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Effect of tillage and water management practices on pearl millet - wheat cropping system productivity, water - balance and soil properties of alluvial soil

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ABSTRACT

In arid and semi-arid tropics, pearl millet-wheat is grown as mono cropping with intensive tillage resulting in depleting system productivity, net returns (NRs) and soil properties. The objective of present study was to improve the system productivity, water use efficiency (WUE) and physico-chemical properties of pearl millet-wheat with conservation tillage (CT) and water management practices. The CT based treatments for system were traditional tillage and seeding (TTS) and zero tillage seeding (ZTS) of pearl millet and wheat. The rainwater conservation in rainy season crop pearl millet with ridge furrow (RF) in 40 cm spacing at 30 days after seeding (DAS) in standing crop as compared to without rainwater conservation farmer's practice (FP), and for winter season wheat- five critical stages irrigations as compared with four irrigations adopted by farmers. The ZTS method significantly increased the yield and its attributing characters, NRs and WUE, while decreased the weed density, cultivation cost and total water use (TWU) of pearl millet and wheat as compared with TTS. The seeding of crop with ZTS increased the grain yield of pearl millet and wheat by 9.8% and 13.4% as compared with TTS, respectively. The treatment of RF at 40 cm was increased the grain yield by 14.4%, savings TWU- 34 mm and enhancing WUE- 25.4% as compared to FP of pearl millet. Like-wise in wheat, five irrigations at critical stages were increased the grain yield by 19.8%, Nrs - 29.1% and WUE - 5.1% as compared to four irrigation levels. The results of system revealed that ZTS method significantly improvement in productivity - 12.2%, reduction production cost ₹ 10,440 ha^{-1}, additional NRs ₹ 24,115 ha^{-1} as compared with TTS. Proportionately RF at 40 cm spacing in pearl millet and five irrigation levels in wheat increased the system productivity 18.1% and additional NRs - ₹ 23,858 ha^{-1} as compared with FP. This study indicates that the higher yield of crops and the system, NRs, WUE and soil physicochemical properties with ZTS of crops along with RF in 40 cm spacing of pearl millet and five irrigation levels at critical stages in wheat grown in old alluvial plains.

1. INTRODUCTION

Pearl millet (*Pennisetum glaucum* L.) - Wheat (*Triticum aestivum* L.) is an important dual-purpose cropping system practiced in India for food grain and green / dry fodder grown in light-medium textured soils of the arid and semi-arid regions in India. It is grown with intensive tillage, pearl millet as rainfed and wheat as irrigated with ground / seasonal supply canal water. In mechanization farming systems depleting the soil quality owing to fractions the soil, disrupts soil structure, accelerating surface runoff, decreasing organic matter additions and inability of return crop residues back to soils (Singh *et al.,* 2021). Moreover, low yields and income from rainy season pearl millet due to dry spells at reproductive stage, winter wheat crop facing the terminal heat at milking stage and shrinking rainy days and winter season in central region of India (Singh and Singh, 2016). In these situations, production system has been showing signs of fatigue, decline system productivity and profitability. Jat *et al.* (2014) have reported that the monocropping of pearl millet-wheat cropping system is gradually declining system productivity and low economic returns. For improving the biophysical and economic sustainability of this cropping system, it requires a shift in soil and crop management that promote conservation and efficient use of precious rain water and cut back the cultivation costs and energy intensive tillage operations. Several field studies have reported that CA has great potential in improving soil quality and enhancing the cropping system productivity (Singh *et al*., 2021).

For practicing CA in dryland areas, one of the major problems is about conflicting claims for crop residues (mulch *vs.* fodder). In Madhya Pradesh state of India, we have observed that small farmers use crop residues for feeding their animals but the big farmers burn them for clean cultivation and timely seeding of the succeeding crops. Small famers in the dryland areas fortunately, practice livestock based integrated farming systems wherein the feed pearl millet and wheat straw to the livestock. Thus, very little organic matter is returned to the soils to build soil organic matter, support biotic activities and to replenish the removal of nutrients by cereal-based cropping systems. The present study was conducted to explore the potential of tillage and seeding methods, innovative rainwater conservation technique in rainy season crop pearl millet and critical stage irrigations in winter wheat on productivity of crop and system, economics, WUE and soil physico-chemical properties alluvial plains of India.

