

## Soil microbial biomass carbon and soil enzymatic activity under nutrient omission plot technique in maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system

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### ABSTRACT

A 2-year (2013 and 2014) field study was carried out at the ICAR-Indian Agricultural Research Institute, New Delhi, to access the effects of omitted nutrients on soil microbial biomass carbon (MBC), enzyme activity, the relationships among these parameters in maize-wheat cropping system and to validate the soil-test-crop response (STCR)-based fertilizer application for targeted yield (5.0 t/ha) of wheat 'HD 2967' and maize 'PEHM 5' each in maize (*Zea mays* L.)–wheat (*Triticum aestivum* L.) cropping system. The experiment comprising 15 treatments involving application of N (–PKZn), NP (–KZn), NPK (–Zn) and NPZn (–K) to both maize and wheat crops, to maize (omitted in wheat) and to wheat (omitted in maize) crop only, absolute control (no nutrient applied), recommended rate of nutrients (RDN) (150-60-40-5.5 kg/ha N-P-K-Zn) and STCR-based application of nutrients (200-75-65-4 kg/ha N-P-K-Zn). The fixed plots experiment was carried out in a 3-time replicated randomized complete block design. The dehydrogenase, alkaline phosphatase and urease enzyme activities in soil and MBC were significantly higher with STCR approach-based NPKZn application than the others for targeted yield of 5 t/ha of both maize and wheat crops. The continuous omission of N, P, K and Zn in a cropping system during both the study years reduced MBC by 51.9, 7.6, 12.7, 6.5% respectively. The recommended dose of NPKZn resulted in higher activity of dehydrogenase, urease and alkaline phosphatase enzyme than N, NP, NPK, NPZn treatments and absolute control. The continuous omission of N, P, K and Zn in a cropping system significantly reduced the soil enzymes activity in maize–wheat cropping system.

**Key words :** Enzymatic activity, Fertilization, Maize, Microbial biomass carbon, Soil test crop response approach, Wheat

Cropping sequence is a system approach which enables efficient utilization of available natural resources for maximizing the system production and productivity and preserves them for future generations. Due to existing fertil-

izer recommendation practices over the years, fixed doses and timing of N, P and K application for vast areas of production, irrespective of crop needs, climate, seasons and soil indigenous nutrient-supplying capacity for supplemental nutrients, the actual yield potentiality of maize–wheat cropping system has not been yet achieved. Though chemical fertilization increases production but the haphazard fertilization results in the improper application of nutrients not needed by the plant, increases the fertilizer costs of the farmer unnecessarily (Joshi *et al.*, 2016). It poses an adverse effect on soil health, its replenishment potential and on diverse array of organisms including micro flora and fauna. Hence site-specific, integrated nutrient management based on crop requirements, soil-test values and yield targets help in arriving at optimum fertilizer recommendations and indicate significant opportunities to further increase the productivity of maize–wheat cropping system for a given variety and climate (Joshi *et al.*, 2020).

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Soil nutrients provide necessary mineral elements for plant growth and lead to fundamental changes in terrestrial carbon pools and fluxes (McLauchlan, 2006). They also act as important indicator for soil natural fertility, as there is a close relationship between soil nutrients and soil enzyme activity (Zebin *et al.*, 2011). Microbial biomass carbon (MBC) is a labile fraction of soil organic matter and is an index of soil microbial activity. Numerous studies have described the effect of fertilization on the soil organic carbon (SOC) pool (Li *et al.*, 2006; Joshi *et al.*, 2018). Enzymes in soil affect soil composition by catalyzing a number of reactions. Studies have shown that higher rate of NPK fertilization enhanced the activities of soil enzymes without any detrimental effect on their dynamics in the soil (Singaram and Kumari, 1995). The soil enzyme indicate changes in soil ecological system function and also highlights the effects of pollution and agricultural practices on soil-physical and chemical properties (Shao and Zheng, 2014). Urease, acid phosphatase, and invertase are enzymes which control mineralization and transformation of soil N, P, and C compounds. They are also involved in the N, P and C cycles (Bremer and Mulvaney, 1978). Little information is available with regard to soil microbial activities, due to soil-test crop-response approach-based fertilization. Therefore, an attempt was made to investigate the effects of omitted nutrients on soil MBC, enzyme activity, the relationships among these parameters in maize–wheat cropping system and to validate the STCR-based fertilizer application for targeted yield of maize and wheat each in maize–wheat cropping system.

## MATERIALS AND METHODS

The field experiment was carried out during 2013 and

2014 at New Delhi (28°35' N, 77°12' E), India. The study site has a monsoon-influenced humid subtropical and semi-arid climate with an average annual rainfall of about 650 mm, of which nearly 80% is received during the monsoon period from July to September and the rest during the period between October and May. There is high variation between summer and winter temperatures and mean maximum temperature in June ranging from 40 to 45°C, while the mean minimum temperature in January is as low as 1.9°C. The average monthly air temperature, relative humidity and bright sunshine hours were almost similar during both the years. The weather data (temperatures, relative humidity, rainfall, and sunshine hours) of the experimental site during the period of the experiment are presented in Fig. 1 and 2. Soil at the site belongs to Order Inceptisols, Mehruli series, having non-calcareous alkaline sandy clay loam texture (sand 64.5%, silt 13.4% and clay 18.5%), with the pH 7.9, cation-exchange capacity 10.7 c-mol/kg and electrical conductivity 0.32 dS/m in the top 15 cm of soil. It was high in organic carbon (0.51%), low in initial N (124 kg/ha) and medium in P (17.37 kg/ha), K (224 kg/ha) and Zn (0.8 ppm) content. Bulk density, field capacity and permanent wilting point were 1.49 Mg/m<sup>3</sup>, 17.9% and 4.33% respectively.

