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Effect of farmyard manure, fertilizers and lime on quality parameters, nutrient uptake and productivity of maize (*Zea mays*) in acidic condition of north-western Himalayas

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) seasons of (June to October) 2020 and 2021 at Research Farm of Chaudhary Sarwan Kumar Krishi Vishvavidyalaya, Palampur, Himachal Pradesh to assess the effect of fertilizers, FYM (farmyard manure) and lime on maize (*Zea mays* L.) productivity and quality in acidic soil. The experiment was conducted in a randomized complete block design (RCBD), comprised of 11 treatments, viz. T_1, Control; T_2, 100% NPK; T_3, 100% NPK + 5 t FYM/ha; T_4, 100% NPK + 10 t FYM/ha; T_5, 100% NPK + lime (full dose through broadcasting); T_6, 100% NPK + lime ($1/10^{th}$ dose through furrow application); T_7, 100% NPK + 5 t FYM/ha + lime (full dose through broadcasting); T_8, 100% NPK + 10 t FYM/ha + lime (full dose through broadcasting); T_9, 100% NPK + 5 t FYM/ha + lime ($1/10^{th}$ dose through furrow application); T_{10}, 100% NPK + 10 t FYM/ha + lime ($1/10^{th}$ dose through furrow application); and T_{11}, Natural farming [*Ghanajeevamrita* (cow dung, 100 kg; cow urine, 10 litre; jaggery, 100 g and gram flour, 100 g)], replicated thrice. After the harvest of maize, the data on grain and stover yield, nutrient uptake and grain quality parameters (crude protein, P, Ca, and Mg content) were recorded. The results revealed that the integrated application of 100% NPK, FYM and lime significantly improved the nutrient uptake over the rest of the treatments. The application of 100% NPK + 10 tonnes FYM/ha + lime incorporation at the rate 100% lime requirement (LR) increased the stover and grain yield by 161 and 179% over 100% NPK, respectively. The quality parameters like crude protein content (10.10%), P content (0.42%), Ca content (0.27%) and Mg content (0.14%) were also recorded higher with application of 100% NPK along with FYM (10 t/ha) and lime (100% LR). The results suggested the importance of sustainable soil fertility management, particularly the beneficial effects of integrating chemical fertilizer with lime and FYM in improving maize yield, nutrient uptake, and grain quality, compared to the sole use of chemical fertilizers in an acidic soil.

Keywords: Maize yield, Nutrient uptake, Organic and inorganic amendments, Quality parameters

Maize (*Zea mays* L.) is one of the most adaptable and versatile crops grown in various agro-climatic conditions. In addition to its high genetic yield potential over other cereals, maize possesses a wide range of grain types and plays varied and vital roles in global agri-food systems and food security, particularly in emerging nations like India. Since 1961, global maize productivity has nearly tripled and overall production escalated five-fold in 2019, driven by rising demand and area expansion (Erenstein *et al.* 2022). Nationwide, maize is the third most important crop after wheat and rice and grown on 11.2 million ha with a production of 37.67 million metric tonnes and productivity of 3351 kg/ha whereas in Himachal Pradesh, maize is grown in 0.25 million ha with a production of 0.61 million metric tonnes and productivity of 2403 kg/ha (UPAg 2024).

Being exhaustive in nature, maize has a higher nutrient demand, thereby leading to unbalanced fertilizer use. Overuse of fertilizers and intensive cropping have accelerated the process of land degradation, adversely affecting the production potential and soil health, leading to yield declination or stagnation. Soil acidity is also a severe constraint that has a detrimental effect on agricultural productivity and sustainability (Thakur *et al.* 2021). Although parent materials substantially contribute to the development of soil acidity, rainfall, temperature and vegetation also favour its development, whilst it is accelerated by certain agriculture practices and unbalanced application of fertilizers (Wakwoya *et al.* 2022). The maize crop is highly susceptible to acidic soil due to the direct

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impact of low *p*H levels on its physiological functions (Wakwoya *et al.* 2022). In acid soils aluminium toxicity first affects root growth and then nutrient uptake and consequently above ground biomass accumulation (Sierra *et al.* 2003). Monitoring soil *p*H is crucial for achieving optimum crop productivity. The use of lime is a potential option for the sustainable management of soils to increase the productivity of maize (Bharti *et al.* 2021, Islam *et al.* 2021). Hence, achieving higher maize yield along with maintaining soil health and sustainability requires a proper soil management approach involving the judicious use of fertilizers, manures and amendments. Current research lacks comprehensive strategies for optimizing the use of organic amendments like FYM and lime with chemical fertilizers to enhance nutrient uptake, grain quality and productivity in acidic soils. The study aims to address these gaps by investigating the combined effects of these amendments, offering insights into sustainable nutrient management, and region-specific strategies for enhancing maize productivity in acidic soils.

