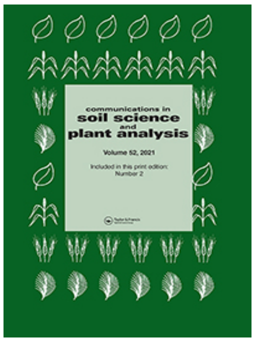

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Maize Grain Quality as Influenced by 46 Years' Continuous Application of Fertilizers, Farmyard Manure (FYM), and Lime in an Alfisol of North-western Himalayas

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ABSTRACT

An understanding of maize nutritional quality response to fertilization is important to counter the widespread nutritional deficiencies among humans; however, little work has been done in this context. This study aimed to evaluate the effect of continuous application of fertilizers, FYM, and lime on the quality and yield of maize (*Zea mays* L.) in a 46-year long-term experiment in an acid Alfisol of Himachal Pradesh, India. The experiment consisted of 10 treatments and one control in three replications in a randomized block design. Results revealed that 100% NPK+FYM and 100% NPK+lime recorded 48% and 37% higher maize grain yield than 100% NPK, respectively. The highest starch (67.09%), reducing (1.13%), and non-reducing sugar content (0.59%) were recorded in 100% NPK+FYM and lowest in control. The omission of sulfur and potassium (100% NPK (-S) and 100% NP, respectively) recorded significantly lower crude protein, fat, and fiber content compared to the treatments where sulfur and potassium were applied along with nitrogen and phosphorus. The grain calcium and zinc content were recorded highest in 100% NPK+lime and 100% NPK+Zn, respectively, whereas phosphorus, magnesium, and iron content in 100% NPK+FYM and lowest in control. From the study, it can be concluded that higher crop yield and better nutritional quality can be achieved with a balanced application of NPK fertilizers along with FYM and lime.

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Fertilizers; FYM; lime; quality; yield

Introduction

Maize (*Zea mays* L.) is a globally important crop, cultivated widely throughout the world. After rice and wheat, it is the third leading cereal crop of the world (Ramzani et al. 2017; Shah, Prasad, and Kumar 2016). Maize is the most versatile among the cereals, finding its uses as food for humans, feed and fodder for livestock and poultry, and raw material for various industries. It serves as a staple food for a large proportion of the world's population and in some countries, it accounts for more than one-third of the total calories and protein intake (Chulze 2010). Maize is consumed in various forms such as tortillas, breakfast foods like corn flakes, porridge, boiled or roasted green ears, and popcorn.

In India, maize contributes nearly 10% to the national food basket (Kumar, Srinivas, and Sivaramane 2013). Maize is cultivated in an area of 9.5 million ha in India, with a total production of 28.7 million tonnes and productivity of 3.0 t ha^{-1} (Agricultural Statistics at a Glance 2018). Even though India is one of the top 10 maize producers in the world, productivity is almost half of the global average of 5.5 t ha^{-1}. Currently, at 1.4 billion, the Indian population is projected to exceed 1.7 billion by the year 2050 (Haub and Sharma 2015). Nearly 190.7 million people in India are undernourished (FAO 2017), zinc (Zn), and iron (Fe) being the most commonly deficient micronutrients. The country

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needs to increase production as well as the nutritional quality of food grains to feed and meet the nutritional requirement of such a huge population. Since horizontal expansion of the area under cultivation is not possible, production per unit area has to be increased with minimum harm to the natural resources, especially soil.

Proper nutrient management is one of the key factors for maintaining soil health and ultimately obtaining higher yields (Meena et al. 2017; Rathod et al. 2013; Yang, Gao, and Ren 2015). The combined use of organic manure and balanced fertilizers has been reported to improve crop growth, uptake of nutrients, and yield of maize (Kumar et al. 2007; Li et al. 2017; Mahmood et al. 2017; Sharma et al. 2014). Soil acidity is the major production constraint in acid soil regions. Amelioration of soil acidity is very effective in enhancing crop yield particularly in acid soil regions (Meena et al. 2017). In addition to increasing production, it is equally important to raise food crops of superior nutritional quality to counter the wide-spread nutritional deficiencies among people. Various workers have documented the effects of integrated nutrient management on maize nutritional quality (Liu et al. 2016, 2004; Verma et al. 2012); however, little is known about the effects of lime application on the nutritional quality of maize.

