Long-term Impact of Zero Tillage and Residue Retention on Soil Nutrients and Microbial Biomass in a Maize-Mustard Cropping System

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ABSTRACT

The objective of this study was to evaluate and compare different cropping systems and tillage practices, specifically focusing on the maize (*Zea mays* L.)-mustard (*Brassica juncea* L.) cropping system. The field experiment on maize (*Zea mays* L.)-mustard (*Brassica juncea* L.) cropping system commenced in monsoon 2010 at ICAR-IARI, New Delhi. Eight treatments were evaluated in a randomized block design, comprising four double cropping ZT (zero till) and two triple cropping ZT systems with or without crops residue retention along with two conventional till systems (control) [T1: ZTMZ-ZTM; T2: ZTMZ+BM-ZTM; T3: ZTMZ(+R)-ZTM(+R); T4: ZTMZ(+R)+BM-ZTM(+R); T5: ZTMZ-ZTM-ZTSMB; T6: ZTMZ(+R)-ZTM(+R)-ZTSMB(+R); T7: CTMZ-ZTM; T8: CTMZ-CTM] with three replications. Result showed that highest mineralizable nitrogen (388 kg ha^{-}1) was found in T6 treatment (in 0-5 cm soil layer) whereas T8 treatment recorded the lowest mineralisable N (297 kg ha^{-1}). ZTMZ(+R)-ZTM(+R)-ZTSMB(+R) treatment obtained a significant increase (81.3%) in Olsen extractable P over CTMZ-CTM treatment. MBP was observed to be maximum in T6 treatment (10.1 mg kg^{-1}) whereas lowest values were recorded in T8 treatment (2.67 mg kg^{-1}) in the upper layer. Therefore, under CA, utilization of microorganisms to increase the availability of P in soil is an attractive proposition for developing a more sustainable agriculture. This is relevant to the high-input production systems of the developed world, and also to developing countries where access to mineral fertilizers is restricted, which will give better results and outputs in future by giving easily available inputs without harming the environment and conserving soil fertility for future generations.

Keywords: *Conservation agriculture, Phosphorus, Zero tillage, microbial biomass phosphorus*

1. INTRODUCTION

Phosphorus (P) is the second most important nutrient for plant development, because of its' roles in root development, cell elongation, respiration, ATP formation, early plant maturity, and increased stalk length etc. [1]. Phosphorus is by far the least mobile and available to plants in the majority of soil conditions when compared to the other key nutrients. As a result, it typically serves as a significant or even the main constraint on plant growth. Despite receiving a lot of attention over the course of decades of intensive research in the 20th century, the mobility of inorganic phosphorus in most soils is still poorly understood and hardly predictable due to the lack of suitable methods for studying its speciation and biogeochemical behaviour. Due to the high reactivity of P ions with several soil components and the resulting significant retention of the majority of soil phosphorus onto those, soil inorganic phosphorus has low mobility. Consequently, only a small percentage Therefore, only a marginal proportion of soil phosphorus is present as P ions in the soil solution [2]. Organic P makes up 50-80% of total P in soil, often in the form of inositol phosphates, phospholipids, nucleic acid, nucleotides, and sugar phosphates. Microbial biomass P makes up a small percentage of overall P in soil and is quickly depleted, supplying inorganic P to plant roots. Until organic P can be absorbed by plants, it must be mineralized into inorganic forms. Enzymes, especially phosphatase and phytase, play a role in mineralization. Soil microorganisms are crucial in the regeneration of certain organic P compounds in soils. A systematic approach to understand the P cycle can assist in identifying potential recovery and increase its' use efficiency.

Conservation agriculture is a method of controlling agro-ecosystems for enhanced production, income, and food security while protecting and improving the resource base and the climate [3]. Under CA, main emphasis is given on minimal soil disruption, use of crop residues or other cover crops, and proper crop rotations to achieve high productivity by using the least amount of resources [4]. The cover crops, being a main component of CA are a useful technique for extracting P from the soil and therefore reducing the need for P as a mineral fertilizer. The retained crop residue is believed to be a rich source of organic P, which may be beneficial towards soil P enrichment, apart from production of some organic acids and secondary metabolites as well as provision of favourable environment for microbial growth [5]. Microorganisms play a crucial part in mediating the availability of P to plants since they are essential to the soil phosphorus cycle. The energy and carbon supply to the soil and the associated microbiological activity suggests a large redistribution of P among different fractions. The microbial soil biomass plays a central role in these interactions, both as a sink and a source of P [6]. Since many years ago, there has been a great deal of interest in understanding the microbial contribution to plant P nutrition and prospects for manipulating certain microbes to increase P availability in soil [7].

