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Moisture conservation practices in maize-mustard cropping system: Effects on productivity, water use and soil fertility

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ABSTRACT

A field experiment was conducted at the Research Farm of ICAR-Indian Agricultural Research Institute (IARI), New Delhi during *kharif* and *rabi* seasons of 2014-15 and 2015-16 with the objective to study the effect of different moisture enhancing practices and conservation tillage on performance of maize-mustard cropping system and soil properties. The main plot treatments consisted of four moisture conservation practices in *kharif* season maize *viz.,* ridges and furrows (RF), RF + crop residue (CR) 4 t ha^{-1}, RF + CR 2 t ha^{-1} + VAM and flat sowing (FS). Five zero tillage (ZT) management techniques in *rabi* season mustard *viz.,* ZT, ZT + seed priming, ZT + CR 4 t ha^{-1}, ZT + CR 2 t ha^{-1} + Hydrogel and conventional tillage (CT) were executed in sub plots under cropping system mode. The experiment was laid out in split-plot design with three replications. Maize kernel yield in RF + CR 4 t ha^{-1} treatment was 10.6, 29.4 and 46.5% higher than RF + CR 2 t ha^{-1} + VAM, RF and FS (control) treatments, respectively. Whereas, in sub-plots (residual effects), ZT + CR 4 t ha^{-1} recorded maximum kernel yield (3.05 t ha^{-1}) followed by ZT + CR 2 t ha^{-1} + Hydrogel (2.99 t ha^{-1}) treatment. Significantly higher mustard yield of 11.5, 23.1 and 35.8% was obtained in RF + CR 4 t ha^{-1} treatment over RF + CR 2 t ha^{-1} + VAM, RF and FS, respectively because of the residual effects of treatments. Whereas, for mustard, direct effects of different planting methods in sub-plots gave maximum yield (2.05 t ha^{-1}) in ZT + CR 4 t ha^{-1} which was closely followed by ZT + CR 2 t ha^{-1} + Hydrogel (1.95 t ha^{-1}). Cumulative effects (direct and residual) showed that bulk density (BD), saturated hydraulic conductivity, infiltration rate and penetration resistance remained unaffected with treatments. Significantly higher availability of nitrogen (149 and 150 kg ha^{-1}), phosphorus (14.5 and 15.6 kg ha^{-1}) and potassium (193 and 192 kg ha^{-1}) in soil was registered under the best yielding treatments *i.e.* RF + CR 4 t ha^{-1} and ZT + CR 4 t ha^{-1} in maize and mustard crops, respectively. Therefore, the adoption best treatment will give sustainable yield of maize and mustard besides maintaining soil health under rainfed conditions.

1. INTRODUCTION

In rainfed areas of India, maize -mustard cropping system is a prominent one particularly in sub-tropical hill ecosystems of north-eastern India, pockets of Rajasthan and Jammu region. Maize is one of the emerging crops of India, and since 1950-51, the area, production and productivity of maize have increased by more than 3.4, 12 and 4.5 times *i.e.* from 3.2 M ha, 1.7 M t and 547 kg ha^{-1} to current level of 8.17 M ha., 19.33 Mt and 2414 kg ha^{-1}, respectively (Farmers' portal, 2016). Indian mustard is the most important oilseed crop of India. It accounts for 23% of the total area and 25% of the total oilseeds production of the country. It is raised in an area of 6.90 M ha with a production of 8.18 M t and average productivity of 1185 kg ha^{-1} (DAC, 2017). The productivity of maize-mustard cropping system is poor particularly in rainfed areas mainly due to low moisture and nutrient availability to crops.

Conservation tillage (CT) and residue retention (mulching) has been found very important in sustaining rainfed farming (Thakur *et al.,* 2011). Using crop residue (CR) as mulch is a viable approach for conserving soil moisture and retaining nutrients under such conditions. Of late, it has been established that disturbing the soil too much through tillage operations is not actually required to obtain good crop yields as well as economic returns (Bhatt, 2017). Also a major portion of energy (25-30%) in agriculture is utilized for either field preparation or crop establishment under CT. Rising cost of fuel and availability of effective package of practices for conservation tillage are redefining tillage in recent years. However, the impact of conservation tillage on soil physical environment is not always positive and varies from one soil to other as well as between the cropping systems (Saha *et al.,* 2010), which leads to varying crop yield.

