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Research Paper

Effect of conservation agriculture practices and irrigation scheduling on productivity and water-use efficiency of maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system

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ABSTARCT

A field experiment was carried out during 2011–12 and 2012–13 at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi, India, in sandy-loam soil, to study effect of conservation agriculture practices and irrigation scheduling on productivity and water-use efficiency of maize (*Zea mays* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] cropping system. The grain yield of maize was significantly higher under raised bed (RB) planting to the tune of 13.3% over conventional tillage (CT) during both the years. The increase in irrigation water-use efficiency (IWUE) of maize was 40–46% and 10–16% higher with RB and zero tillage (ZT) over CT respectively. Residue retention was more beneficial under RB than residue incorporation in CT. In wheat, 6–13% higher grain yield under RB was found in comparison to CT. The increase in IWUE of wheat was found higher in RB (32–40%) compared to ZT (8–12%) over CT, as the grain yield was more with per unit of water applied under RB. The highest system productivity was recorded under RB (9.92 and 9.80 t/ha) followed by ZT (9.08 and 9.04 t/ha) and the minimum under CT (8.63 and 8.84 t/ha during 2011–12 and 2012–13 respectively) during both the years. The yield of crops and system productivity improved owing to application of crop residue. The results also revealed that system productivity of maize–wheat cropping system was significantly influenced because of different irrigation scheduling during both the years. Adoption of RB with crop residue along with 40% available soil-moisture depletion (ASMD) can be recommended for improving resource-use efficiency and productivity of maize–wheat cropping system.

Key words : Field water-use efficiency, Irrigation water-use efficiency, Maize, Wheat, Yield

Maize assumes worldwide significance owing to its utilization as a human food and livestock feed, as well as a source for several hindered industrial products. Its share in the total production of cereals system increased from 26.2% in 1991 to 29.2% in 2001 and further to 36.7% in 2014. Maize, a crop of worldwide economic importance, together with rice and wheat, provides approximately 30% of the food calories to more than 4.5 billion people in 94 developing countries and the demand for maize in these countries is expected to double by 2050. The suitability of maize to diverse agro-ecologies is unmatched by any other crop because of its ability to grow in diverse climatic conditions. The expanded use of maize in industry gives it a prominent place in the agricultural economy. In India, maize is considered as the third most important food crop among the cereals and contributes to nearly 9% of the national food basket (Dass *et al*., 2012). Maize is a third most important cereal crop in the world. In India, it occupies fourth place in area and third in production among cereals. It is grown in 9.3 million ha with production of 24.2 million tonnes and productivity of 2.60 tonnes/ha during 2013–14 (Economic Survey, 2013–14, Ministry of Finance, Government of India). Now-days, maize is gaining importance in conservation agriculture (CA) because maize is wider spaced crop having slow growth rate in its early stage, which leads to more loss of water through evaporation and heavily infestation of weed respectively. To overcome this problem, conservation agriculture is mostly adopted. But production is limited by low fertilizer application. Wheat is the second most important cereal

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crop after rice in India. It is cultivated in 31.3 million ha, with production of 95.8 million tonnes and productivity of 3.59 tonnes/ha (Economic Survey, 2013–14).

Adoption of a suitable conservation-tillage system and its long-term effect on productivity of the system, resource-use efficiency of the system as well soil physical environment are the current research priorities. Adaptive strategies for CA systems are highly site specific. Learning across the sites will be a powerful way in understanding why certain technologies or practices are effective in a set of situation and not effective in another set. In future there is every possibility that area under maize–wheat, maize–maize and maize–chickpea (*Cicer arrietinum* L.) cropping systems is going to increase under resource-conservation technologies to address the aberrant climatic conditions like cold injury, terminal heat stress, depleting watertable, increasing fossil-fuel emission and depleting natural resources, so these problem require suitable mitigation measures through proper crop-establishment methods, optimum irrigation scheduling and residue management. Keeping this background in view, an attempt was made to study the conservation agriculture practices and irrigation scheduling in maize–wheat system.

