero Badeggi, the copper (Cu) content ranged between 0.61 and 0.84mg/kg and 0.73 and 2.18mg/kg, respectively. In general, Gero Badeggi had a higher copper content than Gero Bida. Gero Bida had a mean of 0.75mg/kg, whereas Gero Badeggi had a mean of 1.39mg/kg. Nonetheless, the highest Cu content was found in plantings with one seed per hole, while the lowest was found with four seeds per hole.

3.7. Nutrient Uptake

Table 9 shows the nutrient uptake of two millet varieties as influenced by seeding rate. Two millet varieties' nutrient uptake was significantly impacted by seeding rate, with the exception of K and Cu, whereas the uptake of both micro- and macronutrients was significantly impacted by variety and its interaction with seeding rate.

Table 9: Effects of seeding rate on the nutrient uptake of two varieties of pearl millet

Crop variety	Seeding rate (seeds/hole)	N	P	K	Na	Mg	Ca	Fe	Zn	Mn	Cu
		Mg/g									
Gero Bida	1	12040dc	1003c	3110c	1973c	334.46b	40.13cd	73.6cb	22.40c	2.73a	0.277c
	2	8742c	623d	1420d	946d	199.3c	274.0bc	36.7d	15.44d	1.26bc	0.197c
	3	9306c	750d	1889d	1000d	194.4c	306dc	31.1d	14.72d	1.59b	0.193c
	4	9339c	626d	1651d	1281d	227.8c	256c	33.6d	14.80d	0.86c	0.167c
	Mean	9857	751	2018	1300	239.0	309	43.7	16.84	1.61	0.208
Gero Badeggi	1	1395b	1350a	5167a	2985a	540.09a	675a	110.3a	33.30a	1.54b	0.647a
	2	17274a	1315ba	4209b	2587ba	438.4a	6007ab	85.7b	31.13ba	1.45b	0.637a
	3	17460a	1170cba	4185b	2745a	401.7ab	630ab	69.3c	27.00cb	1.35b	0.553ba
	4	14307ab	1061cb	2929c	2208cb	339.6b	509.4bc	60.7c	22.50c	1.22bc	0.310cb
	Mean	15748	1224	4122	2631	429.9	606	81.5	28.48	1.39	0.573
	SL										
	Variety	*	*	*	*	*	*	*	*	*	*
	Seeding rate	*	*	ns	*	*	*	*	*	*	ns
	Interaction V x D	*	*	*	*	*	*	*	*	*	*

Values with same letters superscript in columns are not significantly different using DMRT at 5% level of Probability. SL: significant level, *: Significant, Ns: not significant, V: variety, D: seeding rates, DMRT: Duncan's Multiple Range Test

In Gero Bida and Gero Badeggi, nitrogen uptake varied greatly, ranging from 8742 to 12040kg/ha and 1395 to 17274kg/ha. Overall, the results showed that Gero Badeggi absorbed more nitrogen than Gero Bida. Gero Bida had an average N uptake of 9857kg/ha, whereas Gero Badeggi had an average of 15748kg/ha. Crops planted at one seed per hole had the highest N uptake, while crops planted at four seeds per hole had the lowest.

In Gero Bida and Gero Badeggi, the mean P uptake ranged from 623–1003kg/ha and 1061–1350kg/ha, respectively. In the millet varieties under study, phosphorus uptake rose as plant seeding rate dropped. Crops planted with one seed per hole had the highest yield, while those planted with four seeds per hole had the lowest. With mean P uptakes of 1224kg/ha and 751kg/ha, respectively, Gero Badeggi outperformed Gero Bida overall.

In Gero-Bida, the range of potassium uptake was 1420-3110kg/ha, while in Gero-Bida, it was 2929-4209kg/ha. As the seeding rate decreased, the K uptake rose. However, compared to Gero Bida 2018kg/ha, Gero Badeggi had a higher K uptake (4122kg/ha). Crops planted with one seed per hole had the highest K uptake, while crops planted with four seeds per hole had the lowest.

