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Growth and Phenology of Minor Millets as Influenced by Fertility Levels under Semi-Arid Conditions of Haryana

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Authors' contributions

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

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Abstract

Decline in productivity of major cereal crops has been observed due to climate change and global warming. The main effects of climate change are increase in temperature, uncertainties in rainfall and enhancement of greenhouse gasses emission. So, under these changed climatic scenario to ensure the nutrition and food security at national level the adoption of millets may be a good choice as millets are climate smart crops because of their high nutritive value, better adaptation to warm and drought conditions with short life, low external inputs requirement and higher tolerance to water and temperatures stress. The extent cultivated for the production of minor millets in India has declined significantly in recent decades due to the dominance of major cereal crops, despite their nutritional and agronomic benefits. Enhancement of millet productivity involves efficient nutrient management practices, especially nitrogen (N) and phosphorus (P), to maximize growth and yield. The goal of this research was to evaluate the growth and phenology response of different minor

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millet varieties under different levels of nitrogen and phosphorus application. Specifically, the study was laid out in split plot design to analyze four species of various minor millets: Foxtail millet (SIA 3156), Barnyard millet (VL 207), Proso millet (TNAU 202), and Finger millet (GPU 67) designated as main plots. Additionally, four levels of nitrogen and phosphorus are applied in sub-plots, categorized as $N_0 + P_0$, $N_{20} + P_{10}$, $N_{40} + P_{20}$, and $N_{60} + P_{30}$ kg ha^{-1}. The recorded data included growth attributes such as plant population (mrl^{-1}), plant height (cm), dry matter accumulation (g mrl^{-1}), and number of tillers (mrl^{-1}). Phenological observations were recorded, including the measurement of days to crop emergence, days to heading, and days to maturity. The results indicated that the application of nitrogen and phosphorus to various minor millets significantly improved the growth and phonological attributes of millets which finally affected yield performance.

Keywords: Growth; minor millets; nitrogen; phenological; phosphorus.

1. Introduction

Minor millets are cereal crops with small seeds that belong to the grass family, the family *Poaceae*, and were cultivated over 5,000 years ago. The major cultivation regions in dry and semi-dry conditions of India are Rajasthan, Uttar Pradesh, and Karnataka (Das et al., 2019). Of the noted 11 minor millet species, the following: finger millet (*Eleusine coracana* L.), foxtail millet (*Setaria italica* L.), barnyard millet (*Echinochloa* spp.), little millet (*Panicum sumatrense* L.), proso millet (*Panicum miliaceum* L.), kodo millet (*Paspalum scrobiculatum* L.), fonio millet (*Digitaria exilis* L.), teff (*Eragrostis tef* (Zucc.) Trotter), brown top millet (*Urochloa ramose* L.), Job's tears (*Coix lacryma-jobi*), and guinea millet (*Urochloa deflexa*) are recognized as being well suited to adverse climatic conditions, having a short growing cycle of about 70 to 80 days and resistant to pests and diseases (Dhaka et al., 2025; Dhaka et al., 2024; Dhaka et al., 2023; Devi et al., 2014; Macauley & Ramadjita, 2015). The largest area under minor millets' production in Madhya Pradesh is 1.65 lakh hectares, followed by Chhattisgarh and Uttarakhand, with each having about 0.48 lakh hectares under production. Madhya Pradesh ranked first in production, with 147,000 tons of production, followed by Uttarakhand with 60,000 tons and Tamil Nadu with 33,000 tons. The highest productivity has been recorded at 2321 kg per hectare in Gujarat, followed by Uttarakhand and Tamil Nadu at 1503 kg per hectare and 1348 kg per hectare, respectively. The area under minor millet cultivation in India has drastically decreased, from 2,447 thousand hectares in 1990-91 to only 458 thousand hectares in 2019-20. The main reason behind this is because of the over-cultivation of major cereals (APEDA, 2024).

