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Influence of Nano DAP on Nutrient Uptake and Yield of Maize in the Mid Hills of the Western Himalayas

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Abstract

A field experiment was conducted during *kharif* 2023 to evaluate the effect of different levels of nano diammonium phosphate (nano DAP) and soil-applied NPK fertilisers on maize yield and nutrient uptake at CSK HPKV, Palampur, Himachal Pradesh (India). The experiment consisted of eight treatments, replicated thrice. Results revealed that application of 100% recommended NPK with FYM recorded the highest grain and stover yield (62.95 and 94.89 q ha^{-1}) and maximum uptake of N, P and K in grains (89.05, 24.55 and 25.56 kg ha^{-1}). Also, 75 % conventional NP fertilisers supplemented with three nano DAP sprays produced comparable grain and stover yield (61.23 and 92.69 q ha^{-1}) and nutrient uptake, indicating the potential to save 25% of conventional NP fertilisers without a yield penalty and economic returns. Further, grain yield showed strong positive associations with N, P and K uptake, confirming nutrient acquisition as the key determinant of productivity.

Keywords: Maize, Nano DAP, NP fertilisers, Productivity, Uptake, FYM

Maize (*Zea mays* L.) is one of the most important cereal crops following wheat and rice globally. In India, maize is grown over an area of 12.02 million hectares (Mha) with production of 42.2 million tonnes (Mt) and productivity of 3.51 tonnes ha^{-1} (t ha^{-1})[1]. The annual production of maize during 2023-24 in Himachal Pradesh is 0.75 Mt[1]. However, sustaining long term productivity of maize in the hill regions poses several challenges, particularly with the acidic nature of soil and erosion-prone lands with high rainfall intensity. These soils are characterised by clay deposition, low nutrient availability, low pH, cation leaching and high phosphorus fixation[2,3]. In addition to this, Indian agriculture is facing a wide spectrum of challenges like crop yield stagnation, declining organic matter, multi-nutrient deficiencies, low use efficiency of fertilisers, shrinking of arable land and water availability[4,5]. Simultaneously, to feed the rapidly growing population amid climate change, it is essential to enhance the productivity of the maize while ensuring long-term environmental sustainability.

Crop production relies heavily on adequate nutrient availability, particularly nitrogen (N) and phosphorus (P) during the growing period, which are essential for plant growth, metabolic functioning and yield formation[6]. Nitrogen is the major constituent of chlorophyll, proteins and nucleic acids[7] and thus plays a significant role in the overall development of the crop[8]. Phosphorus is an essential component of adenosine triphosphate (ATP)[6], promotes root growth,

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seed development, flower formation and provides resistance to diseases[9].

Conventional synthetic fertilisers, though widely used to enhance the yield, often result in soil deterioration and inefficient nutrient delivery[9]. Nitrogen fertilisers often undergo substantial losses through volatilisation, leaching and denitrification, resulting in nearly 60–70 % of the applied nitrogen being lost from the soil system[11], while phosphorus fertilisers face rapid fixation, particularly in acidic soils, making only 15-20 % available to plants[12]. These practices escalate production costs and also contribute to environmental challenges like nutrient toxicity, nitrate leaching, eutrophication of water bodies, greenhouse gas emissions and long-term decline in soil quality[6,13]. Hence, it is high time to catch alternative technologies that can ensure high nutrient use efficiency and sustain yield with minimum negative effects on soil health.

In recent years, nano-fertilizers are an emerging class of inputs in modern agriculture that are designed to improve nutrient use efficiency, minimise losses and support sustainable crop production and profitability. Owing to their nanoscale size (1–100 nm) and large surface area, they provide targeted nutrient delivery and enhance plant uptake, leading to higher crop productivity[14,15]. Researchers have documented that nano-fertilisers can enhance nutrient use efficiency by 20-25 % and yield by 7-10 % as compared to traditional fertilizers[16,17]. Nano fertilisers can sustain crop yield and support multiple Sustainable Development Goals (SDGs), mainly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action) and SDG 15 (Life on Land).

