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Productivity and profitability of drip fertigated wheat (*Triticum aestivum*) – mungbean (*Vigna radiata*) – maize (*Zea mays*) cropping system

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ABSTRACT

An experiment was conducted at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi during 2019–20 and 2020–21 to study the productivity and economic viability of wheat (*Triticum aestivum* L.)–mungbean (*Vigna radiata* (L.) R. Wilczek)–maize (*Zea mays* L.) fertigated with 0, 60, 80, 100% recommended doses of NPK and irrigated at 0.6 and 0.8 crop evapotranspiration (ET_c) through subsurface (SSDI) and surface drip irrigation (SDI). The results were compared with the conventional practice of surface irrigation and soil application of 100% recommended doses of NPK. Grain yields of wheat, mungbean, maize and system wheat equivalent yield (SWEY) improved by 22.9, 7.2, 21.9 and 19.4%, respectively with increase in NPK fertigation doses from 60 to 100% and by 15.6, 9.2, 4.9 and 9.7% with the increase in irrigation frequency from 0.6 to 0.8 ET_c. However, SDI and SSDI had equal system productivity (12.48 and 12.85 Mg/ha). The SWEY at 0.8ET_c fertigated either with NPK_{80} or NPK_{100} was statistically at par (14.2–15.9 Mg/ha) with the conventional practice (14.3–15.2 Mg/ha). The cash inflow, net income and benefit cost ratio (BCR) of the cropping system also increased successively with increase in fertigation doses and irrigation frequency. The net income and BCR followed the order maize>wheat>mungbean. The net income under SSDI at 0.8 ET_c with NPK_{80} or NPK_{100} in wheat, mungbean, maize and system was 11–13, 88–105, 1-9 and 8–14% higher than the conventional practice. At 0.8 ETc and NPK_{100}, BCR in SSDI (1.86) was higher than in SDI (1.71) and conventional system (1.67).

Keywords: Benefit cost ratio, Cropping system, Economic viability, Sub-surface drip, Water use efficiency

Agriculture is the largest water user, consuming about 80–90% of available freshwater (FAO 2012). In surface irrigation (SI), the most common irrigation system, about 71% of water and significant amount of applied nutrients are lost and water use efficiency (WUE) never exceeds 45%. This emphasises on adopting modern irrigation and nutrient application methods like drip fertigation which has WUE of 90%, and N, P and K use efficiency of 90, 45 and 80%, respectively in comparison to 30–50, 20 and 50% in soil application (Chen *et al*. 2015, Brar *et al.* 2019).

Irrigation WUE may be further improved in sub-surface drip (SSDI) because of direct application of irrigation water inside the root-zone and reduced evaporation losses. Compared to SDI, SSDI system has longer life and overcomes the hurdles of tillage operations. However, free or nominal charges of irrigation water discourages the adoption of this water-saving but capital-intensive technology. The focus needs a paradigm shift from the water-saving technology to higher crop productivity and profitability. Drip irrigation is confined to vegetables and high-value horticultural crops but economic benefits can also be derived from wheat, maize or mungbean, if proper fertigation and irrigation schedules are adopted (Sharma *et al.* 2021).

The issues between high capital cost and resources saved in drip fertigation in comparison to the conventional system must be addressed for its successful implementation under Indian conditions (Kishore *et al.* 2022). The economic analysis of different drip fertigation schedules and nutrient doses in wheat-mungbean-maize system has so far not been worked out. Keeping above in view, the present study was carried out with the following objectives: (i) to optimize the irrigation and fertigation schedules for achieving higher crop yields, water use efficiency and system productivity of wheat-mungbean-maize cropping system and (ii) to assess the financial benefits of employing SDI and SSDI systems compared to SI for finding best management practices.

