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RESEARCH ARTICLE

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Impact of Row Spacing and Nitrogen Fertilizer Sources on the Growth, Yield, and Quality of Pearl Millet (Pennisetum Glaucum L.)

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ABSTRACT
field experiment was conducted at the Research Station of the College of Agriculture, University of Kirkuk, during the summer growing season of 2023-2024to examine the impact of planting distances and various nitrogen fertilizer sources on the growth, yield, and quality of pearl millet. The experiment employed a randomized complete block design under a split-plot arrangement with three replications. The main plots comprised row spacings (20, 30, 40, and 50 cm), while the second factor was in subplots encompassed four different nitrogen fertilizer sources (urea, chicken manure, liquid and nano). The data were statistically evaluated, and means were compared by Duncan's multiple-range test at the 0.05 significance level. The results indicated no significant differences in the duration from planting till 50% flowering in terms of row spacing. While row spacing with 50 cm record significant values in traits of tillers per plant (4.30), flag leaf chlorophyll content index (32.66), plant yield (30.56 g) and ash % (0.228%). Whereas the highest grains per panicle (1654.33) was recorded by 40 cm, the last one did not differ significantly with 50 cm in flag leaf chlorophyll content index and plant yield. Nano N fertilizer had high values in most studied traits like duration from planting till 50% flowering (123.83 days), flag leaf chlorophyll content index (38.51) and plant yield (28.55 g). While, liquid N improves tillers per plant (3.91) and grains per panicle (1596.75) in contrast chicken manure had a significant influence on grain quality such as ash percentage (0.240%) compared with other N fertilizer sources. This experiment investigated that 50 cm spacing and nano nitrogen fertilizer performed best for most traits, while liquid nitrogen improved tillering and grain count, and chicken manure enhanced grain quality. The experiment demonstrated that optimal spacing and nitrogen source selection can significantly influence pearl millet productivity and quality.

***Keywords*:** Row spacing, nitrogen fertilizer sources, pearl millet.

INTRODUCTION

The optimal plant density is a crucial component that influences a crop's ability to utilize available resources, including light, nutrients, and water [1].Nitrogen fertilizer is a critical management strategy for attaining optimal yields in any crop. Pearl millet (Pennisetum glaucum L.) is a significant cereal crop globally, positioned sixth after rice, wheat, maize, barley, and sorghum. This crop is a member of the Poaceae family and the Panicoideae subfamily. Pearl millet seeds contain relatively higher protein and essential amino acid content compared to several other cereals [2]. Pearl millet is grown in arid and semi-arid tropical parts of Asia and Africa, covering an area of around 30 million hectares [3]. This crop accounts for over 50% of global millet output and serves as a fundamental food source for approximately 90 million individuals in the Sahel region of Africa and northwest India [4].. The worldwide farmed area totals over 28 million hectares, yielding 21.8 million tons of millet [5]. In the Arab world, over 9.8 million hectares are under cultivation, constituting about 14% of the global cultivated land, predominantly in nations such as Sudan, Yemen, Somalia, and Mauritania, which together account for roughly 98% of Arab agricultural output. The Arab world produces approximately 5.3 million tons of millet, constituting 6% of global production [6].

Materials and methods

The experiment was carried out at the Agricultural Experimental and Research Station in the Al-Sayyadah region, associated with the College of Agriculture, University of Kirkuk, during the 2023-2024 agricultural season to examine the impact of planting distances and nitrogen fertilizer sources on the growth, yield, and quality of pearl millet. The research encompassed two variables:
The initial factor encompassed planting distances, with four row spacings: 20, 30, 40, and 50. The second factor comprised nitrogen fertilizer sources: urea fertilizer (46%) applied at a rate of 100 kg ha^{-1}, animal manure (chicken manure) (4%) at 100 kg N ha^{-1}, liquid Fasto fertilizer (30% N) at 8 liters ha^{-1}, and liquid nano nitrogen fertilizer (17% N) at 20 liters ha^{-1}.

Soil analysis was performed the experiment, with samples collected randomly from various places at a depth of 0-30 cm. Following the amalgamation of the samples, the composite sample was extracted, and various chemical and physical tests were performed in the laboratories of the Soil and Water Division of the Kirkuk Agriculture Directorate, as indicated in Table 1.

