Content list available at http://epubs.icar.org.in, http://www.icarneh.ernet.in; ISSN: 0970-6429

Indian Journal of Hill Farming

Special Issue 2023, Volume 36, Pages 99-106

Long-term effect of target yield-based nutrient management on nutrient uptake and economic performance of maize in North-Western Himalayas

Anjali Thakur* • Shashi Pal Dixit • Naveen Datt

Department of Soil Science, College of Agriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishwavidyalaya, Palampur, India-176062

ARTICLE INFO

Article history:
Received: 25 June, 2023
Revision: 30 June, 2023
Accepted: 14 July, 2023

Key words: *Benefit-cost ratio, FYM, maize, micronutrients, STCR, target yield*

DOI: 10.56678/iahf-spl36.2023.15

ABSTRACT

The present research endeavour was executed in a long-term fertilizer experiment on soil test crop response during 14th and 15th cropping cycle at the experimental farm of Department of Soil Science, CSK HPKV Palampur. The aim was to compare different fertilizer application approaches with respect to maize productivity and economic performance. Results revealed that target yield-based nutrients application significantly increased the maize grain and stover yield over farmers' practice, general recommended dose and soil test-based fertilizer application. The farmyard manure (FYM) application with fertilizers for 30 and 40 q ha^{-1} yield target led to 10.2 and 8.6 per cent increase in maize grain yield over respective yield target treatments without FYM. The highest uptake of N, P, K, S, Ca, Mg, Fe, Mn, Zn and Cu by maize was recorded in 40 q ha^{-1} target yield + FYM treatment (T_8), followed by 40 q ha^{-1} target yield treatment (T_7). The target yield treatments (T_5, T_6, T_7, T_8) recorded significantly higher productivity and nutrients uptake than conventional fertilizer application approaches. The highest B:C (3.03), net returns (₹ 65,524 ha^{-1}) and economic efficiency (₹ 579 ha^{-1} day^{-1}) were recorded in the treatment for 40 q ha^{-1} target (T_7), whereas, gross returns (₹ 1,06,639 ha^{-1}) were maximum under 40 q ha^{-1} target yield + FYM treatment (T_8). This study suggests that target yield-based integrated nutrient application is a sustainable and economically viable approach for enhancing the production and income from the cereal-based cropping system of North-western Himalayas.

1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops of North-western Himalayan region, commonly cultivated in rotation with wheat (*Triticum aestivum* L.). While making a 10 per cent contribution to the national food-basket, it covers nearly 9.9 million hectares of the total cultivated area (Agricultural Statistics at a Glance 2021). The national average production of maize is merely 3.1 t ha^{-1} which is far below the world's average of 5.8 t ha^{-1} (FAOSTAT 2022). In North-western Himalayan region, productivity of maize is even lower. Imbalanced and inadequate use of fertilizers without considering the crop requirements and soil nutrient status has been attributed to its low productivity (Shabnam and Sharma, 2016). After sugarcane, maize is the most exhaustive crop that needs markedly higher amount of macro and micro nutrients to realize its high genetic yield potential (Kumar and Shivay, 2019; Meena *et al.,* 2019). Raising the productivity of the crop in an economic and sustainable manner is the need of the hour to meet the ever-increasing food demand (Parmar *et al.,* 2022).

Higher crop yields can be obtained using chemical fertilizers (Gao *et al.,* 2015), provided they are used judiciously. The soil health has been reported to deteriorate under the continuous imbalanced (N or NP alone), over or under application of fertilizers (Kumari *et al.,* 2013; Jadhao *et al.,* 2019; Thakur *et al.,* 2023). Even with the balanced NPK application, a decline in the crop productivity over time has been observed in the absence of organic manuring (Moharana *et al.,* 2017). However, it is not possible to completely abandon the chemical fertilizers and entirely rely upon organic manures since their limited availability and poor nutrient content cannot meet the high nutrient demands for crop production (Bayu *et al.,* 2006; Yang *et al.,* 2015).

*Corresponding author: thakur.anjali.626@gmail.com

Integration of organic manures with balanced chemical fertilizers, on the other hand, can aid in attaining and sustaining higher yields by improving the soil health (Qin *et al.,* 2015; Chen *et al.,* 2018). The increased availability and uptake of essential macro and micro nutrients through various mechanisms due to the combined application of organic manures and balanced chemical fertilizers has been well documented (Das *et al.,* 2010; Gao *et al.,* 2015). Although, without determining the exact nutritional requirement of the crop and the nutrient status of the soil, a balanced and judicious nutrients' application is not possible.