The experiment was designed in a randomized complete block with 15 treatments and three replicates in fixed plots. Treatments included a zero fertilizer check, application of N (-PKZn), NP (-KZn), NPK (-Zn) and NPZn (-K) to both maize and wheat crop, to maize and to wheat crop only, recommended rate of nutrients (RDN: 120-60-40-5.5 kg/ha N-P-K-Zn) and STCR-based application of nutrients (200-100-55-4 kg/ha N-P-K-Zn). The detailed information of

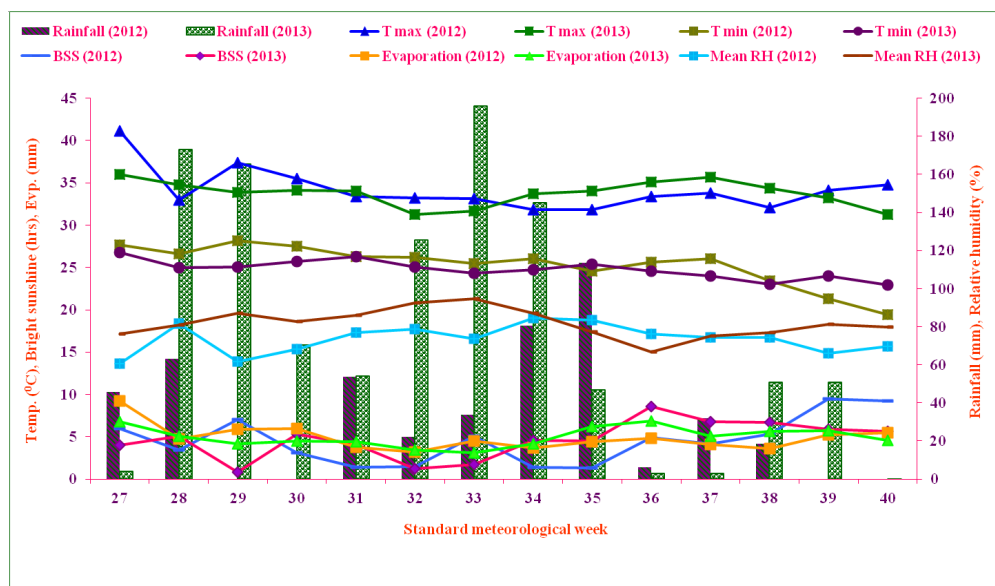


Fig. 1. Weather parameters during crop rainy season (2013–14)

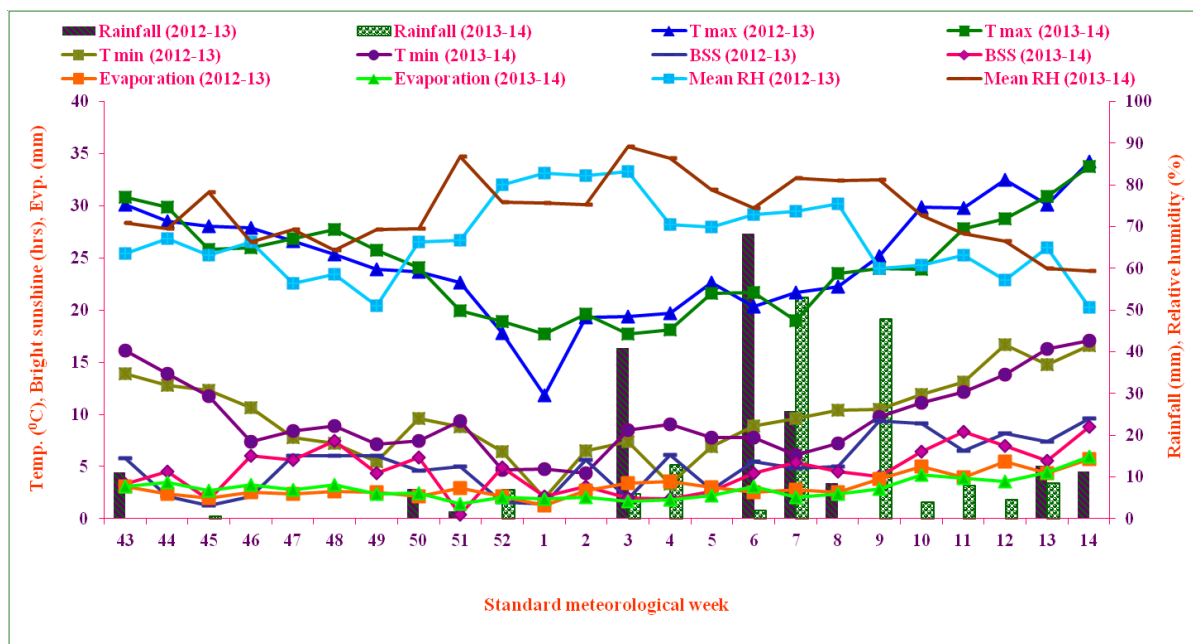


Fig. 2. Weather parameters during crop winter season (2012–13 and 2013–14)