MATERIALS AND METHODS

Experimental site: A field experiment was conducted during rainy (*kharif*) seasons of (June to October) 2020 and 2021 at Research Farm of Chaudhary Sarwan Kumar Krishi Vishvavidyalaya (32°7′ N and 76°31′ E, with an altitude 1290 m amsl), Palampur, Himachal Pradesh. The soil of the study area was silt loam in texture (*Typic Hapludalf)* with an acidic *p*H (5.49), medium in organic carbon (0.83%), and available N (291 kg/ha), P (11.2 kg/ha) and K (228 kg/ha). The average rainfall received during the crop growth period was 80.5 mm in 2020 and 110.5 mm in 2021. The minimum and maximum temperatures were 14.6 and 30.5°C in *kharif* 2020 and 14.9 and 31.1°C in *kharif* 2021, respectively.

Experimental details: Maize variety, K-25 Gold was sown in the second week of June in a plot size of 12 m^2 with a spacing of 60 cm × 15 cm for both the seasons. K-25 Gold is a recommended variety in the north-western Himalayan region. The experiment was conducted in a randomized complete block design (RCBD), comprised of 11 treatments, viz. T_1, Control; T_2, 100% NPK; T_3, 100% NPK + 5 t FYM/ha; T_4, 100% NPK + 10 t FYM/ha; T_5, 100% NPK + lime (full dose through broadcasting); T_6, 100% NPK + lime ($1/10^{th}$ dose through furrow application); T_7, 100% NPK + 5 t FYM/ha + lime (full dose through broadcasting); T_8, 100% NPK + 10 t FYM/ha + lime (full dose through broadcasting); T_9, 100% NPK + 5 t FYM/ha + lime ($1/10^{th}$ dose through furrow application); T_{10}, 100% NPK + 10 t FYM/ha + lime ($1/10^{th}$ dose through furrow application); and T_{11}, Natural farming [*Ghanajeevamrita* (cow dung, 100 kg; cow urine, 10 litre; jiggery, 100 g and gram flour, 100 g)], replicated thrice. The recommended dose of NPK for the crop was 120 kg, 60 kg and 40 kg/ha, respectively. The nutrients were supplied through urea, single super phosphate (SSP), and muriate of potash (MOP) for all treatments except T_1 (control) and T_{11} (Natural farming). A half dose of N and a full dose of P and K were applied at the time of sowing of maize in treatments T_2–T_{10}. The half of the remaining nitrogen was top dressed in two equal splits at knee high and pre-tasseling stage. Farmyard manure (FYM) was incorporated into the soil @5 t/ha for treatments T_3, T_7 and T_9 and @10 t/ha for treatments T_4, T_8 and T_{10} on dry weight basis and thoroughly mixed in the soil before sowing. The lime requirement was assessed using the Shoemaker Mclean and Pratt buffer method (Shoemaker *et al.* 1961), and in treatments T_5, T_7, and T_8, a full dose of marketable lime (4 t/ha $CaCO_3$) was evenly spread across the soil surface and thoroughly mixed in soil. On the other hand, treatments T_6, T_9 and T_{10} received $1/10^{th}$ dose of lime (0.4 t/ha), applied in furrows. Two levels of lime were used to evaluate the potential for reducing lime application while maintaining maize productivity. This approach aims to determine if lower lime rates can achieve similar benefits as the full recommended dose, thereby minimizing lime use and reducing costs (Table 1).