Table 1. Chemical and physical properties of field soil before planting

Attribute		Value	Unit
Chemical properties	PH	7.640	__
	EC	0.590	$Ms.cm^{-1}$
	Available nitrogen	980.700	mg Kg^{-1}
	available phosphorus	3.704	mg Kg^{-1}
	available potassium	197.243	mg Kg^{-1}
	TDS Total Dissolved Solids (TDS)	377.664	mg Kg^{-1}
Physical properties	Sand	58	%
	Silt	34	%
	Clay	8	%
	Soil texture	Sandy loam	
organic matter	1.518	%	
Caco3	29.665	%	

Traits studied

Number of days from planting to 50% flowering: The number of days from planting to 50% flowering of the experimental units was calculated. The maturity time of pearl millet can be estimated from field observations.

Number of tillers (tillers per plant): calculated from the average number of tillers of five plants randomly selected during the flowering stage for each experimental unit.

Flag leaf chlorophyll content index: Flag leaf chlorophyll content was measured using a CCM-200 Plus device as an average of five randomly selected plants per experimental unit at flowering.

The quantity of grains per inflorescence was determined by separating and counting the seeds from five inflorescences, followed by calculating the average.

The yield per plant (grams per plant 1) was determined by harvesting five randomly selected plants from the median lines, and the average yield was used to derive the per-plant yield in grams.

Ash content (%): The ash content was determined using the standard procedure outlined in AACC [7] No. 01-084.

Results and Discussion

Number of Days from Planting to 50% Flowering

Table (2) demonstrates that row spacing has no major impact on the duration from planting to 50% flowering. This may be attributed to the greater influence of genetic and environmental factors compared to plant density. [8] indicated that plants maintained consistent responses to identical environmental conditions irrespective of their field density [9]. This indicates that internal plant elements, including physiological and genetic processes, are crucial in determining flowering timing [10], or that timing may be affected by more dominant factors, such as temperature and moisture availability. [11] The data in Table (2) indicated that nano fertilizer markedly surpassed the trait of days from planting to 50% flowering, achieving the highest average of 123.83 days. In contrast, urea fertilizer exhibited the lowest average of 115.66 days to reach the flowering stage, which was not significantly different from the averages of organic fertilizer and liquid fertilizer, recorded at 118.25 and 117.16 days, respectively. This may result from nano nitrogen fertilizer extending the duration of leaf greenness, hence prolonging the time until flowering. The enhanced plant nutrient uptake from nano-nitrogen fertilizers, attributed to their diminutive molecular size and gradual nitrogen release, resulted in a 50% decrease in the duration from planting to flowering compared to urea. Organic fertilizer, while beneficial for long-term soil fertility, releases nitrogen more slowly, resulting in delayed flowering compared to nano-fertilizers, as noted by [12]. This may result from nano-nitrogen fertilizers facilitating accelerated vegetative development through enhanced absorption efficiency and diminished losses relative to urea, which is susceptible to evaporation or leaching into the soil, as noted by [13]. The interaction between the row planting distance of 20 cm and organic fertilizer yielded the highest significant duration for the number of days from planting to 50% flowering, totalling 127.00 days, whereas the lowest duration occurred with the same planting distance of 20 cm in conjunction with liquid fertilizer, amounting to 112.00 days.

Table 2. Effect of row planting distances, nitrogen fertilizer sources, and their interaction on the number of days from planting to 50% flowering

row planting distances	nitrogen fertilizer				Average
	Urea	Organic	Liquid	Nano	
20	117.00 bcd	127.00 a	112.00 D	119.33 Abcd	118.83 a
30	114.33 cd	117.00 bcd	124.66 Ab	127.00 A	120.75 a
40	114.33 cd	114.66 cd	118.66 Abcd	122.00 Abc	117.41 a
50	117.00 bcd	114.33 cd	113.33 cd	127.00 A	117.91 a
Average	115.66 b	118.25 b	117.16 b	123.83 A	

Means followed by different letters are significantly different Duncan's Multiple Range Test (p<0.05)

Number of tillers (tillers per plant)

Table (3) presents significant disparities in the number of tillers per plant based on row planting distances. The distance of 50 cm significantly surpassed the average of 4.30 tillers per plant, while showing no significant difference from the 40 cm distance, which averaged 4.01 tillers per plant. A distance of 30 cm yielded an average of 3.50 tillers per plant, whereas a distance of 20 cm recorded the lowest significant average of 3.60 tillers per plant. The superiority of the separated distances in tiller quantity can be ascribed to the absence of competition among plants and between the components of the same plant, facilitating an increase in tillers and vegetative development. This outcome aligns with the findings of [14; 15]. The significant superiority of liquid nitrogen fertilizer in the trait of tiller number is attributed to its high efficiency in supplying nitrogen to millet plants in an available and rapidly absorbable form, which enhances cell division and vegetative growth, especially during the branching and tiller formation stages [16]. The liquid form of fertilizer contributes to reducing losses caused by volatilization or fixation in the soil compared to solid fertilizers.