fertilization treatments to maize and wheat are presented in Table 1. The experiment had total 45 plots of size 4.2 m × 4.5 m each. Based on initial soil-test value of N, P and K, the fertilizer recommendation for maize variety ‘PEHM 5’ and wheat variety ‘HD 2967’ for a targeted yield of 5 t/ha was calculated using STCR equation at the beginning of the experiment and computed values were 200, 100, 55, 4 kg/ha and 200, 75, 65, 4 kg/ha of NPKZn for maize and wheat crop respectively. The STCR equations for computation of N, P and K dose are given below:

For maize: FN, 6.61 T–0.52 SN; F P<sub>2</sub>O<sub>5</sub>, 4.77 T, 5.13

SP; F K<sub>2</sub>O, 2.75 T, 0.24 SK

For wheat: FN, 5.31 T, 0.51 SN; F P<sub>2</sub>O<sub>5</sub>, 3.45 T–5.55 SP; F K<sub>2</sub>O, 2.75 T–0.32 SK

Same nutrient-omission treatments were tested on wheat crop also. Recommended dose of fertilizer for maize was 120, 60, 40, 5.5 kg/ha and for wheat it was 150, 60, 40, 5.5 kg/ha N-P-K-Zn (Table 1). The fertilizers used for applying N, P, K and Zn were urea, di-ammonium phosphate (adjusted for its N content) and muriate of potash and zinc sulphate (ZnSO<sub>4</sub>·7H<sub>2</sub>O) respectively.

After receiving pre-monsoon showers, the experimental

Table 1. Fertilization treatments to maize and wheat (kg/ha/year)

Treatment	Maize				Wheat			
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Zn	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Zn
T <sub>1</sub> NPKZn (STCR approach)	200	100	55	4	200	75	65	4
T <sub>2</sub> NPKZn (RDN)	120	60	40	5.5	150	60	40	5.5
T <sub>3</sub> N (-PKZn) in both maize and wheat	120	-	-	-	150	-	-	-
T <sub>4</sub> NP (-KZn) in both maize and wheat	120	60	-	-	150	60	-	-
T <sub>5</sub> NPK (-Zn) in both maize and wheat	120	60	40	-	150	60	40	-
T <sub>6</sub> NPZn (-K) in both maize and wheat	120	60	-	5.5	150	60	-	5.5
T <sub>7</sub> N (-PKZn) only in maize crop	120	-	-	-	-	-	-	-
T <sub>8</sub> NP (-KZn) only in maize crop	120	60	-	-	-	-	-	-
T <sub>9</sub> NPK (-Zn) only in maize crop	120	60	40	-	-	-	-	-
T <sub>10</sub> NPZn (-K) only in maize crop	120	60	-	5.5	-	-	-	-
T <sub>11</sub> N (-PKZn) only in wheat crop	-	-	-	-	150	-	-	-
T <sub>12</sub> NP (-KZn) only in wheat crop	-	-	-	-	150	60	-	-
T <sub>13</sub> NPK (-Zn) only in wheat crop	-	-	-	-	150	60	40	-
T <sub>14</sub> NPZn (-K) only in wheat crop	-	-	-	-	150	60	-	5.5
T <sub>15</sub> Absolute control (No fertilizer)	-	-	-	-	-	-	-	-

STCR, Soil test crop response; RDN, recommended dose of nutrients

field was prepared by cross-cultivation followed by planking to have a uniform and firm seedbed of fine tilth for maize crop sown in the second week of July and harvested in the second week of October. ‘PEHM 5’ was sown at a seed rate of 25 kg/ha at 60 cm × 20 cm spacing. Wheat “HD 2967” was sown by the seed drill in rows spaced at 22.5 cm using 100 kg/ha seed rate. Before sowing, seeds were treated with Captan @ 2.0 g/kg seed for protection against fungal diseases and Chlorpyrifos @ 4 ml/kg seed to protect the seed from termites. Fertilizer was placed below the seed zone with sowing as per the treatments. One-third dose of N and full dose of all other nutrients (P, K and Zn) were applied basal to maize. Remaining N was top-dressed at 30 and 60 days after sowing (DAS) and at the first and second irrigation in 2 equal splits in maize and wheat crop respectively. Three irrigations were provided to maize during 2012 and 2 during 2013. Similarly, 4 irrigations were provided to wheat during 2012–13 and 2 during 2013–14. In order to maintain plant to plant distance of 20 cm in maize thinning was done 25 days after sowing (DAS). Three hand-weedings (HW) were done at 10, 45 and 60 DAS in maize and 2 HW were done at 25 and 60 DAS in wheat. Carbofuran @ 0.6–0.75 kg/ha at 30 DAS was applied to control nematode and stem-borer infestation.

