Indian Journal of Ecology (2022) 49(2): 388-393
DOI: https://doi.org/10.55362/IJE/2022/3534

Manuscript Number: 3534
NAAS Rating: 5.79

Long Term Effect of Fertilizers and Amendments on Macronutrients Uptake by Maize and Relationship with Soil Organic Carbon in Maize-Wheat System in Acid Alfisol of North-Western Himalayas

Anjali Thakur, R.P. Sharma, N.K. Sankhyan and Anjali

Department of Soil Science, CSK Himachal Pradesh Agriculture University, Palampur-176062, India
E-mail: thakur.anjali.626@gmail.com

Abstract: Present study was carried out during *kharif* 2018 in the ongoing long-term fertilizer experiment, initiated in 1972 at the experimental farm of the Department of Soil Science, Chaudhary Sarwan Kumar Himachal Pradesh Agriculture University, Palampur, to study the effect of chemical fertilizers, farmyard manure and lime application on yield and nutrient uptake by maize and their relationship with soil organic C in an acid Alfisol. The experiment consisted of three replications of eleven treatments in a randomized block design. The results revealed that the continuous use of NPK fertilizers along with FYM or lime increased the maize yield by 46.7 and 38.5%, whereas omission of S and K from the fertilization schedule declined the yield by 54.8 and 52.2% over the sole use of NPK fertilizers, respectively. The uptake of N, P, K, S, Ca and Mg by maize grain and stover was significantly higher in 100% NPK+FYM and 100% NPK+lime than rest of the treatments. Soil organic C recorded a positive and significant relation with uptake of macronutrients by maize, the highest being with P uptake by maize grain (r = 0.918**).

Keywords: FYM, Lime, Maize, Nutrient uptake, Soil organic carbon, Yield

Maize is the third most important cereal crop in India, after wheat and rice. It has high genetic yield potential; therefore, its nutrients requirement is also very high. The uptake of nutrients and their transport within the plant system primarily depends upon the growth stage of the plant, soil fertility, amount of fertilizers applied etc. (Bisht et al 2013). Chemical fertilizers are applied to the soil to supplement the soil nutrient supply and increase crop yields. However, inadequate and imbalanced application of fertilizers adversely affects soil health and declines crop productivity (Kalhapure et al 2014). Integration of organic and inorganic sources of plant nutrients may help to supply adequate nutrients in an optimum proportion. Organic manures supply soil organic matter and increase nutrient availability and use efficiency by regulating their supply. Soil organic matter is a reservoir of C as well as nutrients in the soil, contains almost all the nutrients essential for plant growth, therefore, is an important factor affecting the nutrient uptake by the crop (Wang et al 2015). In acid soils, high exchangeable Al, Fe and Mn and deficiency of P, Ca, Mo etc. are the most limiting factors for plant growth (Rajneesh et al 2018). Application of lime is done for remediating the soil acidity but it affects the availability and uptake of the nutrients. It is important to identify the effect of nutrient management practices involving fertilizers and amendments on crop productivity and nutrient availability to the crop over a long period. Long-term fertilizer experiments are very helpful tools in assessing the effect of the use of fertilizers and manures on crop productivity and soil health. Therefore, the present study was carried out to evaluate the effect of chemical fertilizers, FYM and lime application on yield and nutrient uptake by maize after forty-six years in maize-wheat cropping system in an acid Alfisol.

MATERIAL AND METHODS

Experimental site: Present study was carried out during *kharif* 2018 in an on-going long-term fertilizer experiment, initiated in 1972 at the experimental farm of Department of Soil Science, CSK HPKV, Palampur (31°6′ N latitude and 76°3′ E longitude, 1290 meters above mean sea level. The mean weekly temperature during the study period varied from 19.5 to 25.6 °C and the total rainfall received was 2605 mm. The soil of the study site is illitic with silty loam in texture and classified as subgroup Typic Hapludalf. At the start of the experiment, soil pH was 5.9, soil organic carbon (SOC) 7.9 g/kg, available N, P and K were 736, 12 and 194 kg/ha, respectively. The SOC ranged between 0.79 and 1.39% after the harvest of the maize crop in the present study.