Moreover, the nano-fertilizer exhibits a performance close to that of the liquid fertilizer, which is attributed to its small particle size and increased surface area, improving nutrient absorption efficiency through roots or leaves. Nano-fertilizers are considered promising modern technologies for enhancing plant nutrient response at low concentrations [17]

This finding corroborates [18], who asserted that conventional fertilizers were less successful in terms of rooting rate, since plants necessitated extended durations to assimilate the available nitrogen, resulting in a diminished rate of lateral branching. A notable interaction was detected between row planting distances and nitrogen fertilizer sources regarding the number of tillers per plant. Specifically, a row distance of 50 cm combined with liquid fertilizer yielded a significantly higher count of 4.60 tillers per plant, whereas a row distance of 20 cm with organic fertilizer resulted in a significant reduction to 2.86 tillers per plant.

Table 3. Effect of row planting distances and nitrogen fertilizer sources and their interaction on tillers per plant
row planting distances nitrogen fertilizer Average

row planting distances	nitrogen fertilizer				Average
	Urea	Organic	Liquid	Nano	
20	3.00 E	2.86 E	3.40 De	3.00 E	3.06 C
30	3.66 Cd	3.26 De	3.40 De	3.66 Cd	3.50 B
40	3.80 Bcd	3.70 Bcd	4.26 Abc	4.30 Ab	4.01 a
50	3.70 Bcd	4.30 Ab	4.60 a	4.60 A	4.30 a
Average	3.54 B	3.53 B	3.91 a	3.89 A	

Means followed by different letters are significantly different Duncan's Multiple Range Test (p<0.05)

Chlorophyll content in flag leaves

Table 4 indicates that row spacing significantly affected chlorophyll content, with a distance of 30 cm yielding 36.38%, while a distance of 20 cm recorded the lowest significant value of 29.75%.

This may result from wide row spacing diminishing shadowing among plants, allowing leaves to absorb more light and thereby enhancing chlorophyll concentration [19] . Narrow row spacing results in heightened shadowing among plants, diminishing light absorption efficiency and thus lowering chlorophyll concentration [20]. Regarding the second aspect, notable disparities were identified among the average nitrogen fertilizer sources. Nano-fertilizer surpassed chlorophyll by 38.51%, although organic fertilizer exhibited the lowest significant value at 30.68%, which was not significantly different from urea fertilizer at 31.00%.

This may result from the augmentation of the flag leaf's surface area, which enhanced chlorophyll content [21]. Plants subjected to nano-nitrogen fertilizers exhibited elevated chlorophyll concentrations relative to those that did not receive this treatment. The leaves exhibited a more vibrant green hue owing to efficient nutrition absorption [22]. Table (4) demonstrates a significant interaction effect between the two experimental factors on chlorophyll content, with the agricultural distance of 50 cm combined with nano-fertilizer yielding a 43.06% increase, whereas the same distance with organic fertilizer resulted in a lower significant value of 24.61%.

Table 4. Effect of row spacing, nitrogen fertilizer sources and their interaction on flag leaf chlorophyll content (%)
row planting distances nitrogen fertilizer Average

row planting distances	nitrogen fertilizer				Average
	Urea	Organic	Liquid	Nano	
20	28.38 Efg	27.62 Fg	30.74 Defg	32.27 cdef	29.75 b
30	33.98 bcdef	35.03 Bcdef	36.37 Abcd	40.13 Ab	36.38 a
40	32.99 bcdef	35.46 Bcde	35.02 bcdef	38.57 abc	35.51 ab
50	28.64 Efg	24.61 G	34.33 bcdef	43.06 A	32.66 ab
Average	31.00 B	30.68 B	34.11 b	38.51 A	

Means followed by different letters are significantly different Duncan's Multiple Range Test ($p<0.05$)

Number of grains in an inflorescence (one inflorescence grain).

The results in Table (5) indicated a significant impact of row planting distances, with the 40 cm distance yielding an average of 1654.33, while the 20 cm distance recorded the lowest significant average of 1231.91, which did not significantly differ from the 30 cm distance, averaging 1294.25.