MATERIALS AND METHODS

The experiment was conducted during 2011–12 and 2012–13 at Research Farm of Water Technology Centre, ICAR-Indian Agricultural Research Institute, New Delhi (28°35’N and 77°12’E and at an altitude of 228.6 m above mean sea-level). Soil samples were taken before the start of the experiment and were analysed for physical, chemical and biological properties of the soil using standard procedures. The soil at the site was sandy loam in texture of alluvial origin with adequate internal drainage and was poor in organic matter, low in nitrogen and medium in both available phosphorus and potassium. The treatments comprised 3 crop-establishment practices of raised bed (RB), zero-tillage (ZT), conventional tillage (CT), and 3 irrigation regimes, viz. 40%, 50% and 60% available soil-moisture depletion (ASMD), for maize and crop-growth stages (CGS), crop-water stress index (CWSI) and 60% ASMD for wheat with this 2 residue application treatments. These treatments were studied in split and split-split plot design with three replications.

The maize cv ‘HQPM 1’ and wheat cv ‘DBW 17’ were used as experimental materials to test these treatments. The crops were raised as per the standard agronomic practices except the irrigation which was given as per treatments. Irrigation was measured with precise Star flow meter which was based on the principle of Ultrasonic Doppler (Unidata, 2011). Effective rainfall calculated with the help of USDA Soil Conservation Service formula in CROPWAT 8.0 (Smith 1992). The Evapotranspiration (ETo) were also calculated with the help of CROPWAT 8.0 (Smith, 1992). The amount of irrigation water applied to each plot was measured using a starflow meter. Irrigation water-use efficiency (kg/ha-cm) was calculated as the grain yield (kg) divided by the irrigation water applied (ha-cm) (Ibragimov *et al*., 2011). The data recorded for different parameters were analysed with the help of analysis of various (ANOVA) technique for a split-plot design using MSTAT-C software. Source of variation and corresponding degrees of freedom used in the ANOVA for deciphering main and interaction effects. The results are presented at 5% level of significance (P=0.05).

RESULTS AND DISCUSSION

Maize yield

In both the years, the grain yield was significantly higher under RB than the other crop establishment methods. The grain yield was significantly higher under RB planting to the tune of 13.3% over CT during both the years. The grain yield was also influenced significantly owing to different irrigation scheduling during both the years. Significantly lowest grain yield was obtained under 60% ASMD as compared to the other irrigation schedules. The interaction effects between crop-establishment techniques, and irrigation scheduling on yield of maize were found non-significant in both the years.

Moisture use in maize

The irrigation requirement in RB was lower (81 and 44 mm) than CT (117 and 71 mm) (Table 1). The saving in irrigation water to the tune of 30% and 38% in RB and 14% and 9% in ZT was found during 2011 and 2012 respectively. Amongst the irrigation regimes in 2011, both 40% and 50% ASMD received 2 irrigations, while 60% ASMD only one irrigation was required. However, in 2012 there was more rainfall which resulted in no irrigation requirement at 60% ASMD; however, one irrigation was given under 40% and 50% ASMD irrigation schedules. In general, water requirement in RB (320 mm and 324 mm) was lower than CT (356 mm and 351 mm) during both the years respectively (Table 1). In terms of percentage saving of water under RB was 10 and 7.6, while in ZT it was 4% and 1.7% over CT during 2011 and 2012 respectively. Amongst the irrigation regimes, the water requirement at 40% and 50% ASMD was more compared to 60% ASMD during both the years.

Irrigation water-use efficiency (IWUE) in maize

The field water-use efficiency of maize was influenced by crop-establishment techniques and irrigation regimes (Table 1). Remarkably higher IWUE/ water productivity (kg grain/m^3 water) of maize was recorded in RB planting (545 and 1,049), followed by ZT and the lowest in CT system during both the years respectively. Amongst the irrigation regimes, the highest IWUE was observed under 40% ASMD irrigation schedule during 2012. The increase in IWUE was found higher in bed planting (40% and 46%) over conventional tillage, while in ZT it was only 16% and 10% over CT during 2011 and 2012 respectively.

