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RESEARCH ARTICLE

Impact of foliar application of nano urea with varied levels of nutrients in pearl millet varieties under rainfed conditions

Rakesh Kumar[1*], Mohd Sadique[1], Neetu Sharma[1], A P Singh[1], Raju Gupta[2], Joy Samuel MeCarty[1], Hritik Srivastava[3*], C Lalrammawii[1] & Faraaz Farooq[1]

[1]Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu 180 009, Jammu & Kashmir, India
[2]KVK Poonch, R.S. Pura, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu 180 009, Jammu & Kashmir, India
[3]Division of Agronomy, School of Agriculture & Technology, Maya Devi University, Dehradun 248 011, Uttarakhand, India

*Correspondence email - sharmark77ag@gmail.com; hritik.srivastava@mdu.edu.in

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Abstract

In the rainfed conditions of the subtropical region, *Kharif* crops face dry spells and drought due to uneven distribution of rainfall where climate-smart crop like pearl millet can be grown. Nitrogen (N) plays a vital role in growth and productivity of pearl millet; however, nitrogen use efficiency is low as the applied N faces different types of losses. During present time, nano urea is available which is efficiently absorbed by plants and enhances growth and yield of crops. The two foliar sprays of nano-urea were applied at 30 and 45 days after sowing (DAS), corresponding to the active tillering and pre-flowering stages of the crop. Based on the above facts, a field experiment was conducted to evaluate the efficacy of co-application and partial substitution of nano-urea with conventional urea in pearl millet. The study aimed to assess its impact on phyto-productivity, dry matter and nutrient accumulation, yield attributes, grain and stover yield, harvest index and economic returns. The experiment was laid out in a Factorial Randomized Block Design with two factors and three replications. The first factor consisted of three pearl millet varieties: Sulkhaniya bajra, Pusa composite 701 and Pusa composite 383, while the second factor comprised six nutrient levels: N_1 (40:20:0), N_2 (20:20:0 + 2 foliar sprays of Nano-urea @ 250 mL ha^{-1}), N_3 (50:30:15), N_4 (25:30:15 + 2 foliar sprays of Nano-urea @ 312 mL ha^{-1}), N_5 (62.5:37.5:18.75) and N_6 (31.25:37.5:18.75 + 2 foliar sprays of Nano-urea @ 394 mL ha^{-1}). The findings revealed that substituting 50 % of nitrogen with two foliar sprays of nano-urea significantly enhanced nutrient use efficiency and crop performance. Among the different treatments, N_6 (31.25:37.5:18.75 + 2 foliar sprays of nano-urea @ 394 mL ha^{-1}) resulted in the highest yield (1802 kg/ha), gross (₹70407) and net returns (₹49962) and benefit-cost ratio (2.44) under rainfed conditions. These results underscore the potential of nano-urea in reducing conventional urea dependency while promoting efficient and sustainable pearl millet cultivation.

Keywords: nano-urea; nitrogen; partial substitution; pearl millet; rainfed

Introduction

Rainfed agriculture faces significant challenges due to its reliance on unpredictable rainfall, leading to frequent droughts and low crop productivity. In such environments, the cultivation of drought-tolerant crops becomes crucial for ensuring food security and sustainable farming. Millets, known for their resilience and eco-friendly nature, are particularly well-suited to these conditions. Among them, pearl millet stands out for its exceptional adaptability to arid and semi-arid regions, making it an important crop for rainfed areas. Pearl millet (*Pennisetum glaucum* L.) is the fourth most significant cereal crop of Asia after rice, wheat and maize (1). It is a major crop of arid and semi-arid regions of India and is mostly grown as a rainfed crop during the *Kharif* season. Pearl millet grains are eaten cooked like rice or made into 'chapatis' from flour. In 2023-24, pearl millet (bajra) was cultivated on approximately 8.5 million hectares in India, with a total production of about 11.8 million tonnes and an average productivity of around 1360 kg per hectare. Rajasthan is the leading producer, contributing nearly 45 % of national output, followed by Uttar Pradesh, Haryana, Madhya Pradesh and Gujarat (2). It is also used as feed for poultry and green fodder or dry Karbi for cattle. It is grown on a larger scale in rainfed areas of the country mainly due to its drought escaping mechanism coupled with comparatively higher production ability in low fertile soil and high temperature conditions. The newly developed varieties and hybrids of pearl millet including Raj 171, Kaveri Super Boss, MBC 2, PC 383, ICMV 221, Nandi 70 and Nandi 72 were showcased during different field experiments across India. These pearl millet cultivars have seed yields higher than inbred seed parents.

Globally, the application of mineral fertilizers is a key management strategy that plays a significant role in enhancing crop productivity and thus, maintaining sufficient food and feed supplies (1). Nitrogen (N) is the most important nutrient required for crop growth and development. As a constituent of chlorophyll, it greatly supports the photosynthesis process (2). Among the different commercial forms of mineral N fertilizers, Urea [$CO(NH_2)_2$] is the most widely used, mainly due to its high N content (46 % N), in addition to its compatibility with other nutrients (3). The nitrogenous fertilizer use efficiency in the modern farming systems is reported to be only 45-50 % (4). The high N loss coupled with its low use efficiency forced the farmers to increase the amounts of applied N fertilizers in order to achieve better crop production (5), which resulted in rising the costs of the farming practice, meanwhile, increasing the consequent environmental implications (6). Therefore, there is a pressing need to improve the N availability for plants with enhanced N-use efficiency, while reducing its harmful effects to the environment. In this regard, the utilization of nano fertilizers, especially nano particle urea (NPU) was proposed by several researchers (7, 8) to avoid the problems associated with the applications of bulk urea, while not depriving the plant from its benefits.

