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Economic analysis of surface and sub-surface drip fertigated maize (*Zea mays*)–wheat (*Triticum aestivum*) system under different nutrient management practices and irrigation schedules

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ABSTRACT

The study was carried out during two consecutive years (2022–23 and 2023–24) in both rainy (*kharif*) and winter (*rabi*) seasons at Indian Agricultural Research Institute, New Delhi to analyse the financial viability of various nutrient management options i.e. chemical, organic, integrated, and natural farming in maize (*Zea mays* L.)–wheat (*Triticum aestivum* L.) cropping system irrigated at 0.8 and 1.0 crop evapotranspiration (ETc) for surface drip (SDI) and sub-surface drip irrigation (SSDI). The effects were also compared with the farmers' conventional practice of surface irrigation and soil application of 100% of the recommended nitrogen, phosphorus, and potassium fertiliser doses. The system maize equivalent yield (SMEY) obtained with the integrated nutrient management (50% RDN through FYM + vermicompost and 50% RDN through chemical fertilisers) was found to be the higher and at par with that of the chemical nutrient management (10.6 Mg/ha) and conventional system (10.3 Mg/ha) but 14% and 24% higher compared to organic and natural farming nutrient management options, respectively. SMEY productivity was found equal in SDI and SSDI but improved significantly at irrigation schedule of 1.0 ETc compared to 0.8 ETc. At the system level, integrated nutrient management under drip irrigation used substantially less water (2270–2973 m^3/ha) than surface irrigation (100% RDF) (4650 m^3/ha), while simultaneously achieving higher system water use efficiency (3.61–4.78 kg/m^3) compared with surface irrigation (2.23 kg/m^3). The soil properties (available K, microbial carbon and dehydrogenase activity) were found significant in organic and chemical methods. Due to less input cost, the cost of cultivation in natural farming was 12, 20 and 17% lower than that in chemical, organic and integrated nutrient management options, respectively. Pooled analysis showed that integrated nutrient management recorded the highest gross returns, net income, and benefit-cost ratio in the maize–wheat system, with SSDI at 1.0 ETc plus integrated nutrients producing 17% higher net income than conventional surface irrigation with soil-applied NPK.

Keywords: B:C ratio, Drip fertigation, Economic analysis, Natural farming, Organic farming

In view of shifting climate patterns and expanding population, enhancing agricultural output and profitability in major cropping systems have become more vital for sustainable economic development and achieving food security (Yadav *et al.* 2019). Maize (*Zea mays* L.)–wheat (*Triticum aestivum* L.) system is practiced in more than 1.8 million hectares and is a prominent pattern of India. India which supports 17% of world population with just 4% water resources grapples with water scarcity also. Agonies are compounded by unregulated and inefficient surface irrigation method and soil application of fertilizers resulting in substantial water and nutrient losses through evaporation/volatilization, deep percolation and runoff (Tinazzi 2024). In contrast, drip fertigation both through surface and sub-surface drip applies water and nutrients precisely in the active root zone, thereby minimizes the losses and maximizes the water and nutrient use efficiency (Dhayal *et al.* 2023). Several workers found that application of water at 75–80% or 100% of ETc (crop evapotranspiration) produces equivalent yields of maize and wheat (Brar *et al.* 2021).

Most Indian soils are low in organic carbon and poor fertility. Although, high rates of fertiliser application sustain productivity on the other hand they increase cultivation costs. This often makes agriculture a system of net loss. Excessive use of NPK fertilisers reduces soil humus, causes micronutrient deficiencies and adversely affect soil health and crop productivity in the long run. At the same time, the demand for organic and chemical-free food in India is growing due to increasing health and environmental

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awareness. The Indian organic food market was worth ₹8,509 crore in 2021 and is expected to reach ₹30,175 crore by 2028 (Panday *et al.* 2024). Moving away from chemical fertiliser-based farming to integrated, organic, and natural methods can reduce costs and improve soil health (Panday *et al.* 2024). Natural farming helps farmers achieve higher incomes, lower input costs by up to 70%, reduce credit dependence, and produce safer food (Giller *et al.* 2021). A field study was carried out on a surface and sub-surface drip fertigated maize–wheat system under different nutrient and irrigation regimes. It was compared with conventional surface irrigation and soil-applied NPK fertilisers to study cash outflow and benefit-cost ratio.