Fertilization plays a critical role in enhancing both the qualitative and quantitative aspects of crop yield. The quality of crops can be significantly improved through effective management of soil nutrients, as demonstrated in studies by (Ali et al., 2008; Pathak et al., 2012; Dhaka et al., 2023a). The productivity of minor millets is significantly constrained by the sub-optimal utilization of primary nutrients, particularly nitrogen (N) and phosphorus (P), which are essential for plant growth and development. Nitrogen plays a vital role in photosynthetic processes and overall vegetative growth, whereas phosphorus is crucial for root development, energy transfer, and the initial establishment of plants (Sharma et al*.,* 2023; Kamal et al*.,* 2024; Kamal et al*.,* 2023). A suitable balance of these nutrients can markedly improve phenology and biomass accumulation in millets, resulting in enhanced performance in both rainfed and irrigated environments. The current study was undertaken to assess the response of minor millets to different levels of nitrogen and phosphorus, focusing on their phenological stages and overall growth behavior.

2. Materials and Methods

2.1 Experimental Site and Location

The experiment was conducted in the *kharif* season of 2023 at the Agronomy Research Farm of CCS Haryana Agricultural University, Hisar. Hisar is positioned at a latitude of 29°10' N and a longitude of 75°46' E, with an elevation of 215 meters above mean sea level. The soil at the research site has a sandy texture determined by International Pipette Method, slightly alkaline in pH (7.8) determined by Glass electrode pH water method by making soil to water suspension of 1:2.5 ratio, organic carbon (0.51%) determined by Wet oxidation method, low in available N (147 kg ha^{-1}) determined by using Alkaline permanganate method (Subbiah & Asija, 1956), medium in available P (18.2 kg ha^{-1}) determined by Olsen's calorimetric method (Olsen, 1954), medium in available K (280 kg ha^{-1}) determined by Flame photometric method (Richards, 1954).

The experiment was conducted using a split plot design, incorporating sixteen treatment combinations and three replications. Specifically, the study involves four species of various minor millets: Foxtail millet (SIA 3156), Barnyard millet (VL 207), Proso millet (TNAU 202), and Finger millet (GPU 67) designated as main plots. Additionally, four levels of nitrogen and phosphorus are applied in sub-plots, categorized as $N_0 + P_0$, $N_{20} + P_{10}$, $N_{40} + P_{20}$, and $N_{60} + P_{30}$ kg ha^{-1}. The land preparation involved two ploughing operations utilizing a harrow and a cultivator, followed by planking and pre-sowing irrigation to maintain optimal moisture levels. Following the layout procedure utilizing levelling rods, a complete application of phosphorus and fifty percent of the nitrogen dosage, in accordance with the specified treatments, was integrated during the field preparation phase. Sowing was subsequently conducted with a row spacing of 30 cm in mid-June. The residual nitrogen was utilized as a top dressing subsequent to the processes of thinning and gap filling. Urea (46% N) and Di-ammonium Phosphate (DAP) (18% N, 46% P_2O_5) served as the sources of nitrogen and phosphorus. Manual weeding was conducted at 20-25 and 35-40 days after sowing (DAS), with two irrigations provided according to crop requirements during periods of dry weather.

2.2 Observations Recorded

The recorded data included growth attributes such as plant population (mrl^{-1}), plant height (cm), dry matter accumulation (g mrl^{-1}), and number of tillers (mrl^{-1}). The plant population was quantified per metre of row length at 15 days after sowing (DAS). Plant height was recorded at 20, 40, and 60 days after sowing (DAS), as well as at maturity. Measurements were taken from ground level to the apex of the shoot using a metre rod (cm). The accumulation of dry matter in plant samples for a one-meter row length was measured at 20, 40, and 60 days after sowing (DAS), as well as at maturity. The plants were severed at ground level and placed into a brown paper bag. The sample was subsequently dried in a thermally controlled oven at 60 °C until it reached a constant weight, which was recorded in gram per meter row length (g mrl^{-1}). The total number of tillers was counted from a one-meter row length in selected rows of each plot using a measuring rod at 40 and 60 days after sowing (DAS), as well as at maturity. Phenological observations were recorded, including the measurement of days to crop emergence, days to heading, and days to maturity. The recorded data were analyzed using the analysis of variance (ANOVA) technique as outlined by Gomez and Gomez (1984) for a split plot design. The least significance test was employed to analyse the impact of treatments at a 5% significance level.

