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Mini-sprinkler Irrigation Influences Water and Nitrogen Use Efficiency and Wheat Yield in Western Indo-Gangetic Plains of India

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Abstract

Indiscriminate water use and declining water table in western Indo-Gangetic plains (IGP) is threatening sustainability of rice-wheat cropping system. Mini-sprinkler irrigation system (MSIS) in wheat can save considerable amount of irrigation water under conservation agriculture. A four-year field experiment was conducted to study the influence of mini-sprinkler irrigation system on water and nitrogen use efficiency and wheat yield under conservation agriculture. The influence of mini-sprinkler irrigation system in zero tilled wheat with 100% rice residue mulch (MSIS-ZT+RM) was compared with surface irrigation system (SIS) in zero tilled wheat with 100% rice residue mulch (SIS-ZT+RM), and farmers' practice i.e. surface irrigation system in conventionally tilled wheat without residue (SIS-CT-WR). MSIS-ZT+RM saved 43.3 and 25% irrigation water, and 50% nitrogen, as compared to SIS-CT-WR and SIS-ZT+RM, respectively. Although, yield attributes and wheat grain yield in MSIS-ZT+RM was at par with SIS-CT-WR (farmers' practice) but MSIS-ZT+RM recorded 1.8 and 2.0-times higher grain water productivity (GWP) and nitrogen use efficiency (NUE), respectively, than SIS-CT-WR. Considerable water saving, higher NUE with sustained yield suggests that mini-sprinkler irrigation system can be a viable option for ZT-wheat in the present scenario to counter declining water table.

Key words: Grain yield, Mini sprinkler, Mulching, Nitrogen use efficiency, Water productivity, Zero tillage

Introduction

The Indo-Gangetic plain (IGP) is characterized with intensive rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system (RWS), occupying nearly 10.3 million hectares (Mha) in India. IGP is vital for food security as this region contributes more than 75 and 45% of total wheat and rice production, respectively. The sustainability of RWS in western IGP comprising Punjab, Haryana and Utter Pradesh is under tremendous pressure due to indiscriminate use of underground water causing alarming decline in water table depth and its quality. The high-water requirement of intensively irrigated RWS has posed serious problem to groundwater availability and quality (Tomar *et al.,* 2012; Narjary *et al.,* 2014).

Wheat is the second most important cereal crop after rice cultivated on 30.78 Mha with productivity of 3200 kg ha^{-1}. It is an important *rabi* crop grown in rotation with rice in IGP. The consumption of wheat in India was 95.6 million tonnes (Mt) in 2018 (USDA, 2019), and with ever increasing population a production target of 140 Mt by 2050 has been fixed (Ramdas *et al.*, 2019). Therefore, to achieve this production target, its production has to be increased manifold even with continued shortage of freshwater supplies to agriculture and inter-sectoral competition (Cai and Rosegrant, 2003). Hence, the pressure will be more on irrigated agriculture to produce more food with less water. The current annual water deficit is 1.27 M ha-m (Jain and Kumar, 2007), which will further aggravate due to increased water demand from different sectors. The groundwater table in this region is decreasing with a rate of ~1.0 m yr^{-1} between the year 2000 and 2006 (Humphreys *et al.,* 2010). Hence, there is an urgent need to address the issues relating sustainable agriculture and developing alternate strategies for judicious water use in irrigated agro-ecosystem.

Pragmatic solution of the aforesaid concerns may be use of input efficient mini-sprinkler irrigation system in wheat. As reported by Chourushi and Patel (2013), irrigation through mini-sprinkler saved 38.1 and 26.2% irrigation water and 14.5 and 30.3% higher wheat grain yield, respectively with irrigation scheduling at IW/CPE ratio of 0.8 and 1.0 as compared to conventional surface irrigation method. Liu *et al.* (2013) also reported lower evapotranspiration, higher water productivity (WP) and irrigation water productivity (IWP) to the tune of 18-57% and 21-81%, respectively, under sprinkler irrigation as compared to surface irrigated wheat. Recently, Grewal *et al.* (2021) conclusively proved that besides saving huge quantity of water, financial benefits increased by 60 to 80 percent on shifting from flood to mini-sprinkler irrigation and more than 100 percent upon adopting drip irrigation in drought-prone areas of Haryana. Such benefits in vegetable crops cultivated with drip irrigation were more than 200 percent as compared to flood irrigation.

