Long term effect of legume intensified crop rotations and tillage practices on productivity and profitability of maize vis-a-vis soil fertility in North-Western Indo-Gangetic Plains of India


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ABSTRACT

The present study was planned to evaluate the long term effect of legume intensified maize based crop rotations and tillage practices on productivity, profitability of maize vis-a-vis soil health. The experiment consisted of three tillage practices i.e. zero tillage (ZT), permanent bed (PB) and conventional tillage (CT) as main plot treatments and four crop rotations (MWMb; maize-wheat-mungbean, MCS; maize-chickpea-Sesbania, MMuMb; maize-mustard-mungbean, MMS; maize-maize-Sesbania) as sub plot treatments. Results revealed that ZT and PB resulted into significantly (P<0.05) improvement in grain (7.7-14.2%) and stover yield (7.4-13.0%) of maize over CT. Similarly, maize grain and stover yield were invariably higher in MCS and MWMb systems compared to MMuMb and MMS rotations. The total soil carbon (TSC) content increased by 15.4-17.4 and 20.32-20.91% with ZT and PB over CT in 0-15 and 15-30 cm soil depths, respectively. However, MCS and MWMb rotations registered 11.3-18.0% (0-15 cm) and 8.4-11.0% (15-30 cm) higher TSC over MMuMb rotation. Similarly, ZT and PB resulted into significantly (P<0.05) improvement in available soil nitrogen (N), phosphorus (P) and potassium (K) compared to CT. ZT/PB under MCS crop rotations registered higher net returns and BC ratio compared to rest of the treatment combinations. Interaction effect of tillage and crop rotations were significant (P<0.05) for stover yield, net returns, BC ratio and TSC and all these parameters were reported maximum with ZT-MCS. Thus, the present study suggests that CA based crop management practices can be advocated as sustainable intensification strategy in north-western India.

Key words: Chickpea, Legume intensified crop rotations, Maize productivity, Mungbean, Sesbania, Soil health, Tillage, Total soil carbon.

INTRODUCTION

Tillage is most important agro-technical operation performed in order to achieve optimum soil conditions for better crop growth and development. However, tillage in some situations can lead to soil degradation, leading to low levels of soil organic carbon (SOC). Conventional tillage (CT) practices are also known to be associated with higher labour and fuel cost resulting in lower economic returns to the growers (Jat et al., 2013;Jat et al., 2005; Yadav et al., 2016). In contrast, conservation agriculture (CA) based tillage systems such as zero tillage (ZT) and permanent beds (PB) has been reported to reduce biological oxidation of SOC, increases water holding capacity, prevents land degradation by lowering the intensity of soil erosion (Six et al., 2002). These resource conserving technologies are characterized by deposition of most of the crop residue over the soil surface after planting the crops. Long term implementation of ZT and PB in legume diversified cereal based rotations leads to buildup in SOC which enhances soil health (Parihar et al., 2016). However, long term studies to evaluating and understand the effects of various tillage practices on legume intensified maize based crop sequences on productivity, profitability of maize vis-a-vis soil health especially for IGP region of South Asia is still lacking. Introduction and development of dwarf, short-duration and high yielding varieties of rice and wheat during green revolution has resulted into wider adoption of rice-wheat rotation (RWCR) throughout the IGP region (Singh et al., 2011). Being a major cropping system the RWCR covering around 12.5 M ha area and contributing to nearly 22% of total national food basket (Yadav et al., 2000). Currently, the sustainability of RWCR is at stake and the major factors responsible are: (1) intensive use of CT practices causing severe land degradation (Prasad, 2005);
Crop diversification provides lot of opportunities in fulfilling the basic needs and regulating farm income, ensuring balanced food supply, conserving natural resources and creating employment opportunity (Gill and Ahlawat, 2006). Considering present market externalities, environmental concerns, there are opportunities for diversifying the RWCR using suitable legumes, oilseeds and cereals other than rice and wheat (Pandey et al., 2008). In this context maize is viable options to replace rice in rainy season. The other major drivers for replacing of rice with maize are (i) better adaptability of maize to diverse ecologies because of its C4 nature, (ii) increasing demand of maize for poultry, piggery and fishery sectors, (iii) narrowing export market for rice (Dass et al., 2012), (iv) higher productivity potential with more palatable fodder (Singh, 2012). Increasing demand for oilseeds and pulses has further prompted farmers to diversify RWCR using legume and oilseeds as an alternative to wheat during rabi season (Singh et al., 2016). Partial diversification is also possible by accommodating third crop in the system during summer season when fields generally remain fallow after rabi harvest and a summer season mungbean and cowpea crop can be taken during this period. Short-duration summer-legume crops mungbean and cowpea in IGP has great potential in enhancing crop-intensification and thus, harnessing better system productivity and profitability (Sharma and Sharma, 2004; Singh, 2012). Overall, crop diversification in cereal-cereal based production systems is the need of the hour in IGP both through location-specific cereal replacement and crop-intensification as well (Singh et al., 2011). Thus, the current study was undertaken to access the impact of long term tillage practices and legume intensified maize based production systems in relation to enhance productivity, profitability and soil health; besides ameliorating the production vulnerabilities that rice wheat rotation has brought so far.