2. MATERIAL AND METHODS

2.1 Location and climate

The experiment was conducted at the ICAR-IARI, which is located at 28^{o}35´N, 77^{o}12´E, and 229 m above mean sea level. The region is part of the Indo-Gangetic Plain region's Upper-Gangetic Plain transects, which is characterized by automated and input-intensive agriculture. According to the categorization of the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), the experimental site represents Agro-ecological subregion 4.1 i.e., North Punjab Plain, Ganga-Yamuna Doab and Rajasthan Upland, hot, dry semi-arid eco-subregion. New Delhi's climate is subtropical, with dry, scorching summers and bitterly cold winters separated by a three-month monsoon season. The warmest month is May, while the coolest is January. Long-term weather data indicated a mean maximum temperature of 32.1˚C, a mean minimum temperature of 17˚C, and an average rainfall of 788 mm. More than three-fourth of the total rainfall is received through north-west monsoon during July to September.

2.2 Soil characterization

The soil of the experimental site is of Gangetic alluvial origin, very deep (>2 m), well-drained, and of flat to gently sloping topography. Taxonomically, it is classified as Typic Haplaquept. Important soil characteristics at the onset of the field experiment during 2010 are given in

Table 1. Apparently, the sandy clay loam soil was mildly alkaline in reaction, non-saline, medium in organic carbon, and medium in available P (Olsen-P) and available K content.

Table 1. Initial soil characteristics at the onset of the field experiment during kharif 2010

Climatic parameters	
Maximum temperature in summer (˚C)	40 to 44
Minimum temperature in winter (˚C)	3 to 8
Mean annual rainfall (mm)	900
Wind velocity throughout the year (km h^{-1})	3.5 to 4.3
Soil parameters	
Taxonomical classification	Typic Haplaquept
Texture	Sandy clay loam
pH	7.9
Walkley-Black carbon (g kg^{-1})	5.4
Bulk density (Mg m^{-3})	1.50
Available P (g kg^{-1})	25.6
Available K (g kg^{-1})	260

2.3 Layout and experimental details

The field experiment on maize (*Zea mays* L.)-mustard (*Brassica juncea* L.) cropping system commenced in monsoon 2010 at ICAR-IARI research farm 14B as a part of the Conservation project IARI. In the first three years (2010-11 to 2012-13), rice-maize cropping system was followed. The system was changed to rice-mustard system from 2013-14 onwards as winter maize (*Zea mays*) was very much susceptible to frost damage under this region, and then continued for five years till 2017-18. Due to allelopathy effect of mustard on rice crop the rice-mustard system was changed to maize-mustard system which is still being continued. Eight treatments were evaluated in a randomized block design, comprising four double cropping ZT and two triple cropping ZT systems with or without crops residue retention along with two conventional till systems (control) with three replications. Treatments details are furnished below:

T1: Zero till maize–Zero till mustard: ZTMZ–ZTM

T2: Zero till maize with Sesbania brown manuring–Zero till mustard: ZTMZ+BM–ZTM

T3: Mustard residue in Zero till maize–Maize residue in Zero till mustard: ZTMZ(+R)-ZTM(+R)

T4: Mustard residue in Zero till maize with brown manuring–Maize residue in Zero till mustard: ZTMZ(+R)+BM–ZTM(+R)

T5: Zero till maize–Zero till mustard–Zero till summer mungbean: ZTMZ–ZTM-ZTSMB

T6: Mungbean residue in Zero till maize–Maize residue in Zero till mustard–Mustard residue in Zero till summer mungbean: ZTMZ(+R)-ZTM(+R)-ZTSMB(+R)

T7: Conventional till maize–Zero till mustard: CTMZ-ZTM

T8: Conventional till maize–Conventional till mustard: CTMZ-CTM

2.4 Soil sampling and processing

Soil samples (0–5 and 5–15 cm) from replicated plots of all the chosen treatments were collected after the harvest of maize crop. Soil samples were divided into two parts, one part was kept in refrigerator for analysis of biological parameters and the other portion was air dried, ground in wooden mortar and pestle, and sieved to pass through a 2 mm sieve for analysis of different soil parameters. The moisture content was determined immediately by gravimetric method.