MATERIALS AND METHODS

Experimental layout: A field study was carried out during 2022–23 and 2023–24 at ICAR-Indian Agricultural Research Institute (28°37'48" N, 77°09'40" E; with an elevation of 241 m amsl), New Delhi. The experiment was laid out in randomised complete block design (RCBD) with three replications. The experimental site is characterised by a semi-arid subtropical climate, marked by hot summers and cool winters, with a mean annual rainfall of 1129 mm. During the study period, seasonal rainfall varied considerably, ranging from 706–832 mm during the maize growing season, 63–89 mm during the wheat season, and 202–388 mm during the summer fallow period. Annual evaporation losses were high, ranging between 1229 and 1243 mm, reflecting the arid nature of the region. Mean monthly temperatures fluctuated from 17.1°C in winter to 36.8°C during peak summer months. Of the total rainfall received, the effective rainfall contributing to crop water use was estimated at 310 mm for maize and only 40 mm for wheat. The 16 treatments comprised combination of (A) Four nutrient sources, viz. (i) chemical, (ii) organic, (iii) integrated and (iv) natural farming; (B) Two methods of irrigation, viz. (i) surface drip irrigation (SDI) and (ii) sub-surface drip irrigation (SSDI); and (C) Two irrigation schedules, viz. 0.80 crop evapotranspiration (ETc) and 1.0 ETc. The results were compared with the farmer's practice of surface irrigation and soil application of recommended dose of NPK fertilisers. Under the chemical nutrient option, the recommended NPK dose (RDF) of 150:33:50 kg/ha in maize and 150:26:50 NPK kg/ha in wheat were supplied in three splits through urea, mono ammonium phosphate and muriate of potash. In the organic treatment 10.0 Mg/ha farmyard manure (FYM) and 5.0 Mg/ha vermicompost were applied before crop sowing. Fertigation with 50% of the RDF, 5.0 Mg/ha FYM, and 2.5 Mg/ha of vermicompost was carried out before field preparation and it was comprised the integrated nutrient management treatment. The natural farming approach involved seed treatment with *beejamrutha* (fermented cow dung, cow urine, and lime), *jeevamrutha*, a microbial culture made from cow dung, cow urine, jaggery, and pulse flour, and spreading residues of the previous crop @2 Mg/ha on the surface 15 days after sowing as per the method given by Subash Palekar (2006). Irrigation was scheduled on the basis of cumulative crop evapotranspiration (ETc) derived from reference (ETo) using FAO's CROPWAT software.

Soil properties analysis: Plot wise surface soil samples (0–15 cm) were collected before starting of experiment and after the harvest of wheat in 2023–24. Soil *p*H and electrical conductivity (EC) of soil pastes (soil to water weight ratio of 1:2), total organic carbon available nitrogen, phosphorus, potassium were analysed by standard methods. The microbial carbon and dehydrogenase activity were estimated by Chloroform fumigation-incubation and TTC (2,3,5-triphenyl tetrazolium chloride) methods.

Economic analysis: The 80% subsidy on drip irrigation system provided by State Government was accounted for the economic analysis in the present study. The annual rental value of ₹1,00,000/ha for irrigated land was equally divided among maize and wheat. Total annual costs encompassed both fixed and variable components, with fixed costs primarily associated with the drip irrigation system. The Annual Fixed Cost (AFC) was calculated by multiplying the capital recovery factor (CRF) with the system's present value, considering its useful life and a 7% interest rate (*i*) as per GOI (2023) portal. The CRF was derived using a formula incorporating the interest rate and system lifespan (n):

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

The variable costs which included expenses on drip irrigation system operation and maintenance, NPK fertiliser, FYM, vermicompost, labour, plant protection, and machinery hiring charges for maize and wheat cultivation (Fig. 1). The cost on electricity consumed for operating the irrigation system was calculated @10 ₹/kilowatt-h. The returns received from the sale of grain and straw of maize and wheat were accounted as gross income or cash inflow. For estimating system economic returns and productivity, wheat yields were converted into Maize Equivalent Yields (MEY) using market prices of wheat and maize grains and stover/ straw. The wheat and maize grain yields produced from organic manures and natural farming were priced 10% higher as premium for organic food. The annual fixed and variable costs were subtracted from gross income to estimate net income. The discounted Benefit-Cost Ratio (BCR) was calculated by comparing the present value of the benefit stream (gross revenue) to the cost stream (total cost).

Statistical analysis: Different parameters were analysed using ANOVA for a randomised complete block design (Gomez and Gomez 1984) at a 5% significance level. Three-factor ANOVA assessed nutrient management, irrigation methods, and schedules individually and interactively, while single-factor ANOVA compared all 17 treatments, including surface irrigation as a reference.