In the treatment T_{11}, natural farming practices were followed. Prior to sowing, *Ghanajeevamrita* (cow dung, 100 kg; cow urine, 10 litre; jaggery, 100 g and gram flour, 100 g) was applied and incorporated into the plots @250 kg/ha and seeds were treated with *Beejamrita* (cow dung, 5 kg; cow urine, 5 litre; lime, 50 g; water, 20 litre and a handful of soil) @100 ml/kg seed. The seeds were coated evenly with *Beejamrita* using clean hands and then spread out on a plastic sheet in a shaded area to dry for 2–3 h. During sowing, *Jeevamrita* mixture, consisting of cow dung (10 kg), cow urine (10 litre), jaggery (2 kg), gram flour (2 kg), water (200 litre), and a handful of soil, was applied @500 litre/ha. Subsequently, *Jeevamrita* was sprayed every 21 days after dilution with water at a ratio of 1:10. Mulching was done using *Lantana camara* @25 t/ha. One pre-sowing irrigation was provided during field preparation and after that, the water requirement of the crop was fulfilled through rainfall. Standard package of practices was followed for

Table 1 Effect of fertilizers and amendments on grain yield and stover yield over the two *kharif* seasons (2020 and 2021)

	Grain yield	Stover yield
T_1	6.18±0.64^{j}	11.32±0.98^{k}
T_2	17.94±0.52^{h}	29.50±0.35^{i}
T_3	24.20±0.97^{g}	39.06±1.07^{h}
T_4	33.39±1.18^{e}	52.21±1.78^{e}
T_5	31.24±1.03^{e}	48.61±1.49^{f}
T_6	27.53±0.57^{f}	43.88±0.36^{g}
T_7	41.99±0.40^{c}	65.22±0.36^{c}
T_8	50.06±0.98^{a}	77.07±1.51^{a}
T_9	38.83±0.63^{d}	60.78±0.58^{d}
T_{10}	46.01±1.21^{b}	71.76±1.87^{b}
T_{11}	10.88±0.37^{i}	20.88±1.14^{j}

Treatment details are given under Materials and Methods.

raising the crop.

Sampling and analysis

Yield: The crops in both the seasons were harvested in the 2nd week of October. After the harvest of maize, data on grain yield was recorded on 15.5% moisture level and stover yield was recorded on oven dry basis from each plot and expressed in q/ha.

Quality parameters: Five randomly selected cobs were taken and the maize grain and stover samples were dried in an oven at 60˚C. After drying, they were ground in a Wiley mill fitted with stainless steel components to achieve a particle size suitable for passing through a 1 mm sieve. For further analysis, the samples were stored in paper bags. The concentration of total nitrogen in grain and straw samples was assessed using the Micro Kjeldahl method (Jackson 1973), phosphorus and sulphur by UV-V is spectrophometry (Jackson 1973), calcium by flame photometery (Jackson 1973), and magnesium by atomic absorption spectrophotometery (Jackson 1973).

Crude protein content = Per cent nitrogen content × 6.25

Nutrient uptake: The nutrient uptake (kg/ha) was determined by multiplying the nutrient concentration (%) with grain and stover yield (q/ha), respectively. The total uptake of nutrients by the crop was then calculated by adding together the nutrient uptake from grain and stover yields.

Statistical analysis: The data of both the seasons (*kharif* 2020 and 2021) was averaged and the ANOVA (analysis of variance) for randomized block design was performed in R using the 'aov' function. The Fischer's Least Significant Difference test using the 'LSD test' function was performed to determine the grouping of means at 95% probability.

RESULTS AND DISCUSSION

Yield: The findings from the two-year data (2020 and 2021) depicted that the average yield of maize grain ranged between 6.2 to 50.1 q/ha, whereas the yield of straw varied from 11.3–77.1 q/ha (Table 1). The application of two different levels of FYM, 5 t FYM/ha (T_3) and 10 t FYM/ha (T_4) along with 100% NPK recorded 35.2 and 86.6% higher grain yield over 100% NPK alone, respectively. The stover yield followed similar trend as that of the grain yield under various treatments. The highest grain and stover yield were recorded with the combined use of 100% NPK along with the FYM @10 t/ha and lime incorporation @100% LR (T_8), followed by the treatment involving same combination but with lime incorporation @1/10th LR in furrow (T_{10}). The treatments T_8 recorded 87.65 and 85.31% higher grain and stover yield over control (T_1), respectively. The combined use of farmyard manure (FYM), lime, and fertilizers led to the maximum production of both maize grain and stover. The addition of FYM releases organic acids that can bind with aluminium and iron, consequently reducing phosphorus (P) retention and enhancing P availability, thereby promoting greater maize growth and productivity. Similar findings were reported by Malarkodi *et al.* (2019) and Thakur *et al.* (2021). The incorporation of lime enhanced maize productivity possibly by improving soil properties and increasing nutrient availability through the augmentation of soil cation exchange capacity.