Nano fertilizers are defined as materials in the nanometer scale, usually in the form of nano particles, which containing macro and micronutrients that are delivered to crops in controlled mode (9). Urea is also produced by nanotechnology to improve the efficiency of the nutrients of the crops is called as Nano-urea. Nano-urea (liquid) is a source of nitrogen which is required for proper growth and development of the plant. Nano-urea contains 4 % nitrogen by weight in its nano form and nitrogen present in Nano-urea effectively meets the crop nitrogen requirement (10). The nitrogen use efficacy of Nano-urea liquid is over 80 % (11). Nano-urea liquid will boost a balanced nutrition programme because of its greater nutrient use efficiency by decreasing the excessive use of urea in the soil. Further, it would improve yield, biomass, soil health and nutritional quality of the produce. When used as foliar application, nano fertilizers have the ability to enter through the porous cell wall of plant cells due to their minute particle size (<50 nm) allowing for high absorption compared to conventional fertilizers. The study on the supplementation of nitrogenous fertilizer by nano urea on pearl millet is meagre in the Jammu Agroclimatic conditions, hence, the study on the same has been carried out.

Materials and methods

Study site

The field experiment was conducted during *Kharif* season of 2021-22 at the Advanced Centre for Rainfed Agriculture, Dhiansar, SKUAST-Jammu. Advance Centre for Rainfed Farm is located at Pathankot-Jammu National Highway, NH-1 near Bari-Brahmana in Samba district of Jammu region. The centre farm is situated at latitude of 32°39′ North and longitude of 74°53′ East at an elevation of 332 m above the mean sea level. However, the total rainfall and its distribution are subjected to large variations. The soil was found to be sandy loam in texture and the initial properties were as follows: pH 6.65, EC (dSm^{-1}) 0.17, organic carbon (g kg^{-1}) 2.4, available nitrogen (kg ha^{-1}) 147.67, available phosphorous (kg ha^{-1}) 11.65 available potassium (kg ha^{-1}) 90. Previous crop during *Kharif* season was maize followed by wheat in the *Rabi* season.

Meteorological data

Weekly meteorological data for the crop growing periods of both 2021 and 2022 at the Advanced Centre for Rainfed Agriculture, Dhiansar, SKUAST-Jammu, are presented in Table 1 and depicted in Fig. 1. In 2022, the region experienced rainfall patterns similar to 2021, with total rainfall being slightly higher. Maximum temperatures ranged from 32.5 °C to 36.5 °C and minimum temperatures from 20.5 °C to 25.1 °C (Fig. 1). Relative humidity remained moderate to high in both years, supporting optimal growth conditions for pearl millet. The distribution of rainfall across weeks was uneven, but the total precipitation in both years was more than adequate for rainfed pearl millet cultivation (Table 1).

Experimental design

The experiment was laid out in Factorial Randomized Block Design with two Factors (Factor A - Varieties and Factor B - Nutrient levels) making total number of 18 treatment combinations, replicated 3 times. Factor A included three varieties, viz. Sulkhaniya bajra, Pusa composite 701 and Pusa composite 383 and Factor B included six nutrient levels, viz. N1 (40:20:0::$N:P_2O_5:K_2O$ kg ha^{-1}), N2 (20:20:0::$N:P_2O_5:K_2O$ kg ha + 2 foliar spray of nano-urea each @ 250 mL ha^{-1}), N3 (50:30:15::$N:P_2O_5:K_2O$ kg ha^{-1}), N4 (25:30:15::$N:P_2O_5:K_2O$ kg ha^{-1}+ 2 foliar spray of nano-urea each 312 mL ha^{-1}), N5 (62.5:37.5:18.75::$N:P_2O_5:K_2O$ kg ha^{-1}) and N6 (31.25:37.5:18.75::$N:P_2O_5:K_2O$ kg ha^{-1} + 2 foliar spray of nano-urea each @ 394 mL ha^{-1}). Seed rate was 5 kg ha^{-1} with a spacing of 45 × 15 cm.

Agronomic management

The experiment comprised six nutrient management treatments: N1 (40:20:0 kg $N:P_2O_5:K_2O$ ha^{-1}), N2 (20:20:0 kg $N:P_2O_5:K_2O$ ha^{-1} + 2 foliar sprays of nano-urea each @ 250 mL ha^{-1}), N3 (50:30:15 kg $N:P_2O_5:K_2O$ ha^{-1}), N4 (25:30:15 kg $N:P_2O_5:K_2O$ ha^{-1} + 2 foliar sprays of

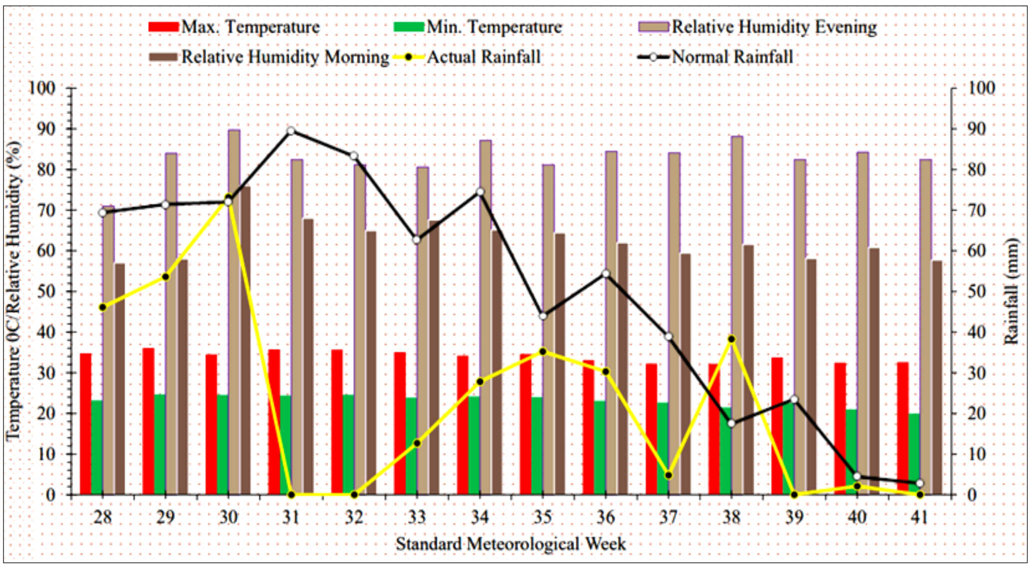

Fig. 1. Graphical representation of meteorological data at experimental site 2021.