Long-term fertilizer experiments have been widely employed in crop nutrition studies (Chen et al. 2018; Zhang et al. 2013). These experiments can provide more reliable and accurate information on the impact of nutrient management practices on crop yield as well as quality (Swarup 2002). Chauhan et al. (2020) studied the nutritional quality of wheat under the long-term use of organic and inorganic fertilizers and lime. But the information on the influence of fertilization on the nutritional quality of maize was lacking, although it is a major crop in the North-Western Himalayan region. In view of the above, this study was conducted with the objectives to evaluate the effects of long-term use of fertilizers, farmyard manure and lime on yield and nutritional quality parameters of maize grains.

Materials and methods

The present study was carried out on maize (Jun–Oct 2018) in the long-term fertilizer experiment on inorganic fertilizers, FYM, and lime in the maize-wheat system at the experimental farm of the Department of Soil Science, CSK Himachal Pradesh Agricultural University, Palampur, Himachal Pradesh, India. This long-term fertilizer experiment is in progress for the last 46 years since its establishment in the year 1972 at Palampur (Himachal Pradesh, India), located at 32°6′N latitude and 76°3′E longitude, 1290 m above the mean sea level.

Climate and soil

The study site falls under the mid-hills sub-humid agro-climatic zone and its climate is characterized as wet temperate. A major portion of the annual rainfall (about 80%) is received during the monsoon season (July–Sept). During the study period, total rainfall of 2604.7 mm was received and weekly relative humidity ranged between 55.6% and 98.3%. The maximum and minimum weekly temperatures varied from 23.9 to 30.6°C and 14.0 to 20.6°C, respectively. The soil of the study site has been classified as *Typic Hapludalf* and the texture is silty loam. The soil properties at the initiation of the experiment in 1972 and before of sowing of maize have been depicted in Table 1.

Details of the experiment

The experiment consisted of eleven treatments in three replications which were laid out in a randomized block design. These treatments were 50% NPK, 100% NPK, 150% NPK, 100% NPK + HW (Hand weeding), 100% NPK + Zn (Zinc), 100% NP, 100% N, 100% NPK+FYM (Farmyard manure), 100% NPK (-S), 100% NPK + lime and control; 100% NPK corresponding to 120 kg nitrogen (N), 33 kg phosphorus (P), and 33 kg potassium (K) ha^{-1} for maize. Urea, single super phosphate, and muriate of potash were used to supply N, P, and K, respectively, except in 100% NPK(-S),

Table 1. Soil properties at the start of the experiment (1972) and before of sowing of maize.

Treatment	pH	Organic carbon (g kg^{-1})	Available nutrients (kg ha^{-1})		
			N	P	K
50% NPK	5.31	10.7	151	22.8	68.2
100% NPK	5.24	10.2	163	28.7	69.8
150% NPK	4.92	9.75	165	65.9	82.0
100% NPK + HW	5.23	11.7	169	53.5	73.3
100% NPK + Zn	5.38	9.25	164	33.8	77.3
100% NP	5.14	9.70	158	49.2	56.8
100% N	4.40	8.10	147	7.03	57.8
100% NPK + FYM	5.54	13.4	177	60.4	90.5
100% NPK (-S)	5.28	9.65	159	51.1	78.5
100% NPK + lime	6.27	11.10	161	34.9	72.5
Control	5.46	8.05	119	6.97	48.7
Initial (1972)	*5.8*	*7.90*	*328.6*	*5.4*	*86.7*

diammonium phosphate was used to supply P. From June 2011 onwards, there was a slight change in some treatments, i.e., the optimal and super optimal doses of P were reduced by half due to the buildup of P, application Zn in 100% NPK + Zn as zinc sulfate was discontinued because of the buildup of Zn and in 50% NPK, the addition of FYM was also included.

Maize (Kanchan Gold hybrid) was sown on 8th June 2018 in 60 cm × 30 cm spacing. One pre-sowing irrigation was given and thereafter, crop water requirement was met through rainfall. The FYM, containing 1.01% N, 0.26% P, and 0.40% K on a dry weight basis, was added @ 5.0 t ha^{-1} on a dry weight basis. Lime @ 0.9 t ha^{-1} was applied at the time of sowing in 100% NPK + lime treatment. The full doses of P and K and half dose of N were applied at the time of sowing and the remaining half N was top-dressed in two equal splits at knee high and pre-tasseling stages. Atrazine was sprayed as pre-emergence herbicide @ 1.125 kg ha^{-1}, except in 100% NPK+HW in which weeds were removed manually and incorporated in the same plot. The crop was harvested manually on 6th October 2018 and the grain and stover yield of maize was recorded at the time of harvesting.

