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Wheat Productivity and Uptake of Primary Nutrients under Long-term Application of Fertilizers and Amendments in an Acid *Alfisol*

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Abstract

The effect of fertilizers and amendments on wheat yield and NPK uptake was studied during *rabi* 2022-23 in an ongoing long-term fertilizer experiment initiated in 1972 at Palampur, Himachal Pradesh. Continuous application of fertilizers and amendments significantly influenced yield and uptake. The application of 100 per cent NPK + FYM outperformed the other treatments, yielding the highest grain (27.8 q ha^{-1}), straw production (42.4 q ha^{-1}) and nutrient (N, P and K) uptake. Conversely, treatments omitting K or S demonstrated a significant decrease in yield and uptake. Notably, the inclusion of FYM or lime, along with NPK significantly enhanced nutrients uptake compared to NPK alone. However, the continuous application of nitrogenous fertilizer for 51 years without the addition of farmyard manure or lime resulted in zero crop yield and therefore, no uptake of nutrients. The study highlights the significance of incorporating organics and amendments for sustainable soil and crop management.

Keywords: *Alfiso*l, Amendments, Fertilizers, Nutrient Uptake, Wheat, Yield

Monitoring soil fertility and ensuring balanced fertilization are essential to attain sustainable crop output to meet out food grain demand of India's expanding populace of more than one billion (Das *et al.* 2022). Among cereal crops, wheat (*Triticum aestivum* L.) is the second most important crop after rice in a global scenario owing to its wider adaptability and high nutritive value. In India, wheat occupies approximately 29.58 million hectares, with a total production of 99.70 million tons (Sharma *et al.* 2021). In Himachal Pradesh, it is cultivated on 0.319 million hectares, producing 0.609 million tons, with a productivity of 1.91 metric tons per hectare, respectively (Anonymous 2023). However, in the current era of its declining yield due to various factors such as declining soil fertility from imbalanced use of fertilizers, improper tillage practices, delayed planting, water scarcity, weed infestation *etc.*, there is an urgent need to increase the crop production (Lodhi *et al.* 2024).

Integrated Nutrient Management (INM) aims to maximize crop yield by taking advantage of all available resources and providing plant nutrition according to crop trends and farming settings. The combined application of organic and inorganic fertilizers in INM is known to enhance yield and production while preserving the soil fertility, as the combination not only increases the fertilizers effectiveness but also decrease the dependency on single nutrient source

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(Sharma *et al.* 2018; Yang *et al.* 2020). Moreover, numerous studies have indicated the importance of combined application of inorganic and organic fertilizer application resulting in more stable wheat yield than organic or NPK fertilizer application alone and especially the manure application has increased the wheat and maize yields more than inorganic fertilizers through improvement in the soil environment (Thakur *et al.* 2023). In acidic soils, plant growth is primarily restricted by high levels of exchangeable Al, Fe, and Mn and deficiencies of P, Ca, Mo, and other elements (Rajneesh *et al.* 2018). Therefore, liming is considered a useful technique for reducing soil acidity, increasing availability of nutrients thereby enhancing crop yields (Sharma & Sharma 2016).

Furthermore, long term studies on use of chemical fertilizers and amendments conducted elsewhere have offered significant insights into the nutrients effect on crop productivity and the soil environment, as well as changes in crop productivity over a period of time for the assessment of agricultural sustainability (Schlegel & Havlin 2017). Therefore, the present study was undertaken to understand the effect of long-term fertilization on wheat production and primary nutrients acquisition.