MATERIALS AND METHODS

The present study was carried out at the research

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farm of ICAR-Indian Agricultural Research Institute, New Delhi (28°38'21.3" N and 77°08'56.5" E) during 2019–20 and 2020–21. The site comprises of sandy loam soil, typic Ustochrepts dominant in illitic clay minerals with *p*H $_{(1:2)}$ 7.3 and electrical conductivity ($EC_{1:2}$) 0.25-0.3 dS/m, available N-202 kg/ha, P-29 kg/ha and K-144 kg/ha. The irrigation water applied had an EC of 1.67 dS/m, RSC of 1.8 meq/L and *p*H of 7.15. The total rainfall received during first year (November 2019-October 2020) and second year (November 2020-October 2021) was 728 and 1023 mm, respectively. The cumulative USWB Class A Open pan evaporation was 1439 and 1585 mm during first and second year, respectively.

Experimental layout: A field experiment on wheat (*Triticum aestivum* L.)–mungbean (*Vigna radiata* (L.) R. Wilczek)–maize (*Zea mays* L.) cropping system was laid out in a randomized complete block design with 3 replications. The experiment consisted of treatment combinations of (A) 2 methods of irrigation (i) surface drip and (ii) sub-surface drip; (B) 2 irrigation schedules (i) 0.6 ET_c and (ii) 0.8 ET_c and (C) 4 fertigation doses (i) 0, 60, 80 and 100% of recommended dose of N, P and K. Additional treatment of conventional system (surface irrigation and soil application of 100% recommended dose of N, P and K) was also kept for comparison. The gross plot size was 7 m × 3 m. Drip system consisted of a polyvinyl chloride (PVC) main line (63 mm) connecting two sub-main lines (50 mm) laid at 50 cm depth. Lateral inlines of 16 mm diameter having discharge of 2 litre per hour and emitters at 30 cm spacing were punched out from the submain. In sub-surface drip, lateral in-lines were installed at 20 cm soil depth. Wheat (HD 3086) was sown at 20 cm spacing in November and harvested in April. Mungbean (Pusa 1431) was sown at 30 cm spacing and harvested in the 1st week of July in 2020 and last week of June in 2021. Maize (Pusa Jawahar) was sown at 60 cm × 20 cm spacing in second fortnight of July and harvested in last week of October. The recommended N, P and K doses were 150, 26 and 50 kg/ha for wheat; 20, 22 and 42 kg/ha for mungbean and 150, 33 and 50 kg/ha for maize, supplied through urea, mono-ammonium phosphate and muriate of potash, respectively. Fertigation was carried in equal multiple splits starting at sowing and thereafter at 20-days interval coinciding the critical growth stages of the crops. For conventional system, half of N and full doses of P and K were applied at the time of sowing by broadcasting. Remaining half of N was applied in two splits for maize and wheat.

Yield and water use efficiency: To compare cropping system productivity, grain yields of maize and mungbean were converted to wheat equivalent yields (WEY). The unit price of 100 kg grain of wheat, mungbean and maize were taken as ₹2015, 7196 and 1850, respectively. Water use efficiency (WUE) was calculated as the ratio of the grain yield produced to the amount of total water used.

Economic analysis: Different state governments provide 80–90% subsidy on the installation of micro-irrigation systems (https://pmksy.gov.in). Accordingly, 80% subsidized cost for installation of subsurface and surface drip was accounted. The annual land rent value considered was ₹100000/ha and allocated as ₹42000, 25000 and 33000/ha for wheat, mungbean and maize, respectively based on their crop cycles of 5, 3 and 4 months.

Total annual cost included both annual fixed and variable cost. The fixed cost included the cost of the drip system. The annual fixed cost (AFC) was calculated by multiplying capital recovery factor (CRF) (equation 1) at pre-determined interest rate (i) of 10% with the present amount (considering farm gate price) and useful life in years (n).

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

The variable cost included expenses of operation and maintenance of drip system as well as cultivation of wheat, mungbean and maize. The electrical cost was calculated at the rate of ₹10/kilowatt-hour based on the operating hours of the irrigation system.

The gross income or cash inflow included market returns from the grain and straw of wheat, mungbean and maize. Net income was estimated by deducting the variable cost from the gross income. Discounted BCR is the ratio of present worth of the benefit stream (gross income) and present worth of the cost stream (total cost) (Michael 2007). Opportunity cost was considered as 7%.