3. Results and Discussion

3.1 Effect of Different Fertility Levels on Growth Parameters

The data on growth traits are presented in Tables 1 & 2. The data of plant population recorded non-significant effect at 15 days after sowing (DAS), however proso millet (TNAU 202) exhibited a slightly higher plant population (9.00 plants mrl^{-1}) compared to foxtail millet (8.83 plants mrl^{-1}), while finger millet (GPU 67) had the lowest plant population (8.42 plants mrl^{-1}). Irrespective of minor millets and nitrogen and phosphorus levels plant height continuously increased up to maturity. The maximum increase in plant height was observed between 20 and 60 DAS, followed by a slight increase from 60 DAS to maturity, except for finger millet. Among different minor millet, proso millet recorded highest plant height at 20 DAS (31.86 cm) and 40 DAS (100.40 cm), whereas, at 60 DAS (143.78cm) and at maturity (146.23cm) highest plant height was recorded with foxtail millet, which was found statistically at par with proso millet at maturity (136.42 cm). Whereas, finger millet recorded minimum plant height during all the growth stages i.e., (15.5 cm) at 20 DAS, (34.04 cm) at 40 DAS, (54.18 cm) at 60 DAS and (88.92 cm). Like other growth attributes, Dry matter accumulation (gram per meter row length) is a significant parameter which determines the final yield output. Significant differences were seen during for dry matter accumulation (g mrl^{-1}) by different minor millets during 20, 40, 60 DAS and at maturity. The dry matter accumulation increased with advancement of growth stages of crop. The dry matter accumulation by barnyard millet was found higher at 20 DAS (1.87 g mrl^{-1}), 40 DAS (35.79 g mrl^{-1}), 60 DAS (136.10 g mrl^{-1}) and at maturity (172 g mrl^{-1}) as compared to other minor millets. However lowest dry matter accumulation with finger millet at 20 DAS (1.45 g mrl^{-1}), 40 DAS (18.36 g mrl^{-1}) and 60 DAS (79.70 g mrl^{-1})

Table 1. Effect of fertility levels on plant population and plant height of minor millets

Treatment	Plant population at 15 DAS (mrl^{-1})	Plant height (cm)			
		20 DAS	40 DAS	60 DAS	Maturity
Minor millets					
Foxtail millet (SIA 3156)	8.83	26.70	94.21	143.78	146.23
Barnyard millet (VL 207)	8.58	23.91	62.41	122.97	128.01
Proso millet (TNAU 202)	9.00	31.86	100.4	132.31	136.42
Finger millet (GPU 67)	8.42	15.50	34.04	54.18	88.92
SE(m) ±	0.27	0.50	1.20	1.94	2.79
CD at 5 %	NS	1.78	4.23	6.83	9.85
Fertility levels (kg ha^{-1})					
T1- Control	8.12	23.39	64.20	104.00	115.19
T2- N20P10	8.58	24.02	72.70	112.92	124.81
T3- N40P20	8.92	25.08	76.19	117.25	128.67
T4- N60P30	8.17	25.47	77.96	119.06	130.92
SE(m) ±	0.29	0.62	0.94	0.78	1.11
CD at 5%	NS	NS	2.77	2.28	3.26

DAS: Days after sowing; mrl: Meter row length

Table 2. Effect of fertility levels on dry matter accumulation and no. of tillers of minor millets