Many studies have been done on conservation tillage and its effect on crop yield and soil quality, but the combined effect of soil moisture enhancing practices with conservation tillage on crop yield and soil quality is still not very clear, especially under rainfed areas of north-western India. Keeping these facts in mind, the present investigation was carried out to study the effect of moisture enhancing practices and conservation tillage on performance of maize-mustard cropping system and to quantify their effect on different soil properties.

2. MATERIALS AND METHODS

Study Area

The field experiment was conducted at the Research Farm of ICAR-IARI, New Delhi during the *kharif* (rainy) and *rabi* (winter) seasons of 2014-15 and 2015-16. The experimental site was situated at 28°38'23" N Latitude, 77°09'27" E Longitude and at an altitude of 228.6 m above mean sea level (msl) in a semi-arid subtropical climatic belt. The total precipitation received during *kharif* season was 395.4 and 710 mm while for *rabi* season was 227.8 and 22.0 mm in first and second year, respectively. The soil was sandy loam in texture and slightly alkaline in reaction (pH 7.7).

Treatments Execution

The main plot treatments consisted of four moisture conservation practices under *kharif* season maize *viz.* RF, RF + CR 4 t ha^{-1}, RF + CR 2 t ha^{-1} + VAM and FS. ZT management techniques in *rabi* season mustard *viz.* ZT, ZT + seed priming (SP) (KNO_3), ZT + CR 4 t ha^{-1}, ZT + CR 2 t ha^{-1} + Hydrogel and CT in sub plots in mustard were also imposed under cropping system mode. Direct effect of *kharif* treatments were studied in maize and residual in mustard whereas residual effects of *rabi* treatments were observed in maize and direct effects in mustard, respectively. The experiment was laid out in split-plot design with three replications. At the time of sowing, VAM treatment @ 5 kg ha^{-1} and seed priming with 0.2% $KMNO_4$ solution was used as moisture conservation practice.

Cultural Operations

In CT, field was prepared with a disc plough followed by two pass of a disc harrow; and planking was done to have uniform seed bed of fine tilth. Under RF system, maize was sown on ridges and mustard in furrows. Under sub-plot treatments, mustard sowing was accomplished with ZT seed drill. The residues of the mustard and maize of previous season were applied to maize and mustard crop, respectively, as per the treatment plan (2 and 4 t ha^{-1} on dry weight basis). The residues were applied after sowing of crops and maintained on the soil surface as mulch by spreading uniformly. Maize and mustard crops were given uniform application of 120:60:40 and 80:40:30 kg ha^{-1} of N, P_2O_5 and K_2O through urea, di-ammonium phosphate (DAP) and muriate of potash (MoP), respectively. Half dose of N, full dose of P_2O_5 and K_2O were applied at the time of sowing of crops. Remaining half dose of nitrogen was applied as top dressing at knee high stage. Maize variety 'Pusa composite 3' and mustard variety 'Pusa mustard 28' were sown with a spacing of 60 cm. In ZT plots, weeds were managed by Glyphosate @ 2.0 l ha^{-1} 10 days before sowing and Pendimethalin @ 0.75 kg *a.i.* ha^{-1} as pre-emergence application.

Data Collection and Analysis

Soil organic carbon (SOC), N, P and K were estimated using Walkley and Black method (Jackson, 1973), modified Kjeldahl method (Subbiah and Asija, 1956), Olsen *et al.* (1954) and flame photometric method (Jackson, 1958), respectively. The procedure for determining BD, infiltration rate, and hydraulic conductivity was followed as described by Chopra and Kanwar (1991); Bouwer (1986) and Mishra and Ahmad (1987), respectively. Relative leaf water content (RLWC) was measured at flowering stage of both crops. Pooled mean data of two years was statistically analysed in split-plot design using the technique of analysis of variance with appropriate critical difference (CD) value at 5% probability level of significance (Gomez and Gomez, 2010).