In order to attain sustainability in agricultural systems with healthy soils, a nutrient management module is needed which supplies the precise amount of essential nutrients to the crop according to its needs and soil fertility. Fertilizer prescription based on soil test crop response correlation (STCR), also known as the target yield based fertilization, takes fertility status of the soil and crop's nutrient requirement for obtaining desired yield levels soil into account to determine the fertilizer doses (Venkatesh *et al.,* 2022). Numerous validation trials and demonstrations in farmers' fields have been carried out under the All India Coordinated Research Project on STCR (AICRP-STCR) to establish the targeted yield-based fertilizer recommendations (Moharana *et al.,* 2017). The conjoint use of chemical fertilizers and organic manures to provide target yield based nutrients to the crop forms the basis for soil test crop response based integrated plant nutrient system (STCR-IPNS). Many researchers have demonstrated considerable improvement in nutrients responses and crop yields with the adoption of STCR-IPNS (Kurbah and Dixit, 2019; Meena *et al.,* 2019; Singh *et al.,* 2021). Yet, limited information is available on the comparative effect of continuous use of STCR-IPNS modules and conventional fertilization approaches in a maize-wheat cropping system of North-western Himalayas. Crop-nutrient dynamics under target yield based fertilization modules with or without FYM can be assessed better in the long-term fertilizer experiments. Bearing these facts in mind, present study was conducted with the prime aim to compare maize productivity and carry out an economic audit of continuous target yield-based fertilizers and farmyard manure (FYM) application in comparison to conventional fertilizer application approaches under a rainfed cereal-based cropping system in North-western Himalayas.

2. Material and Methods

Experimental location

Present investigation was conducted during *kharif,* 2020 and 2021 in a long-term fertilizer experiment on STCR in maize-wheat cropping sequence. The experiment was initiated in *kharif,* 2007 at the experimental farm of the Department of Soil Science, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh. The experimental area is located 1290 m above mean sea level at 32º7' N latitude and 76º3' E longitude. A total rainfall of 1449 and 1989 mm was received during *kharif* 2020 and 2021, and the air temperature varied from 13.2 to 30.5 ℃ and 14.9 to 31.1 ℃, respectively. The Typic Hapludalf soil of the region was silty clay loam in texture. At the start of the experiment (*kharif,* 2007), the soil was acidic in reaction (pH 5.2), medium in organic carbon (7.2 g kg^{-1}), low in available N (236 kg ha^{-1}), high in available P (41 kg ha^{-1}) and medium in available K (272 kg ha^{-1}) and had sufficient DTPA-extractable Fe (23.2 mg kg^{-1}), Mn (21.4 mg kg^{-1}), Zn (1.25 mg kg^{-1}) and Cu (0.75 mg kg^{-1}).

Experimental layout and treatment

The experiment was laid out in a randomized block design. It comprised of eight treatments replicated thrice, T_1: control, T_2: farmers' practice; 25 per cent of general recommended N dose (30 kg ha^{-1}) + 5 t FYM ha^{-1} (dry weight basis), T_3: general recommended dose of N, P_2O_5 and K_2O (i.e., 120, 60 and 40 kg ha^{-1} respectively), T_4: soil test-based fertilizer application, T_5: fertilizers application for 30 q ha^{-1} target yield, T_6: 30 q ha^{-1} target yield + 5 t FYM ha^{-1}, T_7: 40 q ha^{-1} target yield and T_8: 40 q ha^{-1} target yield + 5 t FYM ha^{-1}. Fertilizer doses for target yield treatments were determined using the following equations:

i. $FN = 5.88T - 0.23SN - 0.93ON$

ii. $FP_2O_5 = 4.87T - 1.22SP - 0.81OP$

iii. $FK_2O = 3.66T - 0.49SK - 0.51OK$

Here FN, FP_2O_5, and FK_2O were respective fertilizer doses of N, P_2O_5 and K_2O in kg ha^{-1}; T was the yield target (q ha^{-1}); SN, SP and SK were the respective soil available N, P and K contents (kg ha^{-1}) before sowing of the crop; ON, OP and OK denoted N, P and K supplied by FYM (kg ha^{-1}).

Field operations

During both the years, maize was sown in the month of June and harvested on attaining physiological maturity in the month of October. One pre-sowing irrigation was given to the crop; thereafter, water requirement of the crop was met through rainfall. One-third dose of N and full doses of P and K were applied at the time of sowing through urea, single super phosphate (SSP) and muriate of phosphate (MOP), respectively. The remaining N was top dressed at knee-high and pre-tasselling stages of maize. All other recommended cultural practices were followed during the crop growth period. The grain and stover yields were recorded at the time of harvesting and expressed at 15 per cent moisture content and on dry weight basis, respectively.