2. MATERIALS AND METHODS

Study Site Description

The study was conducted at farmers' field at Santa village of Morena district on lower reach of Chambal canal command at five locations under Operational Research Programme of AICRP-Irrigation Water Management, Zonal Agricultural Research Station, Morena, Madhya Pradesh, India during the 2015 to 2018. The area lies between 26.4897°N latitudes and 77.9139°E longitudes. The study area is characterized as semi-arid, minimum temperature in Dec-Jan (-1.0°C) and maximum in summer months of May-June (49°C). The annual rainfall of the area is about 650 mm (average of 40 years), concentrated in monsoon months of July to Aug and withdrawn at mid-Sept in general. During the 3 yrs study period the average of minimum and maximum temperature ranged between 0 and 48°C. Total annual rainfall was 510, 460 and 682 mm during first (2015-16), second (2016-17) and third (2017-18) year of experimentation, respectively. The rainfall received during pearl millet and wheat periods were 395, 400 and 445 mm and 5, 2 and 7 mm during first, second and third years, respectively.

Description of Soil and Analysis

Soil samples were collected at two depths (0-5 cm and 5-20 cm) for pH, OC and bulk density (BD) at the start (June, 2015) and after the completion of experiment (April, 2018). Like-wise surface soil (0-15 cm) samples were collected for analysis of available nutrients. The soil of experimental fields was sandy loam in texture. The BD was measured by Blake and Hartge (1986); the infiltration rate (IR) was measured after harvest of crop using a double-ring infiltrometer. The soil pH (1:2 soil : water ratio), organic carbon (OC), available N, P, K and S were determined as per methods described by Jackson (1973) and micronutrient by DTPA extraction was determined by AAS. The SOC stock was calculated after harvest of the third wheat from 0-120 cm soil depth. The SOC stock in t ha^{-1} was calculated by the eq. 1:

$$SOC\,stock = SOC \times BD \times SD \qquad \ldots(1)$$

Where, SOC - soil organic carbon content (%), BD - bulk density ($Mg\ m^{-3}$), SD - soil depth (cm).

The initial 0-5 cm and 5-15 cm soil depth having pH 7.94 and 7.85, low in OC content 3.17 and 3.02 g kg^{-1} and BD 1.51 and 1.52 Mg m^{-3}, respectively. The initial soil having low in available N (172 kg ha^{-1}), P (7.4 kg ha^{-1}) and Zn (0.52 mg kg^{-1}), whereas medium in available K (182 kg ha^{-1}). The field capacity and permanent wilting point of soil was 31.6% and 8.4% on dry weight basis (w/w) and IR 3.0 mm hr^{-1}.

Crop Seeding and Management

The experiment on pearl millet-wheat cropping system was planned on tillage and seeding, rain water conservation of rainy season pearl millet, and irrigation levels at critical stages for winter wheat crop, detail descriptions of treatments given in Table 1. Treatments were organized in randomized block design (Panse and Sukhatme, 1954). The treatment was replicated at five locations in a plot size of 600 m^2 (12 m W × 50 m L) and each location was treated as replication. Treatment means were compared at 5% level of significance using least significant difference.

In first year, rainy season pearl millet crop was sown in previous wheat grown field. The sowing of pearl millet MH-1816 (hybrid) was done in the first week of July, 2015 after the onset of monsoon rains as per treatment. The seed rate was 4 kg ha^{-1} for pearl millet. Full recommended doses of P (17.5 kg ha^{-1}), K (16.6 kg ha^{-1}) and Zn (5 kg ha^{-1}), and 40 kg ha^{-1} N was applied at seeding and remaining 40 kg ha^{-1} N at 25 to 30 DAS. No irrigation was applied in the year of 2015, due to timely rains at all the critical stages of pearl millet, while, one irrigation at reproductive stage was applied during 2016 and 2017, respectively.

After harvest of rainy season crop pearl millet, winter season wheat was sown in the third week of Nov after pre-

Table: 1
Treatment details of pearl millet - wheat cropping system

Short description	Rainy season pearl millet	Winter season wheat
Tillage and seeding		
Traditional tillage seeding (TTS)	Two cross 12-14 cm deep tillage with cultivator and broad casting of seed and shallow (5-7 cm) mixing with cultivator along with plunking	Two cross tillage with disc harrow 12-14 cm deep followed by two-time cross tillage with cultivator on same depth and plunked, and crop seeding with seed cum fertilizer drill at 22 cm spacing at 4-5 cm depth
Zero tillage seeding (ZTS)	ZTS at 40 cm spacing with zero till seed cum fertilizer drill at 3-4 cm deep	ZTS at 22 cm spacing with zero till seed cum fertilizer drill at 4-5 cm depth
Water management (WM) practices		
WM_1	Not adopted any practice (FP- Farmers' practice)	Four irrigation (CRI, First node, Jointing and Milking)
WM_2	Tractor operated ridge furrow (RF) in spacing- 40 cm for rainwater conservation	Five irrigation (CRI, First node, Jointing, Booting and Milking)

sowing irrigation. The treated wheat var. MP 4010 was sown at 22 cm spacing. Full recommended doses of P, K, Zn were 26.2, 33.1, 5.0 kg ha^{-1}, respectively, and half dose (60 kg ha^{-1}) of N was applied as basal application and remaining 60 kg N ha^{-1} in two split doses at after first and second irrigation to wheat. The irrigation of wheat crop was applied as per irrigation treatments. The harvesting of matured wheat was done during the second to third week of April in each year.

