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Nutrient stoichiometry and growth characteristics of wheat (*Triticum aestivum* L.) grown with various combinations of nitrogenous and phosphatic fertilizers under alkaline conditions

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Abstract

Inadequate and imbalanced use of plant nutrients might be the major contributing factor towards low productivity of wheat (*Tritium aestivum* L.) in Pakistan. A field study was planned under alkaline conditions to evaluate the effect of various combinations of nitrogenous (N) and phosphatic (P) fertilizers on growth and yield characteristics of wheat. Experimental plan comprised of seven treatments including T_1: control, T_2: NP + CAN, T_3: NP + urea, T_4: NP plus + CAN, T_5: NP plus + urea, T_6: DAP + CAN and T_7: DAP + urea with three replications. Plant growth and yield parameters of wheat in terms of plant height, number of tillers plant^{-1}, number of spikes plant^{-1}, spike length and grain yield were significantly ($p \leq 0.05$) affected by different combinations of N and P fertilizers. Among different fertilizer combinations, NP + CAN showed highest potential for improving wheat growth, yield and nutrients contents in shoots and grains. The said set of treatments improved number of tillers plant^{-1} by 123.8%, number of spikes plant^{-1} by 110.7%, spike length by 119.5%, and grain yield by 139.5% compared to control. Nutrient concentrations in plant tissues was also significantly ($p \leq 0.05$) affected at different growth stages by fertilizer combinations, with maximum increase by NP + CAN. At tillering stage, NP + CAN increased total shoot N by 171.4%, NH_4^+-N by 148.9%, NO_3^--N by 153.5%, shoot P by 101%, and shoot K by 40.14% compared to control. In grains, total N increased by 75.14%, NH_4^+-N by 67.98%, NO_3^--N by 206.9%, P by 86.28%, and K by 24.13% with NP + CAN compared to control. NP + CAN fertilizer combination also increased total N by 53.57%, mineral N by 64.83%, NH_4^+-N by 46.60%, NO_3^--N by 100%, and P by 137.8% in soil compared to control. Among different N and P fertilizers combinations, wheat crop was most responsive to NP + CAN, suggesting that said fertilizers combination could be a promising option for improving wheat productivity under alkaline conditions.

Keywords: CAN; growth stages; grain yield; NH_4+-N; NO_3-N; NP; phosphorous; wheat

Introduction

Wheat (*Tritium aestivum* L.) is the 2nd most important cereal crop after maize. Globally, it is grown on an area of 240 million hectares with total production of 760 million tons. It provides about 20% of the total proteins and dietary calories to human being, worldwide (Zhang *et al*., 2021). It is expected to increase the world population to about 9.8 billion by the year 2050 which demands an increase of at least 50% in wheat yield as compared to the current level (FAO, 2017). Furthermore, rising living standard of people demands more healthy food. Although, wheat production has been increased from 440 million tons in 1980 to 771 million tons in 2017 (FAO, 2020) but not enough to meet need of ever-increasing population. Consequently, extensive efforts need to be made to improve the wheat growth and yield (Shiferaw *et al*., 2013).

Pakistan is ranked at 7th position in wheat production, worldwide (FAO, 2021). It is cultivated on more than 9 million hectares of land in Pakistan with a production of 25.24 million tons in the year 2020 (Economic Survey of Pakistan, 2022). In Pakistan, wheat is the major staple food

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in terms of both area and production. It accounts for more than 37% of total cropped area, 65% of grains cropped area, and 70% of agricultural production (Iqbal *et al*., 2021).The share of wheat in value added agriculture is 8.9% while in GDP is 1.6% (Economic Survey of Pakistan, 2019). Annual wheat consumption in Pakistan is highest over the world, 124 kg per capita (Economic Survey of Pakistan, 2022). However, the average yield of wheat in Pakistan is significantly lower as compared to world average which might be attributed to a number of factors, inadequate and imbalance use of plant nutrients is considered most important among these (Battese *et al*., 2017).

Continuous cultivation of exhaustive crops causes the deficiency of various essential nutrients, particularly nitrogen (N), phosphorous (P) and potassium (K) because of high requirement by plants, and inadequate and imbalanced replenishment (Epstein and Bloom, 2005; Ashraf *et al*. 2011). Rajicic *et al*. (2019) reported that nutrient deficiency may adversely affect various metabolic processes in plants, leading to a reduction of more than 50% in crop productivity. Several studies have demonstrated the role of plant nutrients in the growth and development of wheat (Hawkesford, 2012; Das *et al*., 2017; Ghafoor *et al*., 2021;). Školníková *et al*. (2022) reported that intensive cultivation depleted the soil in essential nutrients, and necessitated the use of appropriate level and source of plant nutrients to get optimum yield with minimum risk of environmental pollution.