Treatment	Dry matter accumulation (g mrl^{-1})				No. of tillers (mrl^{-1})		
	20 DAS	40 DAS	60 DAS	Maturity	40 DAS	60 DAS	Maturity
Minor millets							
Foxtail millet (SIA 3156)	1.83	32.16	125.83	161.91	39.00	46.36	43.61
Barnyard millet (VL 207)	1.87	35.79	136.10	172.00	33.35	39.84	37.81
Proso millet (TNAU 202)	1.67	30.06	88.72	113.27	44.54	45.25	41.16
Finger millet (GPU 67)	1.45	18.36	79.7	135.49	23.99	32.50	35.47
SE(m) ±	0.07	1.27	2.16	2.28	1.45	1.85	1.48
CD at 5 %	0.25	4.11	7.61	8.04	5.12	6.51	5.24
Fertility levels (kg ha^{-1})							
T1- Control	1.3	22.42	92.56	130.53	25.89	30.95	29.50
T2- N20P10	1.68	28.15	106.00	144.10	34.60	40.16	39.36
T3- N40P20	1.88	32.37	114.95	152.90	39.22	45.51	43.88
T4- N60P30	1.96	34.10	116.86	155.17	41.19	47.33	45.31
SE(m) ±	0.06	1.16	2.03	1.96	1.09	0.95	1.28
CD at 5%	0.18	3.72	6.56	5.76	3.22	2.77	3.74

DAS: Days after sowing; mrl: Meter row length

was recorded, whereas the least dry matter accumulation at maturity (113.27 g mrl^{-1}) was recorded under proso millet. The significant effect was also revealed on number of tillers (per meter row length) among different minor millets during all growth stages. The highest number of tillers mrl^{-1} at 40 DAS was recorded in proso millet (44.54 mrl^{-1}), succeeded by foxtail millet (39.00 mrl^{-1}). However, the number of tillers were significantly higher at 60 and at maturity in foxtail millet (46.36 and 43.61mrl^{-1}, respectively), which was statistically at par with proso millet (45.25 and 41.16 mrl^{-1}, respectively). Contradictorily, the lowest no. of tillers at 40 DAS (23.99 mrl^{-1}), 60 DAS (32.50 mrl^{-1}) and at maturity (35.47 mrl^{-1}) was recorded in finger millet. Shorter stature may reflect genetic adaptation to cooler hill agro-ecologies; finger millet originating from Ethiopian highlands shows reduced vegetative growth under >35°C Day temperatures. The growth performance variation among minor millets is determined by genetic diversity, environmental adaptability and physiological efficiency. No significant differences were observed in plant population, likely due to the consistent germination and successful establishment recorded across all species. Foxtail millet showed improved growth traits, particularly height and tiller development. This enhancement can be attributed to efficient nutrient uptake, hormonal balance, and improved photosynthetic efficiency (Bhomte et al., 2016; Patil et al., 2015).

The enhanced dry matter accumulation in barnyard millet reflects a favorable source-sink relation and increased photosynthetic ability, as indicated by the results of Soutade and Raundal (2022). Proso millet, on the other hand, showed lower biomass, possibly due to the diversion of assimilates towards reproductive organs. The relatively lower growth of finger millet could be due to its lower environmental adaptability and higher vulnerability to stress factors. The findings emphasize the influence of genotype, management practices, and environmental factors such as soil fertility, water availability, and climate (Maai et al., 2025).