Plant sampling and analysis

Representative grain and stover samples of maize were collected from each plot after harvesting during both years. The collected plant samples were dried in a hot air oven at 60 ℃ for 48 hours. The dried grain samples were ground to a fine powder using a stainless-steel grinder and stored in air-tight bags for further analysis. The dried stover samples were ground in a Wiley mill fitted with stainless-steel parts and stored in paper bags. The grain and stover samples were subjected to analysis as per the standard methods for N (micro-Kjeldahl distillation), P (spectrophotometric determination of phospho-vanadomolybdate complex), K and Ca (flame photometry), S (turbidimetry) and Mg, Fe, Mn, Zn and Cu (atomic absorption spectrophotometry). The uptake of nutrients by maize grain and stover was calculated using the following formula:

$$\text{Nutrient Uptake} = \frac{\text{Nutrient concentration} \times \text{Dry matter yield}}{100}$$

Economic analysis

The gross returns, net returns and benefit to cost ratio (B:C) of different fertilizer application approaches were computed to assess their economic performance. The total cost of cultivation in Indian Rupee (₹ ha^{-1}) was worked out by adding the cost of seeds, fertilizers, manure, plant protection measures, field preparation and labour. The net returns (₹ ha^{-1}) were calculated by subtracting total cost of cultivation from gross returns (₹ ha^{-1}). The B:C was calculated by dividing gross returns with total cost of cultivation. The economic efficiency (₹ ha^{-1} day^{-1}) was determined by dividing net returns (₹ ha^{-1}) by crop duration (days), where the duration was average of two years (116 days) and same for all the treatments.

Statistical analysis

The data were subjected to analysis of variance and Duncan's multiple range post-hoc test (DMRT) to compare the means at 5 per cent level of significance using an online statistical software by Sheoran *et al.,* (1998).

3. Results and Discussion

Maize yield

The pooled analysis of two-years data (2020 and 2021) indicated a significant effect of different fertilizer application approaches on the maize yield (Fig. 1). General recommended dose (T_3) and soil test-based application (T_4) registered a significant rise in the maize grain yield (22.1 and 32.7 %, respectively) as compared to the farmers' practice (T_2). The balanced NPK fertilization in T_3 and T_4 led to the significant improvement in maize yield (Meena *et al.,* 2021). The maize grain and stover yield were substantially superior in target yield based treatments compared to general recommended dose (T_3) and soil test-based application (T_4), maximum (41.6 q ha^{-1}) being under 40 q ha^{-1} target yield + FYM (T_8). In addition to achieving the yield targets of 30 and 40 q ha^{-1} the adoption of target yield based integrated nutrient management approach resulted in respective 10.2 and 8.6 per cent increase in maize grain yield over targeted yield based application of chemical fertilizers, Marked improvement in maize yield was noted with integrated application of target yield based chemical fertilizers and FYM over sole application of target yield based fertilizers and general recommended dose due to the continuous release and lesser losses of essential secondary and micronutrients from FYM and improved soil properties (Banik *et al.,* 2006; Moharana *et al.,* 2017). These results confirmed the superiority of STCR based integrated nutrient management approach on the conventional fertilizer application modules.

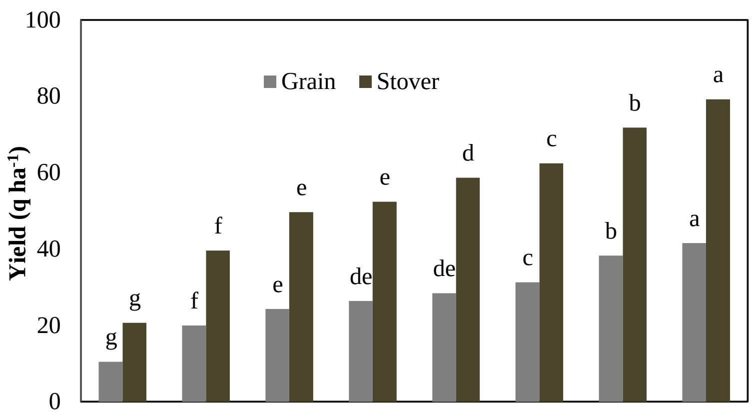

Figure 1. Effect of long-term application of target yield based chemical fertilizers and FYM on productivity of maize (pooled data of year 2020 and 2021). Bars with different lowercase letter are significantly different based on the DMRT (p = 0.05).