Nano DAP, a novel nano-fertiliser introduced by Indian Farmers Fertiliser Cooperative Limited (IFFCO) in 2023, delivers both nitrogen and phosphorus in nanoscale form that offers a promising solution in improving overall plant health and minimising losses. It contains 8% nitrogen and 16% phosphorus by weight in its nano form. Because of its nanoparticles, which boost nutrient absorption and produce healthier plants with higher yield potential. Despite the recognised benefits, there is limited scientific information available regarding the comparative performance of nano DAP versus conventional fertilisers and optimisation of the application dosages for nano DAP. Hence, the present investigation was undertaken to study the effect of nano-DAP (as foliar application) on the nutrient uptake and yield of maize under mid-hill conditions of the western Himalayas.

MATERIALS AND METHODS

A field trial was conducted during *kharif* 2023 at the Research Farm of the Department of Soil Science, Chaudhary Sarwan Kumar Krishi Vishvavidyalaya, Palampur, Himachal Pradesh (India). The experimental farm is located at 32˚6' N latitude and 76˚33' E longitude at an altitude of about 1290 meters above mean sea level (amsl). The study site falls under the Mid Hills Sub-Humid Zone. The rainfall received during the crop growth period was 2219 mm, whereas the average minimum and maximum temperatures were 13.7 and 27.8 °C, respectively.

A field experiment was laid out in a complete randomised block design (RBD), including 8 treatments, *viz.* T_1: Control, T_2: $N_{100}P_{100}K_{100}$, T_3: $N_{75}P_{75}K_{100}$ + one spray of Nano DAP, T_4: $N_{50}P_{50}K_{100}$ + one spray of Nano DAP, T_5: $N_{75}P_{75}K_{100}$ + two sprays of Nano DAP, T_6: $N_{50}P_{50}K_{100}$ + two sprays of Nano DAP, T_7: $N_{75}P_{75}$ K_{100} + three sprays of Nano DAP and T_8: $N_{50}P_{50}K_{100}$+ three sprays of Nano DAP, replicated thrice. One spray of Nano DAP was applied at 30 days after sowing (DAS), two sprays at 30 and 60 DAS and three sprays at 20, 40 and 60 DAS. Farmyard manure (FYM) was incorporated into the soil (10 t ha^{-1}) for treatments T_2 to T_8 on a dry weight basis and thoroughly mixed in the soil before sowing. Maize (variety- K-25 Gold) was sown in the third week of June in a plot size of 15 m^2 with a spacing of 60 × 20 cm. The recommended dose of N, P and K for the crop was 120, 60 and 40 kg ha^{-1}, respectively. The nutrients were supplied through urea, Single Super Phosphate (SSP) and Muriate of Potash (MOP) for all treatments except T_1 (control). Half doses of N and a full dose of P and K were applied at the time of sowing of maize in treatments T_2-T_8. Half of the remaining nitrogen was top-dressed in two equal splits at knee high and pre-tasseling stage.

The grain and stover yields were recorded after the harvest of maize. The grain yield of maize was

calculated at 15.5 per cent moisture content, whereas the stover yield of maize was recorded on air dry basis. The data so obtained was calculated on a hectare basis. The grain and stover samples were ground and digested to measure the content of N using the micro-Kjeldahl method[18], P by the vanadomolybdo-phosphoric acid method[17] and K by the flame photometer[19]. The nutrient uptake was calculated by multiplying the percentage concentration of a particular nutrient by the grain and stover yield.

All expenses involved in each input and operation were aggregated to calculate the cost of cultivation. The cost of cultivation for each treatment was calculated separately. The requirements of labour for various operations were estimated based on the university-approved rates and expressed in ₹ ha^{-1}. Gross returns were calculated by converting the yields of grain and stover into monetary terms in rupees, achieved by multiplying the per-hectare yields of grain and stover under various treatments with the prevailing selling prices of grain and stover, based on prevalent market or university rates and expressed as ₹ ha^{-1}. Net returns were calculated by deducting the cost of cultivation of each treatment from the gross yield and expressed in ₹ ha^{-1}.