Soil aggregate stability was measured using wet sieving techniques (Haynes, 1993). The mean weight diameter (MWD) and geometric mean diameter (GMD) of aggregates was determined using the procedure given by Kemper and Roseneau (1986). At the end of the experiment, penetration resistance of soil was measured with a Rimik CP40 II cone penetrometer (Toowoomba, Queensland, Australia) from soil surface up to 30 cm depth, at 2.0 cm depth intervals. Moisture content in soil was measured by gravimetric method. Effective rainfall was calculated by USDA Soil Conservation Service method in FAO CROPWAT 8.0. The total consumptive use was calculated by using the following equation:

Seasonal consumptive use (mm) = Soil moisture contribution + Effective rainfall soil moisture contribution (mm) = B_j - E_j

Where, B_j = total profile moisture content at the time of sowing, E_j = total profile moisture content at the time of harvesting. Water use efficiency (WUE) of crop was worked out from the seasonal crop consumptive use of water as illustrated by following formula:

WUE (kg ha^{-1}mm^{-1}) = Yield (kg ha^{-1}) / consumptive use (mm).

3. RESULTS AND DISCUSSION

Maize Yield

Pooled data of maize crop indicated (Table 1) the direct effect of *kharif* treatments, among which RF + CR at 4 t ha^{-1} performed best in terms of kernel, stover and biological yields. The kernel yield was 10.6, 29.4 and 46.5% more over RF + CR 2 t ha^{-1} + VAM, RF and FS (control) treatments, respectively. RF + CR 4 t ha^{-1} also recorded significantly higher stover yield by 11.1, 21.4 and 31.1% and biological yields by 11.0, 12.0 and 36.1% over RF, RF + CR 2 t ha^{-1} + VAM and FS treatments, respectively. Moisture conservation techniques and residue application ensured better plant establishment during initial phase and their onwards robust growth, which ultimately translated to higher crop yield (Arora and Bhatt, 2008 and Zhang *et al.,* 2015). The residual effect of different *rabi* treatments in sub-plot showed that, ZT + CR 4 t ha^{-1} recorded maximum kernel yield (3.05 t ha^{-1}) followed by ZT + CR 2 t ha^{-1} + Hydrogel (2.99 t ha^{-1}), but both were statistically at par. This supremacy in yield was also reflected in stover and biological yields where ZT + CR 4 t ha^{-1} recorded 11.5 and 12.4% higher values in comparison to CT. Both the non-residue treatments, ZT and ZT + SP were at par on all yield parameters but significantly higher over CT. No-tillage in conjugation with application of large quantities of CR on soil surface might be the reason for higher overall productivity of ZT with residue retention (Karki and Shretha, 2014 and Kumari and Sudhir, 2016).

Maize Water Use

Direct effects of moisture conservation techniques resulted in minimising consumptive use of water (288.5 mm) in RF with 4 t ha^{-1} CR, which also recorded maximum WUE (12.27 kg ha^{-1} mm^{-1}) (Table 1). This was followed by the treatment RF + CR 2 t ha^{-1} + VAM (10.97 kg ha^{-1} mm^{-1}). Highest consumptive use of water was calculated under FS (294 mm) *vis-à-vis* minimum WUE (8.15 kg ha^{-1} mm^{-1}). The reduction in consumptive use of water due to residue based moisture

Table: 1
Influence of moisture conservation measures and tillage methods on yield and water use efficiency of maize

Treatment	Kernel yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index	CU of water (mm)	WUE (kg ha^{-1}mm^{-1})	RLWC (%)
Moisture consvn. techs. (*kharif*-Direct)							
RF	2.65	5.46	8.11	32.60	291.9	9.30	75.90
RF+CR 4 t ha^{-1}	3.43	6.40	9.83	34.93	288.5	12.27	85.18
RF+CR 2 t ha^{-1} +VAM	3.10	5.76	8.85	35.00	290.7	10.97	80.32
FS	2.34	4.88	7.22	32.37	294.0	8.15	69.27
LSD (P=0.05)	0.34	0.41	0.66	NS	0.59	1.29	3.90
ZT mgt. (*rabi*-Residual)							
ZT	2.87	5.63	8.49	33.63	292.1	10.11	76.14
ZT+ Seed Priming	2.82	5.54	8.36	33.59	291.1	10.00	76.24
ZT+ CR 4 t ha^{-1}	3.05	5.90	8.94	33.97	289.9	10.70	80.43
ZT+ CR 2 t ha^{-1}+Hydrogel	2.99	5.78	8.77	34.05	290.7	10.51	79.50
CT	2.67	5.29	7.95	33.38	292.4	9.52	76.04
LSD (P=0.05)	0.10	0.14	0.15	NS	NS	NS	1.76