MATERIALS AND METHODS

A long-term field experiment was started in 1972 in an acid *Alfisol* at the experimental farm of the Department of Soil Science, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur to study the effect of various fertilizers and amendments combinations on maize-wheat cropping system. The present investigation was carried out during *rabi* 2022-23 with a wheat crop variety HPW-368 in a fixed layout of plot size of 15 m^2 (5.0 m × 3.0 m). Eleven treatments were arranged in a randomized complete block design and replicated thrice. The treatments were 50% NPK + FYM, 100% NPK, 150% NPK, 100% NPK + hand weeding (HW), 100% NPK + Zn, 100% NP, 100% N, 100% NPK + FYM, 100% NPK (-S), 100% NPK + lime, and control. N, P, and K were applied through urea, single super phosphate (SSP) and Muriate of Potash (MOP), and Di-ammonium Phosphate (DAP) was applied as a source of P in the treatment 100% NPK (-S) to evaluate the effect of sulfur-free treatment. The fertilizer dose in the treatment 100% NPK was 120:60:30 kg N: P_2O_5: K_2O per hectare as per the state-level nutrient recommendation. The phosphorus in optimal (100%) and super optimal (150%) doses of P were reduced to half due to the P build-up in soil, and the FYM application at the rate of 5 t ha^{-1} in the treatment 50% NPK + FYM was started in June 2011. The half dose of urea and full doses of SSP were applied at the time of sowing, and the remaining urea was top-dressed in two equal splits at knee-high and the maximum tillering and flowering stages of wheat. In 100% NPK + Zn treated plots, $ZnSO_4$was applied at the rate of 25 kg ha^{-1} every year up to the *rabi*, 2010-11. Lime ($CaCO_3$) at the rate of 900 kg ha^{-1} in the 100% NPK + lime treatment was applied when soil pH dropped to 6.3.

The crop was sown on November 21, 2022, and harvested on May 16, 2023. The plots were ploughed to a depth of 15 cm, and irrigation was applied at the crown root initiation, tillering, late jointing, flowering, and dough stages. Hand hoeing was done 45 days after sowing. For weed control, a post-emergence herbicide, Vesta (Clodinafop Propargyl 15% + Metsulfuron Methyl 1% WP), was applied at 442.5 g ha^{-1} in all treatments except the 100 per cent NPK + HW treatment, where the weeds were removed manually and incorporated in the same plots.

After the harvest of crop, data on grain and straw yield were recorded. The grain and straw samples of wheat were dried in an oven at 60° C. The dried grain samples were then ground in a mixer grinder, passed through a 1 mm sieve and were stored in air-tight plastic bags. The straw samples were ground in a Wiley mill fitted with stainless steel parts and were then kept in paper bags for subsequent analysis. The grain and straw samples of wheat were digested in conc. H_2SO_4, followed by distillation following the micro-Kjeldahl method (Jackson 1973) for determination of N content. Wheat grain and straw samples were also digested in the di-acid mixture (HNO_3: $HClO_4$ in 9:4 ratio) and the aqueous extract was used to determine P content using the vanado molybdo-phosphoric acid method (Jackson 1973) and K content by flame photometer method (Black 1965). The nutrient uptake was

calculated by multiplying the per cent concentration of a particular nutrient with grain and straw yield. The uptake of the nutrients obtained in respect of grain and straw yield was summed up to compute the total amount of nutrients removed by the crop. The results were subjected to statistical analysis using Web Agri Stat Package 2.0, and their mean differences were analyzed using Duncan Multiple Range Test at P≤0.05.

RESULTS AND DISCUSSION

The yield of wheat grain and straw varied significantly among different treatments (Figure 1). Continuous application of only nitrogenous fertilizer *i.e.*, 100 per cent N alone through urea (T_7) led to zero productivity due to soil acidification, toxic levels of Al and Fe ions, and deteriorated soil health (Rajneesh *et al.* 2018). The highest wheat grain and straw yields (27.78 and 42.44 q ha^{-1}, respectively) were observed with the application of 100 per cent NPK + FYM (T_8), as FYM application improved soil characteristics, plant growth and nutrient uptake (Chauhan *et al.* 2018). Notably, treatment comprising 100 per cent NPK + lime (T_{10}) recorded yields that were statistically at par with the 100% NPK + FYM (T_8). However, the unfertilized plot (T_{11}) recorded the lowest wheat grain and straw yield of 3.22 and 5.44 q ha^{-1}, respectively, which could be accredited to the intrinsic nutrient-depleted status of the soils because of continuous cultivation and nutrient mining by the crops over the years. Relative to the 100% NPK treatment, the continuous exclusion of S in 100% NPK (-S) (T_9) and K 100% NP (T_6) from the fertilization schedule decreased grain production significantly, since both the nutrients play an important role in plant development and metabolism. Furthermore, the wheat straw yield followed a similar treatment-wise trend as in grain yield and varied from 5.43 q ha^{-1} in control (T_{11}) to 42.43 q ha^{-1}with the 100 per cent NPK + FYM treatment (T_8).