Sampling and analysis

The maize grain samples, collected after the harvest, were 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, sieved through a 1 mm sieve, and stored in plastic bags under moisture-free conditions. The starch content was determined using the Anthrone method (Hedge and Hofreiter 1962). The starch extract was prepared by removing sugars with ethanol and centrifugation with perchloric acid. Anthrone reagent was added to the extract for color development. The color intensity was read at 630 nm using a spectrophotometer and the starch content was expressed as a percentage. The reducing sugar content was estimated by the dinitrosalicylic acid reagent method (Miller 1959). The sample was treated homogenized in hot ethanol to extract reducing sugars and alcohol was removed in a boiling water bath. Color was developed by adding 3,5-dinitrosalicylic acid reagent was added, followed by the addition of Rochelle salt. The absorbance was recorded at 510 nm using Spectronic-200 spectrophotometer and the amount of reducing sugar was expressed as a percentage. Non-reducing sugar content was determined as per the method given by Malhotra and Sarkar (1979). First, non-reducing sugars were hydrolyzed to reducing sugars with sulfuric acid, and then the reducing sugars were estimated as described earlier. The standard procedure for proximate analysis by AOAC (2005) was followed to estimate crude protein, ash, crude fat, crude fiber, and total carbohydrate content. Maize grain samples were digested in a di-acid mixture (HNO_3:$HClO_4$ in 9:4 ratio) and the aqueous extract was used to determine contents of P with the vanado-molybdophosphoric acid method (Jackson 1973), calcium (Ca) with a flame photometer (Jackson 1973) and magnesium (Mg), Zn, and Fe content with Atomic Absorption Spectrophotometer (Jackson 1973).

Statistical analysis

The data obtained were subjected to analysis of variance (ANOVA) for randomized block design as per the procedure given by Gomez and Gomez (1984) and the difference between treatment means was considered significant at a 5% level of significance. The statistical analysis was carried out using window-based MS EXCEL 2016 and tables were prepared using MS WORD 2016.

Results

Maize yield

The continuous application of fertilizers, FYM, and lime for 46 years influenced maize yield significantly (Table 2). Barring 100% N, all the treatments recorded significantly higher yield than control. The highest grain (4.64 t ha^{-1}) and stover yield (7.7 t ha^{-1}) of maize were recorded under 100% NPK + FYM which were statistically equivalent to 100% NPK + lime. The lowest maize yield was recorded in control which was 79% lower than 100% NPK, while, 100% N recorded zero yields. The use of FYM and lime increased grain yield by 48% and 37% over alone use of NPK, respectively. Application of higher fertilizer doses (150% NPK) registered no significant increase in grain yield over 100% NPK.

Starch content

The significant difference in starch content of maize grain due to long-term use of fertilizers, FYM, and lime was recorded. The values of starch content ranged from 61.55% to 67.09% (Table 3). The starch content under 100% N could not be determined due to zero yield under this treatment. The treatment 100% NPK + FYM recorded 8.02% higher starch content than control. The use of lime resulted in significantly higher starch content (66.51%) of maize grain than 100% NPK (63.56%). Application of 100% NPK + Zn (64.90%) increased the starch content of maize grain significantly over the application of 100% NPK alone, whereas 100% NP (61.55%) recorded significantly lower starch content than 100% NPK. Starch content was positively and significantly correlated with K (r = 0.937**) and Zn (r = 0.766**) content of maize grain (Table 5).

Reducing and non-reducing sugar content

The highest reducing sugar (1.13%) and non-reducing sugar content (0.59%) of maize grain were recorded under 100% NPK + FYM treatment, which was significantly higher over the rest of the treatments (Table 3). Lime application increased the reducing and non-reducing sugar content of

Table 2. Effect of continuous use of fertilizers, FYM, and lime on maize yield (t ha^{-1}).