Soil samples from surface depth (0–15 cm) and near the plant roots were taken in small polythene bags from each plot by core sampler. The soil samples were air-dried,

ground and passed through 2-mm mesh-sieve, and analyzed for microbial parameters, viz. MBC, and soil enzyme activities, viz. dehydrogenase, alkaline phosphatase and urease, were estimated after harvesting of maize and wheat crops of the cropping system. Dehydrogenase was estimated as described by Casida *et al.* (1964). Alkaline phosphatase was analyzed as per the method of Tabatabai and Bremmer (1969). Urease activity was assessed as the rate of urea hydrolysis in the soil samples by determining the urea remaining (un-hydrolyzed) following the method modified (Douglas and Bremmer, 1971) MBC was estimated by chloroform-fumigation method (Nunan *et al.*, 1998).

The data collected on different parameters were subjected to appropriate statistical analysis Gomez and Gomez (1984). Significance of difference between means was tested through ‘F’ test and the critical difference (CD) was worked out where variance ratio was found significant for treatment effect. The treatment effects were tested at 5% probability level for their significance. The correlation and regression coefficients were computed between economic yield and yield components as per Gomez and Gomez (1984).

## RESULTS AND DISCUSSION

### *Yield of maize and wheat*

The STCR approach-based fertilization proved signifi-

**Table 2.** Effect of nutrient omission treatments on enzymatic activity in soil after harvest of maize

Treatment	Dehydrogenase ( $\mu\text{g TPF/g/hr}$ )		Alkaline phosphatase ( $\mu\text{g p-nitrophenol/g/h}$ )		Urease ( $\mu\text{g/g/h}$ )	
	2012	2013	2012	2013	2012	2013
T <sub>1</sub> NPKZn (Based on STCR)	7.48	7.39	8.50	8.41	17.01	16.65
T <sub>2</sub> NPKZn (RDN)	6.88	6.69	7.71	7.69	14.98	14.72
T <sub>3</sub> N (-PKZn) in both maize and wheat	5.77	5.03	5.47	5.34	11.97	11.30
T <sub>4</sub> NP (-KZn) in both maize and wheat	5.80	5.41	6.19	6.03	12.05	12.17
T <sub>5</sub> NPK (-Zn) in both maize and wheat	6.23	6.01	7.00	7.00	13.72	13.56
T <sub>6</sub> NPZn (-K) in both maize and wheat	5.90	5.51	6.26	6.24	12.25	12.20
T <sub>7</sub> N (-PKZn) only in maize	5.50	4.89	5.41	5.30	11.08	11.00
T <sub>8</sub> NP (-KZn) only in maize	5.69	5.08	6.15	5.98	11.14	11.08
T <sub>9</sub> NPK (-Zn) only in maize	6.12	5.30	6.30	6.28	12.47	12.28
T <sub>10</sub> NPZn (-K) only in maize	5.80	5.18	6.23	6.03	11.25	11.18
T <sub>11</sub> N (-PKZn) only in wheat	4.53	4.20	5.18	5.02	10.19	10.25
T <sub>12</sub> NP (-KZn) only in wheat	4.64	4.21	5.28	5.09	10.19	10.43
T <sub>13</sub> NPK (-Zn) only in wheat	4.90	4.25	5.35	5.17	10.20	10.73
T <sub>14</sub> NPZn (-K) only in wheat	4.82	4.20	5.34	5.10	10.15	10.48
T <sub>15</sub> Absolute control (No fertilizer)	4.45	4.10	5.08	4.90	10.20	9.60
SEm $\pm$	0.14	0.13	0.16	0.15	0.28	0.30
CD (P=0.05)	0.41	0.37	0.46	0.45	0.83	0.90
Control vs others						
SEm $\pm$	0.09	0.09	0.10	0.11	0.17	0.22
CD (P=0.05)	0.26	0.27	0.29	0.33	0.53	0.66

STCR, Soil test crop response; RDN, recommended dose of nutrients

cantly superior to all other treatments and the grain yield of maize and wheat crop were higher to the tune of 5.8, 9.7% in 2012–13 and 5.7, 7.1% in 2013–14 respectively, compared to optimally fertilized plot with recommended fertilizer doses (Table 4). Omission of P resulted in 8.9 and 10.4% reduction in maize grain yield during 2012 and 2013, respectively, and significantly reduced wheat grain yield by 11.4 and 13.3% during 2012–13 and 2013–14, respectively, compared to the treatment where only N was applied and other all nutrients were omitted. The reduction in yield due to K-omission in both the crops and directly in maize ranged from 8.1 to 13.3%, signifying the importance of K nutrition in maize crop. The sustained omission of K in the system significantly influenced the grain yield of maize and wheat which was reduced by 8.1, 14.9, 11.2 and 20% during 2012–13 and 2013–14, respectively, compared to recommended dose of NPKZn (Table 4). The yield reduction was slightly lower with Zn omission (2–5%). The stover yield ranged from 4.05 to 7.59 t/ha in 2012 and 3.77 to 7.33 t/ha in 2013. Stover yield of both maize and wheat was strongly correlated with K supply, omission of which resulted in 3–11% reduction in above-ground biomass production during both the years. The reduction was higher during 2013–14 than to preceding year as well as during winter (*rabi*) compared to rainy (*kharif*) season. Omission of P and Zn had comparatively smaller effect on stover production. It might be due to progressive depletion of P

and K in the respective omission plots could not meet the higher requirements of P and K for maize and wheat and therefore, resulted in reduction of yield attributes and yield of crops. Our results confirm the findings of Rawal *et al.* (2017).