Among plant nutrients, N and P are considered most critical to affect plant growth and yield (Jing-xiu *et al*., 2021). Wen *et al*. (2016) reported that N and P interaction not only affect the plant growth and yield characteristics but also the assimilation of each other and other nutrients as well. Nitrogen plays a vital role in growth processes as it is an integral part of chlorophyll, protein and nucleic acid, and comprising almost 1-5% of plant biomass on dry weight basis (Vidal *et al*., 2010; Hodge, 2011). In combination with other elements, it plays an essential role in improving the growth, yield and quality of produced grains (Popovic *et al*., 2017). Plants uptake N in the form of ammonium (NH_4^+) and/or nitrate (NO_3^-). However, a fertilizer which contains both NH_4^+-N and NO_3^--N might be more beneficial for improving plant growth and yield as compared to sole application of NH_4^+-N or NO_3^--N (Ashraf *et al*., 2018; Akanova *et al*., 2021).

Phosphorous is second most growth limiting nutrient in plants, and about 30% of global crop area has P deficiency (MacDonald *et al*., 2011; Alewell *et al*., 2020;). Pakistani soils being alkaline calcareous in nature are more prone to P deficiency stress (Ashraf *et al*., 2009). Plants uptake P in the form of primary orthophosphate ($H_2PO_4^-$) or secondary orthophosphate (HPO_4^{2-}), depending upon the soil conditions (Penn and Camberato, 2019). Being the structural component of numerous biomolecules, it can affect plant growth and development by participating in energy production and storage, photosynthesis, nucleic acid, phospholipids and respiration process (Mubeen *et al*., 2021). Deficiency of P resulted in short internodes, stunted plant growth and poor development of roots, which subsequently affects the uptake and assimilation of other nutrients, leading to poor growth and development (Mumtaz *et al*., 2014). Agricultural soils usually contain sufficiently high concentration of total P, 85-90% of which is precipitated and immobilized with iron (Fe), aluminum (Al) under acidic conditions while with calcium (Ca) under alkaline conditions (van der Bom *et al*., 2019). In arid or semi-arid climates, where pH being alkaline favors the precipitation of phosphate with Ca, decreasing its availability to plants (Fan *et al*., 2021). It emphasizes the use of appropriate source and level of P as well as proper combination of P with N fertilizers to improve not only the fertilizer use efficiency but also the crop growth and yield (Noonari *et al*., 2016; Ikram *et al*., 2019; Fan *et al*., 2022).

Various combinations of N and P fertilizers can greatly affect nutrient dynamics in soil, availability to plants, and subsequently plant growth and yield depending on many plant and soil factors (Wen *et al*., 2016). The most widely used combination of N and P fertilizers in Pakistan is DAP + urea (Economic Survey of Pakistan, 2022). However, said combination of N and P fertilizers cannot be efficient for all types of soils, crops and climates. According to Wang *et al*. (2020), inadequate combination of N and P not only reduced the crop yield but also increased nutrient losses, leading to low fertilizer use efficiency. Kabato *et al*. (2022) also reported that fertilizer use efficiency may vary greatly depending upon fertilizer source, level and combination as well as the nature of soil. The current field study was conducted to evaluate the efficiency of various N and P combinations to affect nutrient availability in soil and productivity of wheat under alkaline conditions.

Materials and Methods

Pre-sowing soil characterization

An experiment was conducted in the field having GPS values of latitude 30º16’27″ N, longitude 71º29’57″ E and altitude 129 m to evaluate the efficiency of different combinations of N and P fertilizers for improving growth, yield and nutrient concentration in the shoots and grains of wheat (*Triticum aestivum* L.) grown under alkaline conditions. Pre-sowing soil analyses for selected physico-chemical properties were done using standard procedures and presented in Table 1.