Experimental layout and treatments: There were eleven treatments in three replications, experiment was laid out in a randomized block design (Table 1). Since 2011, optimal and super-optimal P doses have been reduced by 50% due to the P build-up and FYM application at the rate of 5 t/ha (dry weight basis) has been initiated in 50% NPK (T_1). The optimal dose of NPK for maize corresponds to 120, 60 and 40 kg/ha N, P_2O_5 and K_2O, respectively. Half doses of N and full doses of P and K were applied at the time of sowing and the remaining half N was top-dressed in two equal splits at the knee-high and pre-tasseling stage. Urea, single super phosphate (SSP) and muriate of potash (MOP) were sources of N, P and K in all treatments, except in NPK(-S), diammonium phosphate (DAP) was applied as a source of P. Farmyard manure (60% moisture, 1.01% N, 0.26% P and 0.40% K) was applied at the rate of 5 t/ha (dry weight basis). Till 2011, Zn was applied in T_5 as $ZnSO_4$ at the rate of 25 kg/ha every year to both crops. Lime was applied continuously in T_{10} till the soil pH was raised to 6.5 but in subsequent years, the lime application was only done when the soil pH declined to about 6.3. After ploughing with power tiller, pre-sowing irrigation was done and thereafter, the water requirement of the crop was met through rainfall. Atrazine was applied as a pre-emergence herbicide at the rate of 1.125 kg/ha in all treatments barring 100% NPK + hand weeding (T_4) in which hand weeding was done. Earthing up was done after 45 days of sowing.

Sampling and analysis: Maize grain and stover yield were recorded, the samples were collected from each plot after the harvest of the crop and dried in an electric oven at 60 °C to a constant weight. The dried grain samples were finely ground in a mixer grinder in stainless steel jar and stored in plastic bags under moisture-free conditions. The stover samples were ground in a Wiley mill and store in paper bags. The grain and stover samples were digested in conc. H_2SO_4, followed by distillation with micro-Kjeldahl method (Jackson 1973) for determination of N content. Maize grain and stover samples were digested in the di-acid mixture (HNO_3:$HClO_4$ in 9:4 ratio) and the aqueous extract was used to determine contents of P using the vanado-molybdo-phosphoric acid method (Jackson 1973), K by flame photometer method (Black 1965), S by turbidimetric method (Chesnin and Yein 1950), Ca by flame photometer method (Jackson 1973) and Mg by atomic absorption spectrophotometer method (Jackson 1973). The nutrient uptake was calculated by multiplying the percent concentration of the nutrients with grain and stover yield.

Statistical analysis: The data collected were subjected to statistical analysis using Web Agri Stat Package 2.0. The differences between the means were tested using Duncan Multiple Range Test (DMRT) (P≤0.05).

Table 1. Effect of continuous use of fertilizers and amendments on maize yield (t/ha)

Treatment	Grain yield	Stover yield
50% NPK (T_1)	3.07^c	5.13^c
100% NPK (T_2)	3.15^c	5.27^c
150% NPK (T_3)	2.75^c	4.61^c
100% NPK + HW (T_4)	3.66^b	6.16^b
100% NPK + Zn (T_5)	3.01^c	5.03^c
100% NP (T_6)	1.49^d	2.53^d
100% N (T_7)	0^f	0^f
100% NPK + FYM (T_8)	4.65^a	7.7^a
100% NPK (-S) (T_9)	1.41^d	2.39^d
100% NPK + lime (T_{10})	4.32^a	7.34^a
Control (T_{11})	0.64^e	1.12^e

Values with the same letters are not significantly different at P <0.05.