Measurement of Growth and Productivity

For measuring yield attributing characters, 50 plants were selected randomly in each plot using Fisher's Random table (Panse and Sukhatme, 1954). These randomly selected plants were tagged during the initial period of crop growth. Parameters of yield attributing characters of crops were recorded at maturity. Weed density and biomass in each plot were determined from 2 m × 2 m at maturity stage, dried at 70°C for 3 days and weighed. At maturity, the pearl millet and wheat were harvested and threshed manually, grain and straw/stalk yield were recorded of net plot. All the harvested crops were threshed treatment-wise to record grain and straw yields. To compare the productivity of cropping systems, the yields of pearl millet were converted into wheat equivalent yield (WEY) using the equation with wheat as an eq. 2.

$$WEY\ (t\ ha^{-1}) = \frac{\text{Pearl millet yield } (t\ ha^{-1}) \times \text{minimum support price of pearl millet } (₹\ t^{-1})}{\text{Minimum support price of wheat } (₹\ t^{-1})} \quad ...(2)$$

Economic Analysis

The economic analysis was done by considering the variable production costs. The costs included, human labour, machineries use, inputs cost, irrigation, harvesting, threshing, loading, unloading and transportation to market. These data were obtained based on current market price for inputs. The cost of human labor used for tillage, seeding, irrigation, fertilizer, and pesticide application, weeding and harvesting was based on person-day/hr (Minimum Wages Act., 1948). Gross return (GRs) was calculated by multiplying grain yield of crops by minimum support price in Indian rupees (₹) offered by the Government of India (Economic Survey of India), and straw values were calculated using current market rates. NRs were calculated as the difference between gross returns (GR) and the total cost of cultivation (TCC) using the eq. 3:

$$NRs = GR - TCC \quad ...(3)$$

Water Balance Studies

The volume of irrigation water was measured with the help of water meter fitted in pipe of 2.5” dia. The initial and at harvest of each crops the water content of soil profile (0-120 cm) was measured gravimetrically, at 15 cm increment of the first two layers and 30 cm increment subsequent layers using a tube auger of 7 cm diameter from three places in each treatment plots. Soil moisture (%) was determined thermo-gravimetrically. The TWU was calculated using the field water balance eq. 4:

$$TWU = (I + P + C) - (R + D +/- \Delta S) \quad ...(4)$$

Where, I (mm) is the amount of irrigation that was measured using water meters; P (mm) the effective precipitation was measured from the weather observatory at the site with a standard raingauge; C (mm) is the capillary rise. As the groundwater level was very deep (35-38 m deep), C was assumed to be nil. Runoff was measured in 1.0 m long, 1.0 m wide (at the top) and 1 m deep collector trenches, which were located at the end of each plot and lined with thick plastic sheets. Runoff data were collected at 8 am after each rainfall event by measuring the height of the water in the trenches. The volume of runoff water was measured in trenches-after were calibrated after each runoff of rains as per method described in Araya *et al.* (2016). The D (mm) is the water drainage below the crop root zone, which was negligible since soil moisture measurements indicated that drainage at the site was insignificant. The ΔS (mm) is change in the soil moisture between seeding and harvests of rainy and winter season crops measured gravimetrically.

The water use efficiency (WUE) was calculated in kg grain/mm of water using eq. 5:

$$WUE = Y / TWU \quad ...(5)$$

Where, WUE for grain yield, Y (kg ha^{-1}) was the grain yield and TWU (mm) over the growing season.