Nutrient uptake: The highest N, P and K uptake of grain (80.12, 21.11 and 13.33 kg/ha) and stover (47.03, 8.89 and 51.74 kg/ha) was recorded with T_8 (100% NPK + 10 t FYM/ha + lime incorporation @100% LR) which was significantly superior over rest of the fertilizer management options (Table 2). The treatment wise effect on total NPK uptake by maize was similar to the uptake by grain and stover. Among the FYM levels, application of 10 tonnes FYM/ha recorded significantly higher value of NPK uptake by grains and stover over 5 t FYM/ha. The highest grain, stover and total uptake of N were recorded under treatment where 100% NPK alongwith the farmyard manure @10 t/ha and lime incorporation @100% LR (T_8) were applied together, followed by the treatment involving same combination but with lime incorporation @1/10th LR in furrow (T_{10}) whereas the lowest NPK uptake were recorded under control (T_1).

The nutrient uptake of the crop relies on both its yield and the nutrient concentration within the plant. The increase

Table 2 Effect of fertilizers and amendments on average N, P and K uptakes over the two *kharif* seasons (2020 and 2021)

Treatment	N uptake (kg/ha)		P uptake (kg/ha)		K uptake (kg/ha)	
	Grain	Stover	Grain	Stover	Grain	Stover
T_1	7.15 ±0.72^{k}	3.94 ±0.49^{j}	1.72 ±0.21^{j}	0.60 ±0.04^{j}	0.94 ±0.06^{h}	4.51 ±0.37^{i}
T_2	23.28 ±0.51^{i}	13.98 ±0.32^{h}	5.86 ±0.15^{h}	1.92 ±0.04^{h}	3.56 ±0.06^{f}	13.10 ±0.36^{g}
T_3	33.70 ±1.88^{h}	19.54 ±0.53^{g}	8.38 ±0.44^{g}	2.90 ±0.03^{g}	4.93 ±0.20^{e}	20.00 ±0.59^{f}
T_4	49.95 ±2.53^{e}	28.90 ±0.82^{d}	11.90 ±0.45^{e}	4.16 ±0.05^{e}	8.12 ±0.19^{d}	31.02 ±1.41^{d}
T_5	45.54 ±1.08^{f}	25.87 ±0.75^{e}	11.53 ±0.22^{e}	4.13 ±0.16^{e}	7.42 ±0.43^{d}	27.26 ±1.19^{e}
T_6	39.53 ±0.96^{g}	22.56 ±1.25^{f}	9.91 ±0.26^{f}	3.38 ±0.08^{f}	5.77 ±0.07^{e}	20.42 ±0.85^{f}
T_7	64.34 ±0.98^{c}	37.79 ±1.35^{c}	16.45 ±0.56^{c}	6.75 ±0.18^{c}	10.53 ±0.09^{c}	38.85 ±0.45^{c}
T_8	80.12 ±2.17^{a}	47.03 ±0.77^{a}	21.11 ±0.45^{a}	8.89 ±0.31^{a}	13.33 ±0.79^{a}	51.74 ±2.00^{a}
T_9	58.88 ±0.97^{d}	35.39 ±0.55^{c}	15.01 ±0.25^{d}	5.53 ±0.21^{d}	9.69 ±0.12^{c}	36.67 ±0.77^{c}
T_{10}	71.95 ±0.89^{b}	43.61 ±0.98^{b}	18.76 ±0.19^{b}	7.58 ±0.33^{b}	12.21 ±0.36^{b}	46.96 ±0.78^{b}
T_{11}	13.73 ±0.32^{j}	8.88 ±0.31^{i}	3.37 ±0.18^{i}	1.03 ±0.07^{i}	1.93 ±0.16^{g}	7.31 ±0.47^{h}

Same letter in a column indicates that treatments are statistically indifferent at 5% level of significance. Mean±SE represents the standard error of mean in each treatment.