RF- Ridges and furrows, CR-Crop residue, VAM- Vasicular Arbuscular Mycorrhiza, ZT- Zero tillage, CU- Consumptive use, WUE- Water use efficiency, RLWC-Relative leaf water content conserving treatments led to decrease in evapotranspiration *vis-à-vis* long-term storage and availability of soil moisture. This brought significant improvement in WUE of maize (Singh *et al.,* 2012). RLWC was significantly high in RF + CR 4 t ha^{-1} with values of 85.18%, while minimum value was observed in FS (69.27%). Higher RLWC under residue plots could be attributed to reduced evaporative losses. Furthermore, favourable soil moisture conditions continued for longer time which contributes to favourable water balance in plant system (Choudhary, 2015).

The residual effect of tillage treatments in sub-plots gave non-significant consumptive use of water as well as WUE. Lowest CU of water was recorded in ZT + CR 4 t ha^{-1} (289.9 mm) followed by treatment ZT + CR 2 t ha^{-1} + Hydrogel (290.7 mm). Whereas, in case of WUE, ZT + CR 4 t ha^{-1} and ZT + CR 2 t ha^{-1} + Hydrogel gave numerically higher (10.70 and 10.51 kg ha^{-1} mm^{-1}, respectively) values of WUE in comparison to rest of the sub-plot treatments. Greater soil moisture and nutrient retention along with moderated soil temperature in residue based tillage practices yielded higher and reduced water use, which ultimately led to increased WUE (Singh *et al.,* 2014). ZT + CR 4 t ha^{-1} and ZT + CR 2 t ha^{-1} + Hydrogel treatments gave statistically at par but higher (80.4 and 79.5%) RLWC values in comparison to other treatments. Greater RLWC under ZT + CR treatment can be ascribed to the reduction in the evapotranspiration losses from plants (Kebede *et al.,* 2014).

Mustard Yield

The residual effect of different *kharif* (main plot) treatments brought significant changes in mustard yield (Table 2). Crop residue (CR) at 4 t ha^{-1} in RF system produced numerically higher seed and stalk yield to the tune of 2.12 and 7.46 t ha^{-1}, respectively. Significantly higher seed yield by 11.5, 23.1 and 35.8% was obtained in RF + CR 4 t ha^{-1} over RF + CR 2 t ha^{-1} + VAM, RF and FS, respectively. The increase in yield can be attributed to the better availability of moisture and addition of organic matter through CR. Rapid decomposition of organic residue helped in greater availability of nutrients, which led to increase in growth and yield of mustard (Thierfelder and Wall, 2012). Among different ZT management techniques in sub-plots (direct effects), ZT + CR 4 t ha^{-1} gave maximum yield (2.05 t ha^{-1}) which was closely followed by ZT + CR 2 t ha^{-1} + Hydrogel (1.95 t ha^{-1}). Non-residue based ZT treatments gave marginally higher (1.76 t ha^{-1}) yield over CT (1.65 t ha^{-1}). In case of stalk yield, ZT + CR 4 t ha^{-1} treatment knocked highest value of 7.32 t ha^{-1} which was 25% and 27.7% higher over sole ZT and CT treatments, respectively. A similar trend was observed for biological yield. The effectiveness of thick residue (4 t ha^{-1}) was perceived for developing favourable soil conditions in ZT.