The soil water storage (SWS) after harvest of each pearl millet and wheat crop was measured by the eq. 6.

$$SWS\ (cm\ ha^{-1}) = \%\ moisture \times BD\ (Mg\ m^{-3}) \times soil\ depth\ (m) \quad ...(6)$$

3. RESULTS AND DISCUSSION

Yield and its Attributes of Rainy Season Pearl Millet

The number of plant m^{-2}, 1000 grain wt., grain and straw yield of pearl millet were significantly higher with the treatment of ZTS method as compared with TTS practices (Table 2). Under ZTS treatments, the higher number of plant m^{-2} were recorded due to the seed placement was done at 2 to 3 cm below the surface by narrow width inverted T type of tines of zero-till seed cum fertilizer drill, while under TTS, the placing of seed after tillage operations in moist conditions below 4 to 5 cm of pearl millet seed was done by single box seed drill having wide tines (5 cm). The weeds density and dry biomass was also significantly affected with seeding methods under study. The significantly lowest weed density (21.4%) and dry biomass (30%) was recorded with ZTS as compared with TTS. Similar observations reported by Rani *et al.* (2020). The pearl millet seeded with ZTS was resulted maximum productivity gains between 7.9-12.9% during experimentation years as compared with TTS. Similarly, the average grain and straw yield was higher by 9.8% and 5.5% with ZTS as compared with TTS, respectively. The improved crop performance with ZTS could be due to advance seeding of crop (Singh, 2020), improvement in OC content and stock, SWS, IR, available N, P, K and S (Singh *et al.*, 2021).

Similarly, the plant height, tillers, ear length and 1000 grain wt. were significantly higher with WM_2 treatment (Photo's 1 and 2) as compared with FP (WM_1). The density (33.3%) and biomass (33.2%) of weeds was found significantly higher in WM_1 than WM_2 treatment (Table 2). The

Table: 2
Impact of seeding methods and water management practices on yield attributing characters and yield of pearl millet (Mean of 3 years)

Treatments	No of plant m^{-2}	Weed* density (plant m^{-2})	Weed dry wt. (g m^{-2})	Plant height (cm)	Tillers / plant (no)	Ear length (cm)	1000 grain wt.	Grain yield (t ha^{-1})				Straw yield (t ha^{-1})
								2015	2016	2017	Mean	
Crop seeding												
TTS	28	14	30.7	209.9	2.11	21.9	8.29	2.42	2.56	2.69	2.56	6.38
ZTS	31	11	21.5	211.5	2.28	22.2	8.47	2.61	2.89	2.93	2.81	6.73
CD at 5%	2.4	0	2.1	NS	NS	NS	0.12	0.14	0.16	0.18	0.20	0.31
Water management												
WM_1	32	15	31.3	200.8	2.01	21.1	8.27	2.38	2.52	2.61	2.50	6.22
WM_2	28	10	20.9	220.6	2.38	23.0	8.49	2.65	2.93	3.01	2.86	6.89
CD at 5%	2.1	1.3	1.8	5.4	0.19	1.1	0.10	0.12	0.13	0.15	0.17	0.24

**Commelina benghalensis, Celosia argentea, Trianthema portulacastrum, Echinochloa colonum, Sorghum halepense, Cyprus rotundus*

Photo 1. Ridge furrow at 40 cm spacing

Photo 2. Crop stand at flowering stage

lowest weed density and bio mass was recorded in WM_2 treatment due to RF operation at 30 DAS reduces weed density and biomass. Additionally, 30 days old pearl millet crop suppress the weed growth resulted in decreases of weed biomass. The WM_2 treatment was found to be most effective in controlling broad and narrow leaved weeds in pearl millet crop. The grain yield increased significantly from 11.3-16.3% with WM_2 as compared with WM_1 during experimentation years. The average grain and straw yield were increased by 14.4% and 10.8% with WM_2 as compared with WM_1, respectively. The higher yield and its attributing characters were recorded in WM_2 treatment due to RF operation suppress the weed density, and increased the water and nutrient availability. Similar results in maize crop on rain water conservation with RF making in standing crop reported by Jhakhar *et al*. (2017).

Yield and its Attributes of Winter Season Wheat

The results on yield and its attributing characters (plant

Table: 3
Impact of seeding methods and water management practices on yield attributing characters and yields of wheat (Mean of 3 years)

Treatments	No of plant m^{-2}	Weed* density (plant m^{-2})	Weed dry wt. (g m^{-2})	Plant height (cm)	Tillers / plant (no)	Ear length (cm)	1000 grain wt.	Grain yield (t ha^{-1})				Straw yield (t ha^{-1})
								2015	2016	2017	Mean	
Crop seeding												
TTS	80	81	6.4	94.6	3.61	8.24	35.48	4.01	4.21	4.12	4.11	4.37
ZTS	86	42	3.1	99.6	3.83	8.93	38.03	4.48	4.86	4.63	4.66	4.79
CD at 5%	2	9	0.9	2.4	0.19	0.21	0.78	0.17	0.29	0.21	0.22	0.30
Water management												
WM_1	82	63	4.9	97.2	3.71	8.28	35.54	3.88	4.12	3.96	3.99	4.33
WM_2	83	60	4.6	97.6	3.73	8.89	37.97	4.61	4.95	4.79	4.78	4.87
CD at 5%	NS	NS	NS	NS	NS	0.18	0.58	0.12	0.23	0.18	0.17	0.25