Growth conditions and treatments

Table 1: Pre-sowing analysis of experimental soil

Soil characteristic	Reference	Value	
		0-15 cm	16-30 cm
Soil texture	Gee and Bauder (1986)	Loam	Loam
Electrical conductivity	Bigham (1996)	0.81 dS m^{-1}	0.54 dS m^{-1}
Sodium adsorption ratio	Bigham (1996)	1.30 (mmol $L^{-1})^{1/2}$	1.28 (mmol $L^{-1})^{1/2}$
pH	Bigham (1996)	8.25	8.34
Organic matter	Nelson and Sommers (1982)	0.92%	0.78%
Saturation percentage	Wilcox (1951)	29.45%	25.88%
Total nitrogen	Buresh et al. (1982)	0.052%	0.047%
Available phosphorus	Olsen and Sommers (1982)	3.57 mg kg^{-1}	2.79 mg kg^{-1}
Extractable potassium	Thomas (1982)	112 mg kg^{-1}	92 mg kg^{-1}

Table 2: Growth and yield characteristics of wheat (*Triticum aestivum* L.) grown with various combinations of N and P fertilizers under alkaline conditions

Treatment	Plant height (cm)	Number of tillers $plant^{-1}$	Number of spikes $plant^{-1}$	Spike length (cm)	Grain yield (kg ha^{-1})
Control	76.40b	4.78e	5.01c	15.10e	2455b
NP + CAN	106.6a	10.70a	10.56a	26.56a	5881a
NP + Urea	101.1a	7.67de	6.89c	20.46bc	5127b
NP Plus + CAN	102.9a	8.56cd	8.22bc	17.72cde	5244ab
NP Plus + Urea	106.5a	9.67abc	9.00ab	18.91bcd	4919ab
DAP + CAN	104.3a	10.22ab	9.89ab	16.23de	5236ab
DAP + Urea	109.0a	9.00abc	8.33abc	21.28b	5029ab

Similar alphabets showed non-significant difference among treatment means at $p \leq 0.05$, ns= non-significant, NP = nitrophos, NP plus = nitrophos plus, CAN = calcium ammonium nitrate, DAP = diammonium phosphate

Table 3: Shoot total N concentration at different growth stages in wheat (*Triticum aestivum* L.) grown with different combinations of N and P fertilizers under alkaline conditions

Treatments	Total N (mg g^{-1} DW)			NH_4^+-N (mg g^{-1} DW)			NO_3^--N (mg g^{-1} DW)		
	Tillering	Flowering	Maturity	Tillering	Flowering	Maturity	Tillering	Flowering	Maturity
Control	6.20c	30.20d	16.37b	4.07b	20.03c	11.37b	2.13c	10.17c	5.00c
NP + CAN	16.83a	47.74a	25.73a	10.13a	32.05a	12.80a	5.40a	14.69a	7.80a
NP + Urea	14.80ab	43.16c	22.70ab	9.40a	29.84b	11.87ab	4.37ab	12.32ab	6.46bc
NP Plus + CAN	14.13ab	43.31c	23.00ab	9.23a	30.21ab	12.37a	3.73b	12.10b	5.81c
NP Plus + Urea	12.53b	43.72bc	23.93a	9.20a	30.23ab	11.93ab	3.00bc	12.49ab	7.00ab
DAP + CAN	13.53b	46.39ab	25.27a	9.43a	30.75ab	12.03ab	4.03ab	14.64a	6.78abc
DAP + Urea	13.47b	45.76abc	25.40a	9.60a	30.73ab	12.00ab	3.17bc	14.03ab	6.82abc

For seedbed preparation, field was ploughed thrice with cultivator and then planked at field capacity moisture level. Experimental plan comprised of seven treatments i.e., T_1: Control (No N and P), T_2: Nitrophos + Calcium ammonium nitrate (NP + CAN), T_3: Nitrophos + Urea (NP + urea), T_4: Nitrophos plus + Calcium ammonium nitrate (NP plus + CAN), T_5: Nitrophos plus + Urea (NP plus + urea), T_6: Diammonium phosphate + Urea (DAP + urea), T_7: Diammonium phosphate + Calcium ammonium nitrate (DAP + CAN). Each treatment was replicated thrice. N was applied at 150 kg ha^{-1}, P at 100 kg P_2O_5 ha^{-1} and K at 60 kg K_2O ha^{-1}. Potassium sulfate was used as K source, while different sources of N and P as mentioned in treatment plan were used. Whole P and K were applied at the time of sowing while N in three equal splits (at sowing, 30 and 60 days after sowing). NP is a granulated fertilizer having 22% N and 20% P. In addition to this, NP being a highly acidic product with a pH of 3.5, is the most suitable fertilizer for soils that have a high pH. NP plus contains 18% N and 18% P. CAN contains 26% N, 10% Ca, 0.4% sulfur and 0.05% Mg. DAP contains 46% P and 18% N, while urea contains 46% N. There were 21 plots, and each plot was 2 m × 12 m in size. Wheat cultivar Inqilab-91 was used in the experiment. Seed sowing was done at 125 kg ha^{-1} using manual seed drill. Weeding was done manually after 1st irrigation. Total 6 irrigations were made at crown root initiation, tillering stage, jointing stage, flowering stage, milking stage and dough stage.