Mustard Water Use

Mustard planted under RF + CR 4 t ha^{-1} recorded lowest CU of water (100.3 mm) and significantly higher WUE (21.63 kg $ha^{-1}mm^{-1}$) (Table 2). This was followed by RF + CR 2 t ha^{-1} +VAM (19.12 kg $ha^{-1}mm^{-1}$), whereas lowest value was recorded in FS (15.65 kg ha^{-1} mm^{-1}). In sub-plots, lowest CU was accounted in ZT + CR 4 t ha^{-1} (100.3 mm) followed by ZT + CR 2 t ha^{-1} + Hydrogel (100.6 mm). For WUE, ZT + CR 4 t ha^{-1} and

Table: 2
Influence of moisture conservation measures and tillage methods on yield and water use efficiency of mustard

Treatment	Seed yield (t ha^{-1})	Stalk yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index	CU of water (mm)	WUE (kg $ha^{-1}mm^{-1}$)	RLWC (%)
Moisture consvn. techs. (*kharif*-Residual)							
RF	1.72	6.03	7.75	22.19	101.3	17.30	86.69
RF+CR 4 t ha^{-1}	2.12	7.46	9.58	22.33	100.3	21.63	89.11
RF+CR 2 t ha^{-1} +VAM	1.90	6.51	8.41	22.58	101.3	19.12	88.09
FS	1.56	5.33	6.90	22.80	102.2	15.65	82.81
LSD (P=0.05)	0.15	0.39	0.44	NS	NS	1.46	3.23
ZT mgt. (*rabi*-Direct)							
ZT	1.72	5.90	7.62	22.68	101.8	17.32	84.54
ZT+ Seed Priming	1.76	5.85	7.61	23.21	101.3	17.77	85.06
ZT+ CR 4 t ha^{-1}	2.05	7.32	9.37	22.05	100.3	20.93	90.84
ZT+ CR 2 t ha^{-1}+Hydrogel	1.95	6.85	8.80	22.16	100.6	19.72	89.81
CT	1.65	5.73	7.38	22.27	102.4	16.37	83.13
LSD (P=0.05)	0.14	0.33	0.33	NS	0.63	1.47	1.94

RF- Ridges and furrows, CR-Crop residue, VAM- Vasicular arbuscular mycorrhiza, ZT- Zero tillage, CU- Consumptive use, WUE- Water use efficiency, RLWC-Relative leaf water content

ZT + CR 2 t ha^{-1} + Hydrogel) gave statistically at par but higher values (20.93 and 19.72 kg ha^{-1} mm^{-1}) in comparison to other treatments. Higher soil moisture availability and conducive soil temperature under residue applied tillage practices resulted in higher seed yield and lowering of water use which lead to increased WUE (Kumar *et al.*, 2015).

For RLWC, RF + CR 4 t ha^{-1} treatment achieved maximum values of 89.11% which was 6.3% higher than the minimum values obtained in FS (82.81%). In sub-plot, ZT with residue addition treatments (ZT + CR 4 t ha^{-1} and ZT + CR 2 t ha^{-1} + Hydrogel) gave statistically at par values of 90.84% and 89.81%, respectively. The mentioned treatment values were significantly higher over ZT and CT treatments. Similar improvement in RLWC of ZT sown mustard was reported by Saha and Ghosh (2013). It is worth to mention that, ZT and CT were statistically at par but CT logged minimum value (83.13%).

Soil Physical Properties (cumulative effects)

BD was not influenced significantly in surface (0-15 cm) as well as in sub-surface (15-30 cm) layers of soil (Table 3). In comparison to initial values of 1.48 Mg m^{-3} (surface layer) and 1.52 Mg m^{-3} (sub-surface layer), all treatments showed slight improvement except for control treatments. This indicates that over a short period, application of residue or tillage may not bring about significant changes in BD (Karunakaran and Behera, 2015). The saturated K_s of soil varied between 1.33-1.48 cm hr^{-1} in surface and 1.10-1.19 cm hr^{-1} in sub-surface soil layer but remained uninfluenced. Among main plot treatments numerical higher value of K_s were observed under RF + CR 4 t ha^{-1} (1.45 and 1.18 cm hr^{-1}, respectively). While in different ZT practices, residue application of 4 t ha^{-1} gave numerically higher but statistically at par values (1.48 and 1.19 cm hr^{-1}) in comparison to initial values. In contrast to initial infiltration rate (1.40 cm hr^{-1}), significant improvement was observed in all residue based treatments. Amongst main plot treatments, moisture conservation practice of RF + CR 4 t ha^{-1} registered superior values (1.50 cm hr^{-1}) of infiltration rate over RF and FS. Different ZT management practices in sub-plot exhibited higher infiltration rate than CT. However, difference was not significant, except for ZT + CR 4 t ha^{-1}. This can be attributed to addition of CR which improves structural stability and thus infiltration rate of soil (Kuotsu *et al.*, 2014).