**Phalaris minor, Chenopodium album, Convolvulus arvensis, Fumaria parviflora, Spergula arvensis, Anagallis arvensis, Avena sterilis*

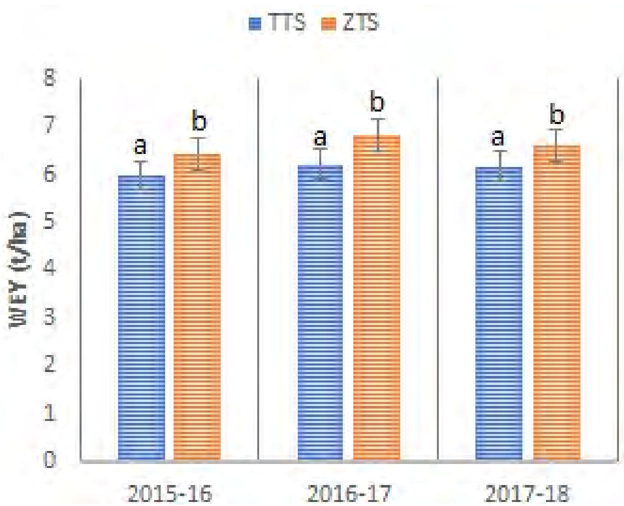

Fig. 1. Tillage and seeding of pearl millet and wheat impact on wheat equivalent system productivity (t ha^{-1}). Bars followed by a and b letters within the years are indicate significantly different statistically at 5%

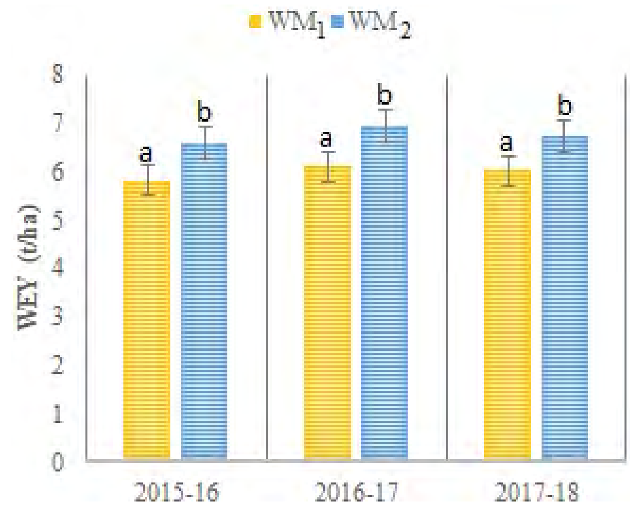

Fig. 2. Water management practices in pearl millet and wheat impact on wheat equivalent system productivity (t ha^{-1}). Bars followed by a and b letters within the years are indicate significantly different statistically at 5%

Table: 4
Impact of seeding methods and water management practices on economics (Mean of 3 years)

Treatments	Cultivation Cost (₹ ha^{-1})			Net returns (₹ ha^{-1})		
	Pearlmillet	Wheat	System	Pearlmillet	Wheat	System
Crop seeding						
TTS	22280	30120	52400	16989	51099	67103
ZTS	18762	24340	41960	24115	67103	91218
CD at 5%	1350	1775	3025	2580	4863	5890
Water management						
WM_1	21580	26310	47890	16838	52879	69717
WM_2	18390	28150	46540	25339	68236	93573
CD at 5%	1136	1564	2283	2356	3674	4971

Minimum support price in INR for the year 2015-16, 2016-17 and 2017-18 for of grain @ 12500, 12750 and 13300 t^{-1} for pearlmillet, and 15250, 16250 and 17350t^{-1} for wheat, and straw in local market @ 750, 1000 and 1250 t^{-1} for pearl millet and 3000, 3250 and 3500 t^{-1} for wheat, respectively

population, height, tillers, ear length and 1000 grain wt.) of wheat were significantly higher with the treatment of ZTS as compared with TTS (Table 3). The weeds density and dry biomass was significantly lowest by 92.8% and 106.5% was recorded with ZTS as compared with TTS, respectively. Like-wise Rani *et al.* (2020) observed that the zero-tillage seeding of wheat substantial reduction in the population of narrow-leaved and broad-leaved compared to conventional tillage practice. The direct seeding technology with ZTS significantly increased the grain yield as compared with TTS. The wheat seeded with ZTS resulted in maximum productivity gains between 11.7-15.4% during experimentation years as compared with TTS. Like-wise the average grain and straw yield was increased by 13.4% and 9.6% with ZTS as compared with TTS, respectively. The ZTS treatment facilitate timely seeding of crop, improved soil moisture and nutrient availability resulted in creating a favorable environment for yield and its attributing characters. Similarly, Singh (2020) reported that the ZTS significantly increased the grain yield of wheat after harvest of cluster bean.