Uptake of Macronutrients

Pooled mean of the N, P and K uptake by maize during 2020 and 2021 has been illustrated in Fig. 2. A perusal of the data indicated that the N, P and K uptake by maize grain varied significantly within the treatments. The highest N, P and K uptake by maize grain was recorded in targeted yield of 40 q ha^{-1} + FYM (T_8) and it was significantly higher than rest of the treatments. The amount of nutrients taken up by the plants primarily depends upon the concentration of these nutrients in the close proximity to the root surface and the quantity of fertilizers applied (Singh and Sarkar, 1985). An increase in the concentration of N, P, K are understandable as the use of organics, when applied along with chemical fertilizers, might have augmented the nutrient supply in the rhizosphere after their mineralization/decomposition. Similarly, FYM application in 30 q ha^{-1} target yield treatment (T_6) significantly improved N, P and K uptake over its non-IPNS counterpart (T_5). Whereas, control (T_1) recorded lowest N, P and K uptake by maize over all other treatments. The continuous cropping over the years exhausted the native nutrient reserves of the soil in absence of addition of nutrients from any external source which declined the crop productivity. Application of general recommended dose (T_3) and soil test-based fertilizer application (T_4) significantly improved the N, P and K uptake by maize over farmers' practice (T_2) and control (T_1), but were statistically inferior to all the STCR treatments. Results documented by Sharma *et al.,* (2016) and Puli *et al.,* (2017) agree with the present findings.

Uptake of Secondary Nutrients

The pooled mean of S, Ca and Mg uptake by maize grain and stover during 2020 and 2021, as affected by the continuous application of target yield based chemical fertilizers and organic manure have been presented in Fig. 2. The effect of different fertilizer application modules on S, Ca and Mg uptake was found to be significant. The highest pooled S, Ca and Mg uptake by maize grain (16.4, 12.8 and 4.9 kg ha^{-1}, respectively) was recorded in 40 q ha^{-1} target yield + FYM (T_8), which was significantly superior than other treatments. This is probably due to the fact that application of FYM not only solubilizes the unavailable nutrients but also adds significant amount of S, Ca and Mg into the soil nutrient pool. Thus, its application resulted in an overall significant increase in the uptake of nutrients. Kumar *et al.,* (2009) and Thakur *et al.,* (2022) have also reported marked improvement in the S, Ca and Mg uptake due to the combined application of organic manure with chemical fertilizers. Application of FYM in farmers' practice (T_2) significantly increased the uptake of secondary nutrients over control, however, imbalanced and insufficient fertilizer application resulted in significant reduction in the nutrients uptake as compared to the general recommended dose (T_3) and soil test-based fertilizer application (T_4). Control (T_1) was found to be statistically inferior to all other treatments. In the absence of addition of S, Ca and Mg from any external source, continuous cropping over the years depleted the nutrient reserves in the soil, which might have attributed towards low crop growth and nutrients uptake (Kundu *et al.,* 2016).