Soil Resistance

Soil resistance measured in terms of cone penetrometer readings (0-30 cm soil depth) varied markedly with moisture

Table: 3
Influence of moisture conservation measures and tillage methods on soil physical properties after completion of the experiment (2016)

Treatment	Bulk density (Mg m^{-3})		Hydraulic conductivity (cm h^{-1})		Infiltration rate (cm h^{-1})	Mean weight diameter (mm)		Geometric mean diameter (mm)		Water stable aggregate			
										> 0.2 mm		< 0.2 mm	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm		0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Mois. cons. tchs. (*kharif*)													
RF	1.45	1.48	1.41	1.16	1.43	0.940	0.576	0.599	0.453	0.47	0.38	0.53	0.62
RF+CR4 t ha^{-1}	1.41	1.45	1.45	1.18	1.50	0.985	0.625	0.629	0.503	0.51	0.42	0.49	0.58
RF+CR2 t ha^{-1}+VAM	1.44	1.47	1.43	1.17	1.46	0.976	0.614	0.630	0.492	0.48	0.40	0.52	0.60
FS	1.47	1.51	1.37	1.11	1.40	0.872	0.501	0.557	0.432	0.45	0.36	0.55	0.64
LSD (P=0.05)	NS	NS	NS	NS	0.06	NS	0.075	NS	NS	NS	0.03	NS	0.03
ZT mgt. (*rabi*)													
ZT	1.45	1.48	1.42	1.17	1.44	0.925	0.561	0.593	0.453	0.49	0.39	0.52	0.61
ZT+ Seed Priming	1.44	1.48	1.40	1.14	1.45	0.904	0.551	0.585	0.465	0.47	0.38	0.53	0.62
ZT+ CR4 t ha^{-1}	1.42	1.45	1.48	1.19	1.49	1.012	0.663	0.628	0.496	0.50	0.41	0.50	0.59
ZT+ CR2 t ha^{-1}+Hydrogel	1.43	1.46	1.46	1.18	1.46	0.983	0.623	0.638	0.488	0.48	0.40	0.52	0.60
CT	1.47	1.53	1.33	1.10	1.41	0.893	0.499	0.575	0.447	0.46	0.37	0.54	0.63
LSD (P=0.05)	NS	NS	NS	NS	0.07	NS	0.060	0.044	NS	NS	NS	NS	NS
Initial values (2013)	1.48	1.52	1.38	1.11	1.40	0.872	0.500	0.558	0.438	0.45	0.35	0.54	0.64

RF- Ridges and furrows, CR- Crop residue, VAM- Vasicular arbuscular mycorrhiza, ZT- Zero tillage conservation practices and ZT management practices (Fig. 1). Across the treatments, surface soil layer offered less resistance (0.26-0.62 M Pa) and the resistance increased (2.36-3.32 M Pa) with soil depth. Among different moisture conservation treatments, RF + CR 4 t ha^{-1} encountered least resistance in comparison to FS (Fig. 1a). This residue based treatment was closely followed by RF + CR 4 t ha^{-1} + VAM treatment. FS posed maximum resistance (0.41 M Pa) right from top layer and maximised (2.6-3.3 M Pa) in lower layers (20-30 cm). Zero tillage offered higher soil resistance in top soil (0-6 cm) than CT, but at deeper layer of soil (20-30 cm) CT offered slightly higher resistance (Fig. 1b). Furthermore, ZT with application of CR 2 t ha^{-1} + Hydrogel resulted in lesser resistance to cone penetration as compared to no residue treatment which further reduced with CR 4 t ha^{-1} applications. Soil penetration resistance positively correlates to BD (Singh and Malhi, 2006). The treatments having less BD offered less resistance to penetration. Greater penetration resistance in ZT and non-residue treatments is also reported by Saha *et al.* (2010).