The effect of irrigation levels on grain yield and its attributing characters (ear length and 1000 grain wt.) were significantly higher with five irrigations (WM_2) at critical stages as compared with four irrigation levels (WM_1). The grain yield was increased from 18.8-21.0% in WM_2 as compared with WM_1 level during experimentation. Like-wise mean grain and straw yield was increased by 19.8% and 12.5% with WM_2 as compared with WM_1. The high temperature stress during grain filling stage leads to terminal heat stress in wheat crop resulted in negative impact on yield. In this situation availability of soil moisture suppress the effect of terminal heat resulted in higher yield when five irrigations were applied to wheat under WM_2 treatment.

System Productivity

The system productivity, WEY of pearl millet-wheat significantly increased with ZTS as compared with TTS method in all the year of experimentation (Fig. 1). The crop seeded with ZTS resulted in productivity gains between 7.3-11.3% than TTS, respectively. It was observed that the system productivity of cropping system showed improvements with time, suggesting positive improvements in soil properties with ZTS under the study. The conservation based direct seeding in zero till provides additional nutrients and improved soil quality (Singh *et al*., 2019; 2021) resulted increased in system productivity.

The *in-situ* rainwater conservation practice in pearl millet and irrigation level treatments of winter season wheat significantly varied the WEY (Fig. 2). The WEY of system was increased from 7.10-16.3% with WM_2 as compared with WM_1 treatment. The increase of WEY was due to uniform availability of nutrition due to longer time availability, distribution of soil moisture and no water submergence in rainy season pearl millet crop. Similarly, five irrigation increases the soil moisture availability during wheat crop escaping with terminal heat stress at milking stage (Singh, 2020).

Economics

The cost of production of crops and the system varied significantly with tillage and crop seeding and with water management treatments (Table 4). The additional savings of cultivation cost in ZTS treatment of pearl millet was ₹ 3518 ha^{-1} as compared with total cost with TTS (₹ 22280 ha^{-1}). In wheat crop the savings ₹ 5780 ha^{-1} with ZTS treatment was recorded as compared with TTS method. The cultivation cost was lower with ZTS method because of direct seeding technology saving cost on tillage for seedbed preparation irrigation water and men-powers (Singh, 2020). Similarly, the maximum production cost of pearl millet was with WM_1 as compared with WM_2, whereas WM_2 treatment in wheat increased the cultivation cost than Wm_1.

Saving cost of tillage and additional value of grain and straw was resulted in maximum NRs with ZTS as compared with TTS method (Table 4). The additional NRs with ZTS of pearl millet and wheat were ₹ 7126 and 16004 ha^{-1} as compared with total NRs with TTS practice, respectively. Similarly, system gave additional of ₹ 24115 ha^{-1} with the technology of ZTS as compared with TTS. The higher NRs with ZTS due to cost of tillage involved disappeared and there were also additional savings on cost of irrigation water and higher productivity. Similar results reported by Sakari and Kar (2015). The NRs were significantly and additional higher ₹ 8501 ha^{-1} with WM_2 as compared with WM_1 in pearl millet, whereas additional NRs of wheat with WM_2 were ₹ 15357 ha^{-1} as compared with WM_1. The system was recorded additional NRs ₹ 23858 ha^{-1} with WM_2 as compared with WM_1 treatment. This shows that the greater net income of system resulted maximized yield with WM_2 (pearl millet with RF-40 cm treatment and five irrigation level in winter season wheat).