RESULTS AND DISCUSSION

Crop yields and water use efficiency (2022–24 pooled): Data pooled over the year 2022–23 and 2023–24 showed that grain yields of maize and wheat ranged from 4.06 to 5.47 and 3.38 to 5.48 Mg/ha, respectively (Fig. 2). The grain

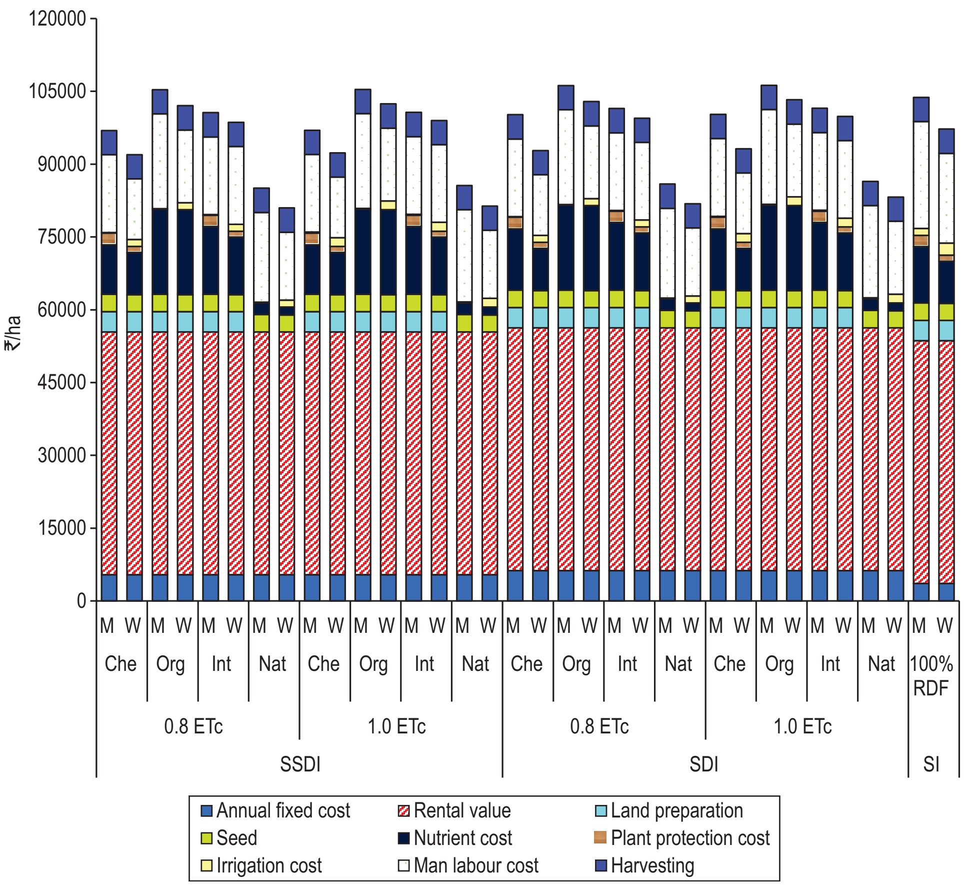

Fig. 2 Effect of nutrient management options, irrigation schedules and methods on grain yields of maize and wheat and maize equivalent yield (pooled data of 2022–24).
Che, Chemical; Org, Organic; Intg, Integrated; Nat, Natural; SSDI, Sub-surface drip irrigation; SDI, Surface drip irrigation; SI, Surface irrigation.

the system (3.15–3.84 kg/m^3). In contrast, surface irrigation with 100% RDF recorded the highest water use and the lowest water use efficiency across maize, wheat, and the system. 0% RD of NPK applied through chemical fertilisers in integrated nutrient management met nutrient requirement of both maize and wheat crops in the initial active growth stages, while the nutrients released after the mineralization of FYM and vermicompost satisfied the crop requirements at later-stages and reflected in higher yields.

With respect to chemical fertiliser treatment, 100% RDF applied via drip fertigation in splits, ensured efficient nutrient use throughout the crop cycle (Sairam *et al.* 2025). Consequently, yield differences between integrated and chemical nutrient options were non-significant. The nutrients released slowly from the organic manures might not be sufficient in meeting the initial crop nutrient requirement, therefore, the yields obtained from organic nutrient option plots were found significantly lower compared to other nutrient options. Similar results of lower yields in organic treatments were earlier reported by the previous workers (Toppo *et al.* 2023). In natural farming, *jeevamrutha,* and *beejamrutha* along with crop residue of previous crop @2.0 Mg/ha added only 60 kg N, 12 kg P in the whole maize–wheat system, which were one fifth of the amounts of nitrogen and phosphorus added in chemical, organic and integrated nutrient options were not sufficient to meet the crop nutrient requirement thus producing significantly lower crop yields (Brichi *et al.* 2023).