2.5 Analytical methodology

Soil physico-chemical properties were measured by the standard methods. Mineralizable N content of soil was determined by steam distillation with alkaline KMnO4 in a Kjeldahl tube. The volatilized NH_3 was captured in boric acid and titrated with a standard H_2SO_4 solution [8]. Available P was extracted with 0.5 M $NaHCO_3$ solution [9]. Phosphomolybdo-blue colour method [10] was followed to determine P content in the extracts at 730 nm on a UV-VIS spectrophotometer. Available K content was determined by extracting the soil with 1 *N* ammonium acetate (pH 7.0) followed by determination with a flame photometer [11].

For determination of microbial biomass phosphorus (MBP), nine portions of 10g moist soil were divided into three sub-sets each containing three samples. The first set was fumigated with chloroform in a desiccator for 24 h, and the second and third sets were incubated aerobically for the same period. The fumigated set and one non-fumigated set were extracted with 0.5 M $NaHCO_3$ (pH 8.5), while the third set of was extracted with the same extractant but containing inorganic P (as KH_2PO_4) equivalent to 25 µg Pi g^{-1} oven dry soil. This third set was used to calculate fraction of P (released from microbial cell after fumigation) that is adsorbed by soil. The P in the extracts was estimated spectrophotometrically by vanado-molybdo blue colour method at 730 nm using a spectrophotometer. The formula used here to calculate MBP is given below. An efficiency factor of 0.40 was used to transform the released P in to microbial biomass P [12].

MBP (µg Pi g^{-1} oven dry soil) = $\{(b–a) \times 25\}/0.4 \times (c–a)\}$

Where, a = P (µg Pi g^{-1} oven dry soil) extracted from unfumigated soil,

b = P (µg Pi g^{-1} oven dry soil) extracted from fumigated soil,

c = P (µg Pi g^{-1} oven dry soil) extracted from unfumigated soil with the extractant spiked with KH_2PO_4 equivalent to 25 µg Pi g^{-1} oven dry soil.

2.6 Statistical analysis

The obtained data were processed to test the significance of treatment effect using one-way analysis of variance pertinent to completely randomized block design [13]. Mean separation was done based on Tukey's HSD test ($p<0.05$) using SPSS (Stanford University, California, US; 1968). Fitting of adsorption-desorption data was done in MS-office excel (2007).

3. RESULTS AND DISCUSSION

3.1 Mineralizable nitrogen

Data pertaining to mineralizable nitrogen content of soil as influenced by different treatments under conservation agriculture are presented in Table 2. It was observed that in 0-5 cm soil layer mineralizable nitrogen content of T6 treatment was 388 kg ha^{-1} which was highest among all the treatments whereas T8 treatment recorded the lowest mineralisable nitrogen (297 kg ha^{-1}) which was also at par with T7 treatment. The treatments with residue retention showed better mineralisable nitrogen as compared to the treatments without residue retention. There was a significant increase of 30.9% that T6 treatment registered over T8 treatment. In case of subsurface soil, a similar type of data was found which denoted that the highest and lowest mineralizable nitrogen was obtained by ZTMZ(+R)-ZTM(+R)-ZTSMB(+R) treatment and CTMZ-CTM treatment respectively where ZTMZ(+R)-ZTM(+R)-ZTSMB(+R) treatment was significantly highest among all the treatments and CTMZ-CTM treatment was at par with CTMZ-ZTM treatment. Also, ZTMZ(+R)-ZTM(+R)-ZTSMB(+R) treatment resulted in 33.4% increase over CTMZ-CTM treatment. The conservation plot with triple zero tillage and residue treatment attributed to the decomposition of maize, mustard, and mung-bean residues on the soil surface, which resulted in the accumulation of soil organic carbon in the top soil and greater microbial population. This might readily mineralize C and N, affecting the C:N ratio, which regulated the mineralization/immobilization cycle of nutrients, articularly N [14, 15].