Wheat yield

The RB planting resulted in significant higher grain yield than ZT and CT (Table 2). The grain yield was higher under RB planting to the tune of 6–13%, while in ZT 2–6 % in comparison to CT during both the years respectively. The results also revealed that the grain yield was significantly influenced by irrigation scheduling. The grain yield was significantly higher under irrigation given at crop-growth stage (CGS). With regards to different residue management, there was no significant difference in grain yield during 2011–12, whereas significantly higher grain yield (4.74) was recorded during 2012–13.

Water requirement in wheat

The water requirement in RB (312 mm and 321 mm) was lower than CT (382 mm and 387 mm) during both the years (Table 2). The saving in water under RB was to the tune of 18.3% and 17.1% over CT during both the year respectively. It was found that there was water saving of 18–30% under 60% ASMD over CGS during 2011–12 and 2012–13 respectively. Similarly, irrigation given on CWSI schedule also saved irrigation requirement as compared to CGS during both the years respectively. Residue application also helps in saving in irrigation water in comparison to without residue treatments during 2011 and 2012 respectively.

Irrigation water-use efficiency in wheat

Irrigation and field water-use efficiency of wheat as influenced by crop-establishment techniques, irrigation regimes and residue management are given in Table 2. Remarkably higher IWUE (kg grain/m^3 water) of wheat was recorded in RB planting (419 and 189), followed by zero tillage and lowest in CT for both the years. The increase in IWUE was found higher in bed planting (32.1% and 40.1%), while in ZT it was 12.2% and 8.5% over CT during 2011–12 and 2012–13 respectively. Different irrigation schedules also resulted in increasing IWUE of water and was found that there was 20.8% and 27.9% higher IWUE under 60% ASMD over CGS during 2011–12 and 2012–13 respectively. In general, there was higher IWUE with residue application (12.2% and 13.8%) over without residue treatments during both the years. Similarly, higher FWUE of wheat was recorded in RB planting (150 and 147), followed by no-till (123 and 118) and lowest in conventional-till system (117 and 105) during both the years respectively. The increase in FWUE was higher in RB (28.7% and 21.8%) over CT. Different irrigation schedules also resulted in increased FWUE and there was 15.8% and 10.8% higher FWUE under 60% ASMD over CGS during both the years respectively.

The crops are planted on the bed surface and irrigation is applied through the furrows. The bed surface remains almost dry and the lateral water movement fulfils the crop-water requirement. The infiltration rate of the furrow bottom remains almost zero due to compaction developed by tractor and machinery movement and irrigation which fa-

Table 1. Effect of crop-establishment methods and irrigation regimes on water use in maize

Treatments	Irrigation requirement (mm)		Effective rainfall (mm)		Water requirement (mm)		Grain yield (t/ha)		IWUE (kg/ha-cm)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Crop-establishment method										
RB	81	44	239	280	320	324	4.41	4.53	545	1029
ZT	101	65	239	280	340	345	3.95	4.00	391	615
CT	117	71	239	280	356	351	3.82	3.92	327	553
SEm±	–	–	–	–	–	–	0.10	0.12	–	–
CD (P=0.05)	–	–	–	–	–	–	0.41	0.46	–	–
Irrigation scheduling										
40% ASMD	112	55	239	280	351	335	4.38	4.60	391	836
50% ASMD	123	65	239	280	362	345	3.98	4.01	324	617
60% ASMD	65	0	239	280	304	280	3.83	3.83	590	0
SEm±	–	–	–	–	–	–	0.16	0.13	–	–
CD (P=0.05)	–	–	–	–	–	–	0.48	0.41	–	–