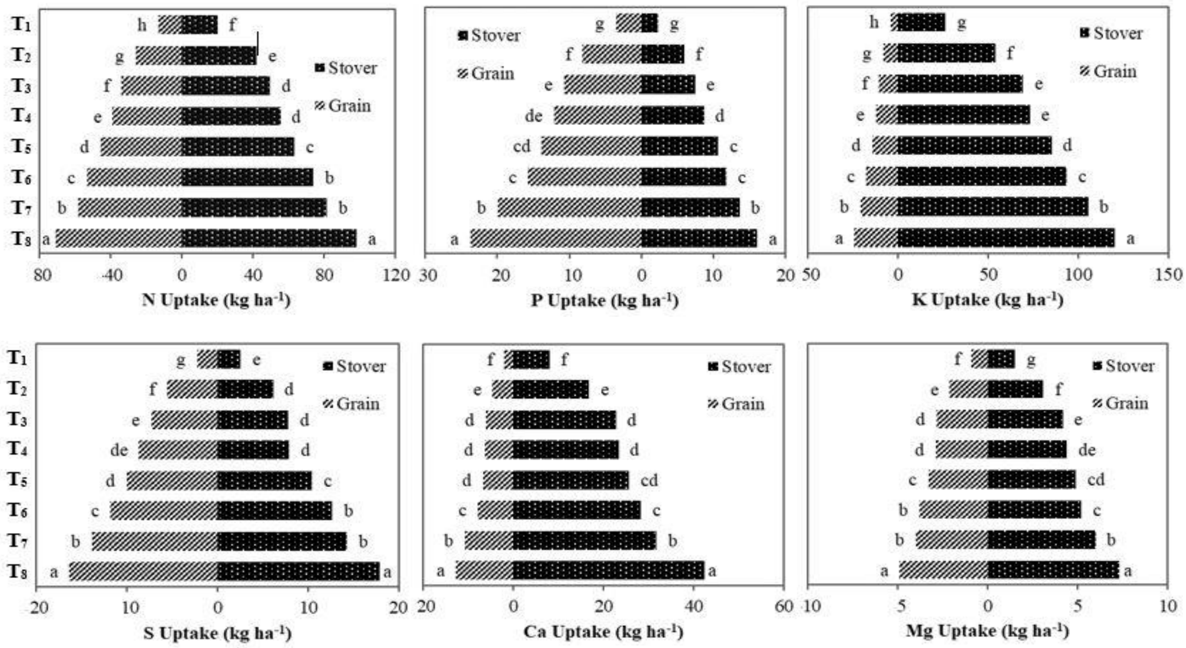

Figure 2. Effect of long-term application of target yield based chemical fertilizers and FYM on N, P, K, S, Ca and Mg uptake by maize (pooled data of year 2020 and 2021). Bars with different lowercase letter are significantly different based on the DMRT (p = 0.05).

Uptake of Micronutrient cations

Figure 3 depicts the impact of continuous application of target yield based chemical fertilizers and organic manure on Fe, Mn, Zn and Cu uptake by maize grain and stover. Application of FYM with chemical fertilizers for 30 and 40 q ha^{-1} target yields (T_6 and T_8) significantly improved the uptake of micronutrient cations by maize grain and stover over their respective non-FYM receiving treatments (T_5 and T_7). This could be ascribed to the release of micronutrients into the soil through organic matter mineralization (Meena *et al.,* 2019). Furthermore, organic matter is believed to form chelates with micronutrients, reduce their losses, thus resulting in their higher uptake in chelated forms by the plants (Saraswat *et al.,* 2013). Favourable effects of the conjoint application of target yield based chemical fertilizers and FYM on micronutrients uptake have also been reported by Jadhav *et al.,* (2009), Shabnam *et al.,* (2017) and Moharana *et al.,* (2017). Farmers' practice (T_2), general recommended dose (T_3) and soil test-based fertilizer application (T_4) recorded significantly higher micronutrients uptake than control (T_1). This could be possibly due to higher availability of nutrients and biomass production in these treatments.

Economic returns

The pooled mean gross and net returns from maize varied significantly under different fertilizer application approaches (Table 1). Variable cost of inputs, effect of treatments on the crop yield and sale price of the produce could be ascribed as the reason for this (Meena *et al.,* 2021). The cost of inputs incurred under different fertilizer application approaches varied from ₹ 21,450 ha^{-1} in control (T_1) to ₹ 44,836 ha^{-1} in 40 q ha^{-1} target yield + FYM treatment (T_8). The highest gross returns from maize (₹ 1,06,639 ha^{-1}) were registered under 40 q ha^{-1} target yield + FYM treatment (T_8), but the net returns were highest under 40 q ha^{-1} target yield treatment (T_7), amounting to ₹ 65,524 ha^{-1}. The net economic returns obtained from the soil test-based fertilizer application (₹ 40,456 ha^{-1}) and 30 q ha^{-1} target yield + FYM treatment (₹ 39,761 ha^{-1}) did not differ significantly. Within different fertilizer application modules, the highest B:C was recorded in T_7 (3.03), followed by T_5 (2.56). Despite the higher gross returns under T_6 and T_8, the B:C of these treatments was lower than T_5 and T_7 because of high input cost of FYM. However, the cost of FYM may not be considered a limitation since the continuous addition of FYM improves the soil health and sustains crop yields over the years (Umesh *et al.,* 2014; Vikram *et al.,* 2015), which far surpasses the momentary economic returns. Moreover, FYM is available to most of the farmers at their own farms do they do not buy it at the high commercial rates (Shabnam *et al.,* 2017). The economic efficiency of T_7 was highest (₹ 579 ha^{-1} day^{-1}), closely followed by T_8 (₹ 554 ha^{-1} day^{-1}). High net returns obtained in these treatments could be attributed to this (Singh *et al.,* 2021). The economic efficiency of maize was improved by almost 14.3 to 77.7 percent due to STCR-IPNS based nutrient management over the general recommended dose application.