Table 1. Standard Meteorological Weekly Data of Agrometeorology Observatory

Date (Week)	Max Temp (°C)	Min Temp (°C)	RH Evening (%)	RH Morning (%)	Actual Rainfall (mm) 2021	Actual Rainfall (mm) 2022	Normal Rainfall (mm)
09–15 July	34.8	23.2	71	57	46.1	52.3	69.4
16–22 July	36.1	24.7	84	58	53.6	56.5	71.4
23–29 July	34.54	24.56	89.71	76.00	73.2	78.4	72.01
30 July–05 Aug	35.71	24.41	82.43	68.00	0.0	9.2	89.5
06–12 Aug	35.69	24.59	81.14	65.00	0.0	5.6	83.24
13–19 Aug	35.10	23.93	80.57	67.57	12.7	15.9	62.65
20–26 Aug	34.19	24.19	87.14	65.14	27.8	32.7	74.45
27 Aug–02 Sept	34.60	24.03	81.14	64.43	35.2	38.1	43.91
03–09 Sept	33.11	23.13	84.43	62.00	30.3	33.5	54.36
10–16 Sept	32.24	22.71	84.14	59.43	4.8	7.4	38.95
17–23 Sept	32.21	21.49	88.14	61.57	38.3	42.0	17.42
24–30 Sept	33.80	22.50	82.43	58.14	0.0	3.2	23.55
01–07 Oct	32.46	21.01	84.29	60.86	2.1	4.7	4.48
08–14 Oct	32.61	20.01	82.43	57.71	0.0	0.0	2.86

nano-urea each @ 312 mL ha^{-1}), N5 (62.5:37.5:18.75 kg $N:P_2O_5:K_2O$ ha^{-1}) and N6 (31.25:37.5:18.75 kg $N:P_2O_5:K_2O$ ha^{-1} + 2 foliar sprays of nano-urea each @ 394 mL ha^{-1}). All fertilizers were applied as a basal dose at the time of sowing. No pre- or post-sowing irrigation was provided, as the crop was grown entirely under rainfed conditions; however, a life-saving irrigation was applied only if a prolonged dry spell occurred during the early establishment phase.

Nano-urea (liquid) used in the experiment was sourced from IFFCO (Indian Farmers Fertiliser Cooperative Limited). Foliar sprays of nano-urea were applied at 30 and 45 days after sowing (DAS) at the respective treatment-specific rates, diluted in water at a concentration of 2.5 mL L^{-1}, as per manufacturer's recommendations.

Weed management was carried out through one hand weeding at 25 DAS, followed by intercultural operations using a hand hoe at 35 DAS to ensure a weed-free environment. No major pest or disease outbreak was observed during the crop season.

The crop was harvested manually at physiological maturity, which occurred between 95 and 105 days after sowing, depending on the variety. All agronomic practices, including sowing, thinning and fertilizer application, were carried out as per the recommended package of practices for pearl millet in the region.

Results

Effect of nano urea and varieties of pearl millet on growth parameters

Plant height (cm)

Plant height varied notably among the tested varieties and nutrient treatments. The tallest plants were observed in the variety Sulkhaniya Bajra (214.96 cm), followed by Pusa Composite 383 (201.03 cm) and Pusa Composite 701 (199.46 cm) (Table 2 & Fig. 2).

Among nutrient management options, the N_6 treatment (31.25:37.5:18.75 kg $N:P_2O_5:K_2O$ ha^{-1} + 2 foliar sprays of nano-urea) resulted in the highest plant height (211.61 cm), closely followed by N_5 and N_4 treatments (Fig. 3). The shortest plants were recorded under the N_1 treatment (194.68 cm). This demonstrates that both varietal choice and enhanced nutrient application, especially when combined with nano-urea foliar sprays, contributed to increased plant height in pearl millet.

Number of tillers m^{-2}

The number of tillers per square meter showed clear differences among the varieties and nutrient treatments. Pusa Composite 701 produced the highest number of tillers (32.57/m^2), followed by Sulkhaniya Bajra (30.79/m^2) and Pusa Composite 383 (28.28/m^2)

Among the nutrient levels, the N6 treatment (31.25:37.5:18.75 kg $N:P_2O_5:K_2O$ ha^{-1} + 2 foliar sprays of nano-urea) resulted in the maximum number of tillers (33.22/m^2), while the lowest tiller count was observed under the N1 treatment (28.11/m^2). This indicates that both improved nutrient management and the use of nano-urea foliar sprays can enhance tiller production in pearl millet (Table 2).

Dry matter accumulation (g m^{-2})

Dry matter accumulation in pearl millet showed marked variation across varieties and nutrient treatments. Among the varieties, Pusa Composite 701 recorded the highest dry matter accumulation at

Table 2. Effect of varieties and nutrient levels on growth parameters of pearl millets

Treatments	At harvest			60 DAS - Harvest
	Plant height (cm)	Number of Tillers/m^2	Dry Matter Accumulation (g m^{-2})	Crop Growth Rate (g m^{-2} day^{-1})
Varieties				
V_1. Sulkhaniya Bajra	214.96	30.79	412.50	2.18
V_2. Pusa composite 701	199.46	32.57	472.06	2.44
V_3. Pusa composite 383	201.03	28.28	430.17	2.06
SEm (±)	2.72	0.68	1.87	0.10
LSD (P = 0.05)	7.86	1.97	5.39	0.30
Nutrient levels ($N:P_2O_5:K_2O$ kg ha^{-1})				
N_1 - 40:20:0	194.68	28.11	397.22	2.20
N_2 - 20:20:0 + 2 foliar spray of Nano-urea each @ 250 mL ha^{-1}	196.11	29.00	413.78	2.46
N_3 - 50:30:15	207.40	30.00	426.44	2.25
N_4 - 25:30:15+2 foliar spray of Nano-urea each @ 312 mL ha^{-1}	210.06	31.11	449.00	2.48
N_5 - 62.5:37.5:18.75	211.03	31.03	461.22	2.32
N_6 - 31.25:37.5:18.75 + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}	211.61	33.22	481.78	2.82
SEm (±)	3.85	0.96	2.64	0.15
LSD (P = 0.05)	11.12	2.78	7.63	0.42