The grain N uptake significantly varied from 4.59 kg ha^{-1} in the control (T_{11}) to 47.42 kg ha^{-1} with the application of 100 per cent NPK + FYM (T_8), and the straw N uptake varied from 2.06 kg ha^{-1} in the unfertilized treatment (T_{11}) to 26.36 kg ha^{-1} in the treatment with 100 per cent NPK + FYM (T_8) (Figure 2). The addition of FYM or lime in the treatments (T_8) and (T_{10}) over the years in combination with an optimal dose of NPK increased the total nitrogen uptake by the wheat crop significantly over the rest of the treatments.

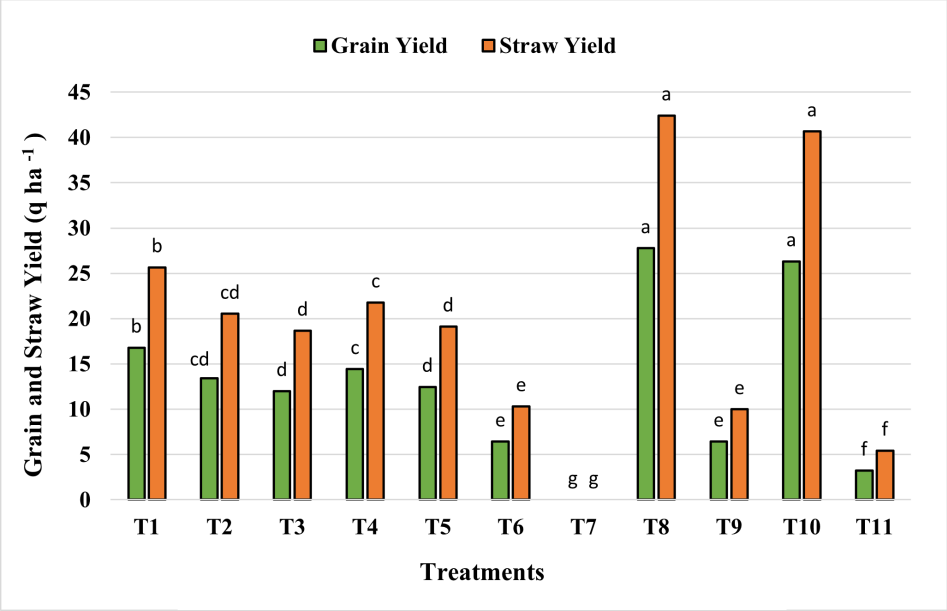


Figure 1. Effect of applications of fertilizers and amendments for five decades on grain and straw yield of wheat (Bars with different letters are significantly different at P ≤ 0.05)