Statistical analysis: The data recorded for different parameters were analysed with the help of single and three factor analysis of variance (ANOVA) for randomized complete block design (Gomez and Gomez 1984, Brar *et al.* 2022). The treatment differences were compared at 5% level of significance. The three factor ANOVA was used for comparing the individual as well as interactive effects between fertilizer doses, methods of irrigation and irrigation scheduling while single factor ANOVA to compare all the 17 experimental treatments inclusive of conventional system.

RESULTS AND DISCUSSION

Crop yields (2019-2021 pooled): The grain yields improved by 35, 58 and 66% in wheat; 25, 30 and 34% in mungbean; and 33, 54 and 63% in maize with 60, 80 and 100% recommended NPK doses, respectively in comparison to fertilizer control (Table 1). Similar improvements in the straw yields were noticed with the increase in fertigation doses. Averaged over irrigation schedules and methods of irrigation, grain and straw yields obtained with NPK_{80} and NPK_{100} fertigation doses were equal. Increase in fertigation doses beyond NPK_{60} could not improve the grain yield of mungbean. Similar results were also reported by the previous researchers (Patra *et al.* 2021). It might be ascribed to its leguminous nature along with high contents of available phosphorus (Singhal *et al.* 2021). Wheat and mungbean when irrigated at 0.8 ET_c resulted in 10–15% higher grain and straw yields as compared to 0.6 ET_c. However, different irrigation schedules had no effect on grain yield of maize as nearly 73% of the crop water requirement was met through rainfall in both the years. Regardless of irrigation and fertigation schedules, statistically equal yields of wheat, mungbean and maize were observed under SSDI and SDI, which might be due to the application of equal amount of irrigation water and nutrient. Crop yields of wheat and maize obtained under conventional system were statistically similar when irrigated at 0.8 ET_c and fertigated with NPK_{80} or irrigated at 0.6 ET_c with NPK_{100}. Consistent nutrient availability and better translocation of assimilates has been reported when major nutrients were supplied through drip fertigation as compared to their soil application (Qin *et al*. 2016). Fertigation of NPK_{60} or higher dose resulted in statistically equal grain yield of mungbean as with conventional practice, regardless of methods of drip irrigation and irrigation schedules.

System wheat equivalent yield (SWEY): The SWEY with fertigation of NPK_{60}, NPK_{80} and NPK_{100} was about 32, 51 and 58% higher than NPK_0, respectively (Fig 1). SWEY obtained with fertigation of NPK_{80} and NPK_{100} at 0.8ET_c under SSDI and SDI were at par with conventional practice. Precise and uniform nutrient distribution directly in the root zone matching crop demand would have resulted in effective absorption and utilization of available nutrients, better proliferation of roots and higher photosynthetic efficiency (Malve *et al*. 2017). Irrigation at 0.8 ET_c resulted 10% higher SWEY than 0.6 ET_c. At given ET_c and NPK level, SSDI and SDI had equal SWEY.

Water use efficiency (WUE): Application of 60, 80 and 100% recommended doses of NPK increased the WUE of cropping system by 32, 51 and 58%, respectively over fertilizer control (Fig 1). Different methods of drip irrigation did not significantly influence the system WUE. Similarly, crops irrigated at 0.8 and 0.6 ET_c had similar WUE mainly due to the reduced amount of water at 0.6 ET_c while proportionately smaller reduction in crop yield. Irrigation at 0.8 ET_c with NPK_{80} or NPK_{100} resulted in

Table 1 Wheat, mungbean and maize grain and stover yields (Mg/ha)