### Microbial biomass carbon

The MBC in soil after harvesting of maize and wheat crop differed significantly under influence of different nutrient-omission treatments (Figs. 3 and 4) in maize–wheat cropping system. The STCR approach-based NPKZn application resulted in significantly higher MBC in soil than all the other treatments and was improved by 10.2 and 5.5% during 2012–13 and 8.4 and 5.8% during 2013–14

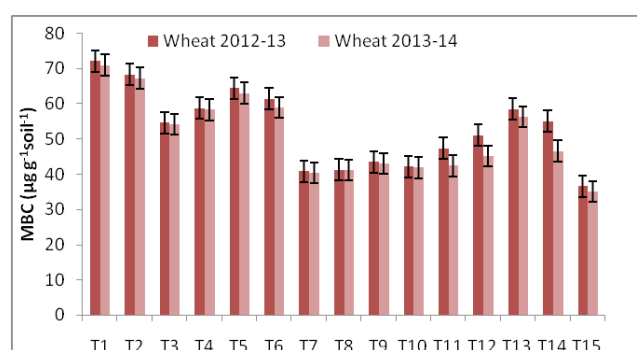


Fig. 3. Effect of nutrient omission treatments on MBC in soil after harvesting of maize (Vertical error bars shows CD at  $P=0.05$ )

Table 3. Effect of nutrient omission treatments on enzymatic activity in soil after harvest of wheat crop

Treatment	Dehydrogenase (µg TPF/g/h)		Alkaline phosphatase (µg p-nitrophenol/g/h)		Urease (µg/g/h)	
	2012–13	2013–14	2012–13	2013–14	2012–13	2013–14
T <sub>1</sub> NPKZn (Based on STCR)	7.07	7.00	8.10	7.97	14.34	14.28
T <sub>2</sub> NPKZn (RDN)	6.37	6.30	7.37	7.39	13.30	13.20
T <sub>3</sub> N (-PKZn) in both maize and wheat	5.00	4.73	5.56	5.51	10.87	10.69
T <sub>4</sub> NP (-KZn) in both maize and wheat	5.13	5.00	6.10	6.24	11.00	10.82
T <sub>5</sub> NPK (-Zn) in both maize and wheat	5.78	5.72	6.89	6.96	12.50	12.20
T <sub>6</sub> NPZn (-K) in both maize and wheat	5.16	5.12	6.16	6.42	11.19	11.02
T <sub>7</sub> N (-PKZn) only in maize	4.16	4.10	5.00	4.75	10.01	9.63
T <sub>8</sub> NP (-KZn) only in maize	4.48	4.31	5.02	4.84	10.11	9.79
T <sub>9</sub> NPK (-Zn) only in maize	4.62	4.46	5.06	5.00	10.24	9.86
T <sub>10</sub> NPZn (-K) only in maize	4.49	4.38	5.04	4.92	10.26	9.88
T <sub>11</sub> N (-PKZn) only in wheat	4.88	4.64	5.08	5.43	10.26	9.83
T <sub>12</sub> NP (-KZn) only in wheat	5.09	4.90	6.08	6.03	10.32	9.94
T <sub>13</sub> NPK (-Zn) only in wheat	5.30	5.22	6.45	6.53	11.29	11.18
T <sub>14</sub> NPZn (-K) only in wheat	5.15	5.01	6.14	6.08	10.37	9.99
T <sub>15</sub> Absolute control (No fertilizer)	4.27	3.80	4.50	4.42	9.02	8.31
SEm±	0.06	0.08	0.08	0.07	0.16	0.12
CD (P=0.05)	0.19	0.24	0.23	0.21	0.48	0.37
Control vs others						
SEm±	0.05	0.06	0.06	0.05	0.12	0.09
CD (P=0.05)	0.14	0.18	0.17	0.15	0.35	0.27

STCR, Soil test crop response; RDN, recommended dose of nutrients

compared to recommended dose of NPKZn in soil after harvesting of maize and wheat in maize-wheat cropping system. Omission of P and Zn to both crops of maize and wheat and to maize crop only did not significantly reduce the MBC in soil after harvesting of maize crop during both study years. But in wheat crop omission of P, K and Zn had significantly reduced the MBC in soil during 2012–13 and 2013–14 compared to recommended dose of nutrients. Omission of K and Zn to both crops in a cropping system reduced the MBC by 11.2 and 6.1% during 2012–13 and 14.2 and 6.9% during 2013–14, respectively, compared to RDN. The cumulative and direct effects of NPK in both maize and wheat resulted in significantly higher MBC in soil than N, NP and NPZn during the second year of ex-

