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Improving productivity of maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping sequence in Mollisols using target yield approach of nutrient management

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ABSTRACT

Maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.) cropping sequence holds immense significance in Mollisols, serving as a vital source of nutrition and income for millions and playing a pivotal role in global food security. The study was carried out during 2019–20 and 2020–21 at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand to increase the productivity of the maize-wheat rotation in Mollisols using the Soil Test Crop Response (STCR) target yield approach. The experiment was conducetd in a randomized block design (RBD) comprised of 9 treatments, viz. T_1 (Control); T_2 (Recommended dose of fertilizers - RDF); T_3 (STCR - Inorganic mode); T_4 (STCR INM mode); T_5 (75% STCR dose of nitrogen + full P and K + Green manuring with *Sesbania*); T_6 (50% STCR dose of N + full P and K + Green manuring with *Sesbania*); T_7 (75% Recommended dose of nitrogen + full P and K + Green manuring with *Sesbania*); T_8 (50% RDN + full P and K + Green manuring with *Sesbania*); and T_9 (Farmyard manure - FYM + Green manuring with *Sesbania* + Urd intercropping), replicated thrice. The results showed the significant improvement in maize and wheat yields in Mollisols with the STCR target yield approach, showcasing enhanced nutrient utilization. The adoption of target yield approach stands as a promising solution to enhance maize-wheat cropping sequence productivity, addressing food security challenges and promoting sustainable agriculture in Mollisols.

Keywords: Maize-wheat rotation, Mollisol, Nutrient management, Productivity, Soil test crop response, Target yield

The sustainable intensification of agricultural systems has become an imperative in the face of mounting global challenges, such as a burgeoning world population, climate change, and dwindling arable land. Mollisols, derived from the latin word *mollis,* meaning soft, are the soils of grassland ecosystem. These soils are characterized by a deep, dark, humus-rich, and fertile upper layer called the mollic epipedon, renowned for its richness in essential nutrients and base content. Mollisols have widespread distribution across the world and play a pivotal role in global food production (Eswaran *et al.* 2012). The practice of crop rotation has long been recognized as a cornerstone of sustainable agriculture. Among the myriad of crop rotations, the maize-wheat rotation system stands out as a promising approach, offering a relation between two staple crops; maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) (Jat *et al.* 2013). This rotation not only addresses the demand for diverse crop production but also holds great potential for mitigating the inherent challenges associated with Mollisol management.

To boost crop productivity, soil nutrient management is essential. Chemical fertilizers offer rapid nutrition but lead to issues like pollution and soil degradation. Organic manures improve soil health but decompose slowly. Combining both organic and inorganic sources enhances fertility and productivity while reducing environmental impact (Wu and Ma 2015). Soil Test Crop Response (STCR) method is pivotal in optimizing nutrient management and crop yields. It consider soil fertility, nutrient input from various sources (organic and inorganic), ensuring a balanced utilization of these resources. Crop yield and nutrient uptake are said to be linearly related according to the target yield approach (Singh 2016). This involves a series of experiments: creating a fertility gradient, growing an exhaustive crop, testing different treatments on the main crop, and converting results into fertilizer prescription equations (Pandey 2020). Post-equation generation, trials are conducted across multiple locations within a specific agro-ecological region to verify their validity. In view of

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the above, current study aims to assess maize-wheat rotation productivity using various soil test crop response-based nutrient application approaches and compare their outcomes with recommended fertilizer doses.

MATERIALS AND METHODS

Experimental site: The experiment was conducted during 2019–20 and 2020–21 at Norman E Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (29° N and 79° 3' E; 243.84 m amsl), Uttarakhand, situated within a narrow belt under the foothills of the Shivalik range of Himalayas. Pantnagar's climate is classified as humid and subtropical, with hot, dry summers and chilly winters. The temperature is maximum during the month of May–June and minimum during December–January. Relative humidity is maximum during July–August and minimum during April–May. Around the third week of June monsoon season usually starts and persists until the final week of September.