Fertigation doses (% RDF)	Methods of irrigation											
	SSDI		SDI		Mean	Conv.	SSDI		SDI		Mean	Conv.
	Irrigation schedule						Irrigation schedule					
	0.6 ET_C	0.8 ET_C	0.6 ET_C	0.8 ET_C			0.6 ET_C	0.8 ET_C	0.6 ET_C	0.8 ET_C		
	Wheat grain yield (Mg/ha)						Wheat straw yield (Mg/ha)					
					2019–2021							
0	3.11	3.55	3.12	3.50	3.32		4.78	5.65	4.78	5.57	5.19	
60	4.20	4.92	4.12	4.73	4.49		6.33	7.90	6.08	7.20	6.88	
80	4.91	5.79	4.75	5.55	5.25		7.61	8.64	7.15	8.13	7.88	
100	5.21	5.86	5.04	5.98	5.52	5.59	8.02	9.11	7.94	8.74	8.45	8.49
Mean	4.36	5.03	4.26	4.94			6.69	7.82	6.49	7.41		
Overall mean	SSDI=4.69, SDI=4.6, 0.6 ET_C=4.31, 0.8 ET_C=4.98						SSDI=7.25, SDI=6.95, 0.6 ET_C=6.59, 0.8 ET_C=7.61					
LSD (5%)	MI- NS, IS- 0.18, FD- 0.36, MI × IS × FD *vs* Conv. -0.56						MI- NS, IS- 0.35, FD- 0.5, MI × IS × FD *vs* Conv- 0.98					
	Mungbean grain yield (Mg/ha)						*Mungbean straw yield (Mg/ha)*					
0	0.52	0.58	0.53	0.60	0.56		2.02	2.28	1.91	2.26	2.11	
60	0.65	0.74	0.68	0.72	0.70		2.41	2.69	2.35	2.60	2.51	
80	0.71	0.78	0.68	0.74	0.73		2.52	2.80	2.44	2.75	2.63	
100	0.72	0.80	0.70	0.78	0.75	0.73	2.63	2.92	2.53	2.83	2.73	2.71
Mean	0.65	0.72	0.65	0.71			2.39	2.67	2.30	2.61		
Overall mean	SSDI=0.68, SDI=0.68, 0.6 ET_C=0.65, 0.8 ET_C=0.71						SSDI=2.53, SDI=2.45, 0.6 ET_C=2.34, 0.8 ET_C=2.64					
LSD (5%)	MI- NS, IS- 0.04, FD- 0.06, MI × IS × FD *vs* Conv – 0.08						MI- NS, IS- 0.08, FD-0.12, MI × IS × FD *vs* Conv- 0.23					
	Maize grain yield (Mg/ha)						*Maize stover yield (Mg/ha)*					
0	4.32	4.77	4.07	4.49	4.41		7.21	8.12	6.91	7.56	7.45	
60	6.01	6.08	5.53	5.89	5.88		9.73	9.67	9.05	9.73	9.55	
80	6.84	7.11	6.58	6.70	6.81		10.20	10.39	9.68	10.39	10.16	
100	7.08	7.45	6.98	7.19	7.17	7.15	10.84	11.01	10.49	11.23	10.89	11.53
Mean	6.06	6.35	5.79	6.07	6.07		7.21	8.12	6.91	7.56	7.45	
Overall mean	SSDI=6.20, SDI=5.93, 0.6 ET_C=5.92, 0.8 ET_C=6.21						SSDI=9.64, SDI=9.38, 0.6 ET_C=9.26, 0.8 ET_C=9.76					
LSD (5%)	MI- NS, IS- NS, FD-0.38, MI × IS × FD *vs* Conv – 0.78						MI- NS, IS- NS, FD- 0.6, MI × IS × FD *vs* Conv – 1.21					

RDF, recommended doses of NPK fertilizers; SSDI, Sub-surface drip irrigation; SDI, Surface drip irrigation; Conv., Conventional system; MI, Methods of irrigation; IS, Irrigation schedules; FD, Fertigation doses; ET_c, Crop evapotranspiration; NS, Non-significant; Interactions, NS.