Growth and yield characteristics

The growth and yield characteristics of wheat in terms of plant height, number of tillers $plant^{-1}$, number of spikes $plant^{-1}$, and spike length were recorded at maturity, while grain yield ha^{-1} was recorded after harvesting and threshing the crop.

Plant nutrients concentration

Plant shoot samples were collected at different growth stages i.e. tillering, flowering and maturity. Plant samples were washed with distilled water, air dried and then oven dried at 70ºC in an oven (SLN 32, POL-EKO-APARATURA). The plant samples were ground, and digested by taking 0.1 g sample and 10 mL of di-acid mixture of nitric acid and perchloric acid in the ratio of 2:1 using hotplate (Labotec EcoPlate) in accordance to the method described by Miller (1998). P was determined by Vanado-molybdate colorimetric method (AOAC, 1975) using spectrophotometer (Beckman Coulter DU 730) at 470 nm wavelength. Shoot K was determined using flamephotometer (FP 902 PG Instruments). Total N in plant tissues was determined by the method described by Kjeldahl (1983), NO_3--N by Burrell and Phillips (1925), and NH_4+-N by Crooke and Simpson (1971) using Kjeldhal Distillation System (Behrotest S3, Ink Gel, Germany). After harvesting and threshing, wheat grains were analyzed for total N, NO_3--N, NH_4+-N, P and K by standard procedures as described for shoot analysis.

Post-harvest soil analysis

Post-harvest soil analysis was done for N by Nelson and Sommers (1972), NO_3^- and NH_4^+-N by Bremner and Keeney (1965) while plant available P by Olsen *et al.* (1954).

Statistical analysis

Experiment was arranged in randomized complete block design (RCBD). Statistical analysis of treatment was performed by ANOVA techniques on Statistics 8.1©. Statistical difference among various treatment means were analyzed by using Fisher's least significance difference test (Steel *et al*., 1997).

Results

Plant growth and yield characteristics

Plant growth and yield characteristics of wheat in terms of plant height, number of tillers $plant^{-1}$, number of spikes $plant^{-1}$, spike length and grain yield were significantly ($p \leq 0.05$) affected by various combinations of N and P fertilizers under alkaline conditions (Table 2). Minimum plant height of 76.40 cm was found in control treatment, while maximum value of 109.0 in DAP + urea fertilized plants. On an average, there was an increase of 39.52% with NP + CAN, 32.32% NP + urea, 34.68% with NP plus + CAN, 38.82% with NP plus + urea, 36.51% with DAP + CAN and 42.67% with DAP + urea as compared to control. Maximum average number of tillers $plant^{-1}$ were observed as 10.70 with NP + CAN fertilization, followed by 10.22 in case of DAP + CAN fertilized plants. Overall, number of tillers $plant^{-1}$ were improved by 123.8% with NP + CAN, 60.46% with NP + urea, 79.08% with NP plus + CAN, 102.3% with NP plus + urea, 113.8% with DAP + CAN and 88.28% with DAP + urea fertilization as compared to control. Number of spikes $plant^{-1}$ were improved by 110.7% with NP + CAN, 37.52% with NP + urea, 64.07% with NP plus + CAN, 79.64% with NP plus + urea, 97.40% with DAP + CAN and 66.26% with DAP + urea fertilization as compared to control. Wheat plants fertilized with NP + CAN produced the spikes with maximum length of 26.56 cm. Overall, there was an increase of 119.5% in spike length with the application of NP + CAN, 69.09% with NP + urea, 46.46% with NP plus + CAN, 56.28% NP plus + urea, 34.13% with DAP + CAN and 75.86% with DAP + urea fertilization as compared to control. Grain yield was improved by 139.5% with NP + CAN, 108.8% with NP + urea, 113.6% with NP plus + CAN, 100.3% with NP plus + urea, 113.2% with DAP + CAN and 104.8% with DAP + urea fertilizer combination as compared to control.