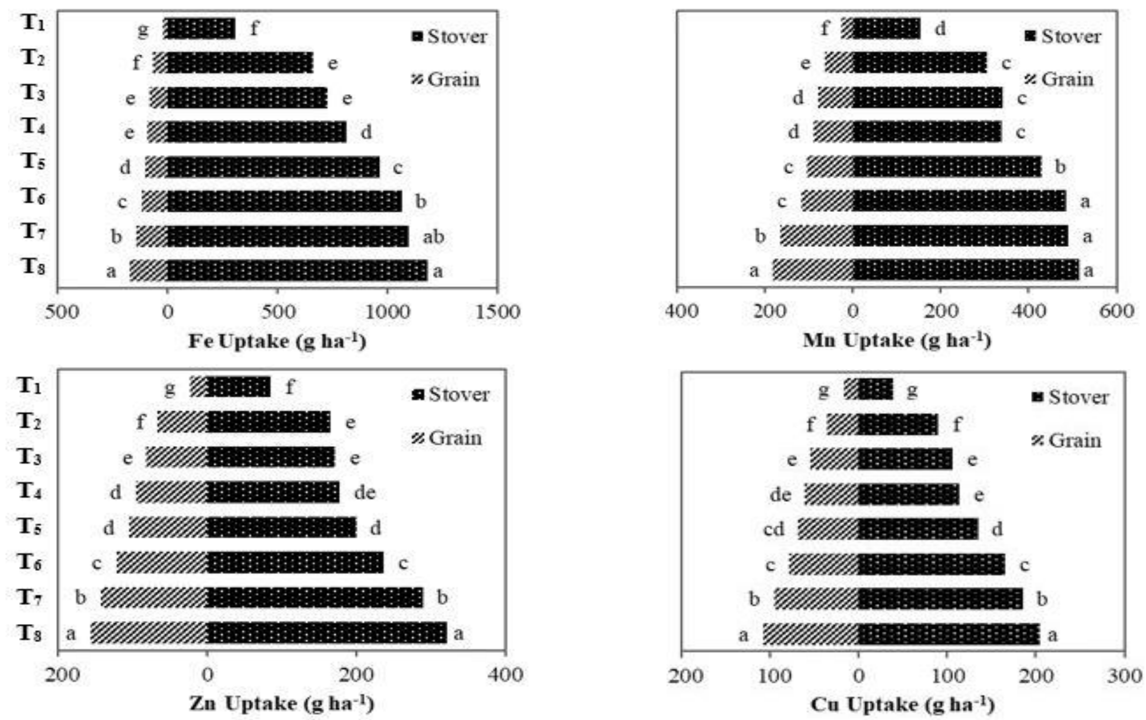

Figure 4. Effect of long-term target yield based application of chemical fertilizers and FYM on Fe, Mn, Cu and Zn uptake by maize (pooled data of 2020 and 2021). Bars with different lowercase letter are significantly different based on the DMRT (p = 0.05).

Table 1. Economics of maize (pooled mean of 2020 and 2021) under different nutrient management modules. Means followed by different lowercase letters within a column are significantly different according to DMRT (p = 0.05).

Treatment	Total variable cost (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	Benefit-cost ratio	Economic Efficiency (₹ ha^{-1} day^{-1})
T_1	21450^{h}	27019^{h}	5569^{g}	1.26	48^{f}
T_2	38114^{c}	51726^{g}	13612^{f}	1.36	117^{e}
T_3	28632^{f}	63408^{f}	34776^{e}	2.22	300^{d}
T_4	27825^{g}	68281^{e}	40456^{d}	2.45	349^{bc}
T_5	29086^{e}	74397^{d}	45311^{c}	2.56	391^{b}
T_6	41418^{b}	81178^{c}	39761^{d}	1.96	343^{cd}
T_7	32317^{d}	97841^{b}	65524^{a}	3.03	565^{a}
T_8	44836^{a}	106639^{a}	61803^{b}	2.38	533^{a}

The continuous application of target yield based chemical fertilizers with FYM led to markedly higher maize grain and stover yield, nutrients uptake and total economic returns as compared to conventional fertilizer application approaches. Even though the cost of production was also higher because of high cost of FYM, however, it could be overlooked because of the additional benefits of FYM on soil health and sustainability of cropping system. It is evident from the fact that FYM addition increased the maize grain yield by 10.2 and 8.6 per cent from corresponding 30 and 40 q ha^{-1} target yield based chemical fertilizers-only treatments. Soil-test based fertilizers and general recommended dose treatment were significantly superior to the control and farmers' practice, but were inferior to targeted yield treatments. Therefore, target yield based integrated nutrient management approaches should be encouraged for sustaining cereal-based cropping systems of north-western Himalayas.

4. Acknowledgement

The authors duly acknowledge the financial assistance provided by ICAR, New Delhi by sponsoring the All-India Co-ordinated Research Project on Soil Test Crop Response and CSK HPKV Palampur for providing facilities to carry out this study.

5. Statements and Declarations

The authors have no competing interests to declare.