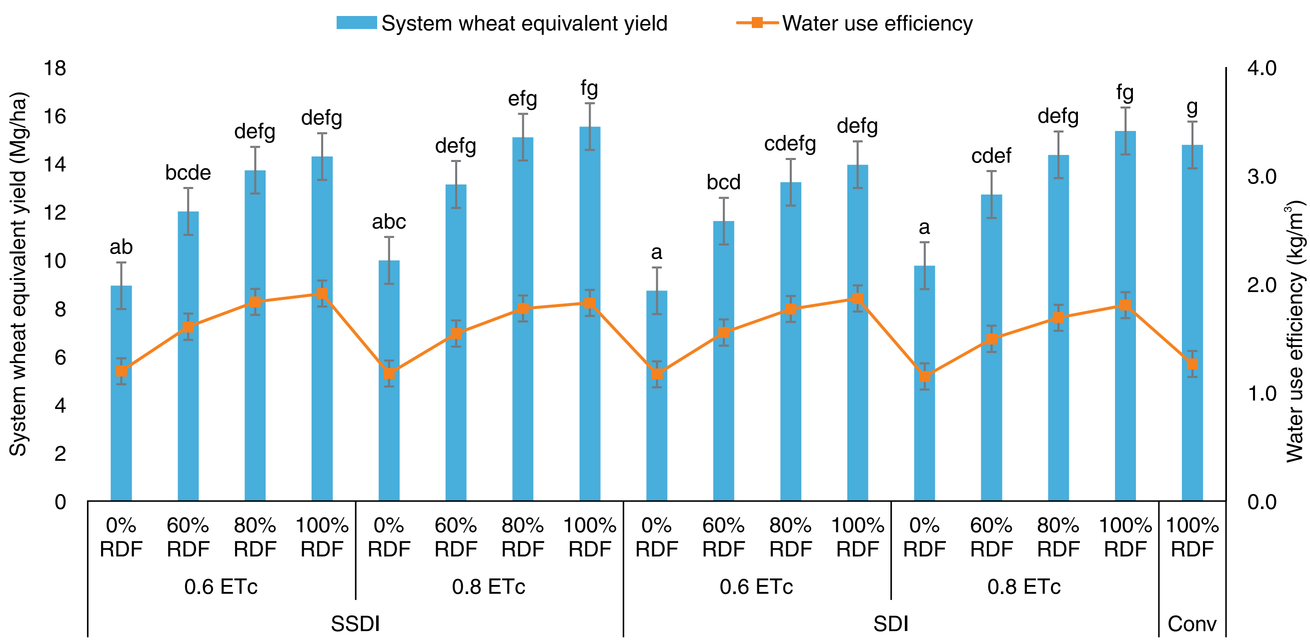

Fig 1 Effect of fertigation doses, irrigation schedules and methods of irrigation on system wheat equivalent yield and water use efficiency (pooled data of 2019–20 and 2020–21).

40–47% higher WUE than conventional practice. It might be owing to statistically equal grain yields obtained with drip irrigation at 0.8 ET_c with fertigation of NPK_{80} or NPK_{100} as compared to conventional practice (Si *et al.* 2020).

The total irrigation water applied to cropping system through SDI/SSDI at 0.8 ET_c (305 mm) was 51.6% lower as compared to surface flood (630 mm). Crops fertigated with either 80 or 100% RDF had similar crop yields when

Table 2 Economic evaluation of wheat, mungbean and maize crops under different methods of irrigation, irrigation schedules and fertigation doses (Average of year 2019–20 and 2020–21)