RESULTS AND DISCUSSION

Yield: All fertilized treatments, barring T_7, recorded significantly higher maize grain and stover yield than the unfertilized control (Table 1). In T_7 treatment, continuous urea application sharply declined the soil pH that increased the Al and Fe ions in the soil to toxic levels, thus adversely affected the crop growth and the crop did not grow beyond the knee-length stage (Thakur et al 2019). The maize grain and stover yield were highest in T_8 (4.7 and 7.7 t/ha, respectively) and was at par with T_{10} (4.3 and 7.3 t/ha, respectively). This could be attributed to the balanced supply of nutrients through chemical fertilizers and additional nutrients added from FYM. In T_{10}, amelioration of soil acidity by lime application corrected the Al toxicity and increased the availability of the nutrients, especially P, Ca and Mg. Application of S and K in T_2 resulted in 55.2 and 52.6% higher grain yield than T_9 and T_6 treatments in which these were omitted, respectively, as both S and K play a key role in plant growth and metabolism.

Nitrogen uptake: The treatment 100% NPK + FYM recorded highest total N uptake (138.8 kg/ha), followed by 100% NPK + lime (119.0 kg/ha) (Table 2). These treatments recorded 74 and 49% higher total N uptake over 100% NPK, respectively. Kalhapure et al (2014), Chaudhary et al (2017) and Rajneesh et al (2017) also reported higher uptake of N by maize with the application of organic manures and attributed this to higher nutrient availability, improved metabolic functions in plants which might have been resulted in higher nutrient uptake and crop yield. The total N uptake in plots receiving of super-optimal dose of NPK (T_3) was less than optimal NPK (T_2), however the difference was non-significant. Apart from 100% N, the lowest total N uptake by maize (13.2 kg/ha) was recorded under control.

Phosphorus uptake: The highest total P uptake (29.27 kg/ha) was recorded under 100% NPK+ FYM which was significantly superior over the rest of the treatments and least in control (2.08 kg/ha) (Table 2). This could be attributed to the solubilization of native P, synchronized the release of P by mineralization of organic matter, and its uptake by crop by the addition of FYM (Sharma et al 2016). Application of 100% NP and 100% NPK (-S) treatments registered 63 and 57% reduction in total P uptake by maize in comparison to 100% NPK, respectively. Application of 100% NPK + lime recorded 61% higher total P uptake over 100% NPK alone, which could be due to increased soil pH, precipitation of Al^{3+} ions, reduced P fixation and thereby increased availability of P. In control plots, continuous cropping without any external inputs exhausted the native P reserves of soil and resulted in low P uptake.

Potassium uptake: The total K uptake by maize varied from 6.73 kg/ha in control to 85.59 kg/ha in 100% NPK + FYM (Table 2). Application of FYM or lime along with the balanced application of chemical fertilizers significantly increased the K uptake over 100% NPK by 74 and 43%, respectively. Improvement in soil properties leading to better crop growth from FYM and lime addition might have resulted in higher uptake of K in these treatments. The omission of K from fertilization schedule (T_6) for the last forty-six years, resulted in almost 66% lower K uptake than 100% NPK.

Sulphur uptake: Barring 100% N, total S uptake by maize varied from 1.68 in control to 33.57 kg/ha in 100% NPK + FYM (Table 3). Application of FYM (T_8) increased the S uptake by maize over 100% NPK by 96% which could be

Table 2. Effect of continuous use of fertilizers and amendments for forty-six years on N, P and K uptake by maize (kg/ha)