MATERIALS AND METHODS

A long-term field experiment established in the monsoon season of 2008 at the research farm (28‘40’ N, 77‘12’ E and 228.6 m elevation) of the ICAR-IMR, Pusa Campus, New Delhi, India. The climate of the study site is semi-arid, with a mean annual rainfall of 650 mm (70-80% of which received during July-September) with the mean annual evaporation of 850 mm. The mean minimum, maximum temperature and total rainfall during this study period of kharif 2014 (July-October) was 23.7°C, 33.3°C and 451 mm, respectively. The soil of experimental site (before kharif 2008) was sandy loam in texture with 7.8 pH, Walkley–Black C (0.42%), EC (0.32 ds m⁻²), KMnO₄ oxidizable N (158.4 kg ha⁻¹), 0.5 M NaHCO₃ extractable P (11.6 kg ha⁻¹) and 1 N NH₄, OAC extractable K (24.8 kg ha⁻¹). The experiment was conducted in split plot design with three main-plot treatments consisting of tillage practices [zero tillage (ZT), permanent bed (PB) and conventional tillage (CT)] and four sub-plot treatments of legume intensified maize based systems [maize-mungbean (MWMb), maize-chick pea-Sesbania (MCS), maize-mustard-mungbean (MMuMb) and maize-maize-Sesbania (MMS)]. The CT planting involved one ploughing each with cultivator, disc harrow and rotavator, however in ZT, no ploughing was done. But in case of PB reshaping of beds were done at the end of every cropping cycle in one-go simultaneously with seed and fertilizer placement using raised bed multi-crop planter. Residues of every preceding crop was retained in ZT and PB and incorporated in CT plots. In the first year of experimentation (before start of experiment in kharif 2008) an equal quantity of mungbean and Sesbania residue (1.5 Mg ha⁻¹, dry weight basis) was retained/ incorporated in all plots. The maize cv HQPM-1, a quality protein maize hybrid was sown with a seed rate of 20 kg ha⁻¹ during first fortnight of July in 2014 with a row spacing of 67 cm and plant to plant distance at 25 cm. The maize crop was harvested at the end of October 2014. A common dose of nutrients amounting 150 kg N + 60 kg P₂O₅ + 40 kg K₂O + 25 kg ZnSO₄ ha⁻¹ were applied in all treatments during first year of study (Kharif, 2008). The 1/3rd N and whole P₂O₅, K₂O and ZnSO₄ was applied as basal, while remaining 2/3rd N was top dressed as urea in two equal splits at V5 and VT vegetative growth phases. In view of proper weed management, herbicide glyphosate was sprayed @ 1.0 L a.i. ha⁻¹ in all the ZT and PB plots about two days before sowing of crop. However, in case of CT plots Atrazine @ 1.0 kg a.i. ha⁻¹ was applied as pre-emergence to control the weeds.