Treatment details are given under Materials and Methods.

in nutrient uptake resulting from fertilizers and FYM application could be attributed to the supply of nutrients (NPK) from both fertilizer and FYM to the plants, along with an increase in plant biomass. Similar results were also concluded by Meena *et al.* (2017). The increase in P uptake with FYM incorporation could be attributed to the release of P from Al-P, Fe-P, and Mn-P complex by the chelating action of organic acids released during organic P mineralization and FYM decomposition (Gourav *et al.* 2019 and Jayanthi *et al.* 2020). Lime application likely to rise the soil *p*H might have enhanced the soil microbial activity, aiding in the mineralization of organic nitrogen (Bharti *et al.* 2021, Thakur *et al.* 2022). The increased P uptake owing to lime treatment could be attributed to a decrease in P fixation caused by decreased Al and Fe ion activity (Rajneesh *et al.* 2018). The increase in K uptake due to application of amendment (lime) might be due to decrease in K fixation and subsequent release of K from the non-exchangeable to exchangeable pool.

Quality parameters of maize

Protein content: The crude protein content in maize grain was recorded lowest (7.30%) in control and highest (10.10%) in 100% NPK + 10 t FYM/ha + lime incorporation @100% LR (T_8) (Table 3). Application of the FYM (5 t/ha and 10 t/ha) along with the chemical fertilizer (T_3 and T_4) also recorded 12.4 and 15.9% higher crude protein content than sole application of 100% NPK, respectively. The crude protein content in maize grains increased by 23.7% by the application of 100% NPK + 10 t FYM/ha + lime incorporation @100% LR (T_8) over 100% NPK (T_2). The natural farming plots also reported significant increase in crude protein content in maize grain over unfertilized plot, but lower than the rest of the treatments.

The increase in crude protein content as a result of combining FYM (Farm Yard Manure) with fertilizers could be attributed to the enhanced availability of nitrogen (N) to the crops. Protein content in grains is directly related to N content in grain. Hence, higher N content might have also enhanced the protein content (Mohammad *et al.* 2017). The beneficial impact of amendment (lime) on crude protein content in grains might be due the improvement in soil conditions leading to higher availability of N to the crop during critical growth stages. Chauhan *et al.* (2020) reported the significant impact on the crude protein content of grains through the integrated application of fertilizers, FYM (farmyard manure), and lime.

Nutrient content (P, Ca, and Mg):

Table 3 Effect of fertilizers and amendments on average crude protein, P, Ca, and Mg content (%) over the two *kharif* seasons (2020 and 2021)

Treatment	Crude protein	P	Ca	Mg
T_1	7.30±0.17^{g}	0.30±0.00^{f}	0.18±0.00^{e}	0.08±0.01^{f}
T_2	8.16±0.02^{f}	0.33±0.00^{e}	0.20±0.00^{d}	0.09±0.01^{ef}
T_3	9.17±0.16^{e}	0.34±0.00^{de}	0.22±0.00^{c}	0.10±0.00^{de}
T_4	9.46±0.14^{bcde}	0.35±0.00^{d}	0.22±0.00^{c}	0.12±0.01^{bcd}
T_5	9.18±0.18^{de}	0.37±0.01^{c}	0.25±0.00^{b}	0.11±0.01^{cd}
T_6	9.27±0.11^{cde}	0.36±0.00^{d}	0.23±0.00^{c}	0.10±0.00^{de}
T_7	9.70±0.07^{b}	0.39±0.01^{b}	0.25±0.00^{b}	0.12±0.01^{bcd}
T_8	10.10±0.11^{a}	0.42±0.01^{a}	0.27±0.00^{a}	0.14±0.01^{a}
T_9	9.56±0.04^{bc}	0.38±0.00^{c}	0.25±0.00^{b}	0.12±0.01^{abc}
T_{10}	9.49±0.11^{bcd}	0.39±0.01^{b}	0.27±0.00^{a}	0.13±0.01^{ab}
T_{11}	8.08±0.08^{f}	0.30±0.01^{f}	0.18±0.00^{e}	0.09±0.01^{ef}

Same letter on the points indicates that treatments are statistically indifferent at 5% level of significance.

Treatment details are given under Materials and Methods.