RB, Raised bed; ZT, zero tillage; CT, conventional tillage; ASMD, available soil moisture depletion;
CGS, critical growth stage; CWSI, crop water-stress index

cilitates the lateral water movement of irrigated water into the bed area. The use of furrows/ beds hastens the speed with which irrigation water reaches the other end of the field and thus reduces irrigation amount, as the furrows occupy less than half the area of the field. Hence the grain yield (output) was more with per unit of water applied in maize–wheat production system under RB. Similarly, higher WUE was also reported bed planting (Ram *et al*., 2010). The better root growth (Aggarwal *et al.,* 2006) and lower infestation of weeds on the beds was might be other possible reasons of higher IWUE under RB. In wheat, IWUE was higher during 2012–13 than 2011–12 due to higher grain yield as well as less numbers of irrigations was applied due to good distribution of rainfall in the year 2012–13.

Bandyopadhyay *et al*. (2010) concluded that under limited water supply, when irrigation water is available up to the crown-root initiation stage, farmers may follow dry sowing of wheat followed by sprinkler irrigation and subsequent irrigation through flooding; and when irrigation water is available up to the tillering or flowering stage, sprinkler irrigation in three or four installments, respectively, at critical growth stages may be practiced to obtain higher yield and water and nitrogen-use efficiency of wheat in Vertisols. The higher infiltration rate (Ferrreras *et al*., 2000) and hydraulic conductivity also maintain better water dynamics under PB and ZT practices compared to CT, which ultimately improves the water availability to crop plants. The Jat *et al.* (2005) and Parihar *et al.* (2011) also reported enhancement in water productivity by adoption of ZT and PB practice over CT.

There was saving 36.4% and 45.2% of irrigation water under 60% ASMD as compared to CGS-based irrigation schedule during 2011–12 and 2012–13 respectively. The main reason for the higher IWUE in ASMD method could be due to the uniform distribution of irrigation water, lower evaporation from the soil surface and easy availability of water and nutrients within the root zone. Also since evaporation from this is minimal, transpiration is increased and increasing transpiration improves stomatal opening, and photosynthesis. Generally, efficient irrigation systems and efficient irrigation-scheduling methods not only led to a considerable reduction in applied water but also led to a significant increase in yield compared to conventional irrigation methods. Igbadun *et al.* (2008) reported that WUE and IWUE were strongly influenced by the number of growth stages in which deficit irrigations were applied and how critical the growth stages were to moisture stress rather than the amount of irrigation water applied. While the maximum WUE may be obtained under full irrigation,

Table 2. Effect of crop-establishment methods, irrigation regimes and residue management on irrigation water use efficiency (IWUE) and field + water-use efficiency (FWUE) of wheat

Treatment	Irrigation requirement (mm)		IWUE (Kg/ha-cm)		Effective rainfall (mm)		Water Requirement including pre-sowing irrigation at 60 mm (mm)		Grain yield (t/ha)	
	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13
Crop-establishment method										
RB	244	115	189	419	8.2	146	312.20	321.00	4.61	4.82
ZT	294	169	146	274	8.2	146	362.20	375.00	4.29	4.63
CT	314	181	128	251	8.2	146	382.20	387.00	4.02	4.54
SEm±	–	–	–	–	–	–	–	–	0.08	0.05
CD (P=0.05)	–	–	–	–	–	–	–	–	0.31	0.17
Irrigation scheduling										
CGS	330	191	136	250	8.2	146	398.20	397.00	4.50	4.77
CWSI	280	143	152	327	8.2	146	348.20	349.00	4.26	4.68
60% ASMD	242	131	172	346	8.2	146	310.20	337.00	4.17	4.54
SEm±	–	–	–	–	–	–	–	–	0.10	0.06
CD (P=0.05)	–	–	–	–	–	–	–	–	0.31	NS
Residue management										
With mulch	269	146	162	325	8.2	146	337.20	352.00	4.35	4.74
Without mulch	301	164	142	280	8.2	146	369.20	370.00	4.27	4.59
SEm±	–	–	–	–	–	–	–	–	0.07	0.05
CD (P=0.05)	–	–	–	–	–	–	–	–	0.20	0.13