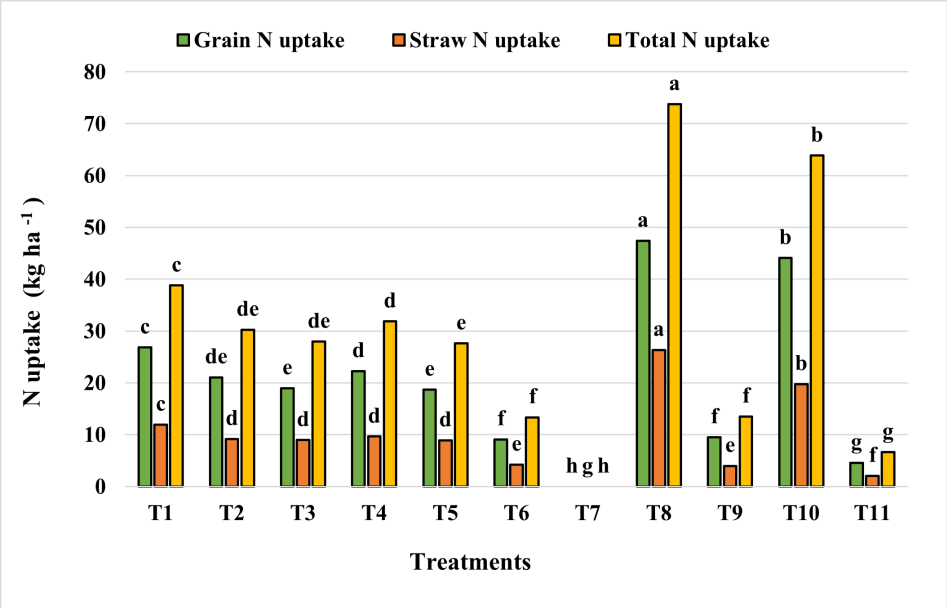


Figure 2. Effect of applications of fertilizers and amendments for five decades on nitrogen uptake by wheat (Bars with different letters are significantly different at P ≤ 0.05)

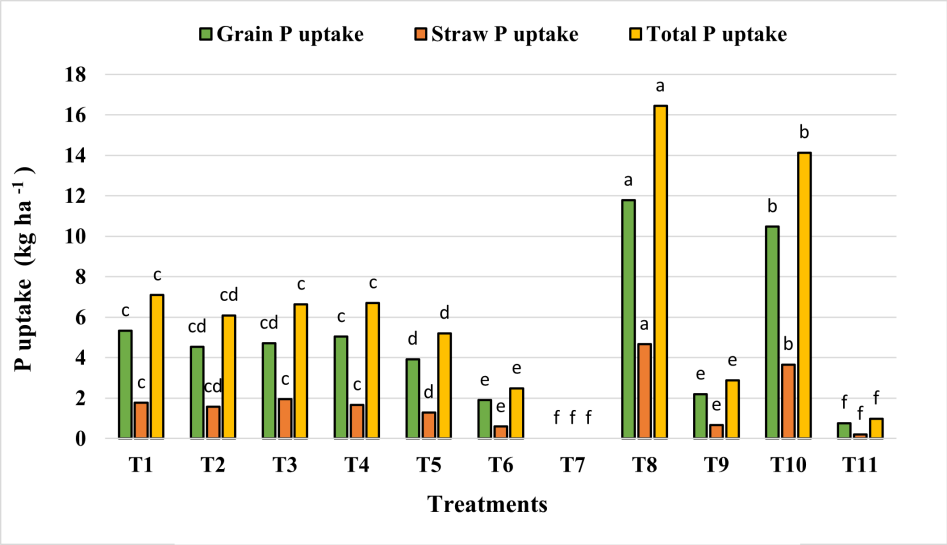


Figure 3. Effect of applications of fertilizers and amendments for five decades on phosphorus uptake by wheat (Bars with different letters are significantly different at P≤ 0.05)

However, the treatment (T_3) with a super-optimal dose of NPK recorded lower total N uptake than the optimal NPK treatment (T_2) due to reduced nitrogen use efficiency and increased environmental losses through leaching and runoff, which limited soil accumulation in the soil under excessive N fertilization (Sharma *et al.* 2016; Zhu *et al.* 2023). No replenishment of nutrients from external sources in the control plot might have depleted the native nutrient reserves over five decades, leading to reduced nitrogen uptake (Gourav *et al.* 2019), and the highest nitrogen uptake under the incorporation of FYM along with NPK might have occurred due to the favourable soil conditions provided with sufficient nutrient supply (Suri *et al.* 2025).