Experimental details: Nine nutrient management treatments [T_1 (Control); T_2 (Recommended dose of fertilizers - RDF); T_3 (STCR - Inorganic mode); T_4 (STCR INM mode); T_5 (75% STCR dose of nitrogen + full P and K + Green manuring with *Sesbania*); T_6 (50% STCR dose of N + full P and K + Green manuring with *Sesbania*); T_7 (75% Recommended dose of nitrogen + full P and K + Green manuring with *Sesbania*); T_8 (50% RDN + full P and K + Green manuring with *Sesbania*); and T_9 (Farmyard manure - FYM + Green manuring with *Sesbania* + Urd intercropping)] were tested for maize-wheat cropping sequences during 2019–2021 (Supplementary Table 1, 2, 3 and 4) in a randomized block design (RBD) (4.0 m × 3.0 m) with three replications. The inorganic fertilizers used were urea, muriate of potash (MOP) and single superphosphate (SSP). As a basal application, one-third of the nitrogen dose and the entire doses of potassium and phosphorus were given at knee high and the tasseling stage of maize, the remaining two thirds of nitrogen were sprayed in two equal splits. In case of wheat crop, two equal splits of nitrogen were applied at CRI stage (20–25 DAS) and at the time of tiller formation (40–45 DAS), respectively. Fertilizers were mixed properly into the soil in respective plots. Green manure crop (*Sesbania*) was sown during mid April each year without fertilizer application and residual effect of green manure incorporation was seen on the subsequent wheat crop. During each cropping season, 1 month before sowing of maize, well decomposed FYM was mixed during land preparation. The maize variety P 3401 was sown on 28th June at a spacing of 60 cm × 20 cm and wheat variety HD 2967 was sown on 5th November and 28th October during 2019 and 2020, respectively at a spacing of 22.5 cm.

Fertilizer adjustment equations: The application of fertilizers was done using basic data of soil and plant analysis based on STCR approach for the desired target yield of maize and wheat crop (Pandey and Srivastava 2021). Separate fertilizer recommendation was given for the use of chemical fertilizers alone as well as for integrated use of chemical fertilizers and organic manures. Based on these fertilizer prescription equations, different dose of nutrients were added to the soil (Supplementary Table 5 and 6).

Experimental soil: The soil of the experimental site is classified as Mollisol with Pattharchatta sandy loam series. With 61.23, 18.95, and 19.82% sand, silt, and clay, respectively, the soil had a sandy loam texture. It was low in available N (147.98 kg/ha), medium in available P (19.98 kg/ha), medium in available K (162.44 kg/ha), and medium in soil organic carbon (0.69%). The soil was neutral in reaction (*p*H 6.53), and its electrical conductivity (EC) was 0.24 dS/m.

Crop performance and nutrient uptake: The performance of maize and wheat crops was assessed by measuring grain yield, straw yield, and nutrient uptake. When the plants were harvested, plant samples were taken, properly cleaned in tap and deionized water, and then dried in a hot air oven at 60 ± 5°C until a constant weight was achieved. The dried plant samples were grounded using an electric grinder. The samples were digested with H_2SO_4 for nitrogen (N) content analysis and with a diacid mixture (HNO_3: $HClO_4$) in a 9:4 ratio for potassium (K) and phosphorus (P) in order to perform nutrient analysis. The modified Kjeldahl method, the vanadomolybdate yellow colour method, and the flame photometer method were used to measure the levels of nitrogen, phosphorus, and potassium in the digests, respectively (Jackson 1973). By multiplying the nutrient content by the corresponding grain or straw yield, the nutrient uptake was determined. Grain and straw uptake measurements were combined to get the total uptake. The data sets were processed for analysis of variance as applicable to RBD using least significant difference. Correlation studies to explain the relationship between two or more series of variables was carried out as per the standard procedures (Supplementary Table 7 and 8).

RESULTS AND DISCUSSION

Yield of maize and wheat crop under various nutrient management practices: Nutrients optimization directly contributes towards nutrient availability to plants, which in turn has remarkable effect in crop's performance. Grain and stover/straw yield were used to assess the performance of the maize and wheat crops during the course of the experiment (Table 1). Yield was recorded during the study years 2019–2020 and 2020–2021.

During *kharif* 2019 and *kharif* 2020, highest grain yield was obtained under treatment T_4 which was significantly at par with T_5 and T_3. During *kharif* 2019, T_4 (STCR INM mode) recorded higher grain yield by 7.30% and 10.28% when compared with STCR inorganic mode and RDF, respectively. During *kharif* 2020, T_4 (STCR INM mode) recorded higher grain yield by 6.97% and 15.21% when compared with STCR inorganic mode and RDF, respectively. Stover yield of maize crop during *kharif* 2019 and *kharif* 2020, was observed highest under T_4 which was significantly at par with T_5. During *kharif* 2019, stover yield of T_4 (STCR INM mode) recorded 9.62% and 8.71% increase

Table 1 Effect of STCR target yield approach of nutrient management on grain and stover yield of maize

Treatment	Grain yield (t/ha)		Stover yield (t/ha)	
	2019	2020	2019	2020
Maize crop				
T_1	2.97	2.82	4.83	4.71
T_2	5.06	4.93	7.23	7.14
T_3	5.20	5.31	7.17	7.38
T_4	5.58	5.68	7.86	8.01
T_5	5.31	5.43	7.40	7.59
T_6	4.31	4.40	6.41	6.53
T_7	4.72	4.81	6.76	6.90
T_8	4.09	4.19	5.94	6.15
T_9	3.80	3.84	5.87	5.98
SEm±	0.16	0.16	0.19	0.19
CD (P=0.05)	0.48	0.47	0.58	0.58

Treatment details are given under Materials and Methods.

over STCR inorganic mode and RDF, respectively. During *kharif* 2020, stover yield of T_4 (STCR INM mode) recorded 8.54% and 12.18% increase over STCR inorganic mode and RDF, respectively.