At maturity, the crop was harvested manually at a height of 40 cm and the stover yields was adjusted on the oven dry weight basis by oven drying at 65°C for 48 hr. The grain
yield was adjusted at 14% moisture content and expressed in kg ha\(^{-1}\). N, P and K content in maize stover were determined by modified Kjeldahl, vanadomolybdophosphoric acid yellow colour method flame photometer, respectively (Prasad et al., 2006). The soil samples were collected from three different depths (0-15, 15-30 and 30-45 cm) were air dried, ground and pass through 2 mm mesh sieve and were analysed for TSC and available soil N, P and K. TSC content of soil was determined by dry combustion using CHNS analyser. The soil available N, P and K were estimated using alkaline KMnO4 (Subbiah and Asija, 1956), Olsen’s method (Olsen et al., 1954) and Normal ammonium acetate extraction (flame photometer) method (Jackson, 1973), respectively. The net returns of each treatment combination were calculated by deducting the total cost of cultivation from gross returns of respective treatments and the BC ratio was calculated by dividing the net returns with total cost of cultivation. All data recorded were analyzed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez, 1984) for split-plot design using SAS 9.3 software (SAS Institute, Cary, NC). The least significant test was used to decipher the main and interaction effects of treatments at 5% level of significance (P<0.05).

RESULTS AND DISCUSSION

Crop productivity: The tillage practices and cropping system effects on maize grain and stover yield were significant (P<0.05). CA practices (ZT and PB) resulted into 7.71-14.21% and 7.44-13.04% higher grain and stover yield compared to CT. The grain and stover yield of maize also differed significantly (P<0.05) under legume intensified cropping systems. The maximum grain (4582 kg ha\(^{-1}\)) and stover yield (11352 kg ha\(^{-1}\)) of maize was recorded under CT-MMS. PB-MWMb and ZT-MCS plots registered highest stover yield was found in PB-MWMb and lowest (P<0.05) interaction effect on stover yield (Fig. 1). Our findings of higher yields of maize under ZT and PB are in close agreement with the findings of Yadav et al., (2016a); Gathala et al., (2013); Parihar et al., (2016a); Parihar et al., (2017). The higher yields of maize in ZT/PB systems could be due to the compound effects of additional nutrients (BlancoCanqui and Lal 2009; Kaschuk et al., 2010) reduce competition for resources due to lesser weed population (Ozpinar, 2006) and improved bio-physico-chemical soil health (Jat et al., 2013 and Parihar et al., 2016; Govaerts et al., 2009) over CT. In addition to these factors, the root growth found better under CA compared to CT due to lesser compaction (Passioura, 2002; Blanco-Canqui et al., 2006). The higher maize yield with MCS might be due to inclusion of two legumes (one winter and another in summer) compared to only summer legume in other cropping systems. The inclusion of legumes might have improved the soil fertility; particularly the N availability thereby improved growth and yields of maize (Congreves et al., 2015). The grain, stover yield was significantly and positively correlated with the TSC content (Table 5) (r=0.818***and 0.803***, respectively).

The higher nutrient density in maize crop due to increased forage area for nutrient extraction. Beside this, the retention of mungbean/Sesbania residue recycled the nutrients in upper soil layers and ultimately enhances nutrient availability in crop root zone which might lead to more nutrient uptake. In addition to this, the chelating forms of nutrients due to higher SOC content in ZT helps in retaining more nutrients with lesser losses of soil applied fertilizer nutrients. The similar finding of higher NPK content of maize under CA practices were also reported by Alam et al., 2014 and Naresh et al., 2014. Legume intensified cropping systems significantly (P<0.05) influenced NPK content in maize stover. The maximum N, P and K content in maize stover was observed in MCS sequence plots as compared to other cropping sequences (Table 2). The MCS sequence registered 3.3, 8.5 and 14.4% increase in total N, P and K content of maize stover over to MMuMb, respectively. The inclusion of deep rooted legumes with shallow rooted cereals in the cropping systems might help in extraction of sub-surface nutrients. This in turn increases the nutrient availability in surface soil layers where maximum concentrations of maize roots existed. The higher nutrient availability might help in higher uptake of N, P and K which in turn leads to higher content of these nutrients in maize stover. The enhancement of NPK content due to inclusion of

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Grain yield (kg ha(^{-1}))</th>
<th>Stover yield (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB</td>
<td>4328*</td>
<td>10847*</td>
</tr>
<tr>
<td>ZT</td>
<td>4589*</td>
<td>11412*</td>
</tr>
<tr>
<td>CT</td>
<td>4018*</td>
<td>10095*</td>
</tr>
<tr>
<td>Cropping systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MWMb</td>
<td>4366*</td>
<td>11131*</td>
</tr>
<tr>
<td>MCS</td>
<td>4582*</td>
<td>11352*</td>
</tr>
<tr>
<td>MMuMb</td>
<td>4225*</td>
<td>10549*</td>
</tr>
<tr>
<td>MMS</td>
<td>4075*</td>
<td>10107*</td>
</tr>
</tbody>
</table>

*Same letter within each column indicate no significant difference among the treatments (at P<0.05) according to Duncan multiple range test.
Legumes has been earlier reported by Parihar, 2014 and Aziz et al., 2015. The available N and P content of maize stover were significantly and positively correlated with the TSC (Table 5) ($r=0.803^{**}$ and $0.65^{**}$, respectively).