Net returns (₹ ha^{-1}) = Gross returns (₹ ha^{-1}) - Cost of cultivation (₹ ha^{-1})

B: C was determined by dividing net returns (₹ ha^{-1}) by the cost of cultivation (₹ ha^{-1}).

Statistical analysis was performed on the data recorded in the lab and field. The data were interpreted using the randomised block design analysis of variance approach. Using R-studio 4.4.2, The Fischer's Least Significant Difference test (DMRT) was performed to determine the grouping of means at 95% probability.

RESULTS AND DISCUSSION

The results revealed that grain and stover yield of maize varied significantly among different levels of nano Diammonium Phosphate (DAP) sprays and soil-based application of Nitrogen, Phosphorus and Potassium (NPK) fertilisers. The highest grain yield, i.e. 62.95 q ha^{-1}, was recorded in plots receiving 100% NPK + FYM (T_2), registering an increase of 169.7 per cent over control (Figure 1). Similarly, T_2 produced the highest stover yield (94.89 q ha^{-1}). This might be attributed to the positive effect of recommended NPK doses along with FYM on the soil's available nutrient pool, physical and biological properties of soil, enhancing nutrient uptake by roots[8,20,21]. Among the nano DAP treatments, $N_{75}P_{75}K_{100}$ + three sprays of nano DAP (T_7) recorded 61.23 and 92.69 q ha^{-1} grain and stover yield, being statistically at par with T_2. The positive response of 75

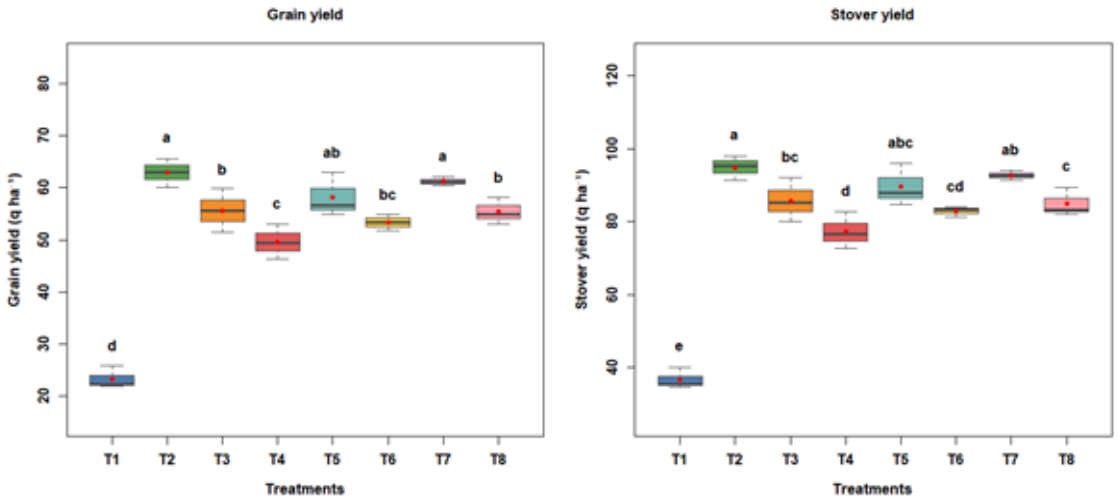


Figure 1. Influence of different levels of nano DAP and NPK fertilisers on grain and stover yield (q ha^{-1}) of maize.