	Yield (t ha^{-1})		
Treatment	Grain	Stover	Biological
50% NPK	3.07	5.1.	8.19
100% NPK	3.15	5.27	8.42
150% NPK	2.75	4.66	7.36
100% NPK + HW	3.66	6.15	9.81
100% NPK + Zn	3.01	5.03	8.05
100% NP	1.49	2.53	4.02
100% N	0.00	0.00	0.00
100% NPK + FYM	4.64	7.70	12.35
100% NPK (-S)	1.41	2.39	3.80
100% NPK + lime	4.31	7.34	11.66
Control	0.64	1.12	1.76
CD (*P* = .05)	0.49	0.75	1.24
SE (m±)	0.21	0.32	0.53

Table 3. Effect of continuous use of fertilizers, FYM, and lime on quality parameters of maize grain.

Treatment	Starch (%)	Reducing sugars (%)	Non-reducing sugars (%)	Total carbohydrate (%)	Crude protein (%)	Ash (%)	Crude fat (%)	Crude fiber (%)
50% NPK	64.33	0.75	0.41	70.94	8.46	1.48	4.72	1.79
100% NPK	63.56	0.82	0.43	70.76	9.13	1.58	4.79	1.81
150% NPK	62.43	0.71	0.39	70.61	9.35	1.52	4.83	1.77
100% NPK + HW	65.69	0.99	0.47	71.22	9.65	1.62	4.85	1.83
100% NPK + Zn	64.90	0.92	0.44	70.78	9.23	1.59	4.82	1.76
100% NP	61.55	0.74	0.33	70.11	8.04	1.42	4.68	1.70
100% N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100% NPK + FYM	67.09	1.13	0.59	72.09	10.33	1.70	4.94	1.88
100% NPK (-S)	62.48	0.72	0.35	70.55	7.96	1.49	4.51	1.68
100% NPK + lime	66.51	1.03	0.52	71.81	9.81	1.66	4.91	1.86
Control	62.01	0.67	0.32	70.09	7.67	1.40	4.45	1.65
CD (P = .05)	1.28	0.06	0.04	0.61	0.27	0.07	0.06	0.03
SE (m±)	0.54	0.03	0.02	0.26	0.11	0.03	0.02	0.01

maize grain significantly over 100% NPK by 25.6% and 20.9%, respectively. Control and 100% NP recorded 18.3% and 9.8% lower reducing sugar content than 100% NPK, respectively, whereas reduction in non-reducing content was to the extent of 25.6% and 23.2%, respectively. A significant increase in reducing sugar content was recorded when NPK dose was increased from 50% to 100% but further increase to 150% decreased the reducing sugar content by 13.4%. However, the non-reducing sugars content in 100% NPK was at par with 50% NPK and 150% NPK.

Total carbohydrate content

Integrated use of fertilizer with organic manure or lime influenced total carbohydrate content of maize grain significantly over sole use of fertilizers. Application of 100% NPK + FYM was found to be at par with 100% NPK + lime (Table 3). Control recorded the lowest carbohydrate content (70.09%) and was statistically comparable to 100% NP, 100% NPK (-S) and 150% NPK. The omission of potassic fertilizers (100% NP) decreased the carbohydrate content of maize grain content significantly in comparison to 100% NPK. On the other hand, Zn application (100% NPK + Zn) showed no significant increase in carbohydrate content over 100% NPK.

Crude protein content

Application of inorganic fertilizers either alone or in combination with FYM and lime increased the crude protein content of maize grain significantly over control (Table 3). The highest crude protein content (10.33%) was recorded under 100% NPK + FYM, followed by 9.81% under 100% NPK + lime and the lowest in control (7.67%), barring 100% N alone. Application of recommended dose of NPK recorded 19.1% higher crude protein content as compared to control. Whereas the integrated use of FYM or lime with 100% NPK increased the crude protein content of maize grain over control by 34.6% and 27.9%, respectively. The use of S-free fertilizers in 100% NPK (-S) decreased the crude protein content of maize grain to the extent of 12.8% compared to 100% NPK (+S). Each increment in NPK dose from 50% to 150% increased the crude protein content significantly. Crude protein content showed perfect correlation with maize grain N content (r = 1.00**), followed by K content (r = 0.982**) (Table 5).