According to Velayutham *et al.* (1985), if the targeted yield was within ±10% variation, the equations were found to be valid. During the first year (*kharif* 2019), the STCR INM mode yielded the highest achievement of target yield (101.45%), followed by T_5 (96.56%) and T_3 (94.56%). Similar results were observed in the second year (*kharif* 2020), with T_4 yielding the highest target yield achievement (103.27%), followed by T_5 (98.73%), and T_3 (96.55%). Furthermore, it was noted that the STCR approach with INM mode, incorporating green manures and replacing 25% of nitrogenous fertilizers, consistently achieved higher yields compared to using STCR (inorganic mode) alone, aligning with findings from Coumaravel *et al.* (2013) and Sekaran *et al.* (2019).

STCR based treatments, guided by soil tests and crop requirements, led to higher grain yields by optimizing nutrient availability, supported by Reddy *et al.* (2018) and Isha *et al.* (2023). Incorporating FYM alongside inorganic fertilizers further increased yields by enhancing soil conditions, as noted by Karem *et al.* (2012) and Rai *et al.* (2016).

FYM also improved soil structure and water retention (Sharma *et al.* 2013 and Nandhini *et al.* 2024). Consistent with Verma *et al.* (2018), green manures improved soil characteristics and increased grain and stover yields. The fact that the control treatment produced the lowest yield highlighted the effectiveness of nutrient optimization strategies.

During *rabi* 2019–20, highest grain yield of wheat crop was observed under T_5 which was significantly at par with T_4. T_5 (75% STCR dose of N + full P and K) recorded 18.93% and 25.64% higher grain yield over STCR inorganic mode and RDF,

During *rabi* 2020–21, highest grain yield of wheat crop was observed under T_4 which was significantly at par with T_3 and T_5. T_4 (STCR INM mode) recorded higher grain yield by 5.49% and 20.30% when compared with STCR inorganic mode and RDF, respectively (Table 2). During *rabi* 2019–20, straw yield of wheat crop was observed highest under T_5, which was significantly superior than all the other treatments. T_5 (75% STCR dose of N + full P and K) recorded 12.48% and 26.33% higher straw yield over STCR inorganic mode and RDF, respectively. During *rabi* 2020–21, highest straw yield of wheat crop was observed under T_4. T_4 (STCR INM mode) recorded higher grain yield by 4.19% and 12.88% when compared with STCR inorganic mode and RDF, respectively.

During first year (*rabi* 2019–20) the highest achievement of the target yield was observed with T_5 (98.0%) followed by T_4 (91.4%). In the second year (*rabi* 2020–21) the highest achievement of the yield target was observed with T_4 (96.0%) followed by T_3 (91%) and T_5 (90.4%). This confirms the effectiveness of the fertilizer prescription equations that were developed for wheat crop. Target yield approach along with use of FYM recorded relatively higher per cent achievement when compared with use of inorganic fertilizers alone.

Combining green manuring with inorganic fertilizers positively impacted wheat yield, with residual effects reducing nitrogen requirements for subsequent crops by 25–30%. STCR-based treatments yielded superior results, optimizing nutrient availability and enhancing soil fertility, as corroborated by Vijayakumar *et al.* (2017). Precise nutrient adjustments under STCR led to target wheat yields. Additionally, combining FYM with inorganic fertilizers boosted straw yield by ensuring nutrient availability and

Table 2 Effect of STCR target yield approach of nutrient management on grain and straw yield of wheat

Treatment	Grain yield (t/ha)		Straw yield (t/ha)	
	2019–20	2020–21	2019–20	2020–21
Wheat crop				
T_1	2.12	2.02	2.89	3.00
T_2	3.90	3.99	4.71	5.28
T_3	4.12	4.55	5.29	5.72
T_4	4.57	4.80	5.37	5.96
T_5	4.90	4.52	5.95	5.53
T_6	4.38	3.73	5.40	4.54
T_7	4.01	3.81	5.04	4.99
T_8	3.67	3.42	4.79	4.40
T_9	3.34	3.19	4.30	4.18
SEm±	0.19	0.26	0.19	0.15
CD (P=0.05)	0.56	0.78	0.56	0.44

Treatment details are given under Materials and Methods.