The observed phenomenon may be ascribed to the enhanced spike length at considerable distances, yielding the highest mean grain count per spike, as noted by [23] Alternatively, the increased spacing between plants may facilitate improved ventilation and light distribution while diminishing disease prevalence, thereby promoting growth and augmenting the grain yield per inflorescence. This outcome aligns with the findings of [24;25]. The second factor's results in Table (5) indicated that liquid fertilizer exhibited a mean of 1596.75, which did not significantly differ from nano fertilizer's mean of 1539.83. In contrast, urea fertilizer yielded a mean of 1309.33, while organic fertilizer recorded the lowest significant value for this trait at 1281.08. The superiority of nano nitrogen fertilizer in this trait can be ascribed to its enhancement of leaf area and chlorophyll content in the flag leaf, which likely resulted in increased photosynthetic products, their translocation and accumulation in the reproductive organs, and diminished competition among them. This positively influenced the proportion of fertilized florets and, subsequently, the seed count in the vine. Moreover, nano nitrogen fertilizer demonstrated superiority in the vine length characteristic [26;27].

A notable connection existed between row planting spacing and sources of nitrogen fertilizer. The row planting spacing of 50 cm combined with liquid fertilizer yielded the greatest mean for the characteristic, at 2027.00, whereas the row planting distance of 20 cm with urea fertilizer resulted in the lowest mean. The mean quantity of grains per inflorescence is 1060.00.

Table 5. Effect of row spacing, nitrogen fertilizer sources and their interaction on grains per panicle

row planting distances	nitrogen fertilizer				Average
	Urea	Organic	Liquid	Nano	
20	1060.00 F	1153.33 ef	1498.66 cde	1215.66 cdef	1231.91 c
30	1186.33 def	1242.33 cdef	1407.33 cdef	1341.00 cdef	1294.25 c
40	1573.33 cd	1590.00 c	1454.00 cdef	2000.00 Ab	1654.33 a
50	1417.66 cdef	1138.66 ef	2027.00 a	1602.66 Bc	1546.500 b
Average	1309.33 B	1281.08 b	1596.75 a	1539.83 A	

Means followed by different letters are significantly different Duncan's Multiple Range Test ($p<0.05$)

Yield per plant (g.plant-¹)

Table 6 reveals that a line spacing of 50 cm substantially surpassed the grain yield trait of a single plant, yielding 30.56 g.plant□¹, but a line spacing of 20 cm produced the lowest significant output at 17.85 g.plant□¹. This may be attributed to the predominance of grain quantity at remote distances. The yield feature of a plant is a fundamental component of overall yield, determined during the stage when competition among plant parts escalates. Consequently, the grain count is the characteristic most intimately associated with the plant's yield [28]. The results in the same table indicate that nano fertilizer was markedly superior, yielding the highest significant value for this feature at 28.55 g.plant, with no significant difference from liquid fertilizer, which produced 27.71 g.plant. Organic fertilizer yielded the lowest significant value, at 20.84 g.plant, with no significant difference from urea fertilizer, which also produced 20.84 g.plant. The interaction between the row planting distance of 50 cm and liquid fertilizer yielded the highest significant grain yield per plant at 38.59 g.plant, whereas the lowest yield was observed with a planting distance of 20 cm and urea fertilizer, at 14.37 g.plant.

Table 6. Effect of row spacing, nitrogen fertilizer sources, and their interaction on grain yield per plant (g plant-¹)

row planting distances	nitrogen fertilizer				Average
	Urea	Organic	Liquid	Nano	
20	14.37 f	16.13 ef	23.70 Bcd	17.19 cdef	17.85 b
30	20.81 bcdef	17.09 def	24.69 B	22.53 bcde	21.28 b
40	23.22 bcd	24.63 b	23.84 Bc	37.28 A	27.24 a
50	24.98 b	21.47 bcde	38.59 A	37.21 A	30.56 a
Average	20.84 b	19.83 b	27.71 a	28.55 A	

Means followed by different letters are significantly different Duncan's Multiple Range Test ($p<0.05$)

Ash Percentage (%)

Table 7 presents notable disparities in the ash content of seeds, with the distance above 50 cm yielding a value of 0.228%, whereas the distance over 20 cm exhibited the lowest significant value of 0.214%.

This may result from the observation that plants separated at intervals more effectively utilize mineral components, hence enhancing the ash content of seeds. [29].

The second element revealed notable disparities in the average nitrogen fertilizer sources, with organic fertilizer surpassing the ash content of seeds by 0.240%, whereas urea fertilizer exhibited the lowest significant value at 0.206%. Table (7) demonstrates a significant interaction effect between the two experimental factors on the ash percentage trait, with an agricultural distance of 50 cm and organic fertilizer yielding a significantly higher rate of %0.4500, whereas a distance of 50 cm resulted in urea exhibiting the lowest significant value at 0.2000%.