RB, Raised bed; ZT, zero tillage; CT, conventional tillage; ASMD, available soil-moisture depletion;
CGS, critical growth stage; CWSI, crop-water stress index

IWUE can be raised above what can be obtained under full irrigation if deficit irrigation is imposed on the crop at vegetative growth stage. More so, if water is limited and deficit irrigation is to be spread over different growth stages of the maize crop, WUE, and IWUE may be improved upon if the flowering growth stage (tasselling to silking) is exempted from the deficit irrigation schedule.

Yuan *et al*. (2005), who found that after 2 years soil-water content in 0.8 m (2.62 ft) wide beds was 5.3% greater than that in traditional flat fields in Central China. Clearly, this result highlights the importance of soil and residue management to increase water infiltration and reduce soil degrada-tion in the arid northwest areas as well as the higher rainfall zones of eastern china. This agrees with Tolk and Howell (2003), who noted that IWUE of irrigated sorghum grown in USA Southern Great Plains Soils declined with increase in irrigation application, but varied in some irrigation treatments due to water stress at critical growth stages. Although the reference treatment which gave the highest dry-matter yield, grain yield and seasonal evapotranspiration also gave the highest values of WUE, the highest value of IWUE was obtained in Treatment 2, which had deficit irrigation at vegetative growth stage.

System productivity

Crop-establishment techniques, irrigation regimes and residue-management practices brought considerable improvement in system productivity of maize–wheat cropping system during both the years (Table 3). Maize-equivalent yield (MEY) of wheat was significantly influenced due to different tillage practices during both years. The highest MEY of was recorded under RB (9.92 and 9.80 t/ha) followed by ZT and minimum under CT during 2011–12 and 2012–13 respectively) during both the years. The results also revealed that system productivity of maize–wheat cropping system were significantly influenced due to different irrigation scheduling during both the years.

Significantly higher system productivity was obtained under irrigation based on CGS as compared to the other irrigation schedules. However, system productivity by residue management not significantly influenced during both the years. Similar to crop-establishment technique, higher system productivity was also recorded under residue-management treatments. Moreover, residue application improved the soil physio-chemical and biological environment in the soil through addition of nutrients, enhanced microbial activity (Singh *et al.,* 2009). Jat *et al* (2005) reported that productivity of maize–wheat system was the maximum (10.84 t/ha) under FIRB system of planting followed by ZT and CT systems respectively. The system productivity of maize–wheat cropping system was higher under CGS irrigation scheduling practices which was owing to good crop growth, lower crop evapotranspiration (ETs), higher values of yield attributes and yields under these treatments.

Based on 2 years of study, it was concluded that conservation agriculture practice of raised bed may be recommended for higher productivity and resource-use efficiency in the maize–wheat cropping system.

Table 3. Effect of crop-establishment methods, irrigation regimes and residue management on system productivity and economics of maize–wheat system

Treatment	System productivity (t/ha) 2011–12	2012–13
Crop establishment method		
RB	9.92	9.80
ZT	9.08	9.04
CT	8.63	8.84
SEm±	0.22	0.14
CD (P = 0.05)	0.87	0.56
Irrigation scheduling		
CGS	9.75	9.76
CWSI	9.07	9.12
60%ASMD	8.81	8.80
SEm±	0.23	0.18
CD (P=0.05)	0.70	0.56
Residue management		
With mulch	9.25	9.33
Without mulch	9.16	9.12
SEm±	0.08	0.05
CD (P=0.05)	NS	0.15

REFERENCES

Aggarwal, P., Choudhary, K.K., Singh, A.K. and Chakraborty, D. 2006. Variation in soil strength and rooting characteristics of wheat in relation to soil management. *Geoderma* **136**: 353–363.