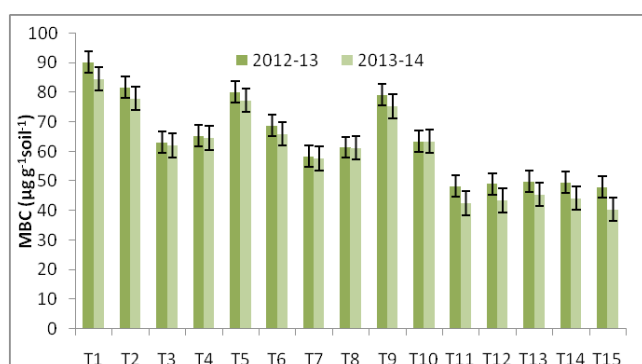


Fig. 4. Effect of nutrient omission treatments on MBC in soil after harvesting of wheat (Vertical error bars shows CD at  $P=0.05$ )

perimentation. The residual effect of NPK applied to wheat and maize significantly increased the MBC in soil after harvesting of maize and wheat crop compared to absolute control, but was at par with N, NP and NPZn application during 2012–13 and 2013–14. The STCR approach-based NPKZn application resulted in significantly higher MBC content in soil than N, NP, NPK and NPZn treatments in soil after harvesting of maize and wheat in maize-wheat cropping system. Omission of P, K and Zn in a cropping system reduced the MBC but the result was not significant compared to all the other treatments except absolute control. These results highlighted the importance of N and P fertilizers in enhancing the organic carbon pool (Ouedraogo *et al.*, 2006). In the present study, initial soil for all treatments were same for experimental land and the nutrient input was mainly fertilization and nutrient output was mainly biomass production. It was assumed to have similar traits at the beginning of the experiment and all treatments were exposed to similar external conditions except the fertilization treatment. The STCR approach-based NPKZn application resulted in significantly higher yields and vigorous root growth in soil under maize-wheat cropping system compared to the application of recommended dose of N, NP, NPK, NPZn and NPKZn. A plausible explanation for these findings where the STCR approach-based balanced and judicious fertilization results in higher microbial load exceeds organic matter loss and in reciprocation

Table 4. Effect of nutrient omission treatments on yield of maize and wheat crop

Treatments	Maize grain yield (t/ha)		Maize stover yield (t/ha)		Wheat grain yield (t/ha)		Wheat straw yield (t/ha)	
	2012	2013	2012	2013	2012–13	2013–14	2012–13	2013–14
T <sub>1</sub> NPKZn (Based on STCR)	5.1	5.0	7.6	7.3	5.0	4.5	6.4	6.0
T <sub>2</sub> NPKZn (RDF)	4.8	4.8	7.5	7.3	4.5	4.2	6.2	5.6
T <sub>3</sub> N (-PKZn) in both maize and wheat	3.9	3.9	6.8	6.5	3.5	3.0	5.4	4.7
T <sub>4</sub> NP (-KZn) in both maize and wheat	4.3	4.3	6.8	6.6	3.9	3.4	5.7	5.1
T <sub>5</sub> NPK (-Zn) in both maize and wheat	4.7	4.6	7.5	7.2	4.5	4.1	6.0	5.5
T <sub>6</sub> NPZn (-K) in both maize and wheat	4.5	4.3	7.2	7.0	4.0	3.5	5.7	5.1
T <sub>7</sub> N (-PKZn) only in maize	3.9	3.7	6.7	6.4	2.0	1.5	3.5	3.1
T <sub>8</sub> NP (-KZn) only in maize	4.2	4.0	6.8	6.5	2.1	1.5	3.5	3.2
T <sub>9</sub> NPK (-Zn) only in maize	4.6	4.5	7.4	7.1	2.2	1.6	3.6	3.2
T <sub>10</sub> NPZn (-K) only in maize	4.4	4.2	7.2	6.9	2.2	1.6	3.6	3.2
T <sub>11</sub> N (-PKZn) only in wheat	2.1	2.1	4.1	3.8	3.5	2.9	5.0	4.7
T <sub>12</sub> NP (-KZn) only in wheat	2.2	2.1	4.1	3.9	3.8	3.2	5.2	4.8
T <sub>13</sub> NPK (-Zn) only in wheat	2.2	2.4	4.2	4.0	4.4	4.0	5.6	5.1
T <sub>14</sub> NPZn (-K) only in wheat	2.2	2.2	4.1	4.0	3.9	3.3	5.6	5.0
T <sub>15</sub> Absolute control (No fertilizer)	2.1	2.0	4.1	3.8	1.9	1.5	3.4	3.0
SEm±	0.08	0.08	0.12	0.12	0.09	0.05	0.10	0.12
CD (P=0.05)	0.24	0.24	0.37	0.36	0.28	0.16	0.29	0.35
Control vs others								
SEm±	0.05	0.06	0.08	0.09	0.07	0.04	0.07	0.09
CD (P=0.05)	0.15	0.17	0.24	0.26	0.20	0.11	0.21	0.26

STCR, Soil test crop response; RDN, recommended dose of nutrients

soil organic carbon would increase, otherwise soil organic carbon would decrease. In the present work, nutrient output was probably higher than nutrient input when recommended dose of N, NP, NPK, NPZn and NPKZn was applied, leading to lower yield and MBC content compared to STCR approach-based NPKZn application. Our findings are in agreement Regmi *et al.* (2002) who reported that, single chemical fertilizer application improved production and enhanced nutrient output. Correlation analysis showed that dehydrogenase, urease, alkaline phosphatase enzymes activity and MBC were significantly associated with one another (Table 5 & 6).