Table 2. Mineralisable nitrogen content in soil under maize-mustard system as influenced by conservation agriculture in an Inceptisol

Treatments	Mineralizable nitrogen (kg ha^{-1})*	
	0-5 cm	5-15 cm
T1: ZTMZ-ZTM	311de	305ef
T2: ZTMZ+BM-ZTM	320d	314de
T3: ZTMZ(+R)-ZTM(+R)	345c	336bc
T4: ZTMZ(+R)+BM-ZTM(+R)	359b	351b
T5: ZTMZ-ZTM-ZTSMB	334c	330cd
T6: ZTMZ(+R)-ZTM(+R)-ZTSMB(+R)	388a	379a
T7: CTMZ-ZTM	302ef	289fg
T8: CTMZ-CTM	297f	284g
Mean	332	323
P<0.05	11.2	18.9

**For each column, different lowercase letters indicate that the treatment means are significantly different at $p<0.05$ according to Tukey's HSD Test for separation of means*

3.2 Available P

Data (Table 3) pertaining to available P content in 0-5 cm and 5-15 cm soil layer, as influenced by conservation agricultural practices showed that there was a significant effect of tillage and residue management on Olsen extractable P content. In surface soil layer, the highest available P was recorded by the treatment comprising of ZTMZ(+R)-ZTM(+R)-ZTSMB(+R) which was significantly higher than all other treatments whereas the lowest available P was obtained by CTMZ-CTM treatment which was also significantly inferior to rest of the treatments, besides it was at par with CTMZ-ZTM treatment. ZTMZ(+R)-ZTM(+R)-ZTSMB(+R) treatment obtained a significant increase of 81.3% over CTMZ-CTM treatment. In case of sub-surface soil layer, ZTMZ(+R)-ZTM(+R) treatment registered highest available P content (68.9 kg ha^{-1}) which showed statistical similarity with ZTMZ-ZTM treatment and followed by ZTMZ(+R)-ZTM(+R)-ZTSMB(+R) treatment. The lowest available P was registered by CTMZ-CTM treatment which was at par with CTMZ-ZTM treatment.

The release of organic acids during decomposition and the solubilization of native P in residue treated plots resulted in an increase in available P in the soil [16, 17]. Furthermore, increased SOM combined with fresh residue retention and limited tillage ensured limited mixing of the applied fertilizer, reduced the chances of fixation, adsorption, and precipitation, also increased competition for the P adsorption sites by reduction of Ca^{2+}, Fe^{3+} and Al^{3+} activities forming stable complexes enhanced the lability and availability of soil P [18, 19, 20]. However, due to maximum soil mixing, the availability of labile P was limited with conventional tillage [21].

Table 3. Available P content in soil under maize-mustard system as influenced by conservation agriculture in an Inceptisol

Treatments	**Available P (kg ha^{-1})***	
	0-5 cm	5-15 cm
T1: ZTMZ-ZTM	78.7b	64.1ab
T2: ZTMZ+BM-ZTM	63.6d	50.8d
T3: ZTMZ(+R)-ZTM(+R)	82.0b	68.9a
T4: ZTMZ(+R)+BM-ZTM(+R)	79.2b	54.6cd
T5: ZTMZ-ZTM-ZTSMB	70.4c	58.5bc
T6: ZTMZ(+R)-ZTM(+R)-ZTSMB(+R)	88.1a	61.8b
T7: CTMZ-ZTM	52.5e	38.0e
T8: CTMZ-CTM	48.6e	36.8e
Mean	70.4	54.2
P<0.05	4.97	6.28

*For each column, different lowercase letters indicate that the treatment means are significantly different at p<0.05 according to Tukey's HSD Test for separation of means

3.3 Available K

Available K data (Table 4) as affected due to tillage and residue management practices in surface as well sub-surface soil layer revealed that in surface soil layer T6 treatment recorded significantly highest (150 kg ha-1) whereas T8 treatment recorded lowest (114 kg ha-1) available K content which was also at par with T7 and T1 treatments. The significant increase of T6 treatment over T8 treatment was 31.6%. In case of sub-surface soil layer, T6 and T8 treatment recorded highest and lowest available K content respectively. However, T8 treatment showed statistical similarity with T1, T2, T5 and T7 treatments, but T6 treatment was significantly different from all other treatments. There was a significant increase of

29.7% that T6 treatment obtained over T8 treatment. Residues provided more K to soil through decomposition under CA methods. Reduced tillage also increased soil organic matter, which acts as a buffer for K content. Similar results were observed [22].