% RDF of NP with three nano DAP sprays might be due to direct foliar nutrient supplementation, which enhances nutrient availability[21], photosynthesis and translocation of starch/sugars to the sink[17]. Owing to nano-sized particles and a slow-release mechanism that facilitated absorption through leaf tissues, thereby reducing nutrient losses through leaching and emissions and promoting their gradual incorporation into the soil–plant system[12,23,24]. In contrast, when soil-applied NP was reduced to 50% of the recommended dose (T_4, T_6 and T_8), nano DAP sprays were less effective, resulting in 12.0 to 21.2 per cent and 11.77 to 22.7 per cent lower grain and stover yield compared with T_2, respectively. This may be due to inadequate soil nutrient supply during early growth stages[10,25], as foliar nano DAP mainly supplements nutrients in later stages and cannot replace soil-applied fertilisers required for early biomass and root development[26].

(The red dots represent the mean value for each treatment group, and the horizontal black line inside the box represents the median, while the letters above the box plots denote statistical grouping based on a post-hoc multiple comparison test (DMRT) performed at the 5% level of significance ($p \leq 0.05$))

Application of 100 % NPK along with FYM (T_2) resulted in the maximum N uptake by grains (89.05 kg ha^{-1}) (Figure 2), which was 261.7 % higher than the control, 75 % NP of the RDF with nano DAP sprays (T_3, T_5 and T_7) resulted in grain N uptake ranging from 71.77 to 85.17 kg ha^{-1}. By contrast, plots receiving 50 % NP with nano DAP sprays (T_4, T_6 and T_8) recorded up to 35.8 per cent significant decrease in comparison to T_2. Similarly, stover N uptake ranged from 12.45 (T_1) to 60.03 (T_2) kg ha^{-1} (Figure 3). The highest stover N uptake among nano DAP treatments was observed in T_7 (56.51 kg ha^{-1}).

Further, application of 100 % NPK along with FYM (T_2) resulted in 377 and 522 per cent higher phosphorus (P) uptake than the control, respectively. Phosphorus uptake by grain and stover under 75 % NP of the recommended dose with nano DAP levels (T_3, T_5 and T_7) ranged from 15.14 to 22.87 kg ha^{-1} and 4.24 to 6.92 kg ha^{-1}, respectively.

The significant upsurge in N and P uptake under 100 % NPK application with FYM confirms the critical role of soil-applied N and P in enhancing root proliferation, nutrient absorption and translocation to sinks[3]. Also, FYM contributed to improved soil porosity, enhanced microbial activity that sustained nitrogen and phosphorus mineralisation throughout the growing season[27]. Plots receiving 75 % RDF of NP supplemented with three nano DAP sprays recorded

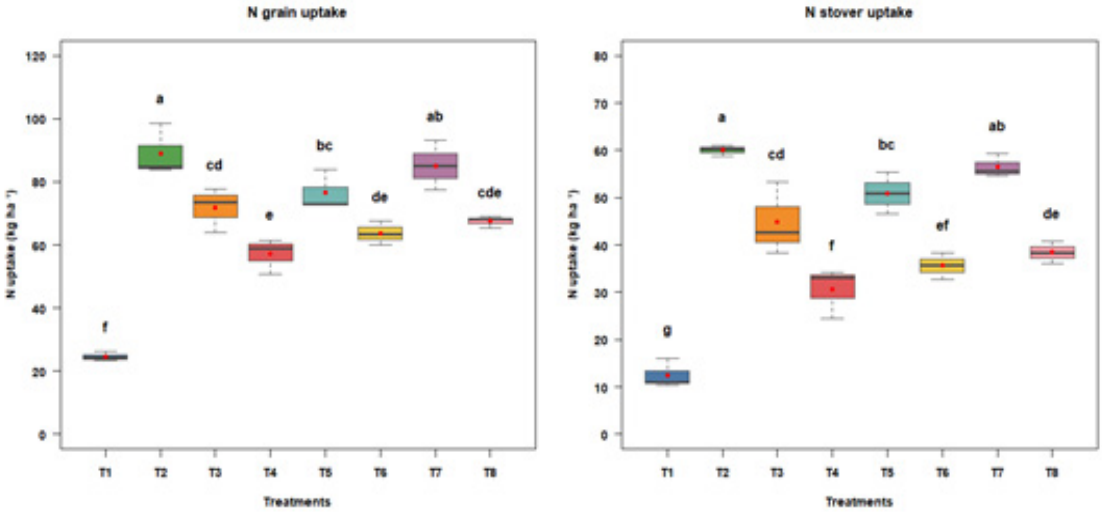


Figure 2. Influence of different levels of nano DAP and NPK fertilisers on nitrogen (N) uptake (kg ha^{-1}) of maize.