Further, mulching and zero tillage can also supplement mini-sprinkler irrigation system to achieve efficient water utilization in wheat. Residue mulch conserves moisture by maintaining optimum soil temperature and reducing soil water evaporation and controls weeds (Kader *et al.*, 2017). Residue mulch also changes soil physical conditions by influencing mechanical and hydro-thermal regime. Keeping these facts in view, the present study was undertaken to evaluate the role of mini-sprinkler irrigation system, zero tillage and residue mulch in enhancing wheat yield, water productivity and nitrogen use efficiency.

Materials and Methods

A four-year field experiment was conducted during *rabi* seasons of 2011 to 2014 at Research Farm (29°43′ N, 76°58′ E, 244 m above mean sea-level) of ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India. The experimental site represents typical reclaimed sodic soil, subtropical monsoonal climate with mean maximum and minimum temperature of 33.5 °C and 23.8 °C, respectively. The rainfall received at the experimental site during experimental period varied from 42.1 mm during 2011-12 to 205.0 mm during 2012-13 (Table 1, Fig. 1). The physico-chemical properties of soil at the initiation of field experiment are given in Table 2.

Three treatments comprising of mini-sprinkler irrigation system in zero tilled wheat with 100% rice residue mulched (MSIS-ZT+RM), surface irrigation system in zero tilled wheat with 100% rice residue mulched (SIS-ZT+RM), and farmers' practice i.e., surface irrigation in conventionally tilled wheat without residue (SIS-CT-WR), were laid out in randomized complete block design with four replications. The plot size was 250 m^2 in surface irrigated treatments (SIS-CT-WR and SIS-

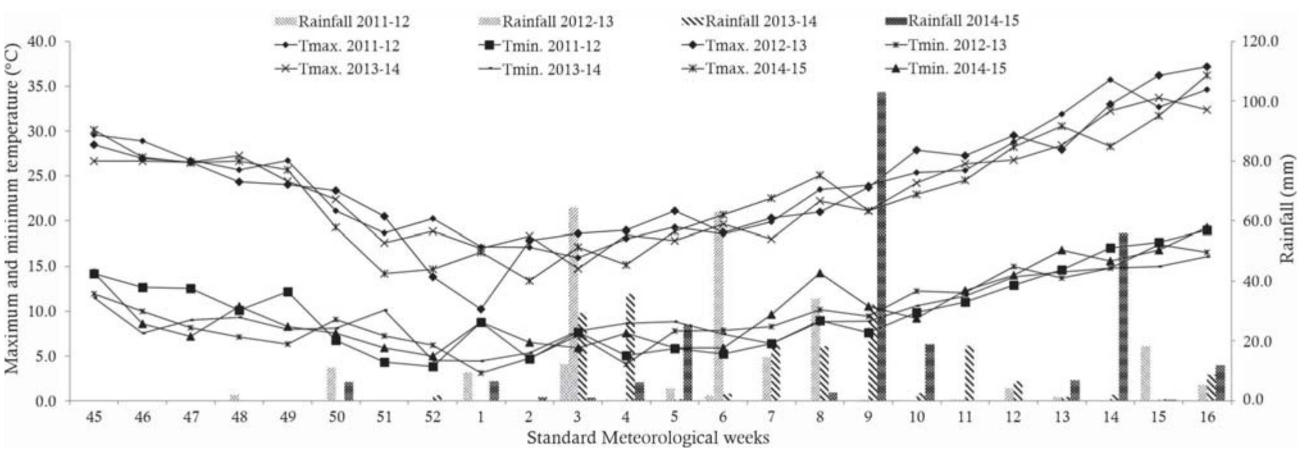

Fig. 1 Weekly rainfall, and mean maximum and minimum temperature during the experimentation period. *Source: Agrometeorology Observatory, ICAR-CSSRI, Karnal, India*