Treatment	N			P			K		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
50% NPK (T_1)	41.6^{d}	32.0^{d}	73.6^{d}	9.11^{d}	3.88^{cd}	12.99^{d}	11.18^{d}	33.25^{d}	44.44^{d}
100% NPK (T_2)	46.0^{d}	33.9^{d}	79.8^{d}	10.36^{d}	4.40^{cd}	14.76^{d}	11.85^{d}	37.48^{d}	49.33^{d}
150% NPK (T_3)	41.2^{d}	32.9^{d}	74.1^{d}	10.28^{d}	4.72^{c}	15.00^{d}	10.63^{d}	33.51^{d}	44.14^{d}
100% NPK + HW (T_4)	56.4^{c}	41.2^{c}	97.6^{c}	12.53^{c}	5.76^{b}	18.29^{c}	13.46^{c}	44.52^{c}	57.97^{c}
100% NPK + Zn (T_5)	44.5^{d}	33.2^{d}	77.7^{d}	9.30^{d}	3.61^{d}	12.91^{d}	10.91^{d}	35.07^{d}	45.98^{d}
100% NP (T_6)	19.2^{e}	15.5^{e}	34.7^{e}	4.22^{e}	1.25^{ef}	5.48^{e}	4.60^{e}	12.38^{e}	16.98^{e}
100% N (T_7)	0.0^{g}	0.0^{g}	0.0^{g}	0.00^{g}	0.00^{g}	0.00^{f}	0.00^{g}	0.00^{f}	0.00^{f}
100% NPK + FYM (T_8)	76.8^{a}	62.0^{a}	138.8^{a}	21.46^{a}	7.81^{a}	29.27^{a}	20.04^{a}	65.55^{a}	85.59^{a}
100% NPK (-S) (T_9)	18.0^{e}	14.4^{e}	32.4^{e}	4.75^{e}	1.60^{e}	6.35^{e}	4.28^{e}	14.84^{e}	19.12^{e}
100% NPK + lime (T_{10})	67.7^{b}	51.3^{b}	119.0^{b}	17.39^{b}	6.40^{b}	23.79^{b}	16.31^{b}	54.25^{b}	70.56^{b}
Control (T_{11})	7.9^{f}	5.3^{f}	13.2^{f}	1.65^{f}	0.44^{fg}	2.08^{f}	1.69^{f}	5.05^{f}	6.73^{f}

*Values with the same letters are not significantly different at P <0.05

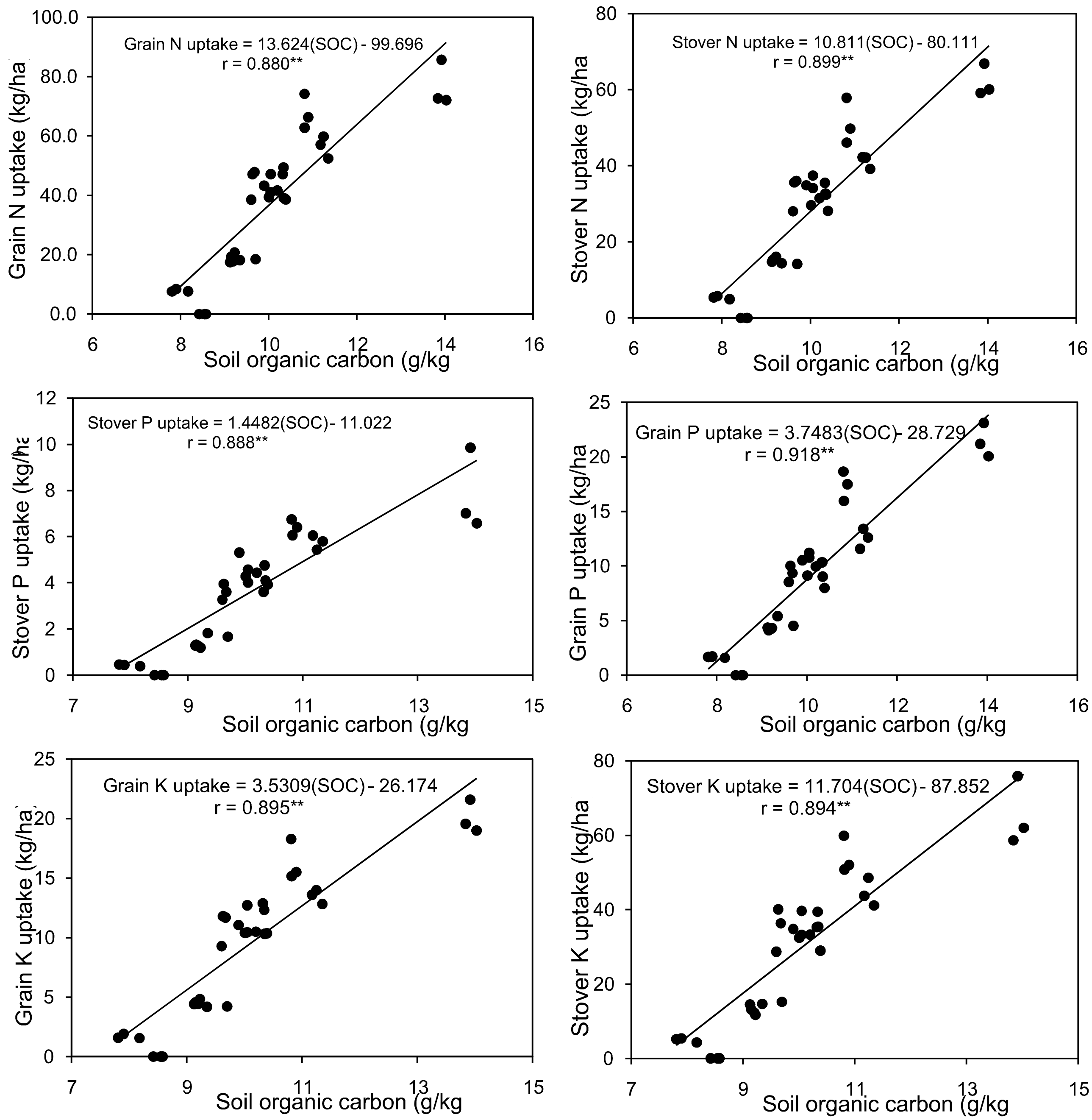
Table 3. Effect of continuous use of fertilizers and amendments for forty-six years on S, Ca and Mg uptake by maize (kg/ha)