6. References

Agricultural Statistics at a Glance (2021). Directorate of Economics and Statistics, Ministry of Agriculture & Farmers Welfare, Government of India. https://eands.dacnet.nic.in/PDF/Agricultural%20Statistics%20at%20a%20Glance%20-%202021%20(English%20version).pdf

Bayu W, Rethman NFG, Hammes PS, Alemu G (2006). Effects of farmyard manure and inorganic fertilizers on sorghum growth, yield, and nitrogen use in a semi-arid area of Ethiopia. J Plant Nutr 29: 391-407. https://doi.org/10.1080/01904160500320962

Banik P, Ghosal PK, Sasmal TK, Bhattacharya S, Sarkar BK, Bagchi DK (2006). Effect of organic and inorganic nutrients for soil quality conservation and yield of rainfed low land rice in subtropical plateau region. J Agron Crop Sci 192: 331-343. https://doi.org/10.1111/j.1439-037X.2006.00219.x

Chen H, Deng A, Zhang W, Li W, Qiao Y, Yang T, Zheng C, Cao C, Chen Fu (2018). Long-term organic plus organic fertilization increases yield and yield stability of winter wheat. Crop J 6: 589-599. https://doi.org/10.1016/j.cj.2018.06.002

Das A, Patel DP, Munda GC, Ghosh PK (2010). Effect of organic sources of nutrients on yield, nutrient uptake and soil fertility of maize (*Zea mays*)-mustard (*Brassica campestris*) cropping system. Indian J Agric Sci 80(1): 85-88

FAOSTAT. 2022. Food and Agriculture Organization of the United Nations (FAO). https://www.fao.org/faostat/en/#data/QCL (extracted on 03-12-2022).

Gao W, Yang J, Ren S, Hailong L (2015). The trend of soil organic carbon, total nitrogen, and wheat and maize productivity under different long-term fertilizations in the upland fluvo-aquic soil of North China. Nutr Cycling Agroecosyst 103: 61-73. https://doi.org/10.1007/s10705-015-9720-7

Jadhao SD, Mali DV, Kharche VK, Singh M, Bhoyar SM, Kadu P, Wanjari RH, Sonune BA (2019). Impact of continuous manuring and fertilization on changes in soil quality under sorghum-wheat sequence on a Vertisols. J Indian Soc Soil Sci 67(1): 55-64. https://doi.org/10.5958/0974-0228.2019.00006.9

Jadhav AB, Kadlag AD, Patil VS, Bachkar SR, Dale RM (2009). Response of chickpea to conjoint application of inorganic fertilizers based on STCR approach and vermicompost on Inceptisol. J Maharashtra Agric Univ 34(2): 125-127

Kumar AK, Sarkar AK, Kumar A, Singh BP (2009). Effect of long-term use of mineral fertilizers, lime and farmyard manure on the crop yield, available plant nutrient and heavy metal status in an acidic loam soil. J Indian Soc Soil Sci 57(3): 362-365.

Kumar V, Shivay YS (2010). Integrated nutrient management: an ideal approach for enhancing agricultural production and productivity. Indian J Fertil 6(5): 41-53.

Kumari G, Thakur SK, Kumar N, Mishra B (2013). Long term effect of fertilizers, manure and lime on yield sustainability and soil organic carbon status under maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system in Alfisols. Indian J Agron 58(2): 152-158.

Kundu DK, Mazumdar SP, Ghosh D, Saha AR, Mazumdar B, Ghorai AK, Behera MS (2016). Long-term effects of fertilizer and manure application on soil quality and sustainability of jute-rice-wheat production system in Indo-Gangetic plain. J Appl Nat Sci 8(4): 1793-1800. https://doi.org/10.31018/jans.v8i4.1042

Kurbah I, Dixit SP (2019). Effect of fertilizer application based on soil test crop response approach on active and passive pools of soil organic matter in maize-wheat cropping system. Arch Agron Soil Sci 66(6): 858-871. https://doi.org/10.1080/03650340.2019.1642468

Meena BP, Biswas AK, Singh M, Chaudhary RS, Singh AB, Das H, Patra AK (2019). Long-term sustaining crop productivity and soil health in maize-chickpea system through integrated nutrient management practices in Vertisols of central India. Field Crops Res 232: 62-76. https://doi.org/10.1016/j.fcr.2018.12.012

Meena BP, Biswas AK, Singh M, Das H, Chaudhary RS,Singh AB, Shirale AO, Patra AK (2021). Energy budgeting and carbon footprint in long-term integrated nutrient management modules in a cereal-legume (*Zea mays-Cicer arietinum*) cropping system. J Clean Prod 314: 127900. https://doi.org/10.1016/j.jclepro.2021.127900