Plant nutrients analysis

Shoot N concentration

Shoot N concentration in the form of total N, NO_3^--N, NH_4^+-N at different growth stages were significantly ($p \leq 0.05$) affected by different combinations of N and P fertilizers (Table 3). At tillering stage, total N was improved by 171.4% with NP + CAN, 138.7% with NP + urea, 127.9% with NP plus + CAN, 102.0% with NP plus + urea, 118.2% with DAP + CAN, and 117.2% with DAP + urea as compared to control. At flowering stage, total N improved by 58.07% with NP + CAN, 42.91% with NP + urea, 43.41% with NP plus + CAN, 44.76% with NP plus + urea, 53.61% DAP + CAN and

51.52% with DAP + urea as compared to control. At maturity stage, total shoot N improved by 57.17% with NP + CAN, 38.66% with NP + urea, 40.50% with NP plus + CAN, 46.18% with NP plus + urea, 54.36% DAP + CAN and 55.16% with DAP + urea as compared to control.

Shoot NH_4^+-N was higher in plants at flowering stage followed by that at maturity and tillering stages, respectively (Table 3). At tillering stage, minimum plant NH_4^+-N was observed as 4.07 mg g^{-1} in control treatment which was improved by 148.9% with NP + CAN, 130.9% with NP + urea, 126.8% with NP plus + CAN, 126.0% with NP plus + urea, 131.7% with DAP + CAN, and 135.8% with DAP + urea as compared to control. At flowering stage, NH_4^+-N was improved by 60.0% with NP + CAN, 48.97% with NP + urea, 50.82% with NP plus + CAN, 50.92% with NP plus + urea, 53.52% DAP + CAN and 53.41% with DAP + urea as compared to control. At flowering stage, NH_4^+-N was improved by 12.57% with NP + CAN, 4.397% with NP + urea, 8.795% with NP plus + CAN, 4.925% with NP plus + urea, 5.804% with DAP + CAN and 5.540% with DAP + urea as compared to control.

Shoot NO_3^--N was markedly improved with the application of different combinations of N and P, with highest improvement in case of NP + CAN. For growth stages, maximum improvement was found at tillering stage (Table 3). At tillering stage, minimum NO_3^--N concentration was observed as 2.13 mg g^{-1} in control treatment which was improved by 153.5% with NP + CAN, 105.1% with NP + urea, 75.11% with NP plus + CAN, 40.84% with NP plus + urea, 89.20% with DAP + CAN, and 48.82% with DAP + urea as compared to control. At flowering stage, NO_3^--N was improved by 44.44% with NP + CAN, 21.14% with NP + urea, 18.97% with NP plus + CAN, 22.81% with NP plus + urea, 43.95% with DAP + CAN and 37.95% with DAP + urea as compared to control. At maturity stage, NO_3^--N was improved by 56.0% with NP + CAN, 29.20% with NP + urea, 16.20% with NP plus + CAN, 40.0% with NP + urea, 35.60%

Table 4: Plant P concentration at different growth stages in wheat (*Triticum aestivum* L.) grown with different combinations of N and P fertilizers under alkaline conditions

Treatment	Shoot P concentration (mg g^{-1} DW)		
	Tillering	Flowering	Maturity
Control	0.99c	2.55c	1.68d
NP + CAN	1.99a	5.90a	3.49a
NP + Urea	1.44b	5.19b	2.83b
NP Plus + CAN	1.16bc	5.29b	2.27c
NP Plus + Urea	1.11bc	5.35b	2.00cd
DAP + CAN	1.88a	5.52b	2.94b
DAP + Urea	1.94a	5.38b	3.21ab

Similar alphabets showed non-significant difference among treatment means at $p \leq 0.05$, ns= non-significant, NP = nitrophos, NP plus = nitrophos plus, CAN = calcium ammonium nitrate, DAP = diammonium phosphate.