As the seeding rate decreased, so did the uptake of sodium. On the other hand, two seeds/hole sown crops had the lowest Na uptake, while one seed/hole had the highest. The ranges of the mean were 2208-2985kg/ha and 946-1973kg/ka, respectively. Overall, Gero Badeggi absorbed more sodium than Gero Bida. Gero Bida had a mean of 1300kg/ha, whereas Gero Badeggi had a mean of 2631kg/ha.

In Gero Badeggi, calcium uptake ranged from 509.4-675kg/ha, while in Gero Badeggi, it ranged from 256-401.3kg/ha. Gero Badeggi outperformed Gero Bida (309kg/ha) overall, weighing 604kg/ha. Crops with one seed per hole produced the most, while those with four seeds per hole produced the least.

The average uptake of magnesium in Gero Bida and Gero Badeggi ranged from 194 to 334.46kg/ha and 339.66 to 540.09kg/ha, respectively. According to the two varieties' combined performance, Gero Badeggi absorbed more magnesium than Gero Bida. Gero Bida had 309kg/ha, whereas Gero Badeggi had 429.9kg/ha. One-seed/hole plants had the highest yield, while four-seed/hole plants had the lowest.

The ranges of iron uptake in Gero Bida and Gero Badeggi were 14.72–73.60kg/ha and 60.7–110.30kg/ha, respectively. In general, Gero Badeggi absorbed more iron (81.5kg/ha) than Gero Bida (43.7kg/ha). Fe uptake was highest in one seed/hole planting and lowest in four seed/hole plantings.

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Compared to Gero Badeggi, Manganese uptake was greater in Gero Bida. Gero Badeggi had a mean of 1.39kg/ha, whereas Gero Bida had a mean of 1.60kg/ha. Crops with one seed per hole had the highest Mn uptake, while those with four seeds per hole had the lowest.

In Gero Badeggi, zinc (Zn) uptake ranged from 22.50 to 33.30kg/ha, while in Gero Badeggi, it ranged from l4.72-22.40kg/ha. Overall, Gero Badeggi weighed more than Gero Bida (16.48kg/ha), weighing 28.48kg/ha. Zn uptake was highest in crops sown at a seeding rate of one and lowest in crops sown at a seeding rate of four seeds/hole.

Copper (Cu) uptake was also highest in crops that were seeded at one seed per hole and lowest in crops that were seeded at four seeds per hole. In contrast, Cu uptake in Gero Bida and Gero Badeggi ranged from 0.17 to 0.28 and 0.31-0.65kg/ha, respectively. Overall, the Cu uptake of Gero Badeggi was higher than that of Gero Bida. Gero Bida had an average of 0.21kg/ha, whereas Gero Badeggi had an average of 0.54kg/ha.

4. DISCUSSION

The findings demonstrated that higher seeding rates led to lower plant height, total leaf area per plant, stem girth, number of leaves per plant, number of branches per plant, and number of tillers per plant. Millet's dry matter yield and forage yield are greatly influenced by vegetative characteristics like plant height, leaf count, and stem girth. Given that the Gero Badeggi with the highest plant height, number of leaves per plant, and stem produced more forage than the Gero Bida, the results showed that these vegetative characteristics affected forage production. Both varieties' high forage and dry matter yields were largely attributed to their production of leaves per plant, total leaf area per plant, and stem girth. The results showed that the variety with the highest forage and dry matter yields was the one with the tallest plants, the highest total leaf area/plant, the highest number of leaves/plant, and the highest stem girth. In general, three key factors that aid in determining growth are plant height, the number of eaves per plant, and stem girth. According to Ayub et al. (2007), the highest forage production was found in seeding rates with the highest vegetative characteristics.

With the exception of the two varieties under study at 6 and 10WAP, seeding rates had no effect on plant height. However, compared to the other number of seeds/hole, the Gero Badeggi plants planted at one seed/hole were noticeably taller. With the exception of 2-4WAP, the low seeding rate had the largest total leaf area/plant over the course of the study. Because of competition between crowded plants for light, water, and nutrients, as well as interactions between neighbors, the crops planted at the seeding rates produced thinner plants with fewer leaves per plant. The findings of this study are consistent with those of Ayub et al. (2007) and Gabatshele et al. (2014), who found that optimal seeding rates resulted in higher vegetative traits because they decreased crop competition for light and nutrients.