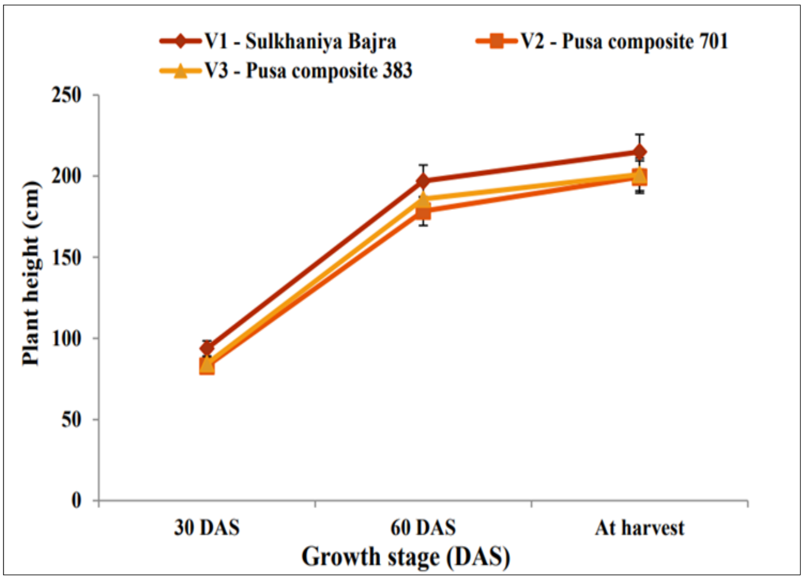

Fig. 2. Effect of pearl millet varieties on plant height.

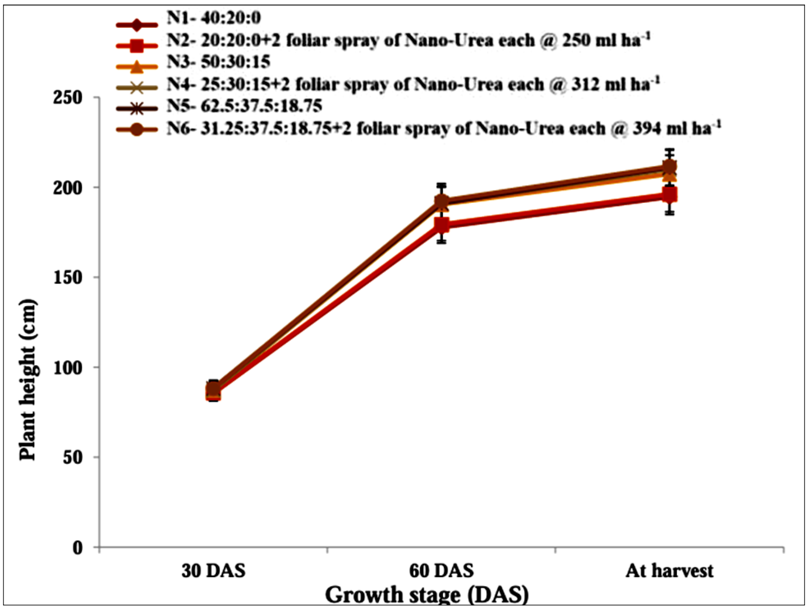

Fig. 3. Effect of nutrient levels on plant height of pearl millet.

harvest (472.06 g m^{-2}), followed by Pusa Composite 383 (430.17 g m^{-2}) and Sulkhaniya Bajra (412.50 g m^{-2}) (Table 2 & Fig. 4).

Regarding nutrient management, the N6 treatment (31.25:37.5:18.75 kg N:P_2O_5:K_2O ha^{-1} + 2 foliar sprays of nano-urea) resulted in the highest dry matter accumulation (481.78 g m^{-2}), while the lowest was observed under the N1 treatment (397.22 g m^{-2}) (Fig. 5). These results indicate that both varietal selection and enhanced nutrient application, especially with nano-urea foliar sprays, substantially increased dry matter accumulation in pearl millet under rainfed conditions.

Crop growth rate (g m^{-2} day^{-1})

Crop growth rate (CGR) in pearl millet reflects the increase in dry matter per unit area per day and is a key indicator of crop vigor and productivity. In this study, CGR varied significantly with both varieties and nutrient treatments. The highest CGR was observed in the variety Pusa Composite 701 (2.44 g m^{-2} day^{-1}), followed by Sulkhaniya Bajra (2.18 g m^{-2} day^{-1}) and Pusa Composite 383 (2.06 g m^{-2} day^{-1}) (Table 2).

Among nutrient treatments, the maximum CGR was recorded under the N6 treatment (31.25:37.5:18.75 kg N:P_2O_5:K_2O ha^{-1} + 2 foliar sprays of nano-urea) with a rate of 2.82 g m^{-2} day^{-1}, indicating enhanced biomass accumulation due to improved nutrient availability and foliar feeding. The lowest CGR was observed in the N1 treatment (40:20:0 kg N:P_2O_5:K_2O ha^{-1}) at 2.20 g m^{-2} day^{-1}. These findings demonstrate that both genetic potential and optimized nutrient management, especially with nano-urea supplementation, significantly improve the growth rate of pearl millet, contributing to better crop performance under rainfed conditions.

Effect of nano urea and varieties of pearl millet on yield attributes

Ear head m^{-2}

Among different varieties of pearl millet, Pusa composite 701 recorded significantly highest number of ear head m^{-2} (31) which was statistically at par with Sulkhaniya bajra, whereas lowest was recorded in Pusa composite 383 (27).