Moharana PC, Sharma BM, Biswas DR (2017). Changes in the soil properties and availability of micronutrients after six-year application of organic and chemical fertilizers using STCR-based targeted yield equations under pearl millet-wheat cropping system. J Plant Nutr 40(2): 165-176. https://doi.org/10.1080/01904167.2016.1201504

Parmar V, Datt N, Kumar P, Dixit SP (2022). Soil test crop response based nutrient management modules for enhancing growth, productivity, profitability and nutrient uptake of maize in an acid Alfisol of north-western Himalayas. Indian J Ecol 49(4): 1369-1374. https://doi.org/10.55362/IJE/2022/3673

Puli MR, Prasad RK, Jayalakshmi M, Rao BS (2017). Effect of organic and inorganic sources of nutrients on NPK uptake by rice crop at various growth periods. Res J Agric Sci 8(1): 64-69. https://doi.org/10.31220/osf.io/9bhk3

Saraswat PK, Kumar S, Singh VK, Tiwari RC (2013). Rice (*Oryza sativa*)-wheat (*Triticum aestivum*) yield, nutrient content and their uptake and soil parameters as influenced by summer green manures and fertilizer management in rice-wheat cropping system. Indian J Agric Sci 83: 689-693.

Shabnam, Sharma SK (2016). Effect of prescription based fertilizer recommendations on micronutrients uptake and maize productivity under acid Alfisol of Himachal Pradesh. Himachal J Agric Res 42(2): 126-130

Shabnam, Sharma SK, Rana RS, Sankhyan NK (2017). Effect of STCR based nutrient management on yield, nutrient uptake and profitability of maize (*Zea mays*) in an acid Alfisol of Northwestern Himalayas. Ecol Environ Conserv 23(4): 2275-2279.

Sharma VK, Pandey RN, Kumar S, Chobhe KA, Suresh C (2016). Soil test crop response based fertilizer recommendations under integrated nutrient management for higher productivity of pearl millet (*Pennisetum glaucum*) and wheat (*Triticum aestivum*) under long term experiment. Indian J Agric Sci 86(8): 1076-1081.

Sheoran OP, Tonk DS, Kaushik LS, Hasija RC, Pannu RS (1998). Statistical Software Package for Agricultural Research Workers. In: Hooda DS,Hasija RC (eds) Recent Advances in Information Theory, Statistics & Computer Applications. Department of Mathematics Statistics, CCS HAU, Hisar, pp 139-143

Singh KP, Sarkar MC (1985). Effect of method of phosphorus application on wheat yield, P uptake and indices of P availability. J Indian Soc Soil Sci 33(4): 695-697.

Singh VK, Gautam P, Nanda G, Dhaliwal SS, Pramanick B, Meena SS, Alsanie WF, Gaber A, Sayed S, Hossain A (2021). Soil test based fertilizer application improves productivity, profitability and nutrient use efficiency of rice (*Oryza sativa* L.) under direct seeded condition. Agron 11: 1756. https://doi.org/10.3390/agronomy11091756

Thakur A, Sharma RP, Sankhyan NK, Anjali (2022). 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. Indian J of Ecol 49(2): 388-393. https://doi.org/10.55362/IJE/2022/3534

Thakur A, Sharma RP, Sankhyan NK, Sepehya S (2023). Effect of 46 years' application of fertilizers, FYM and lime on physical, chemical and biological properties of soil under maize-wheat system in an acid Alfisol of northwest Himalayas. Soil Use Manag 39(1): 357-367. https://doi.org/10.1111/sum.12821Umesh MR, Manjunatha N, Shankar MA, Jagadeesha N (2014). Influence of nutrient supply levels on yield, nutrient uptake, grain quality and economics of corn (*Zea mays* L.) in Alfisols of Karnataka. Indian J Dryland Agric Res Dev 29(1): 73-78.

Vikram AP, Biradar DP, Umesh MR, Basavanneppa MA, Rao KN (2015). Effect of nutrient management techniques on growth, yield and economics of hybrid maize (*Zea mays* L.) in Vertisols. Karnataka J Agric Sci 28(4): 477-481.

Venkatesh MS, Hazra KK, Ghosh PK, Singh KK (2022). Improving productivity of maize-lentil rotation in alkaline Fluvisol following soil test crop response (STCR)-targeted yield approach of nutrient management. Arch Agron Soil Sci 68(7): 929-943. https://doi.org/10.1080/03650340.2020.1864338

Qin W, Wang D, Guo X, Yang T, Oenema O (2015). Productivity and sustainability of rainfed wheat-soybean system in the North China plain: results from a long-term experiment and crop modelling. Sci Rep 5: 17514. https://doi.org/10.1038/srep17514