**Total soil carbon (TSC):** Tillage practices had significant effect ($P<0.05$) on TSC content (Table 3). In general, across the management practices (tillage and crop rotations), the TSC contents in the 0–15 cm depth were higher than the 15–30 cm or 30–45 cm depths. This indicated a stratification of crop residues and organic matter in the surface depth under CA practice. CA practices (PB and ZT) recorded significantly ($P<0.05$) higher TSC in 0-15 and 15-30 cm soil layers (Table 3). PB and ZT plots resulted into 15.4 to 17.4% and 20.3-20.9% higher TSC over CT plots in 0-15 and 15-30 cm soil depth, respectively. The lower TSC under CT might be due to fact that intensive soil disturbance through tillage in case of CT plots leads to higher oxidation of SOC (Balota et al., 2003; Thomas et al., 2007). In contrast, CA practices (ZT and PB) have been reported to reduce the losses of SOC by reducing their oxidation through minimizing the physical manipulation of soil. The stratification of TSC under CA has also been reported by several others researchers (Baker et al., 2007; Kaiser et al., 2014). The legume intensified maize based crop rotations also had significant ($P<0.05$) effect on TSC upto 30 cm soil depth only. The long term implementation of MCS and MWMb rotations recorded significantly ($P<0.05$) higher TSC content, which was 11.3 to 18.0% and 8.4 to 11.0% higher in 0-15 cm and 15-30 cm soil layer, respectively over MMuMb. However, across the soil depths, the MWMb rotation found at par with MCS rotation for TSC. The difference in TSC content among crop rotations might be due to differences in quantity and chemical composition of added crop residue biomass and root exudates of different crops. Inclusion of two legumes in MCS added large quantity of legume residue that leads to higher TSC compared to other cropping sequences as the narrow CN ratio of legume residue facilitate their decomposition (Congreves et al., 2015). The interaction effect of different tillage and diversified crop rotations on TSC content for 0-

<table>
<thead>
<tr>
<th>Treatments</th>
<th>N content (%)</th>
<th>P content (%)</th>
<th>K content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage practices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PB</td>
<td>0.547$^{ab}$</td>
<td>0.205$^{ab}$</td>
<td>1.153$^{b}$</td>
</tr>
<tr>
<td>ZT</td>
<td>0.563$^*$</td>
<td>0.226$^*$</td>
<td>1.198$^*$</td>
</tr>
<tr>
<td>CT</td>
<td>0.537$^b$</td>
<td>0.194$^b$</td>
<td>1.138$^b$</td>
</tr>
<tr>
<td>Cropping systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MWMb</td>
<td>0.551$^*$</td>
<td>0.210$^*$</td>
<td>1.221$^*$</td>
</tr>
<tr>
<td>MCS</td>
<td>0.556$^*$</td>
<td>0.216$^*$</td>
<td>1.233$^*$</td>
</tr>
<tr>
<td>MMuMb</td>
<td>0.538$^b$</td>
<td>0.199$^b$</td>
<td>1.078$^{ab}$</td>
</tr>
<tr>
<td>MMS</td>
<td>0.550$^a$</td>
<td>0.207$^{ab}$</td>
<td>1.119$^b$</td>
</tr>
</tbody>
</table>

*Same letter within each column indicate no significant difference among the treatments (at $P<0.05$) according to Duncan multiple range test.