The average effective rainfall of 310 mm received was able to meet the water requirements of *kharif* maize by 74–89%, therefore, varying irrigation schedules had no significant effect on maize yields. However, in wheat only 15% of its water requirement was met through 40 mm of effective rainfall received during crop growth cycle. Therefore, wheat yields significantly increased with the increase in irrigation schedule from 0.8–1.0 ETc. SDI and SSDI methods had no effect on yields as scheduling was based on weather parameters. Interaction effects were also found non-significant. Similar findings were reported by Umair *et al.* (2019). Conventional practices yielded

yields of both maize and wheat raised with integrated nutrient use were statistically on pareto that obtained from chemical fertiliser and the conventional plots (farmer's practice of surface irrigation and soil application of RDF) but 11–12 and 15–17% higher compared to the yields harvested from organic manures and natural farming plots, respectively. Similar trend was observed in case of maize stover and wheat straw yields. Maize yields were not significantly influenced by irrigation scheduling but grain yield of wheat under treatment irrigated at 1.0 ETc was 4–8% higher than the yields obtained at 0.80 ETc. Irrigation given either through surface drip or sub-surface drip had no significant effect on maize as well as wheat yields.

Irrigation water use and water use efficiency of maize, wheat, and the overall system varied significantly under different irrigation regimes and nutrient management practices (Table 1). Under 0.8 ETc, drip irrigation utilized lower water input (724 m^3/ha for maize and 1546 m^3/ha for wheat) and resulted in higher water use efficiency in maize (6.97–7.57 kg/m^3), wheat (2.81–3.19 kg/m^3), and the system (4.30–4.78 kg/m^3), particularly with integrated nutrient management. Irrigation at 1.0 ETc, higher irrigation water was applied (998 m^3/ha for maize and 1,975 m^3/ha for wheat), with comparatively lower water use efficiency in maize (4.69–5.50 kg/m^3), wheat (2.14–2.77 kg/m^3), and

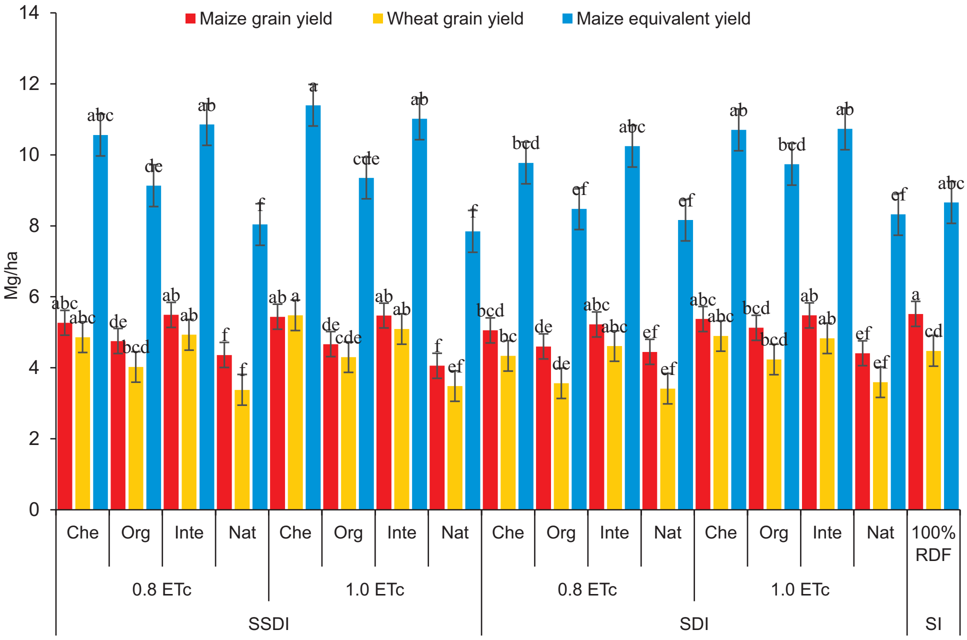

Fig. 1 Costs (₹/ha) involved on cultivation of drip fertigated maize (M) and wheat (W) under different nutrient management options, irrigation scheduling and methods of irrigation.
Che, Chemical; Org, Organic; Intg, Integrated; Nat, Natural; SSDI, Sub-surface drip irrigation; SDI, Surface drip irrigation; SI, Surface irrigation.

similar to integrated and chemical options but the amount of irrigation water added was 12–18% higher in maize and 29–44% higher in wheat. Maize equivalent yields (MEY) of the maize-wheat system ranged from 8.04–11.40 Mg/ha, showing similar patterns across treatments.