#### *Dehydrogenase enzyme activity in soil*

Dehydrogenase activity appeared to be more dependent on the metabolic state of the soil or on the biological activity of the microbial population than on any free enzyme present (Rose, 1971). It is a measure of soil microbial activity which is strongly influenced by the presence of nitrate, which serves as an alternative electron acceptor resulting in low activities (Raghavendra *et al.*, 2018). The different nutrient-omission treatments differed significantly with respect to dehydrogenase activity in soil after harvesting of maize and wheat crop in maize–wheat cropping system (Tables 2 and 3). Dehydrogenase activity, a key biochemical indicator, after harvesting of wheat crop was comparatively slower than maize crop during both years of study. It ranged from 4.3 to 7.5 TPF/g/h soil during 2012–13 and 3.8–7.4 TPF/g/h soil during 2013–14 under influence of various nutrient-omission treatments in maize–wheat cropping system. The STCR approach-based NPKZn application resulted in significantly higher dehydrogenase activity in soil than all the other treatments during 2013 and 2014 after both maize and wheat crop in the system. The STCR approach-based NPKZn application resulted in significantly higher activity of dehydrogenase, alkaline phosphatase and urease in soil after harvesting of maize and wheat crop for 2 cropping cycles of the maize–wheat cropping system. A probable explanation for these findings is that where the STCR approach-based balanced nutrient supply improves the root biomass and rhizosphere leading to higher microbial and enzymatic activities in soil. The rise in the microbial biomass carbon and enzyme activity after harvest under STCR approach-based fertilization could be owing to the availability of residual organic materials and balanced dose of fertilizers especially N and K, which has resulted in more organic carbon accumulation and lead to more microbial activity (Apoorva *et al.*, 2010; Raghavendra *et al.*, 2018).

The cumulative and direct effect of NPK application was significantly superior to N and NP during 2012 and 2013 in both the crops under maize–wheat cropping sys-

tem. Omission of P to both crops had no significant effect on dehydrogenase activity in soil after harvesting of maize during 2012, but significantly reduced its activity during 2013. However, omitting P to both crops and directly in wheat significantly reduced the dehydrogenase activity in soil after harvesting of wheat crop during both years compared to application of N alone. Omitting K and Zn to both crops and only to maize and wheat crop, respectively, significantly reduced its activity in soil after harvesting of both crops in maize–wheat cropping system during both the years compared to recommended dose of NPKZn. The application of NPK to preceding wheat in maize–wheat cropping system had no significant effect on dehydrogenase activity in soil after harvest of maize and was at par with N, NP NPZn application to preceding wheat crop and absolute control during 2013. But, the application of NPK to preceding maize significantly influenced the dehydrogenase activity after harvesting of wheat and was significantly superior to N alone and absolute control during both the years.

#### *Alkaline phosphatase enzyme activity in soil*

Higher rate of NPK fertilization enhanced the activities of soil enzymes without any detrimental effect on the enzyme dynamics of the soil (Singaram and Kumari, 1995). The application of all the nutrient sources significantly increased the alkaline phosphatase enzyme activity in soil after harvesting of crops as compared to no-fertilizer application. The STCR approach (Tables 2 and 3)-based nutrient application resulted in significantly higher alkaline phosphatase activity in soil after harvesting maize and wheat crops compared to all the other treatments and it improved the activity by 9.9 and 7.8% during 2012–13 and 2013–14, respectively, compared to the recommended doses of NPKZn in maize–wheat cropping system. Omission of P to both crops and to maize and wheat crop in maize–wheat cropping system only significantly reduced the alkaline phosphatase activity in soil during both the years and the magnitude of reduction was 13.7 and 9.7% during 2012 and 12.8 and 13.2 % during 2013, respectively compared to treatment where N alone was applied. Soil enzyme activities with the treatment of NPK was higher than N-fertilizer treatment, it showed that P and K significantly increased the soil enzyme activities (Salinas-gracia *et al.*, 2002). Application of P and Si in aerobic rice had significant effect on soil alkaline phosphatase activity at 60 DAS and at harvesting. The maximum alkaline phosphatase activity at 60 DAS (65.85 µg p-nitrophenol/g/h) and at harvesting (37.37 µg p-nitrophenol/g/h) was obtained with 90 kg P<sub>2</sub>O<sub>5</sub>/ha and found at par with 60 kg P<sub>2</sub>O<sub>5</sub>/ha (Jinger *et al.*, 2020).