Table 7: Effect of row spacing, nitrogen fertilizer sources, and their interaction on the ash percentage (%).

row planting distances	nitrogen fertilizer				Average
	Urea	Organic	Liquid	Nano	
20	0.2060 Cd	0.2450 A	0.2043 d	0.2006 D	0.214 B
30	0.2093 Bcd	0.2455 A	0.2115 bcd	0.2140 bcd	0.220 ab
40	0.2100 Bcd	0.2275 abc	0.2300 ab	0.2121 bcd	0.219 ab
50	0.2000 D	0.4500 A	0.2410 a	0.2280 abc	0.228 a
Average	0.206 C	0.240 A	0.221 b	0.213 bc	

Means followed by different letters are significantly different Duncan's Multiple Range Test ($p<0.05$)

Conclusion

There were no significant differences in planting to 50% flowering time across distances. A distance of 20 cm caused significant changes in plant height, whereas 30 cm caused considerable chlorophyll content variances. Distances of 40 cm and 50 cm had more tillers and much more flag leaf area. • Nano fertilizer improved chlorophyll content and extended the time from sowing to 50% flowering , while liquid fertilizer improved tiller count. Nitrogen fertilizer providers and row planting spacing are linked. An interaction of 20 cm row spacing and organic fertilizer produced the greatest significant value for planting to 50% flowering at 127.00 days. Moreover, the 20 cm planting distance with nano fertilizer had superior plant height, whereas the 50 cm with liquid fertilizer had superior branch number. Additionally, a 30 cm planting distance with nano fertilizer increased flag leaf area, whereas a 50 cm planting distance increased chlorophyll content.

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تأثير مسافات الزراعة ومصادر السماد النيتروجيني على نمو وحاصل ونوعية الدخن اللؤلؤي
(Pennisetum glaucum L.)

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[1] قسم قسم المحاصيل الحقلية،كلية الزراعة،جامعة كركوك،كركوك، العراق.

الخلاصة
أجريت تجربة حقلية في محطة أبحاث كلية الزراعة بجامعة كركوك خلال موسم النمو الصيفي 2024 لدراسة تأثير مسافات الزراعة ومصادر الأسمدة النيتروجينية المختلفة على نمو وإنتاجية ونوعية الدخن اللؤلؤي. استخدمت التجربة تصميم القطاعات الكاملة العشوائية بترتيب القطع المنشقة بثلاث مكررات. تضمنت القطع الرئيسية مسافات الصفوف (20، 30، 40، و50 سم)، بينما تضمن العامل الثاني القطع الفرعية التي شملت أربعة مصادر مختلفة للأسمدة النيتروجينية (اليوريا، روث الدجاج، السائل، والنانو). قُيّمت البيانات إحصائيًا، وقورنت المتوسطات باختبار دنكن متعدد الحدود عند مستوى 0.05. أشارت النتائج إلى عدم وجود فروق معنوية في المدة من الزراعة حتى 50% تزهير بتأثير مسافات الزراعة. بينما سجلت المسافة بين الخطوط 50 سم قيمًا كبيرة في عدد الأشطاء لكل نبات (4.30) ومحتوى الكلوروفيل لورقة العلم (32.66) وحاصل النبات الواحد (30.56 غم) ونسبة الرماد (0.228٪). في حين سجلت عدد حبوب لكل سنبلة (1654.33) أعلى قيمة للمسافة 40 سم، والتي لم يختلف الأخير معنوياً عند 50 سم في محتوى الكلوروفيل لورقة العلم وحاصل النبات الواحد. كان للسماد النيتروجيني النانوي قيم عالية في معظم الصفات المدروسة مثل المدة من الزراعة حتى 50٪ تزهير (123.83 يوم) ومحتوى الكلوروفيل لورقة العلم (38.51) وحاصل النبات الواحد (28.55 غم). بينما ساهم النيتروجين السائل في زيادة عدد الأشطاء لكل نبات (3.91) وعدد الحبوب لكل نورة (1596.75) على العكس من ذلك كان لسماد العضوي (روث الدجاج) تأثير كبير على الصفة النوعية مثل نسبة الرماد (0.240٪) مقارنة بمصادر الأسمدة النيتروجينية الأخرى. أظهرت هذه التجربة أن المسافة ٥٠ سم واستخدام سماد النيتروجين النانوي كانا الأفضل لمعظم الصفات، بينما حسّن النيتروجين السائل من عدد الأشطاء وعدد الحبوب، وحسّن روث الدجاج من جودة الحبوب. وأظهرت التجربة أن التباعد الأمثل واختيار مصدر النيتروجين يمكن أن يؤثرا بشكل كبير على إنتاجية وجودة الدخن اللؤلؤي.

الكلمات المفتاحية: تباعد الصفوف، مصادر الأسمدة النيتروجينية، الدخن اللؤلؤي.