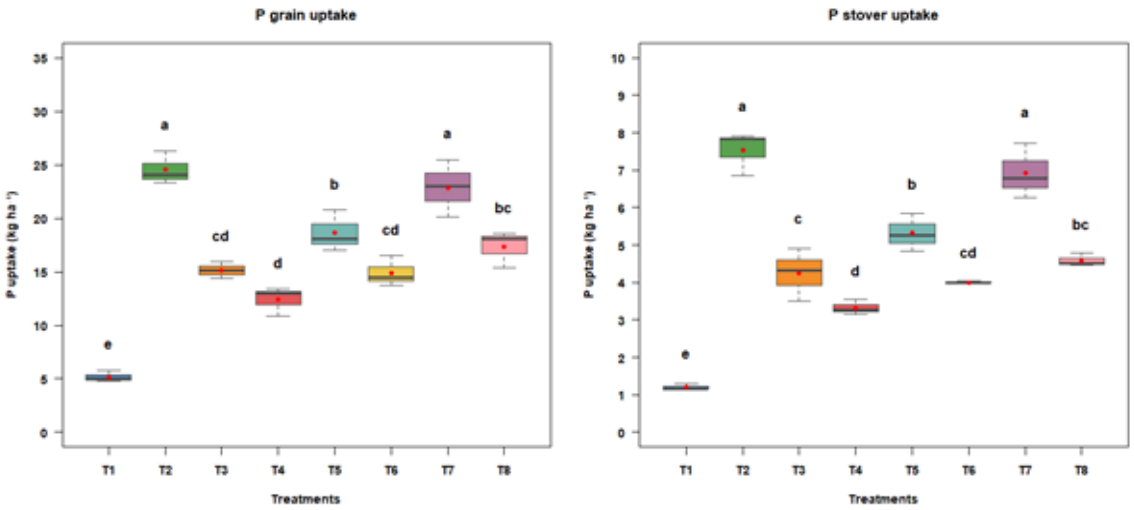


Figure 3. Influence of different levels of nano DAP and NPK fertilisers on phosphorus (P) uptake (kg ha^{-1}) of maize.

N and P uptake levels comparable to full NPK fertilisation. The combined use of conventional and nano DAP improved N and P availability, enhancing photosynthesis and translocation, which increased plant uptake[17]. Further, foliar application of nano DAP covers a larger surface area and particles smaller than the pores of plant leaves, can penetrate into the plant more deeply and improve nutrient uptake[23]. Adequate soil applied NP supply ensured early root development and canopy establishment, enabling the crop to efficiently utilise both soil and foliar applied nutrients[13,26].

The highest potassium uptake by grain and stover was recorded under 100 % NPK with FYM (T_2), respectively (Figure 4). This might be attributed to