Ash content

The ash content of maize grain ranged from 1.40% in control to 1.70% in 100% NPK + FYM (Table 3). Application of 100% NPK + FYM recorded significantly higher ash content of maize than the rest of the treatments except 100% NPK + lime. A significant increase in ash content was recorded due to the application of 100% NPK over control, the increase being 12.8%. The ash content recorded at 100% NPK was statistically comparable to 150% NPK, 100% NPK + HW and 100% NPK + Zn. A positive and significant correlation was recorded between ash and nutrient content of maize grain, highest with N content (r = 0.991**) (Table 5).

Crude fat content

Crude fat content was positively and significantly influenced by the continuous application of fertilizers, FYM, and lime (Table 3). Application of 100% NPK + FYM and 100% NPK + lime increased crude fat content by 3.1% and 2.5% over 100% NPK, respectively. The crude fat content recorded at 100% NPK + lime (4.91%) was statistically comparable to 100% NPK + FYM (4.94%). The application of the recommended dose of NPK increased the crude fat content over control by 7.6%. A significant reduction (5.8%) in the crude fat content of maize grain was recorded in 100% NPK (-S) compared to NPK (+S). Crude fat content was significantly and positively correlated with maize grain S content (r = 0.809).

Crude fiber content

Application of 100% NPK + FYM recorded the highest crude fiber content (1.88%) of maize grain which was at par with 100% NPK + lime (1.86%). Recommended dose of NPK increased the fiber content of maize grain over control by 8.8% (Table 3). The conjoint use of 100% NPK with FYM and lime resulted in 13.9% and 12.7% higher crude fiber content than control, respectively. Imbalanced fertilization, i.e., 100% NP and 100% NPK (-S) reduced the grain fiber content by 6.1% and 7.2%, respectively, as compared to the balanced application of fertilizers (100% NPK).

Nutrient content

The continuous application of fertilizers and amendments (FYM or lime) significantly influenced the nutrient content of maize grain (Table 4). The highest P, Mg, and Fe content of maize grain were recorded under 100% NPK + FYM treatment. However, 100% NPK + lime and 100% NPK + Zn recorded the highest Ca and Zn content, respectively. The addition of FYM or lime with 100% NPK increased the P content of maize grain by 39.3% and 21.1% compared to 100% NPK, respectively. The Ca and Zn content of maize grain recorded a significant increase with lime and Zn application over 100% NPK, the increase being 30.5% and 66.6%, respectively. Significant reduction in P, Ca, Mg, Fe,

Table 4. Effect of continuous use of fertilizers, FYM, and lime on the nutrient content of maize grain.

Treatment	Phosphorus content (%)	Calcium content (%)	Magnesium content (%)	Iron content (mg kg^{-1})	Zinc content (mg kg^{-1})
50% NPK	0.30	0.20	0.09	63	24
100% NPK	0.33	0.23	0.11	67	27
150% NPK	0.37	0.25	0.12	70	28
100% NPK + HW	0.34	0.24	0.11	72	28
100% NPK + Zn	0.31	0.23	0.10	65	45
100% NP	0.28	0.18	0.08	53	21
100% N	0.00	0.00	0.00	0	0
100% NPK + FYM	0.46	0.26	0.13	79	33
100% NPK (-S)	0.34	0.17	0.08	55	21
100% NPK + lime	0.40	0.30	0.12	65	29
Control	0.26	0.14	0.06	41	17
CD (P = .05)	0.05	0.02	0.02	5	4
SE (m±)	0.02	0.02	0.01	2	2

Table 5. Correlation coefficients between quality traits and nutrient content of maize grain (*P* = .05).

	N	P	K	Ca	Mg	S	Fe	Cu	Mn	Zn
Reducing sugars	0.942**	0.925**	0.923**	0.920**	0.876**	0.868**	0.925**	0.924**	0.918**	0.826**
Non-reducing sugars	0.944**	0.943**	0.951**	0.936**	0.917**	0.912**	0.943**	0.961**	0.940**	0.811**
Starch	0.973**	0.886**	0.937**	0.864**	0.830**	0.786**	0.902**	0.864**	0.921**	0.766**
Total carbohydrate	0.960**	0.868**	0.923**	0.840**	0.811**	0.759**	0.884**	0.843**	0.904**	0.740**
Crude protein	1.00**	0.944**	0.981**	0.942**	0.909**	0.891**	0.965**	0.939**	0.972**	0.825**
Crude fiber	0.982**	0.899**	0.955**	0.887**	0.855**	0.816**	0.923**	0.888**	0.941**	0.770**
Crude fat	0.978**	0.891**	0.948**	0.878**	0.845**	0.809**	0.916**	0.879**	0.934**	0.775**
Ash content	0.991**	0.926**	0.963**	0.906**	0.870**	0.832**	0.939**	0.906**	0.950**	0.802**

** Significant at (*P* = 0.05)

and Zn content of maize grain was recorded with imbalanced fertilization (100% NPK (-S) and 100% NP) in comparison to 100% NPK.