Table 1. Pan evaporation (Ep), crop evapotranspiration (ETc), and rainfall received during crop season in different years

Crop season	Pan evaporation (mm) (Ep)	Crop evapotranspiration (mm) (ETc)	Rainfall (mm)
2011-12	324.2	253.2	42.1
2012-13	290.2	212.4	205.0
2013-14	260.6	188.0	167.2
2014-15	257.4	190.3	178.7

Table 2. Chemical and physical characteristics of soil of the experimental site in 2011

Soil Property	Depth (cm)	
	0-15	15-30
pH (1:2)	7.90	7.48
EC (dS m^{-1}) (1:2)	0.25	0.24
Organic Carbon (%)	0.73	0.61
Texture	Sandy clay loam	Sandy clay loam
Available N (kg ha^{-1})	153	149
Available P (kg ha^{-1})	34.1	15.3
Available K (kg ha^{-1})	246.3	217.3
Bulk density (g cm^{-3})	1.50	1.53
Infiltration rate (mm hr^{-1})	3.5	

ZT+RM) and 450 m^2 in mini-sprinkler treatment (MSIS-ZT+RM). Observations were recorded at four places in each plot. In conventional tillage, a sequence of tillage operations with tractor drawn disc harrow and tiller (twice each) followed by *planking* was done to prepare a fine seedbed. In zero tillage, no–tillage operation was performed and soil remained undisturbed. while sowing was done using 'Happy Seeder'. Seeding of wheat (cv. HD 2967) was done in the first fortnight of November, using 100 kg seed ha^{-1} with row to row spacing of 22 cm. The crop was harvested in end of April. The 100% residue of previous rice crop was spread uniformly in zero till treatments, while residue was removed completely from conventional tilled wheat (SIS-CT-WR, farmers' practice).

In conventionally tilled wheat (SIS-CT-WR), 150 kg N, 60 kg P_2O_5 and 60 kg K_2O per hectare were applied uniformly. Full dose of P, K and one–third of N was applied as basal dose while remaining two–third N was applied in two equal splits with first and second irrigation in surface irrigation treatments. In mini-sprinkler (MSIS-ZT+RM) and surface irrigated zero tilled wheat (SIS-ZT+RM) treatments, crop was fertilized with 50, 60 and 60 kg per hectare each of N, P and K at the time of sowing. Remaining N was applied in split based on the leaf colour chart (LCC) reading. In MSIS-ZT+RM, the nitrogen was applied with sprinkler water while in SIS-ZT+RM, top dressing of nitrogen was done. The experimental plots were kept free from weeds, insects, pests and diseases by following recommended cultural practices.

Parshall flume and water meter were used to measure the amount of water applied in surface and mini-sprinkler systems, respectively, which were used to compute irrigation water applied, water productivity, and water saving in the respective treatments. About 60 mm of irrigation depth was maintained in surface irrigation method considering rainfall contribution. In mini-sprinkler system, irrigation scheduling was done based on crop evapotranspiration. The amount of water applied (m^3) in each irrigation was computed while recording weekly cumulative pan evaporation (E_p), pan factor (K_p), crop coefficient (K_c) from seed germination to the crop maturity (Tyagi *et al.*, 2000; Kumar *et al.*, 2019).

The crop evapotranspiration (ET_c) was estimated using the following equation:

$$ET_o = E_p \times K_p \qquad \ldots(1)$$

$$ET_c = ET_o \times K_c \qquad \ldots(2)$$

where ET_0 is potential evapotranspiration, K_p is pan coefficient (0.75), and K_c is locally developed crop coefficient (Tyagi *et al.*, 2000).

The grain water productivity (GWP) and nitrogen use efficiency (NUE) were computed as

GWP (kg m^{-3}) = Grain yield (kg ha^{-1})/ Total irrigation water applied (m^3 ha^{-1}) …(3)

NUE (kg grain kg^{-1} N) = Grain yield (kg ha^{-1})/ Nitrogen applied (kg ha^{-1}) …(4)

The flow rate of sprinkler nozzle was 434 l ha^{-1} hr^{-1} at system operating pressure of 2.0 kg cm^{-2}. The wetted radius of each nozzle was 10 m at 2.0 kg cm^{-2} operating pressure. The uniformity coefficient was determined as 85% at 2.0 kg cm^{-2} operating pressure.