Treatment	Wheat			Mungbean			Maize		
	Total annual cost (₹/ha)	Net income (₹/ha)	Discounted BCR	Total annual cost (₹/ha)	Net income (₹/ha)	Discounted BCR	Total annual cost (₹/ha)	Net income (₹/ha)	Discounted BCR
SSDI × 0.6ETc × 0% RDF	71624	6556	0.98	43134	-774	0.81	63955	37486	1.42
SSDI × 0.6ETc × 60% RDF	72749	31975	1.31	49969	1412	0.88	70574	68351	1.79
SSDI × 0.6ETc × 80% RDF	73790	48453	1.51	50581	5952	0.96	71696	83851	1.98
SSDI × 0.6ETc × 100% RDF	74832	54569	1.09	51193	6175	0.59	72818	88769	1.39
SSDI × 0.8ETc × 0% RDF	69698	20127	1.16	48275	-1696	0.81	67281	44599	1.5
SSDI × 0.8ETc × 60% RDF	72823	50435	1.55	50111	8031	0.99	70648	69422	1.81
SSDI × 0.8ETc × 80% RDF	73865	68773	1.77	50723	10763	1.04	71771	89142	2.05
SSDI × 0.8ETc × 100% RDF	74906	70103	1.78	51335	11715	1.06	72893	95884	2.12
SDI × 0.6ETc × 0% RDF	72624	6463	0.95	51587	-8888	0.68	70812	25871	1.21
SDI × 0.6ETc × 60% RDF	76506	26650	1.2	53423	875	0.85	74180	54679	1.56
SDI × 0.6ETc × 80% RDF	77547	41054	1.38	54035	713	0.85	75302	74649	1.79
SDI × 0.6ETc × 100% RDF	78589	47730	1.45	54647	1625	0.86	76424	82847	1.88
SDI × 0.8ETc × 0% RDF	73456	16033	1.08	51729	-3282	0.77	70887	35204	1.33
SDI × 0.8ETc × 60% RDF	76580	41642	1.39	53565	4227	0.9	74254	63162	1.66
SDI × 0.8ETc × 80% RDF	77622	59662	1.6	54177	5204	0.92	75377	78649	1.84
SDI × 0.8ETc × 100% RDF	78664	68609	1.7	54789	4302	0.91	78499	86532	1.9
Conv. (SI × 100% RDF)	78252	62102	1.52	53794	5713	0.84	75751	87839	1.83

RDF, Recommended doses of NPK fertilizers; SSDI, Sub-surface drip irrigation; SDI, Surface drip irrigation; SI, Surface irrigation; Conv., Conventional system; ET_c, Crop evapotranspiration.

irrigated at 0.8 ET_c, which were also statistically similar to the conventional system, indicating a potential saving of 20% of the recommended dose of NPK fertilizer. This accounts to be 64, 16 and 28 kg of N, P_2O_5 and K_2O/ha, respectively in one cropping year with an additional expenditure of ₹1042/ha in wheat, ₹612/ha in mungbean and ₹1122/ha in maize.

Economic analysis: The net income and BCR increased successively with increase in fertigation doses in wheat and maize, however, this trend was not so visible in mungbean (Table 2). The higher net returns obtained from fertigation doses of 80 and 100% RDF were also reported by previous researchers (Brar *et al*. 2019). Wheat, mungbean and maize crops when irrigated at 0.8 ET_c provided higher net returns as compared to when irrigated at 0.6 ET_c. It was mainly because of favourable soil moisture conditions resulting in higher crop yields with little extra cost on irrigation water at frequent irrigation schedule. Brar *et al*. (2019) and Parashar *et al*. (2017) also noted higher gross returns, net returns and benefit cost (B: C) ratio in drip irrigated crops at 1.0 ET_c than 0.6 ET_c. The net returns obtained from wheat, mungbean and maize irrigated with SSDI were 14, 9 and 15% higher, than SDI. The higher net returns with SSDI compared to SDI were due to the longer lifespan of drip system (10–12 years in SSDI compared to 8–10 years in SDI) and comparative saving of labour to be incurred on layering and removal of drip lateral every season in case of SDI (Brar *et al*. 2022). The highest net income of wheat, mungbean and maize was obtained with SSDI at 0.8 ET_c and NPK_{100} which were 13, 105 and 9%, higher than the crops raised with conventional practice. It could be due to improved crop productivity and enhancing the water and nutrient use efficiency (Sandhu *et al*. 2019). Nevertheless, drip fertigation system reduces the labour costs by 15–20%, increase nutrient use efficiency allows mechanized and easy crop cultivation (Pramanik *et al*. 2014, Rana *et al.* 2021).