Table 5: Shoot K concentration (mg g^{-1} DW) at different growth stages in wheat (*Triticum aestivum* L.) grown with different combinations of N and P fertilizers under alkaline conditions

Treatment	Tillering stage	Flowering stage	Maturity stage
Control	19.53±0.6c	17.45±0.4c	13.38±0.4b
NP + CAN	27.37±0.8a	23.22±0.7a	17.76±0.4a
NP + Urea	25.17±0.7ab	21.25±0.7ab	17.08±1a
NP Plus + CAN	25.93±0.7ab	21.93±0.7ab	16.95±0.4a
NP Plus + Urea	24.67±3b	20.83±3b	16.82±2a
DAP + CAN	24.93±1.9b	21.04±1.7b	16.40±1a
DAP + Urea	26.13±1.1ab	22.10±1ab	17.06±0.6a

Similar alphabets showed non-significant difference among treatment means at $p \leq 0.05$, ns= non-significant, NP = nitrophos, NP plus = nitrophos plus, CAN = calcium ammonium nitrate, DAP = diammonium phosphate.

with DAP + CAN and 36.40% with DAP + urea as compared to control treatment.

Shoot P concentration

Shoot P concentration at different growth stages of wheat grown with various combinations of N and P fertilizers greatly differed; highest increase with NP + CAN, and at flowering stage (Table 4). At tillering stage, minimum shoot P concentration was found as 0.99 mg g^{-1} in control treatment which was improved by 101.0% with NP + CAN, 45.45% with NP + urea, 17.17% with NP plus + CAN, 12.12% with NP plus + urea, 89.90% with DAP + CAN, and 95.96% with DAP + urea as compared to control. At flowering stage, shoot P increased by 131.37% with NP + CAN, 103.52% with NP + urea, 107.45% with NP plus + CAN, 109.80% with NP plus + urea, 116.40% with DAP + CAN, and 110.98% with DAP + urea as compared to control. At maturity stage, shoot P concentration was increased by 107.7% with NP + CAN, 68.45% with NP + urea, 35.12% with NP plus + CAN, 19.04% with NP plus + urea, 75.0% with DAP + CAN, and 91.07% with DAP + urea as compared to control.

Shoot K concentration

Shoot K concentration was markedly affected by different combinations of N and P, with highest increase in case of NP + CAN, and at tillering stage (Table 5). At tillering stage, minimum K concentration was found as 19.53 mg g^{-1} in control treatment, which was improved by 40.14% with NP + CAN, 28.87% with NP + urea, 32.77% with NP plus + CAN, 26.32% with NP plus + urea, 27.65% with DAP + CAN, and 33.79% with DAP + urea as compared to control. At flowering stage, K increased by 33.06% with NP + CAN, 21.77% with NP + urea, 25.67% with NP plus + CAN, 19.36% with NP plus + urea, 20.57% with DAP + CAN, and 26.64% with DAP + urea as compared to control. At maturity stage, shoot K concentration increased by 32.73% with NP + CAN, 27.65% with NP + urea, 26.68% with NP plus + CAN, 25.71% with NP plus + urea, 22.57% with DAP + CAN, and 27.50% with DAP + urea as compared to control. It was

Table 6: Grain nutrient concentrations (mg g^{-1} DW) and forms in wheat (*Triticum aestivum* L.) grown with different combinations of N and P fertilizers under alkaline conditions

Treatment	Total N	NH_4^+-N	NO_3^--N	P	K
Control	15.93ab	9.90b	2.73c	2.26f	15.58b
NP + CAN	27.90a	16.63a	8.38a	4.21a	19.34a
NP + Urea	25.50ab	14.33a	7.17ab	3.49c	19.71a
NP Plus + CAN	25.13ab	13.93a	5.80b	3.16d	18.83a
NP Plus + Urea	23.30b	16.17a	6.13ab	2.88de	17.95ab
DAP + CAN	23.70b	16.90a	6.13ab	3.71e	18.38a
DAP + Urea	24.20ab	16.37a	6.20ab	4.04ab	17.90ab

Similar alphabets showed non-significant difference among treatment means at $P \leq 0.05$, ns= non-significant, NP = nitrophos, NP plus = nitrophos plus, CAN = calcium ammonium nitrate, DAP = diammonium phosphate.

Table 7: Nutrient concentrations in soil after harvesting wheat (*Triticum aestivum* L.) grown with different combinations of N and P fertilizers under alkaline conditions

Treatment	Total N (%)	Mineral N (mg kg^{-1})	NO_3^--N (mg kg^{-1})	NH_4^+-N (mg kg^{-1})	P (mg kg^{-1})
Control	0.056de	18.00c	8.00c	5.00a	3.62e
NP + CAN	0.086a	29.67a	16.00ab	8.33a	8.61a
NP + Urea	0.066cd	22.33bc	12.67b	5.67a	7.20c
NP Plus + CAN	0.070c	23.00abc	14.33ab	6.36a	4.39d
NP Plus + Urea	0.074bc	23.33abc	13.67ab	5.62a	7.64bc
DAP + CAN	0.077b	25.33ab	17.00a	7.33a	8.04b
DAP + Urea	0.063cd	21.33bc	14.67ab	6.67a	7.41bc

Similar alphabets showed non-significant difference among treatment means at $P \leq 0.05$, ns = non-significant, NP = nitrophos, NP plus = nitrophos plus, CAN = calcium ammonium nitrate, DAP = diammonium phosphate.

observed that K was higher in plants during tillering stage regardless of treatments.