Water Balance

Rainy season pearl millet

The soil water addition (SWA) is very important for sustain production particularly in scarce irrigation areas of dry land. The additional SWA in soil profile (0-120 cm) was 30 mm was recorded with ZTS as compared with total SWA (138 mm) with TTS at harvest of pearl millet (Table 5). Moreover, SWA with ZTS was 56 mm and with TTS was 32 mm at harvest as compared with the values of SWA at seeding time. The reduction in the mean value of the runoff was 17.6% and saved applied irrigation water by 22.0% with ZTS as compared with TTS. The Govaerts *et al.* (2007) reported that residue retention increased with ZTS at soil

Table: 5
Impact of seeding methods and water management practices on water balance of pearl millet (Mean of 3 years)

Treatments	SWS at seeding* (mm)	SWS at harvest* (mm)	SWA* (mm)	Rainfall (mm)	Runoff (mm)	Irrigation applied (mm)	TWU (mm-ha)	WUE (kg grain mm^{-1})
Crop seeding								
TTS	106	138	32	403	48.2	60	383	6.68
ZTS	112	168	56	403	41.0	51	357	7.87
CD at 5%	-	-	-	-	-	-	18	0.82
Water management								
WM_1	106	129	23	403	55.3	62	387	6.46
WM_2	112	177	65	403	33.9	49	353	8.10
CD at 5%	-	-	-	-	-	-	16	0.61

*SWS - Soil water storage, SWA - Soil water addition, TWU - Total water use, WUE - Water use efficiency, *0-120 cm soil depth*

Table: 6
Impact of seeding methods and water management practices on water balance of wheat (Mean of 3 years)

Treatments	SWS at seeding* (mm)	SWS at harvest* (mm)	SWD* (mm)	Rains (mm)	Irrigation applied (mm)	TWU (mm)	WUE (kg grain mm^{-1})
Crop seeding							
TTS	161	125	36	4.7	266	307	13.38
ZTS	179	149	30	4.7	245	280	16.64
CD at 5%	-	-	-	-	-	21	0.81
Water management							
WM_1	159	121	38	4.7	231	274	14.50
WM_2	184	156	28	4.7	282	315	15.24
CD at 5%	-	-	-	-	-	19	0.73

*SWS - Soil water storage, SWD - Soil water depletion, WUE - Water use efficiency, *0-120 cm Soil depth*

Table: 7
Impact of seeding methods on soil physicochemical properties after harvest of 3rd wheat crop

Treatments	pH		OC (g kg^{-1})		BD (Mg m^{-3})		SOC*stock (t ha^{-1})	IR (mm hr^{-1})	Available nutrients (kg ha^{-1})**			
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm			N	P	K	S
Baseline values	7.94	7.85	3.17	3.02	1.51	1.52	19.4	3.0	172	7.4	182	12.8
Crop seeding												
TTS	7.91	7.88	3.28	3.14	1.51	1.52	19.2	2.7	184	8.8	190	13.9
ZTS	7.79	7.80	4.31	3.32	1.46	1.50	21.5	3.3	208	10.4	218	15.8
CD at 5%	0.11	NS	0.08	NS	0.04	NS	1.3	0.4	16	0.8	18	1.1
Water management												
WM1	7.82	7.87	3.72	3.19	1.49	1.53	19.8	2.8	202	9.9	207	15.3
WM2	7.88	7.89	3.87	3.27	1.47	1.49	20.9	3.4	190	9.3	201	14.4
CD at 5%	NS	NS	0.06	NS	NS	NS	0.9	0.3	12	0.6	NS	0.8

*SWS - Soil water storage, SWA - Soil water addition, TWU - Total water use, WUE - Water use efficiency, *0-120 cm soil depth, **0-15 cm soil depth*

surface resulted in slow surface runoff and favor infiltration. Like-wise Singh *et al.* (2020) observed that the higher IRs with continuity of soil pores and reduced evaporation due to mulching of residue retention on surface soil in ZTS method. Among crop seeding methods, the WUE was 17.8% greater with ZTS as compared with TTS. The higher WUE with ZTS due to undisturbed soil with surface retention of residues supports of better soil moisture environment and subtract the nutrients during decomposition resulted in higher yield and SWAs (Singh *et al*., 2020; 2021).

As compared with WM_1, the 48 mm additional SWA at harvest of pearl millet was recorded with WM_2 (Table 5). Moreover runoff rain water also reduced by 21.4 mm with WM_2 as compared with the value of WM_1 (55.3 mm). The significantly higher TWU was recorded with WM_1, as compared with WM_2 treatment. The RF making for conservation of rainwater and greater water application uniformity in furrows resulted saving irrigation water-21.0% with WM_2 treatment as compared with WM_1. As compared with WM_1, the significant higher WUE with WM_2 was recorded due to higher yield with lower amount of irrigation water application and higher SWS additions between seeding to harvesting. The WUE under WM_2 was greater by 25.4% as compared with WM_1. Singh *et al.* (2018) reported that the decrease in water consumption was due to the changing from flood irrigation to localized furrow irrigation, which decreased irrigation amount and also lowered evaporation from surface soil resulted in increased WUE in pigeon pea crop.