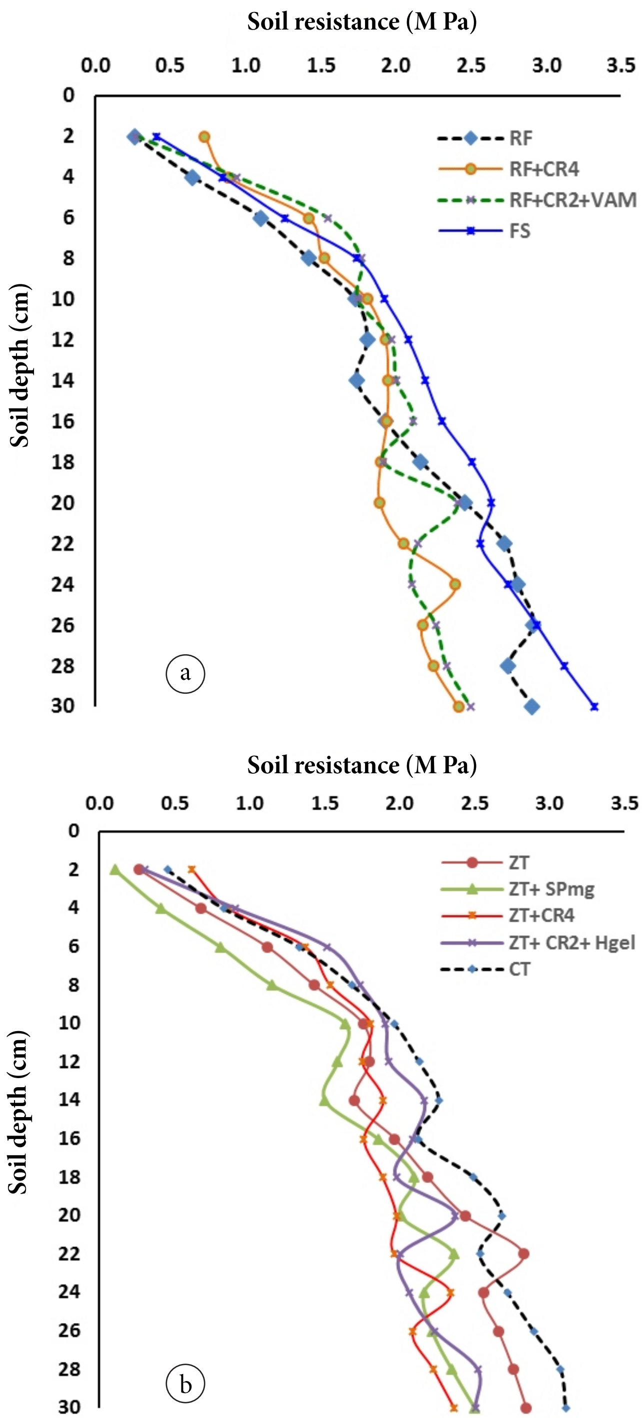

Fig. 1. Effect of a) moisture conservation treatments and b) zero tillage management practices on soil resistance at different depth

Soil Aggregation

None of the main plot treatments showed significant impact for MWD and GMD (Table 3), whereas, for sub-plots, ZT management practices gave significant output for MWD of sub-surface soil and GMD of surface soil. ZT + CR 4 t ha^{-1} gave significantly higher values of MWD in sub-surface soil which was 33% higher in comparison to initial values (0.50 mm). In case of GMD, ZT + CR 2 t ha^{-1} + hydrogel gave maximum values (0.638 mm) which was 14.3% higher than initial value (0.558 mm) and 11% over CT (0.575 mm). However, residue based treatment ZT + CR 2 t ha^{-1} + Hydrogel and ZT + CR 4 t ha^{-1} were statistically at par. In case of WSA >0.2 mm, both the residue based treatments (ZT + CR 2 t ha^{-1} + Hydrogel and ZT + CR 4 t ha^{-1}) maintained their numerical supremacy in both the soil layers. While, reverse trend was observed for soil aggregates <0.2 mm. Significantly higher percentage of >0.2 mm soil aggregates (10-20 cm soil depth) were recorded under RF + CR 4 t ha^{-1} (0. 42) followed by RF + CR 2 t ha^{-1} + VAM (0.40) and lowest in FS (0.36). Residues incorporated into soils by tillage operations improves aggregation and counters the destructive impacts of tillage on aggregation (Wright and Hons, 2005).