Grain nutrients concentration

Grain N concentration in term of total N, NH_4^+-N and NO_3^--N was significantly (*p*≤ *0.05*) affected by different combinations of N and P fertilizers under alkaline conditions (Table 6). Minimum value of total-N concentration i.e. 15.93 mg g^{-1} was observed in control treatment, which was improved by 75.14% with NP + CAN, 60.07% with NP + urea, 57.75% with NP plus + CAN, 46.26% with NP plus + urea, 48.77% with DAP + CAN, and 51.91% with DAP + urea as compared to control. NH_4^+-N was increased by 67.98% with NP + CAN, 44.74% with NP + urea, 40.70% with NP plus + CAN, 63.33% with NP plus + urea, 70.70% with DAP + CAN, and 65.35% with DAP + urea as compared to control. Grain NO_3^--N was improved by 206.9% with NP + CAN, 162.6% with NP + urea, 112.4% with NP plus + CAN, 124.5% with NP plus + urea, 124.5% with DAP + CAN, and 127.1% with DAP + urea as compared to control. It was observed that NH_4^+-N contents were higher than NO_3^--N contents in wheat grains regardless of experimental treatments.

Grain P concentration was significantly (*p*≤ *0.05*) affected by different combinations of N and P fertilizers (Table 6). It was found that grain P concentration was increased by 86.28% with NP + CAN, 54.42% with NP + urea, 39.82% with NP plus + CAN, 27.43% with NP plus + urea, 64.16% with DAP + CAN, and 78.76% with DAP + urea as compared to control. Grain K concentration was increased by 24.13% with NP + CAN, 26.50% with NP + urea, 20.86% with NP plus + CAN, 15.21% with NP plus + urea, 17.97% with DAP + CAN, and 14.89% with DAP + urea fertilization as compared to control (Table 6).

Post-harvest soil N and P

Soil N in terms of total N, mineral N, NH_4^+-N and NO_3^--N was significantly (*p*≤ *0.05*) affected by different combinations of N and P fertilizers (Table 7). Total N concentration in soil was improved by 53.57% with NP + CAN, 17.85% with NP + urea, 25.0% with NP plus + CAN, 32.14% with NP plus + urea, 37.50% with DAP + CAN, and 12.50% with DAP + urea fertilization as compared to control. Minimum mineral N concentration of 18.0 mg kg^{-1} was recorded in control treatment, while maximum value of 29.67 mg kg^{-1} in NP + CAN fertilized plots. Mineral N concentration was improved by 64.83% with NP + CAN, 24.05% with NP + urea, 27.77% with NP plus + CAN, 29.61% with NP plus + urea, 40.72% with DAP + CAN, and 18.50% with DAP + urea fertilization as compared to control. NH_4^+-N concentration in soil was increased by 46.60% with NP + CAN, 13.40% with NP + urea, 27.20% with NP plus + CAN, 12.40% with NP plus + urea, 46.60% with DAP + CAN and 33.40% with DAP + urea fertilized plots as compared to control. NO_3^--N concentration in soil was increased by 100.0% with NP + CAN, 58.37% with NP + urea, 79.12% with NP plus + CAN, 70.87% with NP plus + urea, 112.5% with DAP + CAN, and 83.37% with DAP + urea as compared to control. It was observed that NO_3^--N concentration was higher in soil than NH_4^+-N concentration.

Application of various combinations of N and P fertilizers significantly (*p*≤ 0.05) increased the P concentration in soil after wheat harvesting grown under alkaline conditions (Table 7). Results revealed that minimum soil P concentration was found as 3.62 mg kg^{-1} in control treatment plots, whereas maximum concentration of 8.61 mg kg^{-1} was recorded in NP + CAN fertilized soil. Soil P concentration was increased by 137.8% with NP + CAN, 98.89% with NP + urea, 21.27% with NP plus + CAN, 111.0% with NP plus + urea, 122.1% with DAP + CAN, and 104.7% with DAP + urea fertilization as compared to control treatment soil.