Omission of K and Zn to both crops and to maize and

wheat crop only in maize–wheat cropping system also significantly reduced the alkaline phosphatase activity in soil during both the years. The cumulative effect of NPK-applied plots in maize on alkaline phosphatase activity in soil after harvesting of maize was significantly superior to N, NP and NPZn-applied plots and the direct effect of NPK applied to maize was significantly superior to application of N alone during the second year of experimentation. Similarly, the cumulative and direct effects of NPK application on alkaline phosphatase activity in soil after harvesting of wheat crop was significantly superior to N, NP and NPZn during 2012–13 and 2013–14. The residual effect of NPK application on alkaline phosphatase activity in soil after harvesting of maize and wheat crop in maize-wheat cropping system was at par with absolute control plot during both the years of experimentation. In the experimentation it was observed that P fertilizer treatments (NP, NPK, NPZn and NPKZn) resulted in P accumulation which caused higher alkaline phosphatase activity. Zhang *et al.* (2008) found that when the biological demand for P increased, P application in soil enhanced the activity of alkaline phosphatase. However, when P supplies from chemical P fertilizer exceeded biological demand for P, the activity of acid phosphatase was inhibited by P fertilizer.

#### Urease enzyme activity in soil

Soil enzyme activities are related to microbe quantity. In the present study urease, alkaline phosphatase and dehydrogenase showed high correlation with MBC content in soil. Soil nutrients provide necessary mineral elements for plant growth and lead to fundamental changes in terrestrial

carbon pools and fluxes (McLauchan, 2006). They also act as important indicator for soil natural fertility, as there is a close relationship between soil nutrients and soil enzyme activity (Zebin *et al.*, 2011). Urease enzyme activity was significantly superior under STCR approach-based NPKZn-applied plots to all the other treatments and the absolute control plot (no nutrient applied) exhibited the lowest activity of urease in soil after harvesting of maize and wheat crops and decreased by 66.8 to 73.4% and 59 to 71.8% during 2012–13 and 2013–14 (Tables 2 and 3) in maize and wheat crop, respectively, compared to STCR approach-based fertilization. Omission of K and Zn to both crops of the cropping system significantly reduced the urease activity in soil by 22.3 and 9.2% and 18.9 and 6.4% during 2012–13 and 20.7 and 8.6% and 19.8 and 8.2% during 2013–14 in maize and wheat crop, respectively compared to recommended dose of NPKZn. But omitting P to both crops and only to maize and wheat crop numerically reduced its activity but has no significant effect during both the years. The cumulative and direct effects of NPK application in both maize and wheat crop in the cropping system resulted in significantly higher urease activity in soil compared to N, NP and NPZn application during both the years. The residual effect of NPK applied to preceding maize and wheat crop was at par with N, NP and NPZn for urease activity in soil after harvesting of wheat and maize in maize–wheat cropping system during both years of study. It was also found that, urease, alkaline phosphatase and dehydrogenase activities were lower if no soil fertilizer was applied, K fertilizer alone was applied, or P fertilizer was concurrently applied with other chemical

**Table 5.** Correlation studies between maize grain yield and soil enzymes activity.

Characters	Alkaline phosphatase ( $\mu\text{g p-nitrophenol/g/h}$ )	Dehydrogenase ( $\mu\text{g TPF/g/h}$ )	MBC ( $\mu\text{g/g}$ )	Urease ( $\mu\text{g/g/h}$ )	Yield (t/ha)
Alkaline phosphatase	1				
Dehydrogenase	0.93***	1			
MBC	0.91***	0.87***	1		
Urease	0.75***	0.81***	0.83***	1	
Yield	0.86***	0.90***	0.91***	0.95***	1

\*\*\* $P < 0.01$ ; \*\* $P < 0.05-0.1$ ; \* $P = 0.1$ ; So, highly significant correlation at  $P < 0.01$

**Table 6.** Correlation studies between wheat grain yield and soil enzymes activity

Characters	Alkaline phosphatase ( $\mu\text{g p-nitrophenol/g/h}$ )	Dehydrogenase ( $\mu\text{g TPF/g/h}$ )	MBC ( $\mu\text{g/g}$ )	Urease ( $\mu\text{g/g/h}$ )	Yield (t/ha)
Alkaline phosphatase	1				
Dehydrogenase	0.93***	1			
MBC	0.93***	0.90***	1		
Urease	0.66***	0.67***	0.73***	1	
Yield	0.87***	0.83***	0.93***	0.81***	1

\*\*\* $P < 0.01$ ; \*\* $P < 0.05-0.1$ ; \* $P = 0.1$ ; So, highly significant correlation at  $P < 0.01$

fertilizers (Acosta-martinez *et al.*, 2011). Omission of Zn had no significant effect on enzyme activities in soil after harvesting of maize and wheat during both the years of study.

#### Correlation between yield and soil enzymes activity

A correlation among various variables like soil MBC, urease, alkaline phosphatase, dehydrogenase soil enzymes activity and yield of maize and wheat crop is presented in Table 5 and 6. All the variables showed a positive and highly significant correlation with each other at ( $P < 0.01$ ).

### CONCLUSION

It was concluded that, balanced application of NPKZn based on STCR approach to both maize and wheat crops of the system significantly increased MBC content and improved the activities of dehydrogenase, alkaline phosphatase and urease enzyme in soil over the recommended dose of NPKZn, which indicates that the recommended dose for the maize-wheat cropping system is suboptimal and establishes STCR-based nutrient application as more scientific approach for improving soil biomass carbon and enzyme activities in the cropping system. The continuous omission of N, P, K and Zn in a cropping system significantly reduced the MBC and soil enzymes activity in maize-wheat cropping system. The continuous omission of P and K in the cropping system highlighted the significance of P and K application to both the crops.

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