Production cost and gross returns for different treatments were estimated with the assumption that the salvage value of different components of sprinkler irrigation systems will be zero after their useful life of 10 years. The annual fixed costs were calculated using the following relationship (James and Lee, 1971):

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where CRF = capital recovery factor, i = interest rate (fraction) 9%, n = useful life of the component (yr). Annual fixed cost per ha was estimated by multiplying CRF and fixed cost per ha. The operating cost included labour charges and agronomic practices such as tillage operations, irrigation, application of fertilizers and chemicals, harvesting and threshing etc., residue management, diesel fuel, fertilizers and chemicals, electricity charges, repair and maintenance etc. The gross returns included returns from both grain as well as straw yield considering minimum support price of wheat grain and prevailing market price of wheat straw.

The yield attributing characters i.e., effective tillers per meter-row-length (m. r. l.), grains $spike^{-1}$ and 1000-grain weight were recorded at harvest using quadrate (3 m × 3 m) placed randomly at 4 places in each plot. These samples from each treatment plot were sun dried, threshed manually and aggregated to compute the grain yield expressed in Mg ha^{-1}.

All the data were analysed using analysis of variance (ANOVA) technique using SAS 9.4 (SAS Institute, 2004). Treatment means were compared at $p \leq 0.05$ level of significance.

Results and Discussion

Pan evaporation, crop evapotranspiration and rainfall

The pan evaporation (Ep), crop evapotranspiration (ETc) and rainfall received during the cropping seasons in different years are given in Table 1. The pan evaporation varied from 257 mm (2014-15) to 324 mm in (2011-12). The highest Ep (324.2 mm) was recorded during 2011-12 and the lowest (257.4 mm) in 2014-15. Likewise, ETc followed the similar trend as of Ep. The rainfall remained more erratic, being highest during 2012-13 (205.0 mm) and the lowest in 2011-12 (42.1 mm).

Irrigation water

Variation in irrigation water applied under different treatments varied in accordance with seasonal crop water requirements and rainfall received (Table 3). The data revealed that irrigation methods had significant influence on IW requirement in wheat; variation being 93-215 mm, 120-245 mm, and 180-300 mm in MSIS-ZT+RM, SIS-ZT+RM, and SIS-CT-WR, respectively. On average the total water demand remained 142, 196, and 250 mm in MSIS-ZT+RM, SIS-ZT+RM, and SIS-CT-WR, respectively.

Water saving (four-year average) in MSIS-ZT+RM was found to be 43.3 and 25.0%, respectively as compared to SIS-CT-WR and SIS-ZT+RM. The irrigation water saving in SIS-ZT+RM was 21.5% as compared to SIS-CT-WR. The considerable saving in IW with mini- sprinkler irrigation method may be attributed to higher

Table 3. Effect of different irrigation methods and residue management on irrigation water applied in wheat crop (Average data of 2011-15)

Treatments	Irrigation water applied (mm)					Saving of irrigation water (%)	Average number of irrigations
	2011-12	2012-13	2013-14	2014-15	Mean		
MSIS-ZT+RM	215	147	93	112	142	43.3	10
SIS-ZT+RM	240	180	120	245	196	21.5	4
SIS-CT-WR	300	240	180	280	250	-	4

Table 4. Effect of different irrigation methods and residue management on yield attributes and grain yield of wheat (pooled data of 2011-15)

Treatments	Effective tillers per m.r.l.	Grains per spike	1000-grain weight (g)	Grain yield (Mg ha^{-1})
MSIS-ZT+RM	82.2	45.1	41.2	5.47
SIS-ZT+RM	88.4	46.6	41.7	5.75
SIS-CT-WR	80.9	46.0	42.5	5.46
p-Value	0.0038	0.4856	0.0038	0.0025

water application efficiency as compared to surface irrigation method. Kumar *et al*. (2006) also found lesser irrigation demand with efficient micro irrigation system as compared to conventional method of irrigation.