Table 3 Effect of STCR target yield approach of nutrient management on nitrogen, phosphorus and potassium uptake in maize and wheat

Treatment	Maize						Wheat					
	Kharif 2019			*Kharif* 2020			*Rabi* 2019–20			*Rabi* 2020–21		
	TNU	TPU	TKU	TNU	TPU	TKU	TNU	TPU	TKU	TNU	TPU	TKU
T_1	47.7	18.8	46.2	50.5	22.0	48.8	37. 8	10.6	34.2	35.5	10.8	34.0
T_2	109.6	39.4	113.1	115.0	47.6	121.3	78.6	22.3	74.6	83.7	25.0	83.2
T_3	102.1	32.0	72.1	115.5	46.4	84.8	88.4	27.1	88.3	99.1	31.0	100.0
T_4	107.1	44.2	112.4	117.4	55.1	122.8	99.4	33.5	83.6	109.1	37.4	98.4
T_5	133.3	33.7	76.3	143.7	41.2	83.7	119.4	31.2	102.7	116.0	30.4	103.0
T_6	111.0	29.7	79.7	121.0	38.5	89.5	104.1	29.6	91.4	93.1	26.8	85.3
T_7	146.1	39.2	109.9	153.0	46.0	121.0	92.5	24.1	88.5	90.7	24.9	90.3
T_8	121.1	35.3	89.6	126.2	40.8	97.0	81.2	21.9	75.6	75.2	21.3	70.7
T_9	93.2	27.1	88.0	98.0	30.8	91.3	67.6	19.5	63.7	66.6	19.6	59.9
SEm±	4.4	1.6	2.9	7.1	2.5	3.9	4.1	1.7	3.5	5.8	1.8	2.7
CD (P=0.05)	13.2	4.7	8.6	21.2	7.4	11.9	12.1	5.2	10.6	17.4	5.3	8.1

TNU, Total nitrogen uptake (kg/ha); TPU, Total phosphorus uptake (kg/ha) and TKU, Total potassium uptake (kg/ha). Treatment details are given under Materials and Methods.

improving soil fertility, supported by Singh and Shivay (2013) and Sahoo *et al.* (2024).

Nutrient uptake in maize and wheat crop: The data on nitrogen, phosphorus, and potassium (NPK) uptake in wheat and maize crops is presented in Table 3. In 2019 and 2020, the total N uptake in maize ranged from 47.7–146.1 kg/ha and 50.5–153.0 kg/ha, respectively. In 2019 and 2020, the total P uptake in maize ranged from 18.8–44.2 kg/ha and 22.0–55.1 kg/ha, respectively. In 2019 and 2020, the total K uptake in maize ranged from 46.2–113.1 kg/ha and 48.8–122.8 kg/ha, respectively. Similarly, during 2019–20 and 2020–21, the total N uptake in wheat varied from 37.8–119.4 kg/ha and 35.5–116.0 kg/ha, respectively. In 2019–20 and 2020–21, the total P uptake in wheat varied from 10.6–33.5 kg/ha and 10.8–37.4 kg/ha, respectively. The total K uptake in wheat for 2019–20 and 2020–21 varied from 34.2–102.7 kg/ha and 34.0–103.0 kg/ha, respectively. Overall, maize and wheat crops showed higher N, P, and K uptake in treatments with STCR based nutrient application or balanced chemical fertilization.

The study demonstrates that STCR approach enhance nitrogen uptake compared to RDF, attributed to balanced nutrient management (Suresh and Santhi 2018). Incorporating organic manures like FYM and green manures significantly boosts nitrogen, phosphorus, and potassium uptake in maize, improving yields and nutrient allocation to grains (Yang *et al.* 2018). Treatment T_4, integrating FYM, enhances phosphorus uptake by increasing soil organic matter, aligning with findings of Kurbah (2017). INM practices, enhance crop yield and nutrient use efficiency (Muralidharudu 2010). Green manure incorporation improves phosphorus availability through residue decomposition. STCR-based fertilizer application enhances soil fertility, resulting in higher phosphorus uptake compared to RDF. The combination of organic manure and fertilizers in T_4 exhibits the highest phosphorus uptake, which is attributed to FYM decomposition releasing carbonic acid. Potassium uptake is higher in stover than grain, with combined organic manures and fertilizers increasing uptake in both crops. Green manure incorporation and STCR approach further boost potassium uptake. Conversely, control treatments showed the lowest potassium uptake due to reduced yields and nutrient concentrations. These results highlight the significance of integrated nutrient management in optimizing nutrient uptake and maximizing crop yield.

In light with these findings, it is clear that the STCR target yield approach holds great promise for enhancing maize-wheat cropping system productivity in Mollisols. However, successful implementation will require collaboration among farmers, researchers, and agricultural extension services to promote awareness and adoption of this approach. Additionally, ongoing research and monitoring are essential to fine-tune recommendations and adapt them to evolving agricultural practices and environmental conditions. As we move forward, it is imperative that we continue to explore innovative approaches like the STCR target yield approach to meet the increasing demand for food on a worldwide scale, protect our natural resources, and ensure the long-term viability of agricultural systems in the Mollisols and beyond.

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