A higher rate of seeding led to fewer leaves per plant. In both varieties, it was found that crops sown at low seeding rates yielded noticeably more leaves than those planted at higher rates. Overall, the number of leaves per plant in both varieties at 2, 4, and 10 was not substantially impacted by plant density. Lower seeding rates produced taller plants with slightly more leaves, likely because there was less competition, even though there was no discernible difference between the two varieties. As the number of seeds/plant increased, both varieties produced fewer branches and tillers. However, fewer branches and tillers/plants are produced at higher seeding rates. Seeding rates had a significant impact on the number of branches per plant but not on the number of tillers per plant produced by either variety. As a result, it was noted that one seed per hole produced the fewest tillers per plant, which might have happened as a result of less interplant competition. When millet was planted at lower seeding rates, Rostamaza et al. (2011) and Raslan et al. (2016) noted the greatest and lowest number of tillers/plant.

The variety, seeding rates, and variety x seeding rate interaction all had an impact on the number of days until 50% flowering. Increased vegetative growth could be the cause of the increase in days to flowering seen with crops at one seed/hole population. According to the study's findings, the number of days until flowering decreased as seeding rates rose. Rostamaza et al. (2011) also noted that competition during the vegetative growth stage caused an increase in the number of days until flowering.

Seeding rates had no discernible effect on the two varieties' dry matter and fodder yields. Low seeding rates increased forage and dry matter yield, while decreasing rates resulted in a decrease. Nonetheless, the highest yields of dry matter and fodder were produced by crops planted at one seed per hole. As seeding rates increased, the percentage of dry matter increased as well. But compared to other rates, crops sown at four seeds per hole had more moisture. The results of Jimba and Adedeji (2003) and Agha-Alikhani and Eshaq-Ahnmadi (2008), who noted low moisture from crops sown at optimal density, are consistent with this.

The two millet varieties' mineral levels were impacted by seeding rates. However, based on the flag leaves, Gero Badeggi planted at the population one seeding/hole had the highest concentrations of the macro- and micro-nutrients. When compared to the critical levels for ruminant livestock production proposed by ARC (1985); McDowell (1992), the mineral composition in both varieties at different seeding rates showed some degree of sufficiency, particularly for N, P, K, Na, Fe, and Zn, marginal in Ca, and deficient in Mg, Mn, and Cu.

With the exception of K and Cu uptake, seeding rates had a significant impact on the two millet varieties' nutrient uptake. In general, crop growth performance and nutrient composition during the growing season were demonstrated by nutrient uptake. P, K, Na, Mg, Ca, Fe, Zn, and Cu uptake was significantly higher in Gero Badeggi planted at one seed/hole than in Gero Bida and other rates. The accumulation of dry matter and interactions between nearby plants as a result of the low seeding rate (one seed per hole) caused this notable difference. According to Ahmad et al. (2011) and Rostamaza et al. (2011), low seeding rates were associated with high significant forage and dry matter yield as well as nutrient uptake.

Pearl millet is a multipurpose crop valued for its use in food, animal feed, brewing, and soil improvement. Its versatility and adaptability, particularly in humid agro-ecological zones, position it as a key crop for promoting food and livestock feed security (Sharma et al. 2015; Adebiyi et al. 2017). Findings from studies on varietal and seeding rate effects on forage yield and nutritional composition provide crucial insights for agricultural extension services. These insights enable extension agents to disseminate tailored recommendations that promote sustainable land use and livestock productivity.

One primary implication is the ability of extension agents to guide farmers on optimal seeding rates that maximize forage yield per hectare. Demonstration plots and field days can be used to educate farmers on the practical benefits of adopting specific seeding rates and improved pearl millet varieties suited to local conditions. The study also emphasizes how seeding rate influences the nutritional composition of pearl millet forage. This enables extension officers to promote agronomic practices that enhance the feed value of forage, ultimately improving livestock health and productivity for smallholder farmers.