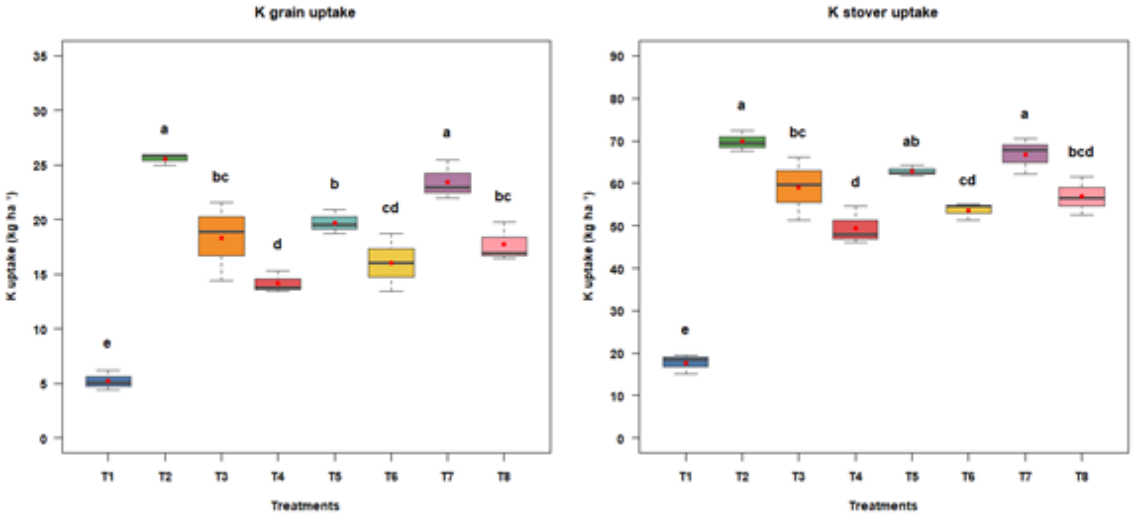


Figure 4. Influence of different levels of nano DAP and NPK fertilisers on potassium (K) uptake (kg ha^{-1}) of maize.

optimal soil nutrient availability, promoting maximum K absorption and translocation[28]. The contribution of FYM likely improved soil structure, cation exchange capacity and moisture retention, creating favourable conditions for K availability and uptake[27]. Plots receiving 75% NP recommended dose supplemented with three nano DAP sprays (T_7) recorded K uptake values comparable with full NPK fertilisation (T_2). This suggested that improved N and P nutrition through foliar DAP indirectly enhanced the K uptake by sustaining vigorous vegetative growth and higher transpirational demand, thereby facilitating greater potassium absorption from the soil[29]. Furthermore, 50% NP treatments reported comparatively lower nutrient uptake, even with three nano DAP sprays. This can be ascribed to reduced soil N and P supply that restricted root growth, leaf area expansion and sink development[11], thereby reducing the plant's physiological capacity to absorb and redistribute nutrients later in the growth cycle.

Economics

The cost of cultivation (Table 1) varied from ₹34,800 under T_1 (control) to ₹57,144 under T_7 ($N_{75}P_{75}K_{100}$ + three sprays of nano DAP). The highest gross return (₹174,803), net return (₹124,234) and BC ratio (2.46) were recorded under T_2 ($N_{100}P_{100}K_{100}$). Among the nano DAP treatments, T_7 ($N_{75}P_{75}K_{100}$ + three sprays of Nano DAP) resulted in comparatively higher net returns and BC ratio (1.98). The lowest economic returns and BC ratio (0.87) were observed under T_1 due to the absence of fertiliser and nano DAP application.

Relationship Between Nutrient Uptake and Yield

Correlation results revealed that the maize yield was closely associated with nutrient uptake by both grain and stover (Figure 5). Grain yield was strongly associated with stover yield ($r = 0.99$), indicating that higher biomass production directly contributed to increased grain yield. Grain yield showed a strong positive relationship with nitrogen uptake in grain ($r \approx 0.98$) and stover ($r \approx 0.93$), suggesting that enhanced nitrogen acquisition and translocation played a major role in yield improvement[27]. Phosphorus uptake by grain ($r \approx 0.92$) and stover ($r \approx 0.89$) was also positively

Table 1. Influence of different levels of nano DAP and NPK fertilisers on the economics of maize