Among the different nutrient levels, N_6 (31.25:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}) recorded highest number of ear heads m^{-2} (33) which was statistically at par with N_5 (62.5:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1}), N_4 (25:30:15::N:P_2O_5:K_2O kg ha^{-1} +2 foliar spray of Nano-urea each @ 312 mL ha^{-1}) and N_3 (50:30:15::N:P_2O_5:K_2O kg ha^{-1}). The significantly lowest number of ear head m^{-2} were recorded in N_1

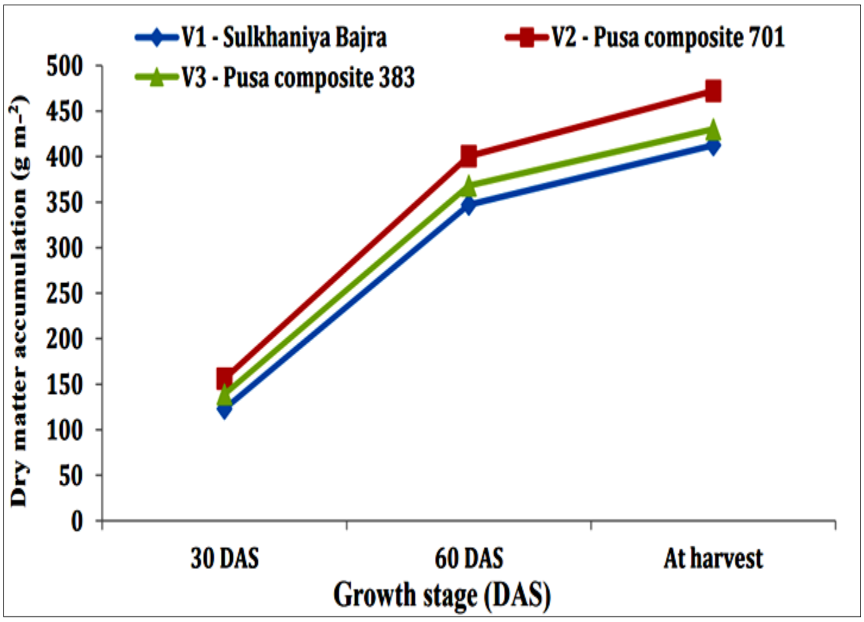

Fig. 4. Effect of varieties on dry matter accumulation (g m^{-2}) of pearl millet.

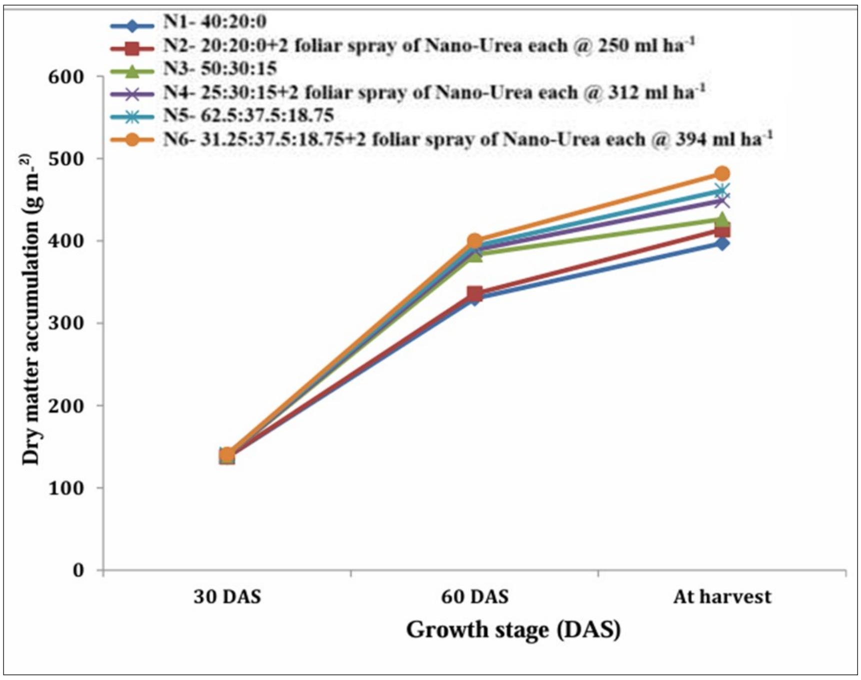

Fig. 5. Effect of nutrient levels on dry matter accumulation (g m^{-2}) of pearl millet.

Table 3. Effect of varieties and nutrient levels on yield attributes of pearl millets

Treatments	Ear head (m^{-2})	Length of ear head (cm)	Weight of grain ear head^{-1} (g)	1000 grain weight (g)
Varieties				
V_1. Sulkhaniya Bajra	29	43.70	40.11	7.18
V_2. Pusa composite 701	31	27.94	45.78	7.91
V_3. Pusa composite 383	27	30.91	40.78	5.48
SEm (±)	1	0.77	0.63	0.11
LSD (P = 0.05)	2	2.21	1.82	0.33
Nutrient Levels ($N:P_2O_5:K_2O$ kg ha^{-1})				
N_1 - 40:20:0	24	32.54	39.78	6.57
N_2 - 20:20:0 + 2 foliar spray of Nano-urea each @ 250 mL ha^{-1}	24	33.87	40.67	6.67
N_3 - 50:30:15	30	33.40	41.11	6.85
N_4 - 25:30:15+2 foliar spray of Nano-urea each @ 312 mL ha^{-1}	31	34.73	43.00	6.95
N_5 - 62.5:37.5:18.75	32	34.95	43.33	7.03
N_6 - 31.25:37.5:18.75 + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}	33	35.62	45.44	7.05
SEm (±)	1	1.08	0.89	0.16
LSD (P = 0.05)	3	NS	2.57	NS

(40:20:0::N:P_2O_5:K_2O kg ha^{-1}) and N_2 (20:20:0::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 250 mL ha^{-1}) (Table 3).

Length of ear head (cm)

Among the three varieties of pearl millet, Sulkhaniya bajra recorded significantly higher length of ear head (43.70 cm) than Pusa composite 383 (30.91 cm) and Pusa composite 701 (27.94 cm).