Fig.1: Interaction effects of long term tillage practices and legume intensified cropping systems on stover yield of maize grown after six cropping cycles.
15 and 15-30 cm soil layers was also significant (P<0.05). The significantly (P<0.05) highest TSC content was recorded under PB-MCS followed by ZT-MCS treatment and lowest with CT-MMuMb. PB-MCS and ZT-MCS plots registered 35.8-37.7% (0-15 cm) and 23.4-30.6% (15-30 cm) higher TSC content compared to CT-MMuMb. CA practices attributed to less soil disturbance leads to lower oxidation of SOC and at the same time residue retention under these practices through crop diversification (legume inclusion) further facilitate greater carbon inputs which ultimately resulted into higher TSC with CA practices.

Available soil macronutrients: The long-term CA practices (PB and ZT) had significant (P<0.05) effect on available NPK content of different soil layers (Table 4). The slightly higher balance of N and P in top soil layer (0-15 cm) was reported in PB which was at par to ZT. This might be due to more oxidation of organic material in non-disturbed soil leads the improvement of soil nutrient status in different soil depths (Singh et al., 2005). The similar findings of higher accumulation of macro nutrients due to CA practices in soil were also reported by Graham et al. (2002) and Wang et al. (2008) for N; Betrol et al. (2007) and Malhi et al. (2011) for P and Du Preez et al. (2001) and Govaerts et al. (2007) for K. The effect of legume intensified maize based crop rotations on available NPK contents were significant (P<0.05) for 0–15, 15–30 and 30-45 cm soil depths (Table 4). Maximum NPK contents across the soil depths were recorded in MCS sequence. The MCS crop rotation attributed to 8.3-19.3%, 17.7-43.4% and 10.0-15.5% higher N, P and K respectively, compared to MMuMb, MMS crop rotations in 0-45 cm soil depth. The significantly (P<0.05) superior NPK contents in PB and ZT plots were significantly (P<0.05) superior to CT plots. The available N and P content in PB and ZT plots were significantly (P<0.05) higher (24.1-32.7% N and 26.6-55.8% P) than the CT plots for 0-45 cm soil depths. Likewise, adoption of CA practices (ZT and PB) resulted into 21.1-24.2% higher available K in 0-45 cm soil depth (Table 4). The recycling of the higher amount of previous crops residue due to higher biomass yield in these treatments lead to addition of more nutrients in ZT and PB practices compared to CT. While, in case of CT the stover/ straw get incorporated in deep soil layer which in turn reduces the available these nutrients in CT. Moreover, the chelating of these nutrients with organic matter in non-disturbed soil leads the improvement of soil nutrient status in different soil depths (Singh et al., 2005). The similar findings of higher available K in 0-45 cm soil depth (Table 4). The differences in quantity and chemical composition of crop

15 and 15-30 cm soil layers was also significant (P<0.05). The significantly (P<0.05) highest TSC content was recorded under PB-MCS followed by ZT-MCS treatment and lowest with CT-MMuMb. PB-MCS and ZT-MCS plots registered 35.8-37.7% (0-15 cm) and 23.4-30.6% (15-30 cm) higher TSC content compared to CT-MMuMb. CA practices attributed to less soil disturbance leads to lower oxidation of SOC and at the same time residue retention under these practices through crop diversification (legume inclusion) further facilitate greater carbon inputs which ultimately resulted into higher TSC with CA practices.

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Table 4: Long term (after harvest of seventh kharif season crop) effect of legume intensified crop rotations and tillage practices on macro nutrients accumulation capacity (kg ha⁻¹) at different soil layers.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Available N 0-15 cm</th>
<th>Available N 15-30 cm</th>
<th>Available N 30-45 cm</th>
<th>Available P 0-15 cm</th>
<th>Available P 15-30 cm</th>
<th>Available P 30-45 cm</th>
<th>Available K 0-45 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tillage practices</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent bed</td>
<td>224.2a</td>
<td>200.0a</td>
<td>185.3a</td>
<td>26.7a</td>
<td>18.1a</td>
<td>12.2a</td>
<td>222.9a</td>
</tr>
<tr>
<td>Zero tillage flat</td>
<td>223.8a</td>
<td>206.9a</td>
<td>189.5a</td>
<td>26.6a</td>
<td>18.8a</td>
<td>13.4a</td>
<td>228.5a</td>
</tr>
<tr>
<td>Conventional tillage</td>
<td>180.4b</td>
<td>155.9b</td>
<td>145.1b</td>
<td>18.7b</td>
<td>14.3b</td>
<td>8.6b</td>
<td>184.0b</td>
</tr>
<tr>
<td><strong>Cropping systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MWMb</td>
<td>217.0ab</td>
<td>192.2ab</td>
<td>177.6a</td>
<td>24.9ab</td>
<td>17.0b</td>
<td>12.9ab</td>
<td>216.9ab</td>
</tr>
<tr>
<td>MCS</td>
<td>225.9a</td>
<td>202.1a</td>
<td>185.7a</td>
<td>27.3a</td>
<td>19.9a</td>
<td>14.0a</td>
<td>227.1a</td>
</tr>
<tr>
<td>MMuMb</td>
<td>205.6b</td>
<td>183.6b</td>
<td>171.4ab</td>
<td>22.4b</td>
<td>16.2b</td>
<td>11.9b</td>
<td>206.5b</td>
</tr>
<tr>
<td>MMS</td>
<td>189.4c</td>
<td>172.6b</td>
<td>158.5b</td>
<td>21.4b</td>
<td>15.2b</td>
<td>9.76c</td>
<td>196.6b</td>
</tr>
</tbody>
</table>