Table 4. Available K content in soil under maize-mustard system as influenced by conservation agriculture in an Inceptisol

Treatments	**Available K (kg ha^{-1})***	
	0-5 cm	5-15 cm
T1: ZTMZ-ZTM	120cd	117bcd
T2: ZTMZ+BM-ZTM	123c	118bcd
T3: ZTMZ(+R)-ZTM(+R)	136b	126bc
T4: ZTMZ(+R)+BM-ZTM(+R)	137b	129b
T5: ZTMZ-ZTM-ZTSMB	126c	119bcd
T6: ZTMZ(+R)-ZTM(+R)-ZTSMB(+R)	150a	144a
T7: CTMZ-ZTM	118cd	112cd
T8: CTMZ-CTM	114d	111d
Mean	128	122
P<0.05	8.17	14.16

**For each column, different lowercase letters indicate that the treatment means are significantly different at p<0.05 according to Tukey's HSD Test for separation of means*

3.4 Microbial biomass P

The microbial biomass P (MBP) of soil as affected by various tillage and residue management practices in both surface and sub-surface soil layer are presented in Table 5. It was observed that in surface soil layer, T6 treatment and T8 treatment recorded the highest (10.1 mg kg^{-1}) and lowest (2.67 mg kg^{-1}) MBP respectively.

Table 5. Microbial biomass phosphorus in soil under maize-mustard system as influenced by conservation agriculture in an Inceptisol

Treatments	**Microbial biomass phosphorus (mg kg^{-1})***	
	0-5 cm	5-15 cm
T1: ZTMZ-ZTM	6.14e	4.62e
T2: ZTMZ+BM-ZTM	6.31e	5.24d
T3: ZTMZ(+R)-ZTM(+R)	8.48c	8.14b
T4: ZTMZ(+R)+BM-ZTM(+R)	8.99b	8.48b
T5: ZTMZ-ZTM-ZTSMB	7.27d	6.78c
T6: ZTMZ(+R)-ZTM(+R)-ZTSMB(+R)	10.1a	9.31a

T7: CTMZ-ZTM	3.69f	3.48f
T8: CTMZ-CTM	2.67g	2.24g
Mean	33.5	30.2
P<0.05	0.36	0.46

**For each column, different lowercase letters indicate that the treatment means are significantly different at p<0.05 according to Tukey's HSD Test for separation of means*

Also, in sub-surface soil layer a similar type of result was observed where the highest and lowest value was recorded by T6 treatment and T8 treatment respectively both of which were significantly different from all other treatments. Hence it was found that the conservation agricultural practices significantly affect the microbial biomass phosphorus in both the soil layers.

Microorganisms play a critical role in organic P transformations in soil [23], and P in their biomass contribute to the soil nutrient pool [24]. P produced from cells as microorganisms die and decompose becomes readily available to plants, making microbial biomass an important source of P for crops [23]. Changes in the physical, chemical, and biological environment caused by tillage and crop residue addition have a significant impact on their development and abundance [25]. In comparison to the conventional tillage treatment, the present study found that residue retention with zero tillage enhanced MBP content in soil. This might be attributed to more favorable soil conditions for soil microbe growth with little soil disturbance from crop residues than conventionally tilled soil, as well as increased organic matter content in the top layer [26]. Following the normal turnover of the microbial biomass, an increase in P in the microbial biomass is a potential source of P [27]. Greater MBP in the surface layer than below depth might be owing to a decrease in biomass as soil depth increases and/or greater impacts of tillage and residue management on MBP in the top layer than in the layer below [28]. Proper tillage and residue management should be undertaken to increase MBP, which might further boost P availability and sustain cropping systems [29].

4. CONCLUSION

Based on the results, it can be concluded that adoption of conservation agriculture significantly increased mineralizable N, available P, available K and MBP, while greater advantage was noticed with retention of legume residue. In a nutshell, triple zero tillage with residue retention treatment ZTMZ(+R)-ZTM(+R)-ZTSMB(+R) (T6 treatment) was proved to be best in all the above aspects. Therefore, under conservation agriculture, utilization of microorganisms to increase the availability of P in soil therefore is an attractive proposition for developing a more sustainable agriculture. This is relevant to the high-input production systems of the developed world, and also to developing countries where access to mineral fertilizers is restricted, which will give better results and outputs in future by giving easily available inputs without harming the environment and conserving soil fertility for future generations.

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