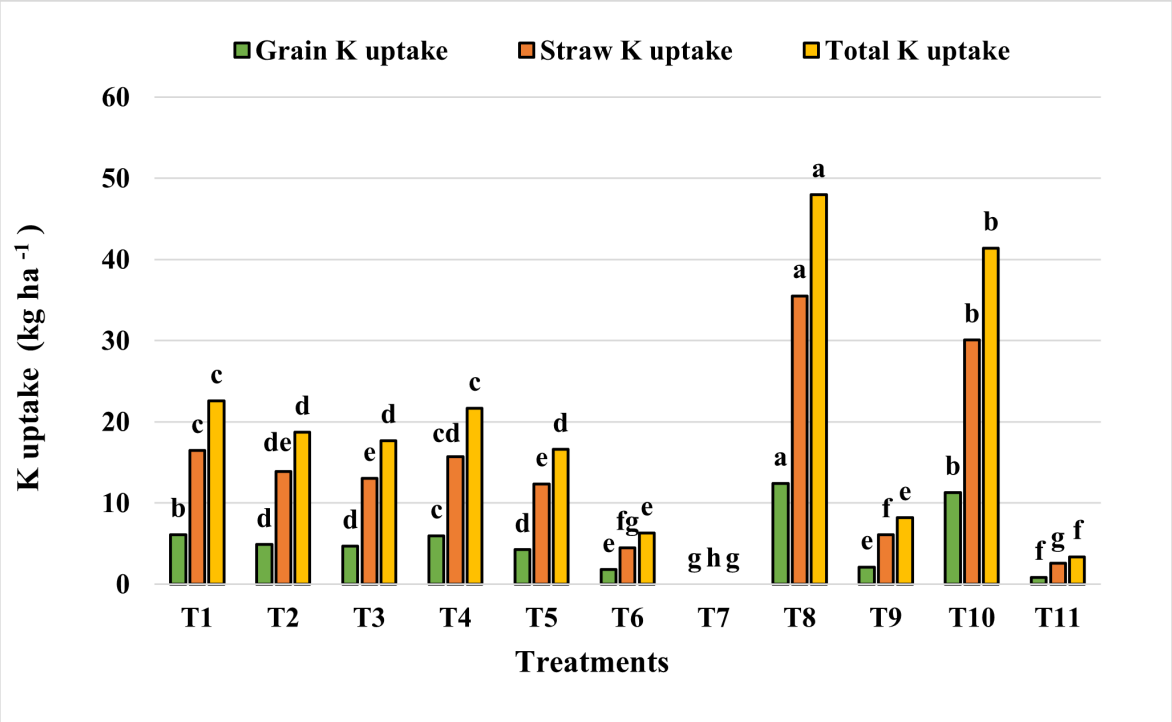


Figure 4. Effect of applications of fertilizers and amendments for five decades on potassium uptake by wheat (Bars with different letters are significantly different at P≤0.05)

The grain P uptake ranged from 0.76 kg ha^{-1} in the unfertilized treatment (T_{11}) to 11.78 kg ha^{-1} in 100 per cent NPK + FYM (T_8) and the straw P uptake ranged from 0.21 kg ha^{-1} in control (T_{11}) to 4.66 kg ha^{-1} with the application of 100 per cent NPK + FYM (T_8) (Figure 3). Treatments comprising FYM (T_8) or lime (T_{10}) along with an optimal dose of NPK (T_2) recorded a higher total P uptake than the rest of the treatments. Total P uptake was considerably lower in the 100% NP (T_6), 100% NPK (-S) (T_9), and unfertilized control treatments than in the 100% NPK treatment (T_2). Additionally, the enhanced P absorption in FYM treated plots might be due to the fact that organic materials decrease P fixation and increases P availability in acid *Alfisols* with high P-fixing capacity and the application of lime causes Al^{3+} to precipitate at higher pH values, decreasing P fixation in the soil and leading to an increase in the amount of P available for crop growth (Rajneesh *et al.* 2017).

The grain K uptake varied from 0.82 kg ha^{-1} in the control (T_{11}) to 12.42 kg ha^{-1} with the application of 100 per cent NPK + FYM (T_8), and the straw K uptake varied from 2.55 kg ha^{-1} in the unfertilized control (T_{11}) to 35.52 kg ha^{-1}in the treatment with 100 % NPK + FYM (T_8) (Figure 4). Application of 100 per cent NPK+ FYM (T_8) recorded the highest total K uptake followed by 100 per cent NPK and lime (T_{10}). The application of 100 per cent NP (T_6), 100 per cent NPK (-S) (T_9), and unfertilized control treatments recorded significantly lower K uptake compared to 100 per cent NPK (T_2) treatment. Higher K uptake due to FYM and lime addition over years might have led to improved soil characteristics that improved crop development in these treatments (Anjali *et al.* 2022). However, when K was excluded *i.e.*, 100 per cent NP (T_6) treatment, crop yields were lower, and K uptake was subsequently reduced in comparison to the balanced fertilization. Higher K uptake in balanced fertilization might be due to the steady accumulation of K over time through the addition of muriate of potash.