Soil Fertility

In comparison to initial SOC (4.68 g kg^{-1}), slight improvement was observed in all the treatments except FS in main plot and CT in sub-plot (Table 4). Significantly higher nitrogen availability was noticed among different treatments in which RF + CR 4 t ha^{-1} registered maximum value (149 kg ha^{-1}), closely followed by RF+ CR 2 t ha^{-1} + VAM (142 kg ha^{-1}). For ZT management practices, ZT + CR 4 t ha^{-1} and ZT + CR 2 t ha^{-1} + hydrogel treatments yielded values 150 and 148 kg N ha^{-1}, respectively. Among main plot treatments, RF + CR 4 t ha^{-1} showed significant superlative

Table: 4
Influence of moisture conservation measures and tillage methods on nutrient availability of soil (0-30 cm)

Treatment	SOC ($g\ kg^{-1}$)	Nutrient availability ($kg\ ha^{-1}$)		
		N	P	K
Mois. cons. tchs. (*kharif*)				
RF	4.69	136	12.9	177
RF+CR4 t ha^{-1}	4.81	149	14.5	193
RF+CR2 t ha^{-1}+VAM	4.81	142	13.7	187
FS	4.67	130	12.1	173
LSD (P=0.05)	NS	10.3	1.30	11.5
ZT mgt. (*rabi*)				
ZT	4.75	134	12.5	179
ZT+ Seed Priming	4.70	135	12.3	184
ZT+ CR4 t ha^{-1}	4.84	150	15.6	192
ZT+ CR2 t ha^{-1}+Hydrogel	4.82	148	14.5	190
CT	4.62	129	11.6	168
LSD (P=0.05)	NS	8.9	1.43	14.5
Initial values (2013)	4.60	135	13.2	180

RF- Ridges and furrows, CR- Crop residue, VAM- Vasicular Arbuscular Mycorrhiza, ZT- Zero tillage, SOC- Soil organic carbon

value of 14.5 kg P ha^{-1}. In comparison to FS, an improvement of 6.8, 19.8 and 13.2% available P was observed in RF, RF + CR 4 t ha^{-1} and RF + CR 2 t ha^{-1} + VAM treatments, respectively. Potassium availability was in the range 108-180 kg ha^{-1} falling under medium class. For different treatments, K availability followed similar trend as of N and P with maximum values in RF + CR 4 t ha^{-1} (193 kg ha^{-1}) and ZT + CR 4 t ha^{-1} (192 kg ha^{-1}), in main and sub-plots, respectively. The findings indicated the beneficial effect of CR of about 16 t ha^{-1} of maize and mustard, was applied in field over two cropping cycles. Furthermore, the study also emphasized that for improving the nutrient availability, of residue incorporation outperformed the tillage practices. Residue incorporation brought the synergetic effects of soil water and nutrients on yield of the crop (Gebrekidan and Uloro, 2015).

4. CONCLUSIONS

Raising maize under RF technique with application of CR at 4 t ha^{-1} and mustard with ZT + CR 4 t ha^{-1} were found superior in terms of productivity in maize-mustard cropping system. Soil physical properties *viz.* BD, saturated hydraulic conductivity, infiltration rate and penetration resistance modified themselves to a condition conducive for crop growth due to the adoption of ZT and incorporation of CRs. The significant increase of water stable aggregates due to the conservation treatments especially the treatment ZT with CR 4 t ha^{-1} emphasises about the effectiveness of this treatment for improving soil physical condition in semi-arid part of India along with significantly high nutrient availability. Therefore, large scale adoption of the best conservation treatments *i.e.* raising maize in RF with 4 t ha^{-1} and mustard in ZT with 4 t ha^{-1} residue in the semi-arid track of India will be a practical solution to improve the soil quality. But the econometric analysis of this treatment and a long term experiment regarding this is needed to judge its sustainability.

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