Highest P, Ca, and Mg (0.42, 0.27 and 0.14%) of maize grain was recorded under 100% NPK + 10 t FYM/ha + lime incorporation @100% LR (T_8) treatment (Table 3). The lowest value (0.30%, 0.18%, and 0.08%) of P, Ca and Mg content were recorded under control plots which was statistically similar with natural farming (T_{11}). The combined application of organic manure and amendment (lime) with 100% NPK (T_7–T_{10}) enhanced the content of maize grain P by 18.2, 27.3, 15.2 and 18.2% compared to

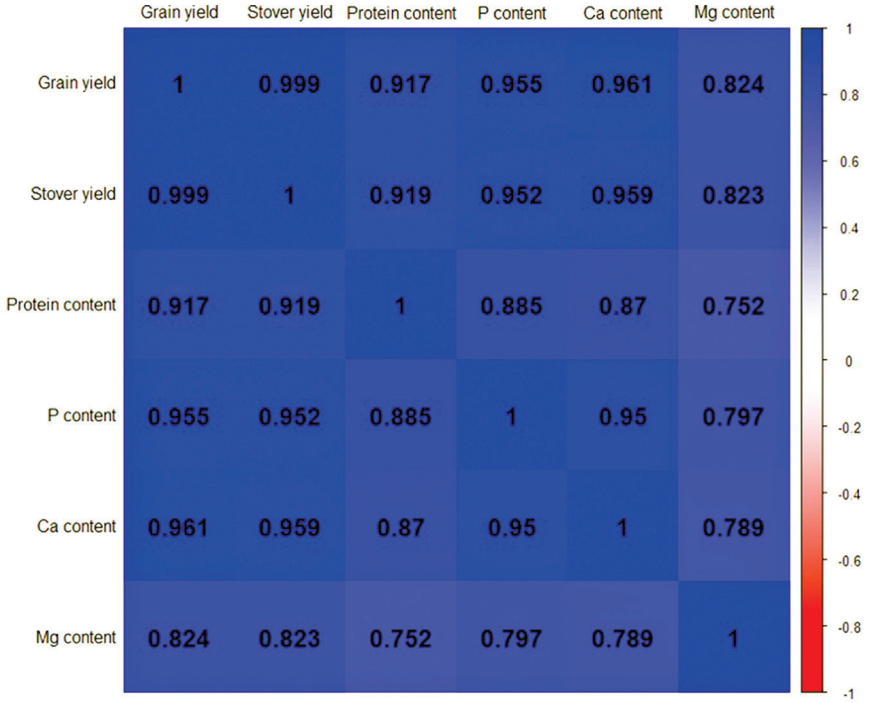

Fig. 1 Coefficient of correlation (r) between quality parameters (%) and grain and stover yield of maize (q/ha).

100% NPK, respectively.

The conjoint use of FYM and NPK fertilizers increases the nutrient content of maize grain significantly compared to when NPK fertilizers were applied alone, may be attributed better root development, enrichment of soil nutrients through farmyard manure addition (Saha *et al.* 2019), enhanced native nutrient accessibility (Gosal *et al.* 2018) and increased nutrient absorption (Chauhan *et al.* 2020). Furthermore, the availability of calcium is enhanced through soil acidity neutralization and the addition of calcium through lime application, leading to increased calcium content in maize grain (Castro and Crusciol 2015). These findings support the conclusions of Chauhan *et al.* (2020) and Thakur *et al.* (2021).

Relationship of different quality parameters with grain and stover yield of maize: The data (Fig. 1) indicates a significant and positive correlation between quality parameters of maize and grain and stover yield. The highest correlation coefficient with grain yield was observed for the calcium (Ca) content of maize grains (r=0.961), followed closely by phosphorous (P) content (r=0.955), protein content (r=0.917), and magnesium (Mg) content (r=0.824). Similarly, the stover yield of maize also exhibited a significant positive correlation with Ca content (r=0.959), followed by P content (r=0.952), protein content (r=0.919), and Mg content (r=0.823).

Combining farmyard manure and lime with inorganic fertilizers in acidic soil significantly improved maize yield and nutrient uptake in grain and straw, including protein and nutrient content (P, Ca and Mg). Quality parameter and nutrient uptake by maize were highest occurred with NPK fertilizers integrated with farmyard manure and lime in acidic soils, while unfertilized plots had the lowest quality parameter and nutrient uptake by maize. Hence, an integrated approach in acid soil management is essential for optimizing yield, quality and nutrient uptake without compromising soil health and sustainability in north-western Himalayan region.

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