On an average, the system net income improved by ₹60790, 97291 and 110290/ha, with 60, 80, 100% RDF compared to fertilizer control respectively, (Table 3). Similarly, scheduling irrigations at 0.8 ET_c resulted in about 27% higher net income than at 0.6 ET_c, whereas SSDI resulted in 19% higher net income compared to SDI. The highest discounted BCR and minimum payback period were obtained with irrigation schedule of 0.8 ET_c and higher fertigation doses (NPK_{80} and NPK_{100}) with both SSDI and SDI. Clearly, SSDI with 0.8 ET_c and NPK_{100} or NPK_{80} resulted in higher net income, better discounted BCR and lower payback period, showing it more profitable compared to SDI and conventional practice.

Conclusively, wheat-mungbean-maize cropping system when irrigated at 0.8 ET_c and fertigated with NPK_{80}, regardless of the drip irrigation method, can significantly reduce amount of fertilizer and irrigation water while increasing WUE and profitability as compared

Table 3 Economic evaluation of wheat-mungbean-maize cropping system under different methods of irrigation, irrigation schedules and fertigation doses (Average of year 2019–20 and 2020–21)

Treatment	Total annual cost (₹/ha)	Cash outflow (₹/ha)	Cash inflow (₹/ha)	Net income (₹/ha)	Discounted BCR	Discounted payback period (years)	Discounted payback period (Months)
SSDI × 0.6 ETc × 0% RDF	178713	168467	211735	43269	1.20	1.60	19
SSDI × 0.6 ETc × 60% RDF	193292	183046	284784	101739	1.49	0.66	8
SSDI × 0.6 ETc × 80% RDF	196068	185822	324078	138256	1.67	0.49	6
SSDI × 0.6 ETc × 100% RDF	198844	188598	338111	149513	1.71	0.40	5.4
SSDI × 0.8 ETc × 0% RDF	185255	175009	238039	63030	1.30	1.07	13
SSDI × 0.8 ETc × 60% RDF	193583	183337	311224	127888	1.62	0.53	6
SSDI × 0.8 ETc × 80% RDF	196359	186113	354791	168678	1.82	0.40	5
SSDI × 0.8 ETc × 100% RDF	199135	188889	366591	177703	1.86	0.38	5
SDI × 0.6 ETc × 0% RDF	195781	183718	207165	23447	1.07	3.16	38
SDI × 0.6 ETc × 60% RDF	204109	192046	274250	82204	1.36	0.84	10
SDI × 0.6 ETc × 80% RDF	206885	194822	311238	116416	1.52	0.59	7
SDI × 0.6 ETc × 100% RDF	209661	197598	329800	132202	1.59	0.52	6
SDI × 0.8 ETc × 0% RDF	196072	184009	231964	47955	1.20	1.47	18
SDI × 0.8 ETc × 60% RDF	204400	192337	301367	109031	1.49	0.63	8
SDI × 0.8 ETc × 80% RDF	207176	195113	338628	143516	1.65	0.48	6
SDI × 0.8 ETc × 100% RDF	211952	199889	359332	159443	1.71	0.43	5
Conv. (SI × 100% RDF)	207797	192191	347844	155653	1.67	0.83	10

RDF, Recommended doses of NPK fertilizers; SSDI, Sub-surface drip irrigation; SDI, Surface drip irrigation; SI, Surface irrigation; Conv., Conventional system; ET_c, Crop evapotranspiration.

to the conventional practice. Besides, SSDI at 0.8 ET_c and NPK_{100} resulted in the highest net income and BCR, which was higher than SDI with 0.8 ET_c and NPK_{100} and the conventional practice. The results of extant study can serve as a guideline for optimum use of irrigation water, balanced fertilizer uses and choosing best method of irrigation for higher system productivity and profitability.

REFERENCES

Brar A S, Buttar G S and Vashist K K. 2019. Enhancing crop and water productivity of spring maize (*Zea mays*) through drip fertigation. *Indian Journal of Agronomy* **64**(1): 87–92.