Soil properties: The post-harvest soil properties after wheat crop *p*H, EC, soil organic carbon (SOC), available N, available P, available K, microbial biomass carbon (MBC) and dehydrogenase activity varied significantly and increased in SOC, available N and K in organic nutrient management treatment compared to chemical and natural farming and integrated method of nutrient management (Table 2). With respect to biological properties organic nutrient management demonstrated significantly higher MBC and dehydrogenase activity compared to chemical method, but was statistically comparable with integrated and natural farming approaches. However, soil parameters like *p*H did not vary significantly among the treatments. Similarly, soil physical, chemical and biological properties were not influenced by irrigation schedules, methods of

Table 1 Effect of nutrient management options, irrigation schedules and methods on irrigation water use (m^3) and water use efficiency (kg/m^3) of drip fertigated maize–wheat cropping system (pooled data of 2022–24)

Treatment combinations	Irrigation water applied (m^3/ha)			Water use efficiency (kg/m^3)		
	Maize	Wheat	System	Maize	Wheat	System
SSDI × 0.8 ETc × Chemical	724	1546	2270	7.27^{a}	3.15^{ab}	4.65^{a}
SSDI × 0.8 ETc × Organic	724	1546	2270	6.56^{bc}	2.60^{bc}	4.02^{ab}
SSDI × 0.8 ETc × Integrated	724	1546	2270	7.57^{ab}	3.19^{a}	4.78^{a}
SSDI × 0.8 ETc × Natural	724	1546	2270	6.01^{cd}	2.19^{de}	3.54^{cd}
SSDI × 1.0 ETc × Chemical	998	1975	2973	5.46^{de}	2.77^{bc}	3.84^{bc}
SSDI × 1.0 ETc × Organic	998	1975	2973	4.69^{ef}	2.18^{cd}	3.15^{de}
SSDI × 1.0 ETc × Integrated	998	1975	2973	5.50^{de}	2.58^{bc}	3.71^{bc}
SSDI × 1.0 ETc × Natural	998	1975	2973	4.08^{f}	1.76^{f}	2.64^{f}
SDI × 0.8 ETc × Chemical	724	1546	2270	6.97^{ab}	2.81^{ab}	4.30^{a}
SDI × 0.8 ETc × Organic	724	1546	2270	6.34^{bc}	2.31^{cd}	3.74^{bc}
SDI × 0.8 ETc × Integrated	724	1546	2270	7.20^{a}	2.99^{a}	4.51^{a}
SDI × 0.8 ETc × Natural	724	1546	2270	6.13^{bc}	2.21^{cd}	3.60^{cd}
SDI × 1.0 ETc × Chemical	998	1975	2973	5.40^{de}	2.48^{cd}	3.60^{cd}
SDI × 1.0 ETc × Organic	998	1975	2973	5.15^{cd}	2.14^{de}	3.28^{de}
SDI × 1.0 ETc × Integrated	998	1975	2973	5.50^{cd}	2.45^{cd}	3.61^{bc}
SDI ×1.0 ETc × Natural	998	1975	2973	4.43^{ef}	1.82^{ef}	2.80^{ef}
Surface irrigation × 100% RDF	1575	4675	4650	3.50^{g}	1.46^{ef}	2.23^{g}
SEM±	-	-	-	0.09	0.20	0.21
LSD (*p*=0.05)	-	-	-	0.18	0.41	0.43

SSDI, Sub-surface drip irrigation; SDI, Surface drip irrigation; ETc, Crop evapotranspiration.

irrigation and the interaction effects between different treatment were also non-significant.

The higher available N and K after harvest of wheat crop in organic treatments can be attributed to lower nitrogen uptake by plants during early growth stages due to lower mineralisation of organic manure. Furthermore, the application of bulk organic manures (FYM and vermicompost) contributed to increased available nitrogen and potassium levels in the soil due to their inherent N and K content. The addition of bulk organic materials in both organic and integrated nutrient management systems provided abundant substrate for soil microorganisms. This enhanced conditions for fungal colonization, resulting in increased microbial populations and increased enzyme activity in both organic farming and INM treatments. Microbial carbon and dehydrogenase activity were found to be higher under NF treatment as compared to chemical treatment. This might be due to application of NF inputs (*Beejamrutha* and *Jeevaamrutha*) having rich microbial population under NF treatment. Similar findings were reported by Boraiah *et al.* (2017).