Discussion

Maize yield

The application of FYM combined with mineral fertilizers improved chemical, biological, and physical properties of soil and maintained a balanced supply of nutrients (Macholdt, Piepho, and Honermeier 2019) which resulted in better growth and higher crop yield. Sharma et al. (2014), Singh et al. (2017) and Rajneesh et al. (2018) also reported higher yield of maize under integrated nutrient management as compared to chemical fertilizers alone. The higher yield in 100% NPK + lime could be due to amelioration of soil acidity (Manna et al. 2007), increased availability of macro and micronutrients (Castro and Crusciol 2015), and biological activity (Badalucco et al. 1992; Dhiman et al. 2019). Development of acute soil acidity, accumulation of toxic level of NH_4^+ ions (Hynes 1986), Al^{3+} ions (Rajneesh, Sankhyan, and Kumar 2017) due to the application of urea alone for more than four decades are probably the reasons for zero yields recorded under 100% N treatment. The crop yield increases with higher fertilization but not above optimum level (Hao et al. 2007), probably due to this, application of the super optimal dose of fertilizers (150% NPK) could not increase the yield of maize significantly over 100% NPK probably due to the deficiency of secondary nutrients particularly Mg. These results corroborate the findings of Brar et al. (2015) and Dhiman et al. (2019).

Starch content

The combined application of FYM and NPK fertilizers recorded the higher starch content than NPK alone or imbalanced fertilization, i.e., 100% NP and 100% NPK (-S). Release of macro and micronutrients, hormones, and growth-promoting substances from FYM leading to improved physio-chemical reactions in plants could be responsible for this increase in the starch content (Chen, Liu, and Jiang 2017; Mariappan et al. 2016). Significant improvement in starch content with liming over 100% NPK alone could be attributed to the increased nutrient availability due to the neutralization of soil acidity (Singh et al. 2017). Higher starch content in 100% NPK than 100% NP could be due to the adequate supply of K that plays an important role in the conversion of sugars into starch (Radulov et al. 2012). Das, Ram, and Sirari (2012) also recorded a reduction in wheat grain starch content when K was omitted from fertilization schedule. The application of Zn along with balanced fertilization improved the starch content probably due to the physiological role of Zn in carbohydrate synthesis (Kumar and Bohra 2014).

Reducing and non-reducing sugar content

Integration of FYM with inorganic fertilizers recorded higher sugar content than inorganic fertilizers alone which might be due to the balanced supply of essential nutrients playing a vital role in the synthesis of sugars (Bhatt et al. 2016; Safiullah et al. 2018). Integrated nutrient management treatment might have improved the overall soil health, leading to an ideal supply of almost all the nutrients, required for various physiological and biochemical reactions in the plants (Sujith, Sudhir, and Shivraj 2016). Since K plays a key role in the synthesis and efficient transportation of sugars in plants (Radulov et al. 2012), its low availability to the plants in 100% NP treatment and control might have hampered transportation of sugars from source to sink thereby resulting in lower sugar content under these treatments.

Total carbohydrate content

The adequate and balanced supply of nutrients required for various metabolic activities within the plants (Castro and Crusciol 2015; Chauhan et al. 2020; Fadlalla, Abukhlaif, and Mohamed 2016) might have resulted in high carbohydrate content under 100% NPK + FYM and 100% NPK + lime. The omission of K in 100% NP led to K starvation in plants (Hernández-Pérez et al. 2019), impairing the synthesis of carbohydrates and their translocation from leaves to the grains (Cakmak 2005). Kamalakumari and Singaram (1996) and Sujith, Sudhir, and Shivraj (2016) have also reported a significant reduction in the total carbohydrate content of maize grain due to the omission of potassium fertilizers. Inadequate plant nutrition led to low carbohydrate content in control.