Discussion

N and P are the most required plant nutrients in agriculture due to their widespread deficiency, particularly in alkaline calcareous soils (Jing-xiu *et al*., 2021). Therefore, application of N and P is necessary to replenish the nutrients supply in soil for fulfilling the demand of plants, and sustaining the crop yield (Abid *et al*., 2020). N and P fertilizers have varying use efficiencies depending on the nature of soil, type of fertilizer, method and time of application, and fertilizer combinations (Mukhtar *et al*., 2011). The role of N and P in plant growth has been reflected by an increase in plant height, number of tillers, spikes number and length, and consequently the grain yield of wheat. Increase in plant growth and yield by various combinations of N and P fertilizers was attributed to the role of these plant nutrients in protein synthesis, cell division, cell elongation, photosynthesis and other growth processes (Rawal *et al*., 2022; Fan *et al*. 2019; Wen *et al*., 2016; Khursheed and Mahammad, 2015). Better efficiency of NP + CAN combination to improve the plant growth and yield was due to the low pH of NP and presence of both NH_4^+-N and NO_3^--N in CAN. Furthermore, Ca in CAN could improve soil properties, making the growth medium more favorable for plant growth and development (Jamal and Fawad, 2019). NP being highly acidic in reaction (pH 3.5), proved most appropriate phosphatic fertilizer for alkaline soils, causing highest increase in wheat growth and yield (Ali *et al*., 2012).

Likewise, superiority of CAN over urea for improving wheat growth was attributed to the combined presence of NH_4^+-N and NO_3^--N which made CAN a special product with neutral pH (Akanova *et al*., 2021).

Differential accumulation of N, P and K in plant shoots and grains of wheat under different combinations of N and P fertilizers was associated with the varying potential of these fertilizer combinations to control the supply of N and P in soil. Highest accumulation of plant nutrients in case of NP + CAN combination was related to the higher availability of N from CAN due to the presence of both NH_4^+-N and NO_3^--N, release of Ca and sulfur (S) from CAN, and acidic reaction of NP fertilizer. The presence of readily available NO_3^--N and reserved N obtained after the conversion from NH_4^+-N into NO_3^- in CAN was found optimal for making targeted nutrition of wheat crop. NO_3^--N became available immediately after application, dissolved in water, and absorbed directly by the plants (Ren *et al*. 2021). Furthermore, CAN being hygroscopic in nature required less moisture for absorption by plants. It is more effective under arid and semiarid conditions like in Pakistan. Furthermore, Ca and S present in CAN made it effective to improve soil properties which, in turn, enhanced nutrients accumulation by plants (Akanova *et al*., 2021).

The concentration of N and P in soil was differently improved with different fertilizer combinations probably due to their varying utilization efficiencies, and effect on physico-chemical properties of soil. Better efficiency of NP + CAN to cause highest increase in N and P concentration in soil was attributed to increased N availability in soil due to the presence of both NH_4^+-N and NO_3^--N in CAN and acidic reaction of NP. Fosu-Mensah and Mensah (2016) reported that N and P fertilizers significantly improved the concentration of N and P in soil. Wang *et al*. (2015) also reported an increase in concentration of total N, NO_3^--N and NH_4^+-N in the soil with application of fertilizers. Akanova *et al*. (2021) reported that CAN contained both NH_4^+-N and NO_3^--N whereas urea has amide-N which hydrolyzed to NH_4^+-N, and then nitrified to NO_3^--N. Due to this reason, CAN was found to be more efficient to enhance N concentration in soil. Acidic reaction of NP made it most efficient for improving P solubilization and availability in soil under alkaline conditions (Ali *et al*. 2012).

Conclusions

Plant growth and yield characteristics of wheat in terms of plant height, number of tillers plant^{-1}, number of spikes plant^{-1}, spike length and grain yield as well as nutrients stoichiometry were significantly ($p \leq 0.05$) affected by various N and P fertilizer combinations under alkaline conditions. Fertilizer combination of NP + CAN showed superiority over others to improve nutrient concentrations in wheat shoots and grains as well as growth and yield attributes. NP + CAN combination also caused highest increase in soil N and P. Combined presence of NH_4^+-N and NO_3^--N, and Ca in CAN while acidic reaction of NP was principally responsible for highest efficiency of NP + CAN for improving wheat productivity under alkaline conditions.

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