Treatments	Cost of Cultivation (₹ ha^{-1})	Gross Return (₹ ha^{-1})	Net Return (₹ ha^{-1})	B:C
T_1: Absolute control	34800	65184	30384	0.87
T_2: $N_{100}P_{100}K_{100}$	50569	174803	124234	2.46
T_3: $N_{75}P_{75}K_{100}$ + one spray of Nano DAP	52344	154981	102637	1.96
T_4: $N_{50}P_{50}K_{100}$ + one spray of Nano DAP	50918	138351	87433	1.72
T_5: $N_{75}P_{75}K_{100}$ + two sprays of Nano DAP	54744	162094	107350	1.96
T_6: $N_{50}P_{50}K_{100}$ + two sprays of Nano DAP	53318	148787	95469	1.79
T_7: $N_{75}P_{75}K_{100}$ + three sprays of Nano DAP	57144	170125	112981	1.98
T_8: $N_{50}P_{50}K_{100}$+ three sprays of Nano DAP	55718	154207	98489	1.77

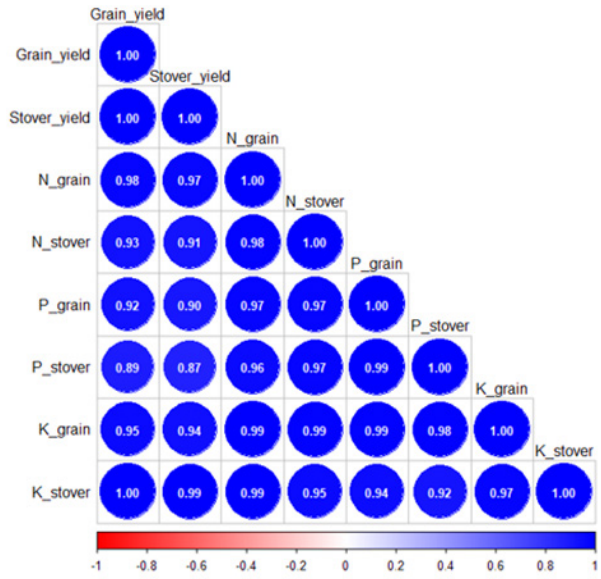


Figure 5. Pearson correlation analysis of grain, stover yield and N, P and K uptake in maize.

Where,

N_grain= N grain uptake, P_grain= P grain uptake, K_grain= K grain uptake N_stover = N stover uptake, P_stover = Pstover uptake, K_stover = Kstover uptake

correlated with grain yield, reflecting the importance of phosphorus in grain development. Potassium uptake, particularly in stover (r ≈ 0.99), exhibited a strong association with grain yield, indicating that potassium mediated vegetative growth and assimilate transport indirectly enhanced productivity[29]. It is evident from the results that yield improvement was closely linked with increased uptake of N, P and K by grain and stover.

CONCLUSION

It can be concluded from the above study that maize productivity and nutrient uptake were significantly influenced by varying levels of fertilisers and nano DAP. Application of the recommended NPK with FYM (@ 10 t ha^{-1}) produced the highest grain and stover yield and maximum N, P, and K uptake. The study also showed that soil-applied N and P can be reduced by 25% when supplemented with three foliar sprays of nano DAP and FYM without significant yield losses. Economically, 100% NPK (T_2) recorded the highest BC ratio, while 75% NP + 100% K with three nano DAP sprays (T_7) also gave higher returns among reduced fertiliser treatments. Furthermore, adoption of nano DAP in combination with reduced conventional fertilisers can improve nutrient use efficiency, lower input costs for farmers and contribute to environmental protection by reducing nutrient losses and potential groundwater contamination. In addition, partial replacement of conventional fertilisers with nano DAP could help to reduce the growing fertiliser subsidy burden and dependence on imported fertilisers. Future research should focus on long-term effects of nano DAP on soil health, the environmental fate of nanoparticles, optimisation of application schedules for different agro-ecological conditions, and support evidence-based agricultural policies and sustainable fertiliser management strategies.

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CONFLICT OF INTEREST

The authors hereby declare that there is no conflict of interest among the authors.

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AUTHORS CONTRIBUTION

P: conducted the experiment, data curation and wrote the original manuscript. RPS and NKS: conceptualize the research programme, methodology, provided resources and edited the manuscript. SM: conceptualize the, methodology and edited the manuscript. SM: Analyzed the data, figures and manuscript review.