The different nutrient levels failed to show any significant effect on length of ear head. However, nutrient levels N_6 (31.25:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}) recorded numerically higher length of ear head (35.62 cm) (Table 3).

Weight of grains ear head^{-1} (g)

Among three varieties of pearl millet, Pusa composite 701 recorded significantly higher weight of grains ear head-1 (45.78 g) as compared to Pusa composite 383 (40.78 g) and Sulkhaniya bajra (40.11 g) both of which were statistically at par with each other.

Among the different nutrient levels, N6 (31.25:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 394 mL ha-1) recorded highest weight of grains ear head^{-1} (45.44 g) which was statistically at par with N5 (62.5:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1}) and N4 (25:30:15::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 312 mL ha^{-1}). The lowest weight of grains ear head^{-1} (39.78 g) was recorded in N1 (40:20:0::N:P_2O_5:K_2O kg ha^{-1}) which was statistically at par with N2 (20:20:0::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 250 mL ha^{-1}) (Table 3).

1000 grain weight (g)

Among the three varieties of pearl millet, Pusa composite 701 recorded significantly higher 1000 grain weight (7.91 g) than Sulkhaniya bajra (7.18 g) and Pusa composite 383 (5.48 g).

On the other hand, different nutrient levels failed to show any significant effect on 1000 grain weight (g). However, nutrient levels N_6 (31.25:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano -urea each @ 394 mL ha^{-1}) was recorded numerically highest 1000 grain weight (7.05 g) (Table 3).

Effect of nano urea and varieties of pearl millet on yield

Grain yield (kg ha^{-1})

Among different varieties of pearl millet, Pusa composite 701 recorded significantly higher grain yield (1832 kg ha^{-1}) than Pusa composite 383 and Sulkhaniya bajra. The lowest grain yield was recorded in Sulkhaniya bajra (1541 kg ha^{-1}), which was statistically at par with Pusa composite 383 (1585 kg ha^{-1}).

Among the different nutrient levels N_6 (31.25:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}) recorded highest grain yield (1802 kg ha^{-1}) and found statistically at par with N_5 (62.5:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1}), N_4 (25:30:15::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 312 mL ha^{-1}) and N_3 (50:30:15::N:P_2O_5:K_2O kg ha^{-1}). While lowest grain yield was recorded in N_1 (40:20:0::N:P_2O_5:K_2O kg ha^{-1}) (1451 kg ha^{-1}) which was statistically at par with N2 (20:20:0::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea @ 250 mL ha^{-1}) (Table 4).

Stover yield (kg ha^{-1})

Among the different varieties of pearl millet, Pusa composite 701 recorded significantly higher stover yield (5244 kg ha^{-1}) as compare to Pusa composite 383 and Sulkhaniya bajra. The lowest stover yield was recorded in 42 Sulkhaniya bajra (4685 kg ha^{-1}), which was statistically at par with Pusa composite 383 (4790 kg ha^{-1}).

Among the different nutrient levels N_6 (31.25:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}) was recorded with highest stover yield (5612 kg ha^{-1}) and found statistically at par with N_5 (62.5:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1}). The lowest stover yield was recorded in N_1 (40:20:0::N:P_2O_5:K_2O kg ha^{-1} (4050 kg ha^{-1}) which was statistically at par with N_2 (20:20:0::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 250 mL ha^{-1}) (Table 4).

Harvest index (%)

The effect of varieties and nutrient levels on harvest index of pearl millet was found significant. However, among the different nutrient levels N_1 (40:20:0::N:P_2O_5:K_2O kg ha^{-1}) recorded highest harvest index (26.38 %) which was statistically at par with N_2 (20:20:0::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 250 mL ha^{-1}). The lowest harvest index was recorded in N_6(31.25:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}) which was statistically at par with N_5 (62.5:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1}) (Table 4).

Economics

Among different varieties, Pusa composite 701 fetched higher gross return (₹69278 ha^{-1}) than Pusa composite 383 and Sulkhaniya bajra. Sulkhaniya bajra showed lowest gross return (₹59631 ha^{-1}). Among different nutrient application, N_6 (31.25:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of nano-urea each @ 394 mL ha^{-1}) showed the

Table 4. Effect of varieties and nutrient levels on yield of pearl millets

Treatments	Grains (kg ha^{-1})	Stover (kg ha^{-1})	Harvest index
Varieties			
V_1. Sulkhaniya Bajra	1541	4685	24.75
V_2. Pusa composite 701	1832	5244	25.89
V_3. Pusa composite 383	1585	4790	24.86
SEm (±)	41	110	0.33
LSD (P = 0.05)	118	317	0.95
Nutrient Levels (N:P_2O_5:K_2O kg ha^{-1})			
N_1 - 40:20:0	1451	4050	26.38
N_2 - 20:20:0 +2 foliar spray of Nano-urea each @ 250 mL ha^{-1}	1482	4190	26.13
N_3 - 50:30:15	1690	5069	25.00
N_4 - 25:30:15+2 foliar spray of Nano-urea each @ 312 mL ha^{-1}	1706	5137	24.93
N_5 - 62.5:37.5:18.75	1784	5379	24.90
N_6 - 31.25:37.5:18.75 + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}	1802	5612	24.30
SEm (±)	58	155	0.46
LSD (P = 0.05)	166	448	1.34

highest gross return (₹70407 ha^{-1}). The lowest gross return (₹54361 ha^{-1}) was fetched with N_1 (40:20:0::$N:P_2O_5:K_2O$ kg ha^{-1}).

Among the different varieties of pearl millet Pusa composite 701 recorded higher net return (₹49621 ha^{-1}) than Pusa composite 383 and Sulkhaniya bajra. The lowest net return was recorded in Sulkhaniya bajra (₹39874 ha^{-1}).

Among the different varieties of pearl millet Pusa composite 701 recorded higher net return (₹49621 ha^{-1}) than Pusa composite 383 and Sulkhaniya bajra. The lowest net return was recorded in Sulkhaniya bajra (₹39874 ha^{-1}).