Treatment	S			Ca			Mg		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
50% NPK (T_1)	6.75^{d}	6.17^{e}	12.92^{e}	6.02^{d}	19.98^{d}	26.00^{c}	2.66^{d}	3.78^{d}	6.44^{d}
100% NPK (T_2)	8.08^{d}	9.09^{d}	17.17^{d}	7.35^{c}	21.92^{d}	29.27^{c}	3.34^{bcd}	4.09^{d}	7.43^{d}
150% NPK (T_3)	8.26^{cd}	7.36^{de}	15.62^{de}	6.97^{cd}	21.03^{d}	28.00^{c}	3.41^{bc}	4.13^{d}	7.54^{d}
100% NPK + HW (T_4)	9.79^{c}	11.09^{c}	20.87^{c}	8.83^{b}	27.75^{c}	36.58^{b}	3.92^{b}	5.07^{c}	8.99^{c}
100% NPK + Zn (T_5)	7.51^{d}	8.37^{d}	15.88^{de}	6.86^{cd}	21.58^{d}	28.43^{c}	2.86^{cd}	3.61^{d}	6.46^{d}
100% NP (T_6)	3.59^{e}	3.70^{f}	7.29^{f}	2.75^{e}	9.01^{e}	11.76^{d}	1.24^{e}	1.49^{e}	2.72^{e}
100% N (T_7)	0.00^{g}	0.00^{h}	0.00^{h}	0.00^{f}	0.00^{f}	0.00^{e}	0.00^{f}	0.00^{f}	0.00^{f}
100% NPK + FYM (T_8)	16.30^{a}	17.27^{a}	33.57^{a}	12.23^{a}	41.56^{a}	53.79^{a}	5.99^{a}	7.80^{a}	13.79^{a}
100% NPK (-S) (T_9)	1.98^{f}	1.91^{fg}	3.89^{g}	2.44^{e}	8.24^{e}	10.69^{d}	1.19^{e}	1.62^{e}	2.80^{e}
100% NPK + lime (T_{10})	13.38^{b}	13.95^{b}	27.32^{b}	12.92^{a}	36.73^{b}	49.64^{a}	5.39^{a}	7.06^{b}	12.45^{b}
Control (T_{11})	0.86^{fg}	0.83^{gh}	1.68^{gh}	0.92^{f}	2.80^{f}	3.72^{e}	0.40^{f}	0.60^{f}	1.00^{f}