Bandyopadhyay, K.K., Misra, A.K., Ghosh, P.K., Hati, K.M., Mandal, K.G. and Moahnty, M. 2010. Effect of irrigation and nitrogen application methods on input use efficiency of wheat under limited water supply in a Vertisol of Central India. *Irrigation Science* **28**: 285–299.

Dass, Sain, Jat, S.L., Chikkappa, G.K., Kumar, B., Kaul, Jyoti, Parihar, C.M., Kumar, Ashok, Kumar, R., Kamboj, M.C., Singh, Vishal, Yatish, K.R., Jat M.L. and Singh, A.K. 2012. Genetic enhancement and crop management lead maize revolution in India. *Maize Journal* **1**(1): 7–12.

Ferreras, L.A., Costa, J.L., Garcia, F.O. and Pecorari, C. 2000. Effect of no-tillage on some soil physical properties of a structural degraded Petrocalcic Paleudoll of the southern "Pampa" of Argentina. *Soil and Tillage Research* **54**: 31–39.

Ibragimov, N., Evett, S., Esenbekov, Y., Khasanova, F., Karabaev, I., Mirzaev, L. and Lamers, J. 2011. Permanent beds vs. conventional tillage in irrigated arid central asia. *Agronomy Journal* **103**(4): 1,002–1,011.

Igbadun, H.E., Salim, B.A., Tarimo, A.K.P.R. and Mahoo, H.F., 2008. Effects of deficit irrigation scheduling on yields and soil water balance of irrigated maize. *Irrigation Science* **27**: 11–23.

Jat, M.L., Srivastava, A., Sharma, S.K., Gupta, R.K., Zaidi, P.H., Rai, H.K. and Srinivasan, G. 2005. Evaluation of maize–wheat cropping system under double no-till practice in Indo-Gangetic Plains of India. (In) *Proceeding of 9th Asian Regional Maize Workshop, held during* 5–9 September 2005, Beijing, China, pp. 25–26.

Parihar, C.M., Jat, S.L., Singh, A.K. and Singh, D.K. 2011. Impact of conservation agriculture and legume inclusion in maize–wheat cropping system (In) *Abstracts of 11th Asian Maize Conference on Addressing Climate Change Effects and Meeting Maize Demand for Asia,* held on 7 to 11 November 2011 in Nanning, China.

Ram, Hari, Kler, D.S., Singh, Yadvinder and Kumar, K. 2010. Productivity of maize (*Zea mays*) – wheat (*Triticum aestivum*) system under different tillage and crop establishment practices. *Indian Journal of Agronomy* **55**(3): 185–190.

Singh, G., Marwaha, T.S. and Kumar, D. 2009. Effect of resource-conserving techniques on soil microbiological parameters under long-term maize (*Zea mays*)–wheat (*Triticum aestivum*) crop rotation. *Indian Journal of Agricultural Sciences* **79**(2): 94–100.

Smith, M. 1992. CROPWAT: A Computer Programme for Irrigation Planning and Management. FAO Irrigation and Drainage Paper 46, Food and Agriculture Organization of the United Nations, Rome, pp.126.

Tolk, J.A. and Howell, T.A., 2003. Water use efficiencies of grain sorghum grown in three USA southern Great Plains soils. *Agricultural Water Management* **59:** 97–111.

www.fao.org. The State of food Insecurity in the world 2015 international hunger targets taking stock of uneven progress.

www.indiabudget.nic/budget2014–15/survey.asp Economic Survey 2013–14-Union Budget and Economic Survey, Government of India, Chapter 8 Agriculture and Food Management, p. 138.

Yuan, G., Luo, Y. Sun, X. and Tang, D. 2005. Evaluation of a crop water stress index for detecting water stress in winter wheat in the North China Plain. *Agricultural Water Management* **64**: 29–40.