*Same letter within each column indicate no significant difference among the treatments (at P < 0.05) according to Duncan multiple range test.

residue biomass and/or root exudates among the crop rotations (Congreves et al., 2015). The narrow CN ratio of legume residue caused rapid decomposition and hence higher SOC compared to other cropping sequences which facilitate higher accumulation of available NPK in the soil. Further, tap roots of the legume resulted higher SOC and NPK content in deeper layers. Generally, across the tillage and crop rotations the NPK content decreased in sub-surface soil layers. The available N and P of soil were significantly and positively correlated with the TSC content (Table 5) (r=0.866*** and 0.937***, respectively).

Farm profitability: The net returns and BC ratio were influenced significantly (P<0.05) due to different tillage practices. The maximum net returns (₹45,681 ha⁻¹) and BC ratio (1.85 invested) were obtained under ZT, while minimum net returns (₹35,363 ha⁻¹) and BC ratio (1.34 invested) were obtained under CT, respectively. Similarly, the net returns and BC of maize were also significantly (P<0.05) differed when it was sown under legume intensified cropping systems. The highest net returns (₹44,973 ha⁻¹) and BC ratio (1.78 invested) were fetched with MCS, which was statistically at par with MWMb system. The lowest net returns (₹37,216 ha⁻¹) and BC ratio (1.48 invested) was obtained in MMS system. The returns to investment was much higher in ZT practices due to twin reasons viz; lower production cost by 1350 ₹ ha⁻¹ and enhancement in yields, which lead to increase in net returns by 29% over CT. In our study ZT and PB found to be economical as well as ecological viable option as compared to CT for maize. The similar results were also reported by Singh et al. (2014). In contrast, Pal and Bhatnagar (2014) reported higher net returns in CT compared to CA. The higher net returns of maize planted.

![Fig.2: Interaction effects of long term tillage practices and legume intensified cropping systems on BC ratio of kharif maize grown after six cropping cycles.](image1)

![Fig.3. Interaction effects of long term tillage practices and legume intensified cropping systems on BC ratio of kharif maize grown after six cropping cycles.](image2)
under MCS system was due to that the inclusion of two legumes in this system provided an additional yields of maize compared to others cropping systems. The long term tillage practices and crop rotations interaction effect on net returns and BC ratio were found significant (P<0.05) (Fig. 2 and Fig. 3). The highest net returns and BC ratio were found in ZT-MCS, followed by ZT-MWMb and lowest was in CT-MMS. ZT-MCS and ZT-MWMb crop rotations registered 47.1-56.8% and 58.7-67.9% higher net returns and BC ratio compared to CT-MMS plots, respectively. The higher net returns with legume inclusion and their positive effects were also reported by Parihar et al. (2011) and Khatri et al. (2014).

CONCLUSIONS

In north-western India, legume intensified maize-based rotations being advocated as alternative to rice-wheat rotations to address the issues of declining water table, soil health deterioration particularly decline in SOC which results in declining factor productivity and farm profitability. Our results from long term study at fixed site demonstrated that establishment of maize under CA based tillage practices (ZT and PB) and legume intensified crop rotations (MCS and MWMb) resulted in significant improvement in the total soil carbon dynamics, grain protein and stover yield of maize with higher net returns and BC ratio as well as the NPK content in maize stover.

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