Relationship of wheat grain and straw yield with N, P, K uptake

Wheat grain and straw yield correlated highly with N, P, K uptake by grain, straw and the total N, P, K uptake (Figure 5) signifying the role of the nutrients for plant growth and development (Sharma *et al.* 2022).

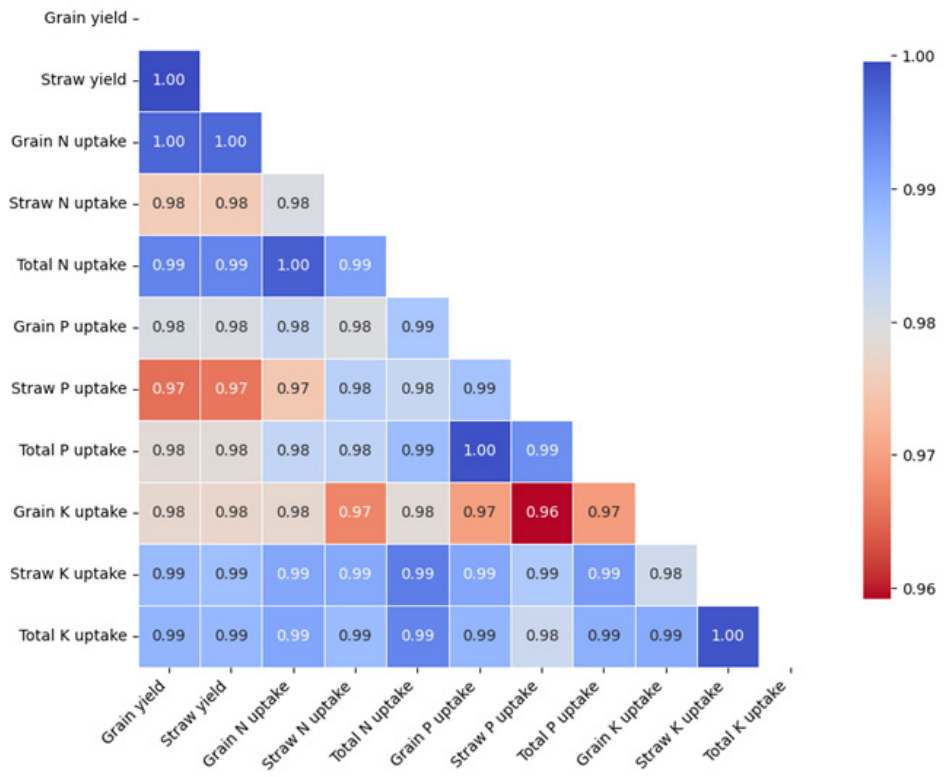


Figure 5. Pearson's correlation matrix among yield and nutrient uptake in wheat crop

CONCLUSION

Continuous application of fertilizers and amendments for a period of 50 years significantly influenced wheat yield and the uptake of primary nutrients. The application of 100% NPK + FYM consistently outperformed the other treatments, yielding the highest grain and straw yield and nutrient (N, P, K) uptake by wheat, whereas, the continuous application of nitrogen fertilizer without the addition of farmyard manure or lime, has resulted in zero yield, thereby no nutrient acquisition by the wheat crop. Treatments omitting K or S from the fertilization schedule demonstrated a decrease in the nutrient uptake and yield of wheat compared to the optimal dose of fertilizer application. Thus, the results highlight the importance of balanced and integrated use of chemical fertilizers and amendments in improving the wheat productivity and nutrients uptake.

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Conflict of interest: Authors declare no competing interest.

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