Crude protein content

The crude protein content was significantly and positively influenced by integrated use of chemical fertilizers and FYM which could be ascribed to the sufficient supply of essential and beneficial nutrient elements particularly N from FYM and fertilizers (Liu et al. 2016; Zafar et al. 2011). The positive effect of lime application on the crude protein content of maize grain could be due to the increased activity of nitrifying bacteria leading to higher availability of N for uptake (Castro and Crusciol 2015). In 100% NPK (-S), low crude protein content was recorded probably because of the deficiency of S in the soil, leading to poor S uptake and thereby, reduced synthesis of S-containing amino acids (Sujith, Sudhir, and Shivraj 2016).

Ash content

Ash content is the measure of the total amount of minerals present in produce. The treatments comprising NPK fertilizers, FYM, and lime registered an increase in ash content over control. The addition of FYM, and lime along with NPK fertilizers increased the availability and uptake of mineral nutrients leading to the higher mineral content of maize grain since there is a positive relationship between available soil nutrients and ash content of maize grain (Thakur et al. 2019). Karforma et al. (2012) and Nwite et al. (2018) have also reported the positive effect of organic manure on the ash content of maize. The low ash content of maize grain under control could be attributed to continuous cropping without fertilization resulting in low soil fertility (Bhattacharyya et al. 2016).

Crude fat content

Significantly higher crude fat content in maize grain under 100% NPK alone over control might be due to higher fat metabolism associated with higher soil nutrient levels. However, 100% NPK + FYM treatment was most effective among all the treatments which might be ascribed to the release of higher contents of essential nutrients, better uptake, and synthesis of more glycosides (Aldalin 2017). The favorable effect of organic manure on the crude fat content has been earlier reported by Chen, Liu, and Jiang (2017), and Chauhan et al. (2020). The deficiency of S in soil due to the continuous use of S-free fertilizers in 100% NPK (-S) might have resulted in the lower crude fat content since S plays an essential role in biosynthesis of fats (Liu et al. (2016)).

Crude fiber content

Crude fiber is an important constituent of the human diet. Nutrient availability greatly affects the crude fiber content of plants (Elsheikh and Mohameszein 1998). Thakur et al. (2019) have reported a positive correlation between available soil nutrients and crude fiber content of maize grain. Therefore, a significant increase in crude fiber content with the integration of chemical fertilizers and organic manure could be ascribed to the optimum nutrient availability and improved soil properties (Meena et al. 2013; Nwite et al. 2018,; Chauhan et al. 2020). Liming significantly improved the crude fiber content of maize grain, which might be due to the positive effect of lime application on physical, chemical, and biological properties of soil (Kumar et al. 2014; Singh et al. 2009).

Nutrient content

The significant increase in the nutrient content of maize grain with combined application of FYM and NPK fertilizers over NPK fertilizers alone could be due to better root growth (Bandyopadhyay et al. 2010), the addition of nutrients into the soil through organic manure (Saha et al. 2019), increased availability of native nutrients (Gosal et al. 2018) and higher nutrient uptake (Chauhan et al. 2020; Hossain, Kibria, and Osman 2012). The high Ca content of maize grain due to the lime application might be attributed to the increased availability of Ca by neutralization of soil acidity and addition of Ca through lime (Moreira, Fageria, and Garcia 2011). Castro and Crusciol (2015) also reported an increase in Ca concentration of maize grain with lime application in the soils of Botucatu, Brazil. The decrease in nutrient content due to continuous intensive cropping with imbalanced fertilizer addition in 100% NP and 100% NPK (-S) treatments is understandable. The lowest nutrients' content of maize grain in control could be attributed to the depleted soil fertility in the absence of the addition of fertilizers.

Conclusion

Results from the present study demonstrated that balanced use of fertilizers alone or in combination with FYM or lime significantly improved the maize grain quality in terms of starch content, reducing and non-reducing sugar, crude protein content, ash content, crude fat content, crude fiber content, total carbohydrate content, nutrient content. Omission of sulfur and potassium not only declined the maize yield significantly but grain quality also. Thus, it can be concluded from the study that conjoint use of inorganic fertilizers and FYM and amelioration of soil acidity is essential to improve the nutritional quality of maize grains and obtain higher yields.

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