In case of different nitrogen and phosphorus levels, no significant effect was found on plant population. However, significant effect except at 20 DAS was found on plant height. The data indicated that as the levels of nitrogen and phosphorus increased, plant height also increases. The maximum plant height was recorded in the treatment T_4 (60:30 kg NP ha^{-1}) with 21.43, 14.48 and 13.66 percent increase over control during 40 DAS (77.96 cm), 60 DAS (119.06 cm) and at maturity (130.92 cm) respectively, and was statistically at par with T_3 (40:20 kg NP ha^{-1}). On the contradictory, the lowest plant height at different growth stages was observed in treatment T_1(control) with plant height of 64.2 cm at 40 DAS, 104 cm at 60 DAS and 115.19 cm at maturity. Similarly, higher dry matter accumulation was recorded with treatment T_4 (60:30 kg NP ha^{-1}) with 50.77, 52.10, 26.25 and 18.88 percent increase over control during 20 DAS (1.96 g mrl^{-1}), 40 DAS (34.10 g mrl^{-1}), 60 DAS (116.86 g mrl^{-1}) and at harvest (155.17 g mrl^{-1}) which was found significantly at par with T_3 (40:20 kg NP ha^{-1}) at all the growth stages whereas lowest dry matter accumulation at different growth stages was observed in treatment T_1 (control) with dry matter accumulation of 1.30 g mrl^{-1} at 20 DAS, 22.42 g mrl^{-1} at 40 DAS and 92.56 cm at 60 DAS and 130.53 g mrl^{-1} at maturity. In case of number of tillers (mrl^{-1}), the treatment T_4 (60:30 kg NP ha^{-1}) resulted into maximum number of tillers with 59.10, 52.92 and 53.59 percent increase over control at 40 DAS (41.19 mrl^{-1}), 60 DAS (47.33 mrl^{-1}) and at maturity (45.31 mrl^{-1}), which was statistically at par with T_3 (40:20 kg NP ha^{-1}) whereas minimum number of tillers at 40 DAS (25.89 mrl^{-1}), 60 DAS (30.95 mrl^{-1}) and at maturity (29.50 mrl^{-1}) was observed in treatment T_1 (Control). A positive increase in height, number of tillers, and dry weight accumulation at 40 DAS, 60 DAS, and at harvest by the 60:30 kg N: P ha^{-1} was highly associated with comparable responses to the application of 40:20 kg N:P ha^{-1}. Such response is attributable to increased availability of nutrients, particularly nitrogen, that promotes photosynthesis, synthesis of proteins, and cell elongation. These activities contribute to internode elongation and plant height (Munirathnam & Kumar, 2015; Shahin et al., 2013). Phosphorus helped in root development, thus enhancing nutrient uptake and growth of the plant (Khan et al., 2023; Divyashree et al., 2018). Vegetative growth enhancement, which was nitrogen-induced hormonal activity, was associated with elevated tillering (Mahajan et al., 2017). The increased dry matter accumulation that was recorded at a nitrogen to phosphorus ratio of 60:30 kg ha^{-1} may be linked with higher root activity, stomatal conductance, and carbon assimilation, as noted by Charate et al. (2018). Excessive application of nutrients may lead to imbalances and increased losses through leaching and volatilization. Proper irrigation and favorable environmental conditions, such as optimal temperature and sufficient sunlight, facilitated efficient nutrient uptake and collectively supported plant growth.

3.2 Effect of Different Fertility Levels on Phenological Attributes

The data pertaining to days taken for different phenological stages *i.e.,* emergence, 50 % heading and maturity under different treatments are presented in Table 3. Days taken to crop emergence was significantly affected by minor millets crops. Maximum days were taken to crop emergence by finger millet (6.92 days) which was found statistically at par with barnyard millet. However, lowest days taken to crop emergence was in proso millet (3.17 days). Days taken to 50 % heading was also significantly affected by minor millets. Maximum days were taken to 50 % heading by finger millet (86.92 days), followed by foxtail millet (51.50 days). However, lowest days taken to 50 % heading was in proso millet (41.75 days). Significant differences in time taken to reach maturity was found among different minor millets. The longest period to attain maturity was recorded in finger millet (126.00 days). In contrast, the shortest time for maturity was observed in proso millet (69.17 days). Among various minor millets examined, finger millet took the longest to crop emergence (6.92 days), 50% heading (87 days), and maturity (120 days), with barnyard and foxtail millets having at par effects. Proso millet took the least amount of time to 50% heading (42 days) and maturity (69 days). The