Among the different nutrient levels N6 (31.25:37.5:18.75::$N:P_2O_5:K_2O$ kg ha^{-1} + 2 foliar spray of nano-urea each @ 394 mL ha-1) recorded higher net returns (₹49962 ha^{-1}) than rest of the nutrient levels. The lowest net return was recorded in N1 (40:20:0::$N:P_2O_5:K_2O$ kg ha^{-1}) (₹35638 ha^{-1}).

The highest B:C ratio (2.52) was recorded in Pusa composite 701 followed by Pusa composite 383. The lowest B:C ratio (2.01) was recorded in Sulkhaniya bajra.

Among different nutrient levels, N6 (31.25:37.5:18.75::$N:P_2O_5:K_2O$ kg ha^{-1} + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}) showed the highest B:C ratio (2.44). The lowest B:C ratio (1.90) was recorded in nutrient level N1 (40:20:0::$N:P_2O_5:K_2O$ kg ha^{-1}) (Table 5).

Discussion

Effect of partial substitution of nitrogen through Nano-urea on growth parameters of pearl millet

The growth parameters of pearl millet were significantly influenced by the varieties and levels of nutrients applied which may be attributed due to enhanced absorption or assistance in transport of plant nutrients that increases the cell division capacity and cell protein content. Combined use of conventional fertilizers with nano -based fertilizers, stimulate the root and shoot development, which eventually reflect in enhanced plant height, which was supported in the previous studies (11, 12). The data pertaining to plant height indicated that among the varieties of pearl millet, Sulkhaniya bajra exhibited the greatest plant height at 60 days post-sowing and at the time of harvest. The potential explanation for this discrepancy among the varieties may be attributed to their distinct genetic composition, which was also supported in the previous study (13). Further, similar effect on plant height was observed amongst the different nutrient levels N_6 (31.25:37.5:18.75::$N:P_2O_5:K_2O$ kg ha^{-1} + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}) gave highest plant height at 60 DAS and at harvest than fertilizer application without Nano-urea spray. Foliar application of Nano-urea resulted in the highest plant height of pearl millet.

Among the three varieties of pearl millet, Pusa composite 701 produced highest number of tillers $meter^{2}$ followed by Sulkhaniya bajra at 60 DAS and then declined towards harvest stage in all varieties (11). Among the different nutrient levels N_6 (31.25:37.5:18.75::$N:P_2O_5:K_2O$ kg ha^{-1} + 2 spray of Nano-urea each @ 394 ml ha^{-1}) produced higher number of tillers m^{-2}at 60 DAS and at harvest than the non nano-urea based treatments, which was supported by the findings in earlier studies (12, 13). It may be observed that the foliar application of Nano-NPK enhances nutrient availability to plants through the stomata of their leaves. This results in an increase in chlorophyll formation and content, a higher rate of photosynthesis and the highest dry matter accumulation. Consequently, the overall growth of the plant is improved (11, 12).

Increased dry matter production of pearl millet may be attributed due to significant improvement in growth parameters viz. plant height, number of tillers m^{-2} and leaf area index. High LAI aids in enhanced utilization of solar energy and available nutrients especially nitrogen, which is essential for higher dry matter production (13). Dry matter accumulation increased at a decreasing rate for both varieties and different nutrient levels from 60 DAS to harvest. Pusa composite 701 had the highest dry matter accumulation in this given experiment. Treatments with Nano-urea spray showed increase in dry matter accumulation. The treatment N_6 produced the highest dry matter among all treatments.

Effect of varieties and nutrient levels on yield attributes and yield

Among the three varieties, Pusa composite 701 produced highest number of ear head m^{-2} which was statistically at par with the Sulkhaniya bajra. However, highest length of ear head was found in Sulkhaniya bajra followed by the variety Pusa composite 383 and least was observed in variety Pusa composite 701.

Among the different nutrient levels N_6 (31.25:37.5:18.75::$N:P_2O_5:K_2O$ kg ha^{-1} + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}) gave highest ear head m^{-2}, length and girth of ear head, weight of grains ear^{-1} head and 1000 grain weight (g). The increase in yield attributes in treatments with Nano-urea spray may be attributed that Nano-urea promotes the overall plant growth and enhances nutrients uptake, improve photosynthesis rate and

Table 5. Economics of pearl millet as influenced by varieties and nutrient levels

Treatments	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio (₹ ha^{-1})
Varieties				
V_1. Sulkhaniya Bajra	19757	59631	39874	2.01
V_2. Pusa composite 701	19657	69278	49621	2.52
V_3. Pusa composite 383	19557	61189	41632	2.12
Nutrient levels ($N:P_2O_5:K_2O$ kg ha^{-1})				
N_1 - 40:20:0	18723	54361	35638	1.90
N_2 - 20:20:0 +2 foliar spray of Nano-urea each @ 250 mL ha^{-1}	18705	55771	37065	1.98
N_3 - 50:30:15	19801	65065	45263	2.29
N_4 - 25:30:15 + 2 foliar spray of Nano-urea each @ 312 mL ha^{-1}	19797	65782	45984	2.32
N_5 - 62.5:37.5:18.75	20469	68811	48342	2.36
N_6 - 31.25:37.5:18.75 + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}	20445	70407	49962	2.44

biological efficiency which is reflected as improved yield contributing traits (14).

Among the three varieties of pearl millet, Pusa composite 701 gave higher grain and stover yield (kg ha^{-1}) than Pusa composite 383 and least was observed in Sulkhaniya bajra. Highest harvest index was observed with variety Pusa composite 701 followed by Pusa composite 383 and least in Sulkhaniya bajra. Among the different nutrient levels N6 (31.25:37.5:18.75) N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano-urea each @ 394 mL ha^{-1}) resulted in highest grain and stover yield (kg ha^{-1}). The harvest index was found highest in nutrient levels N_1 (40:20:0::N:P_2O_5:K_2O kg ha^{-1}) and least in N_6 (31.25:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1} + 2 spray of Nano-urea each @ 394 mL ha^{-1}). From the data, it was observed that higher grain and stover yield (kg ha^{-1}) is produced in treatments with Nano-urea sprays. This might be due to sufficient amount of nitrogen Nano-urea at critical stage which would have maintained continuous supply to nitrogen, led to meristematic cell activity, stimulation to cell elongation in crops and improve photosynthesis rate. These result findings were in close agreement with the findings in earlier studies (12, 13).