*Values with the same letters are not significantly different at P <0.05

ascribed to the addition of S and other essential nutrients through FYM. Continuous addition of S-free fertilizers in 100% NPK (-S) and continuous cropping for forty-six years might have led to the depletion of soil S reserves (Kundu et al 2016), resulting in poor crop yield and thereby low S uptake which was at par with control. Das et al (2012) have also reported that lower S uptake with the continuous use of S-free fertilizers from their study at Pantnagar (India).

Calcium uptake: The highest total Ca uptake (53.79 kg/ha) was recorded in 100% NPK + FYM and the lowest was recorded in control (3.72 kg/ha), apart from 100% N (Table 3). Application of either FYM (T_8) or lime (T_{10}) along with recommended NPK improved the total Ca uptake to the extent of 84 and 70 %, respectively, over use of 100% NPK alone. The application of FYM (T_8) improved soil properties, enhanced root growth, resulting in better nutrient uptake and

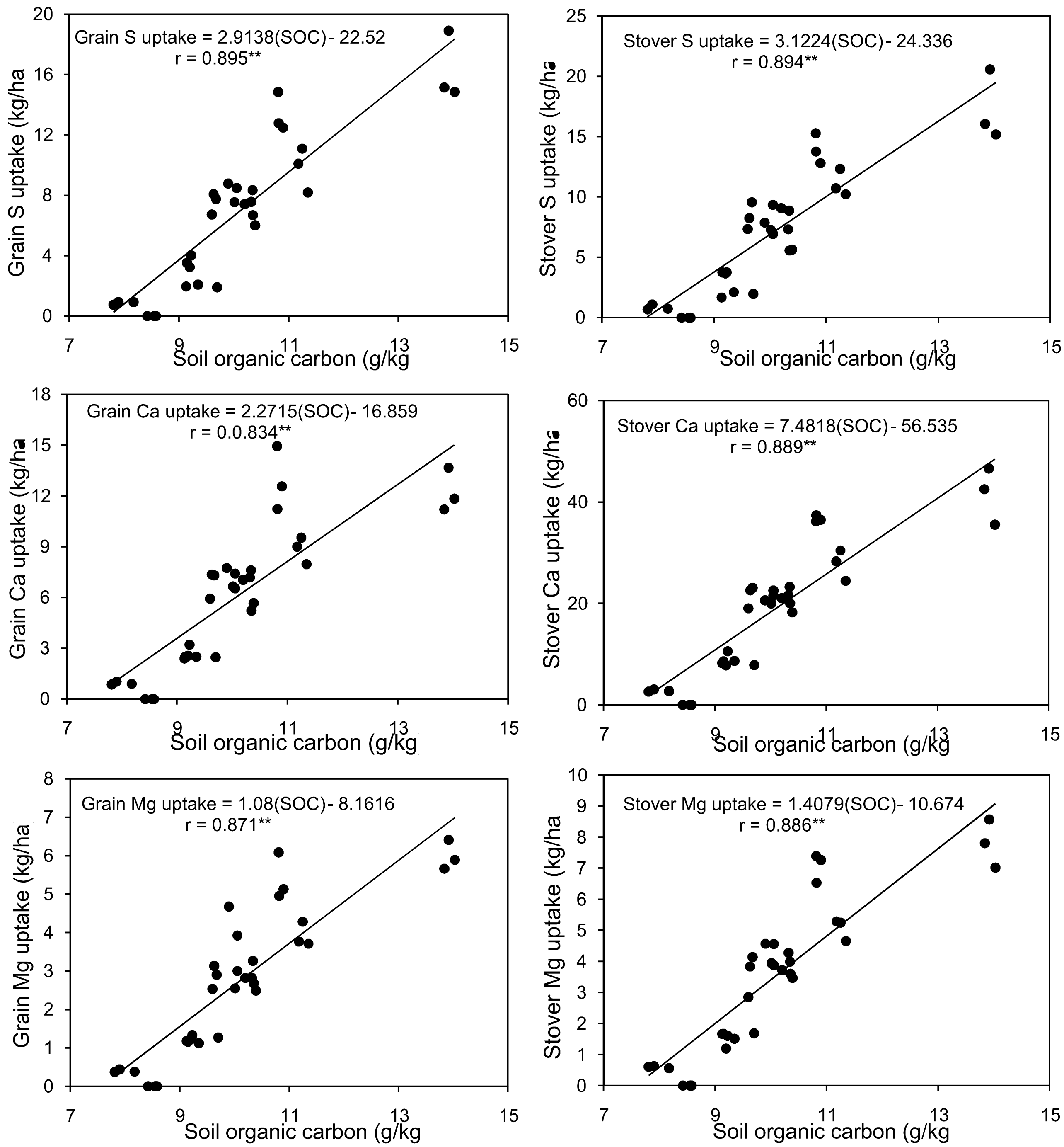


** Significant at the 1% levels of probability according to t-test (n=33)

Fig. 1. Linear regression relationship of soil organic carbon (SOC) with (a) grain N uptake, (b) stover N uptake, (c) grain P uptake, (d) stover P uptake, (e) grain K uptake and (f) stover K uptake

increased crop yield, hence recorded higher Ca uptake. The addition of lime in T_{10} increased the Ca content in soil and also neutralized the soil pH thereby increased Ca availability to the crop.

Magnesium uptake: The highest total Mg uptake was recorded under 100% NPK + FYM (5.99 kg/ha) treatment and lowest in control (0.40 kg/ha), except 100% N (Table 3). The treatment 100% NPK + lime was at par with 100% NPK + FYM. Application of FYM in T_8 increased exchangeable Mg content of soil due to the release of Mg from added FYM, improved root growth, and increased crop yield. Whereas, higher Mg uptake in T_{10} where lime was being applied might