Yield attributes and grain yield

The field data of four years indicate that methods of irrigation and mulching treatments had significant influence on yield attributes (effective tillers per m.r.l. and 1000-grain weight), and grain yield (Table 4). Significantly the highest wheat grain yield was recorded in SIS-ZT+RM treatment (5.75 Mg ha^{-1}) while grain yield in MSIS-ZT+RM (5.47 Mg ha^{-1}) was at par with SIS-CT-WR (farmers' practice) (5.46 Mg ha^{-1}). Effective tillers also follow similar trend as of grain yield. The 1000-grain weight was maximum in SIS-CT-WR (42.5 g) at par with SIS-ZT+RM (41.7 g) while significantly higher than MSIS-ZT+RM (41.2 g). Irrigation methods and mulching has non-significant effect on grain per spike of wheat crop. The lower grain yield in SIS-CT-WR may be attributed to formation of impervious layer and soil compaction due to continued puddling in preceding rice crop which restricted root growth, nutrient uptake and produced lower grain yield of wheat in SIS-CT-WR (Gathala *et al.,* 2011; Jat *et al*., 2017). Likewise, the highest grain yield in surface irrigation with 100% rice residue mulched (SIS-ZT+RM) might be due to the fact that direct seeding of rice improves soil health, increases soil organic matter (Jat *et al.,* 2017) and assures better germination, root growth, nutrients and water uptake and ultimately higher grain yield of next season wheat crop.

Water productivity

The grain water productivity (GWP) was estimated to assess the effect of irrigation systems on production per unit volume of water applied; being highest in MSIS-ZT+RM (4.12 kg m^{-3}) followed by SIS-ZT+RM (3.20 kg m^{-3}) and SIS-CT-WR (2.27 kg m^{-3}) (Fig. 2). Significantly higher GWP in MSIS-ZT+RM and SIS-ZT+RM than SIS-CT-WR could be attributed to lesser irrigation water application (43.3 and 21.5%, respectively) in these treatments during crop growing season. These results confirmed the earlier findings of higher water productivity with micro-irrigation than surface irrigation (Singh and Kumar, 2007; Kumar *et al.*, 2013).

Nitrogen applied and nitrogen use efficiency (NUE)

The total nitrogen applied in wheat was 75 kg ha^{-1} in MSIS-ZT+RM treatment while 150 kg ha^{-1} was applied in SIS-ZT+RM and SIS-CT-WR treatments. Fertigation through mini-sprinkler saved 50% nitrogen as compared to top dressing in SIS-ZT+RM and SIS-CT-WR. This saving in nitrogen under mini-sprinkler may be due to less leaching losses with split application of urea dissolved in water (Kumar, 2015). The similar trend was observed for NUE as of GWP. Significantly higher NUE was recorded in MSIS-ZT+RM (72.9 kg grain kg^{-1} N) while it was at par in SIS treatments i.e., SIS-ZT+RM (38.4 kg grain kg^{-1} N) and SIS-CT-WR (36.4 kg grain kg^{-1} N) (Fig. 2). Total nitrogen applied for different treatments explains the significant difference in NUE. Similar results of higher NUE in sprinkler irrigated durum wheat were reported by Mon *et al*. (2016).

Economics

Econometric analysis revealed that significantly higher gross return was obtained in SIS-ZT+RM (78.3 ×10^{3} ₹ ha^{-1}), followed by MSIS-ZT+RM