Additionally, the evaluation of varietal performance under humid conditions equips extension services with evidence-based recommendations. Farmers often rely on informal trial-and-error methods for varietal selection. Data from this study can reduce that uncertainty, guiding them toward high-yielding and nutritionally superior options. Participatory extension approaches, involving farmer feedback, can further support breeding programs aimed at producing genotypes with market-preferred traits (Lubadde et al. 2016; Drabo et al. 2019).

Efficient use of inputs such as seed, land, and labor is another benefit of promoting optimal seeding practices. This not only enhances profitability for smallholders but also aligns with sustainable farming goals. Pearl millet also plays a vital economic role, especially for women, by providing income through grain and flour sales in local markets (Obilana 2003; Taylor 2016; Olodo et al. 2020). Extension messages should emphasize its dual-purpose potential as a grain and forage crop to encourage integration into mixed crop-livestock systems.

Pearl millet compares favorably with maize and sorghum in animal feeds, offering higher protein content and fewer mycotoxins (Alonso et al. 2017; Masenya et al. 2021). Although its use in feed is still limited, its climate resilience and nutritive value make it a future crop of choice. Residues are also valuable for fodder, fencing, firewood, and even brewing (Lubadde et al. 2016; Balli et al. 2023). Traditional brewing practices, despite occasional health concerns, highlight the socio-cultural value of pearl millet in certain regions.

Extension agents can use the study to craft site-specific recommendations that consider local soils and climate. Dissemination through field schools, training manuals, and radio programs can facilitate wide adoption. Furthermore, policymakers can leverage these findings to support varietal distribution and seeding rate subsidies. Ultimately, this study strengthens extension capacities to support sustainable forage production and resilient livestock systems in humid regions.

5. CONCLUSION

The purpose of this study was to ascertain how seeding rate affected the forage yield, mineral makeup, and nutrient uptake of two millet varieties. The following is a summary of the outcomes:

With the exception of the number of tillers per plant, there were notable variations in the vegetative characteristics at certain phases of the millet's growth due to the seeding rates.

1. Compared to other Gero Bida seeding rates, Gero Badeggi that were planted in a single seed per hole had the tallest plants, the most leaves per plant, the total leaf area per plant, and the stem girth.
2. Compared to Gero Badeggi and other rates, Gero Bida planted at one seed/hole had a noticeably higher number of synchronous tillers (branches)/plant.
3. One-seed/hole crops flowered before other rates, and Gero flowered before Gero Badeggi.
4. Compared to other seeding rates and Gero Bida, the highest forage yield (27.6t/ha) and dry matter yield (4.49t/ha) were obtained from Gero Badeggi planted at one seed/hole.
5. When gero Badeggi was planted in a single seed or hole, it absorbed the most micro- and macronutrients.

   Using the determined critical values for these nutrients, both millet varieties had marginally higher levels of Ca, N, P, K, Na, Fe, and Zn, but lower levels of Mg, Mn, and Cu for ruminant livestock nutrition.

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RECOMMENDATIONS

The following suggestions are offered in light of the findings:

1. The best millet for producing dry matter and fodder for ruminant animal nutrition is one seed per hole.
2. It was discovered that the macronutrients and certain micronutrients in Gero Badeggi and Gero Bida were sufficient. As a result, it can be cultivated in the humid conditions of this study to feed ruminant livestock.

DECLARATIONS

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Conflicts of Interest: The authors declare that they have no competing interests that could have affected the conduct or results of this study.

Data Availability: All data generated from the study are presented in this article.

Ethics Statement: Ethical Approval was obtained from the university community and the department of Crop and Biotechnology Science Research Demonstration Farm Faculty of Agriculture, Ambrose Alli University Ekpoma, Edo State.

Author's Contributions: All authors contributed equally to the conception, execution, and reporting of this research, and jointly accept full responsibility for its integrity and accuracy.

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