** Significant at the 1% levels of probability according to t-test (n=33)

Fig. 2. Linear regression relationship of soil organic carbon (SOC) with (a) grain S uptake, (b) stover S uptake, (c) grain Ca uptake, (d) stover Ca uptake, (e) grain Mg uptake and (f) stover Mg uptake

be attributed to the amelioration of soil acidity, and increased biomass production (Rajneesh et al 2017).

Relationship between nutrient uptake and soil organic carbon: The relationship between nutrient uptake by maize grain and stover, and SOC was determined with nutrient uptake as the dependent variable and SOC as the independent variable (Fig. 1 and 2). It was observed that the nutrient uptake by grain and stover exhibited a strong and positive relationship with SOC for all the nutrients. It could be attributed to the addition of organic C from FYM and plant biomass, which enhanced the microbial activity in the soil, increasing the nutrient cycling and subsequently the availability of nutrients to the crop (Jadhao et al 2019). Therefore, uptake of nutrients was highest in 100% NPK + FYM treatment, in which organic C was added through FYM.

CONCLUSIONS

Integrated use of optimal NPK dose along with FYM or lime increased the maize grain and stover yield significantly over sole use of NPK fertilizers. Also, uptake of nutrients was highest when NPK fertilizers were applied in integration with FYM and lowest in unfertilized control. Soil organic C exhibited a strong and positive relationship with the macronutrient uptake by grain and stover of maize crop, thus, indicating the importance of maintaining optimum levels of organic C in soil.

ACKNOWLEDGEMENTS

The authors are highly thankful to the Indian Council of Agricultural Research (ICAR) for funding the study under the All-Indian Coordinated Research Project on Long-Term Fertilizer Experiments (AICRP-LTFE) and CSK Himachal Pradesh Agricultural University, Palampur for providing essential facilities.

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Received 23 October, 2021; Accepted 21 February, 2022