Brar A S, Kaur K, Sindhu V K, Tsolakis N and Srai J S. 2022. Sustainable water use through multiple cropping systems and precision irrigation. *Journal of Cleaner Production* **333**: 130117. doi: 10.1016/Jjclepro.130117

Chen R, Cheng W, Liao J, Fan H, Zheng Z and Ma F. 2015. Lateral spacing in drip irrigated wheat: the effects on soil moisture, yield, and water use efficiency. *Field Crops Research* **179**: 52–62.

Food and Agriculture Organization of the United Nations (FAO). AQUASTAT Database. 2012. http://www.fao.org/nr/aquastat

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*, 2nd Edn, 680 pp. John Wiley and Sons, New York,.

Kishore P, Chand S and Srivastava S K. 2022. Potential area of micro-irrigation and its outreach across Indian states. *Indian Journal of Agricultural Sciences* **92**(9): 1056–60.

Malve S H, Rao P and Dhake A. 2017. Impact of drip irrigation and N-fertigation scheduling on wheat (*Triticum aestivum*) under semi-arid tropical environment. *Indian Journal of Agricultural Sciences* **87**: 580–88.

Michael A M. 2007. Economic evaluation of irrigation projects and water pricing policy. *Irrigation: Theory and Practice,* pp. 695–24. Vikas Publishing House Pvt Ltd, Noida.

Parashar G, Singh D and Jat B L. 2017. Drip fertigation study in spring maize (*Zea mays* L.). *International Journal of Agricultural Engineering* **10**(2): 379–400.

Patra K, Parihar C M, Nayak H S, Rana B, Singh V K, Krishnan P, Pandey R, Mandal B N, Rathi N, Meena B R, Singh L K, Sidhu H S and Jat M L. 2021. Crop performance and nitrogen use-efficiency in maize under conservation agriculture coupled with sub-surface drip fertigation. *Indian Journal of Agricultural Sciences* **91**(3): 474–79.

Pramanik S, Tripathi S K, Ray R and Banerjee H. 2014. Economic evaluation of drip fertigation system in banana cv. Martaman (AAB, Silk) cultivation in new alluvium zone of West Bengal. *Agricultural Economics Research Review* **27**(1): 103–09.

Qin W, Assinck F B T, Heinen M and Oenema O. 2016. Water and nitrogen use efficiencies in citrus production: a meta-analysis. *Agriculture, Ecosystems and Environment* **222**: 103–11.

Rana B, Parihar C M, Nayak H S, Patra K, Singh V K, Krishnan P, Pandey R, Rathi N, Meena B R, Kumar A, Gupta N, Sidhu H S and Jat M L. 2021. Optimization of N dose in rice under conservation agriculture with sub-surface drip fertigation. *Indian Journal of Agricultural Sciences* **91**(4): 509–14.

Sandhu O S, Gupta R K, Thind H S, Jat M L, Sidhu H S and Singh Y. 2019. Drip irrigation and nitrogen management for improving crop yields on nitrogen use efficiency and water productivity of maize-wheat system on permanent beds in north-west India. *Agricultural Water Management* **219**: 19–26.

Sharma R, Kumar D S and Brar A S. 2021. Effect of drip-fertigation levels on *gobhi sarson* (*Brassica napus*) performance under Punjab conditions. *Indian Journal of Agricultural Sciences* **91**(8): 1251–56.

Si Z Y, Zain M, Mehmood F, Wang G S, Gao Y and Duan A W. 2020. Effects of nitrogen application rate and irrigation regime on growth, yield, and water-nitrogen use efficiency of drip-irrigated winter wheat in the North China Plain. *Agricultural Water Management* **231**: 106002.

Singhal N, Sharma P, Sharda R, Siag M and Cutting N G. 2021. Assessment of growth parameters and yield of pea (*Pisum sativum*) under different irrigation methods. *Indian Journal of Agricultural Sciences* **91**(9): 1378–81.