Winter Season Wheat

The SWS of soil profile (0-120 cm) with ZTS was added 18 mm and 24 mm at seeding and harvest over TTS, respectively, points towards with ZTS treatment improvement in soil physical properties and reduced evaporation due to increased the OC on soil surface (Table 6). Results showed that winter season wheat depleting less amount of SWS (30 mm) with ZTS, whereas slightly higher with TTS (36 mm) method from seeding to harvest. The TWU was significantly higher with TTS as compared with ZTS. The ZTS method saved TWU was 8.8% as compared with TTS. The WUE was 24.4% higher with ZTS as compared to TTS. The higher WUE was due to higher yield advantage with lesser irrigation water, better soil moisture environment and higher SWS with ZTS as compared with TTS. The direct seeding of wheat with ZTS improved WUE after harvest of pearl millet, pigeon pea and cluster bean crop reported by Singh *et al*. (2019).

The irrigation water supply is the major limiting factor in winter season productivity of wheat in water scarce area. The results of trial showed that the additional SWS at harvest time were 35 mm with WM_2 (five irrigation level) as compared with WM_1- four irrigations (121 mm) in wheat (Table 6). The soil water depletion was higher with WM_1 treatment (38 mm) as compared with WM_2 treatments (28 mm) from seeding to harvest of wheat. The TWU was significantly greater with WM_2 as compared with WM_1 treatments. The TWU with WM_2 treatments was 315 mm, while 274 mm with WM_1 were recorded. The WUE was markedly influenced with changes in irrigation levels and significantly greater with WM_2 treatments (15.2 kg grain mm^{-1}) as compared with WM_1. The higher numbers of irrigation under WM_2 treatments preserve soil moisture and diminished heat stress effect of wheat at reproductive period resulted higher yield in climatic change scenario.

Soil Physico-chemical Properties

The results on soil physicochemical properties after harvest of third wheat crop significantly affected with the treatment of ZTS as compared with TTS, while water management practices did not show the significant effect. The ZTS plots had significantly additions OC by 1.03 g kg^{-1} and IR, while decrease of pH and BD of surface (0-5 cm) soil layer as compared with TTS. A similar finding of lower BD values under ZTS was also reported by Singh *et al*. (2020). The higher IR under ZTS might be due to greater continuity of soil pores and undisturbed dead root channels (Singh *et al*., 2021). Shukla *et al*. (2003) reported that tillage disrupts pore continuity resulted in decreases IR. The treatment impacts on pH, OC and BD were not significant at sub-surface (5-15 cm) soil layer (Table 7). Singh *et al.* (2013) also reported that ZTS technology significantly increased the SOC, IR, whereas decrease in pH and BD as compared with conventional tillage and seeding.

The additions in available N, P, K and S were 24, 1.6, 28 and 1.9 kg ha^{-1} with ZTS as compared with TTS, respectively. The removals of crop residues as well as traditional intensive tillage (4-6 operations) practices for seed bed preparation are depleting SOC and nutrients over the years (Singh *et al*., 2018; 2021). The nutrients accumulated due to the retention of higher amounts of crop residue and minimal soil disturbance in ZTS, whereas under traditional practices residues were removed/burned and small amount stubbles thoroughly incorporated in the plough layer by tillage operations in semi-arid environment reported by Singh *et al.* (2021). The significantly increased the OC, SOC and IR, while slightly decreased the availability of N and S was recorded with RF technology of rainy season pearl millet and with five irrigation level in winter season wheat crop over time. The increase of OC, SOC and IR was due to higher root and shoot biomass with uniform and longer time availability of nutrition under the treatment of RF technology of rainy season pearl millet and five irrigation level in wheat. Similarly longer time availability of soil available moisture decreases in available N and S due to mobile nature in soil, whereas available P and K had not significant affected. Similar results reported by Shirazi *et al*. (2014).

4. CONCLUSIONS

In mechanization farming systems decreased the content of SOC resulting in declining soil quality, productivity and profitability of crops and cropping system. Based on our results, the significantly increased the pearl millet and wheat seeding in zero tillage conditions sustain yield, net income and physicochemical properties of soil. Likewise RF making in standing crop of pearl millet at 40 cm spacing by RF maker at 30 DAS and five irrigations at critical stages for wheat gave maximum and significantly higher yield, net income and WUE. Research study conclude that the zero-tillage seeding of pearl millet and wheat crop, rainwater conservation with RF at 40 cm spacing in standing pearl millet crop and five irrigations in wheat sustainably improved the system productivity, economic profitability, WUE and saving cultivation cost in alluvial plains under changing climatic scenario.

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