Economic analysis

The economic analysis of treatments viz., varieties and nutrient levels, revealed that among the three varieties, highest gross return of ₹69278 ha^{-1}, net return of ₹49621 ha^{-1} and B:C ratio of 2.52 was observed in Pusa composite 701. Among the different nutrient levels, N_6 (31.25:37.5:18.75::N:P_2O_5:K_2O kg ha^{-1} + 2 foliar spray of Nano -urea @ 394 mL ha^{-1}) has highest gross return of ₹70407 ha^{-1}, net return ₹49962 ha^{-1} and B:C ratio 2.44 which may be attributed to higher grain and straw yields of pearl millet. Our present findings are also supported in the previous studies (14-16) who also reported that use of nano-fertilizers in combination with conventional fertilizers enhances the grain yield and straw yield, thus maximize the gross and net return.

Conclusion

Pusa Composite 701 and the N6 nutrient management strategy (including nano-urea foliar sprays) significantly enhanced growth, yield and profitability of pearl millet under rainfed conditions. Future research should explore the long-term effects of nano-urea on soil health and its performance across different environments to further optimize pearl millet production.

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Authors' contributions

RK conducted the research component of the study. MS carried out the corrections. NS contributed to the modifications. APS participated in the sequence alignment. RG assisted with the table arrangements. JSM helped in the rearrangement of the subheadings and finishing. HS assisted in organizing the subtopics. CL contributed to the search for relevant data. FF helped in analysing data. All authors read and approved the final manuscript.

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Conflict of interest: Authors do not have any conflict of interest to declare.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this word, the authors used Quillbot and Claude AI/Google collab in order to paraphrase/correct grammatical mistakes and python code generation, respectively. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the published article.

References

1. Barkha R, Nirali B, Zalawadia NM, Buha D, Rushang K. Effect of different levels of chemical and nano nitrogenous fertilizers on content and uptake of NPK by sorghum crop. J Pharmacogn Phytochem. 2021;8(5):454-8.
2. Chaudhary S, Dheri GS, Brar BS. Long-term effects of NPK fertilizers and organic manures on carbon stabilization and management index under rice-wheat cropping system. Soil Till Res. 2020;166:59-66. https://doi.org/10.1016/j.still.2016.10.005
3. Chhowalla M. Slow release nanofertilizers for bumper crops. Am Chem Soc. 2017;3:156-7. https://doi.org/10.1021/acscentsci.7b00091
4. Elemike EE, Uzoh IM, Onwudiwe DC, Babalola OO. The role of nanotechnology in the fortification of plant nutrients and improvement of crop production. Appl Sci. 2019;9(3):499. https://doi.org/10.3390/app9030499
5. Jassim RA, Kadhem HN, Nooni GB. Impact of levels and time of foliar application of nano fertilizer (super micro plus) on some components of growth and yield of rice (*Oryza sativa*). Plant Arch. 2019;19(1):1279-83.
6. Kumar Y, Tiwari KN, Singh TNK, Laxmi S, Verma R, Sharma GC, Raliya R. Nanofertilizers for enhancing nutrient use efficiency, crop productivity and economic returns in winter season crops of Rajasthan. Ann Plant Soil Res. 2020;22(4):324-35. https://doi.org/10.47815/apsr.2020.10001
7. Mandeh M, Mansoor O, Mahdi R. *In vitro* influences of TiO_2 nanoparticles on barley (*Hordeum vulgare* L.) tissue culture. Biol Trace Elem Res. 2022;150:376-80. https://doi.org/10.1007/s12011-012-9480-z
8. Marchiol L. Nanofertilisers: An outlook of crop nutrition in the fourth agricultural revolution. Ital J Agron. 2023;14(3):183-90. https://doi.org/10.4081/ija.2019.1367
9. Panda P, Maitra S, Panda SK, Shankar T, Adhikary R, Saira M, Gaikwad DJ. Influence of nutrient levels on productivity and nutrient uptake by finger millet (*Eleusine coracana* L.) varieties. Crop Res. 2020;56:128-34. https://doi.org/10.31830/2454-1761.2021.021
10. Rathnayaka RMNN, Mahendran S, Iqbal YB, Rifnas LM. Influence of urea and nano-nitrogen fertilizers on the growth and yield of rice (*Oryza sativa* L.). Int J Res Publ. 2019;5(2):7.
11. Shang Y, Hasan MK, Ahammed GJ, Li M, Yin H, Zhou J. Applications of nanotechnology in plant growth and crop protection. Ital J Agron. 2021;24(14):2558. https://doi.org/10.3390/molecules24142558
12. Song CZ, Liu MY, Meng JF, Chi M, Xi ZM, Zhang ZW. Promoting effect of foliage sprayed zinc sulfate on accumulation of sugar and phenolics in berries of *Vitis vinifera*. Soil Till Res. 2022;20(2):2536-54. https://doi.org/10.3390/molecules20022536

13. Suriyaprabha R, Karunakaran G, Yuvakkumar R, Prabu P, Rajendran VN. Growth and physiological responses of maize (*Zea mays* L.) to porous silica nanoparticles in soil. J Nanopart Res. 2023;14:1294. https://doi.org/10.1007/s11051-012-1294-6
14. Tripathi M, Kumar S, Kumar A, Tripathi P, Kumar S. Agronanotechnology: A future technology for sustainable agriculture. Int J Curr Microbiol Appl Sci. 2023;7:196-200.
15. Wu J. Electrocatalytic activity of nitrogen-doped graphene synthesized via a one-pot hydrothermal process towards oxygen reduction reaction. J Power Sources. 2022;227:185-90. https://doi.org/10.1016/j.jpowsour.2012.11.074

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