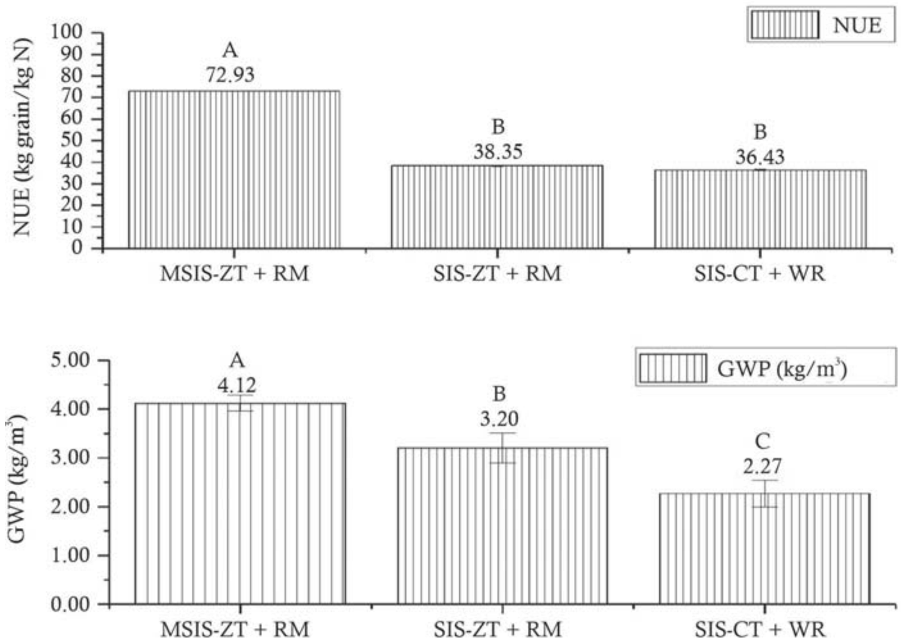

Fig. 2 Grain water productivity (GWP) and nitrogen use efficiency (NUE) under different irrigation systems in wheat crop (pooled data of 2011-15)

(74.5 ×10^3 ₹ ha^{-1}), and the lowest in SIS-CT-WR (74.4 ×10^3 ₹ ha^{-1}) (Table 5). The maximum gross return in SIS-ZT+RM treatment may be ascribed to the highest wheat grain yield.

The cost of cultivation was maximum in MSIS-ZT+RM (31.3 ×10^3 ₹ ha^{-1}) followed by SIS-ZT+RM (26.1 ×10^3 ₹ ha^{-1}) and SIS-CT-WR (25.3 ×10^3 ₹ ha^{-1}). The higher cultivation cost in MSIS-ZT+RM was due to initial investment on mini-sprinkler irrigation system, and cost of rice residue. The cost incurred in mulched rice residue nullified the cost saved in tillage operations in zero tilled wheat under surface irrigation (SIS-ZT+RM). Likewise, the higher cost of cultivation under SIS-CT-WR was attributed to more tillage operations which consumes more fuel and energy.

Table 5. Economic difference of irrigation and residue management practices in wheat crop (pooled data of 2011-15)

Treatments	Gross return (×10^3 ₹ ha^{-1})	Cost of cultivation (×10^3 ₹ ha^{-1})	B:C ratio
MSIS-ZT+RM	74.5	31.3	1.38
SIS-ZT+RM	78.3	26.1	2.00
SIS-CT-WR	74.4	25.3	1.94
p-Value	0.0008		<.0001

Significantly higher B:C was computed in SIS-ZT+RM (2.00), at par with SIS-CT-WR (1.94), while higher than MSIS-ZT+RM (1.38). The highest B:C ratio in SIS-ZT+RM was due to the highest gross return and lower cost of cultivation. The lower B:C ratio in MSIS-ZT+RM than SIS-CT-WR was due to proportionally less increase in gross return per unit of cultivation cost. Since, the B:C ratio was more than one in all the treatments, therefore all the treatments were economically viable.

Conclusions

Mini-sprinkler irrigation system coupled with zero tillage and rice residue mulch (MSIS-ZT+RM) saved 43 and 25% irrigation water as compared to surface irrigated conventionally tilled wheat without residue (SIS-CT-WR) and surface irrigated zero tilled wheat with mulched rice residue (SIS-ZT+RM), respectively. The grain yield in MSIS-ZT+RM treatment was at par with SIS-CT-WR (farmers' practice). The MSIS-ZT+RM recorded the highest GWP and NUE amongst all treatments. The gross return in MSIS-ZT+RM was almost equal compared to surface irrigated conventionally tilled wheat without residue (SIS-CT-WR). The significant water saving, better input use efficiency and similar grain yield in comparison of prevailing farmer's practice advocates the use of mini-sprinkler in wheat under limited water availability.

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