Table 3. Effect of fertility levels on phenological attributes of minor millets

Treatment	Phenological stages		
	Days to crop emergence	Days to 50 % heading	Days to maturity
Minor millets			
Foxtail millet (SIA 3156)	4.83	51.50	84.83
Barnyard millet (VL 207)	5.17	54.92	86.26
Proso millet (TNAU 202)	3.17	41.75	69.17
Finger millet (GPU 67)	6.92	86.92	126.00
SE(m) ±	0.22	0.42	0.77
CD at 5%	0.79	1.48	2.72
Fertility levels (kg ha^{-1})			
T1 - Control	4.50	56.58	86.08
T2 - N20P10	4.83	58.42	90.08
T3 - N40P20	5.16	59.83	93.66
T4 - N60P30	5.58	60.25	94.50
SE(m)±	0.26	0.31	0.69
CD at 5 %	NS	0.92	2.32

majority of these variations are genetically regulated, but partly by environmental variations such as soil fertility, photoperiod, and temperature, and also influenced by management practice such as watering and nutrient levels. These findings are consistent with those of Triveni et al. (2018) and Dhaka et al. (2025a).

In case of effect of different nitrogen and phosphorus levels, no significant effect was found on days taken to crop emergence. However, its effect was found to be significant on days to 50 % heading and days to maturity. Maximum days to 50 % heading (60.25 days) was undertaken by treatment T_4 (60:30 kg NP ha^{-1}), which was found 6.49 percent higher over control treatment. It was also found to be statistically at par with T_3 (40:20 kg NP ha^{-1}). The least days taken to 50 % heading (56.58 days) by treatment T_1 (Control). Similarly, it was revealed that the days to maturity were also significantly affected by the levels of nitrogen and phosphorus fertilizers. The treatment with 60:30 kg NP ha^{-1} (T_4) took the longest time to maturity (94.50 days) whereas treatment T_1 (control) resulted in the shortest time to maturity (86.08 days).

The levels of nitrogen and phosphorus did not significantly affect the number of days to crop emergence. However, an increase in NP application resulted in a notable extension of the days to reach 50% heading and maturity. The longest durations were recorded with 60:30 kg NP ha^{-1}, which were statistically comparable to 40:20 kg NP ha^{-1}. The delay can be attributed to enhanced vegetative growth stimulated by greater nutrient availability, which in turn postpones the onset of reproductive development. Nutrient-deficient conditions, similar to those observed in the control group, accelerated phenological stages as a result of restricted vegetative development. The results are consistent with the findings reported by Yadav and Yadav (2013), Triveni et al. (2018) and Gautam et al. (2020).

4. Conclusions

This research depicted significant impacts of millet selection and nutritional treatments on the growth and phenology of minor millets. Among millets, foxtail millet (SIA 3156) showed improved performance in terms of plant height, dry matter accumulation, and tillering. On the other hand, barnyard millet (VL 207) had maximum dry matter accumulation at maturity. By comparison, finger millet (GPU 67) had sub optimal vegetative growth, delayed phenological development, and lower tillering, indicating its relatively lower adaptability to the given agro-climatic and nutritional conditions. The use of fertility treatments also impacted both phenological and morphological parameters immensely. The use of 60:30 kg N:P ha^{-1} (T_4) caused significant increases in plant height, dry matter production, and the number of tillers highlighting the crucial role of nitrogen and phosphorus in maximizing vegetative development of millets. Phenological observation revealed that higher NP levels delayed the time to 50% heading and maturity, which is due to increased vegetative growth caused by enhanced nutrient supply.

The present study concludes that the application of 60:30 kg N:P ha^{-1} significantly improved growth and biomass yield of minor millets, enhancing overall productivity. The results highlight their resilience and nutrient use efficiency, emphasizing the importance of balanced fertilization for sustainable production under resource limited conditions.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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