Economic analysis

Cost of cultivation: Fixed costs were primarily associated with the expenses on installation of drip irrigation system. Sub-surface drip installation cost was estimated to be 3,34,284 ₹/ha, about 15% higher than the installation cost of surface drip mainly due to the placement of inline at a depth of 20 cm. The 80% subsidised costs for SSDI and SDI were 66856 and 66,557 ₹/ha, respectively. Using the capital recovery factor (CRF), the annual fixed cost was found to be 12,532 ₹/ha for SSDI system with a life span of 15 years and 10,832 ₹/ha for SDI system with a life span of 10 years. The annual fixed cost was equally divided between maize and wheat. The annual fixed cost in case of surface irrigation was 54,924 ₹/ha, primarily on pump sets and pipes, with no subsidy provision. Considering a 15-year life span, the annual fixed cost for surface irrigation was 7,222 ₹/ha (Fig. 1).

Variable costs per hectare for maize and wheat cultivation comprised of land rent (₹50,000 each), field preparation (₹4,200), seeds (maize ₹3,600; wheat ₹3,500), fertilizers/manures, plant protection (maize ₹2,420; wheat ₹1,250), irrigation, labour, and harvesting/threshing (Fig. 1). No cost was assigned towards field preparation and plant protection in natural farming. The cash out flows (₹/ha) towards nutrient applications in chemical, organic, integrated and natural farming nutrient options were ₹10,169, 17,500, 13,933 and 1,412, in maize and 8,669, 17,500, 11,834 and 1,644 in wheat, respectively while the total man-days employed @450 ₹/man-day were 31, 38, 32 and 36 in maize and 25, 30, 31 and 28 in wheat. Harvesting and threshing cost assumed similar for all treatments was 5,000 ₹/ha. Summing the fixed and variable costs, the total annual cultivation cost was the highest in nutrient option of organic (1,05,800 ₹/ha), followed by integrated (1,01,063 ₹/ha), chemical (97,389 ₹/ha), and lowest for natural farming (85,512 ₹/ha) in maize. The similar trend was observed in case of wheat and total annual cultivation cost, ranged from 81,605 ₹/ha–1,02,661 ₹/ha. Irrigation schedules and methods had non-significant effects on cultivation costs for both crops.

Net income: The two years pooled data showed that maize grown with integrated nutrient management option yielded a net income of 54,987 ₹/ha which was comparable with that obtained in case of chemical (54,267 ₹/ha) but 24% higher compared to organic treatment (41,870 ₹/ha) and 13% in natural farming (49,705 ₹/ha). Similarly, the net income in wheat grown either with chemical fertilisers or integrated nutrient management option was equal but 51% higher than obtained with organics and 43% higher than that in natural farming (Table 3). The system net income followed the same pattern and was in the order: chemical (1,03,815 ₹/ha) = integrated (97,424 ₹/ha) > natural farming (₹75,946 ₹/ha) = organic (66,385 ₹/ha). The highest net income of 1,24,460 ₹/ha was obtained from maize-wheat cropping system fertigated with chemical fertilisers and irrigated at 1.0 ETc through sub-surface drip. The system net income was not significantly influenced by methods of irrigation but found to be 13% higher at 1.0 ETc compared to 0.8 ETc. The interaction effects between nutrient options, methods of irrigation and irrigation scheduling were also non-significant. Compared to conventional practice of surface irrigation and soil application of RDF, the system net income was 22 and 14% higher when the crops were supplied nutrients through chemical fertilizer alone and integration with manures, respectively.

Discounted benefit-cost ratio (BCR): The pooled data

Table 2 Effect of nutrient management options on biological properties of soil after harvest of wheat

Nutrient management options	Chemical properties						Biological properties	
	*p*H	EC	SOC (g/kg soil)	Available nutrient (kg/ha)			MBC (µg/g/soil)	Dehydrogenase activity (µg TPF/soil/h)
				N	P	K		
Initial	7.56	0.54	3.1	232	36	152	41.5	8.6
Chemical	7.71	0.58	3.1	235	39	152	62.2	10.4
Organic	7.46	0.61	4.4	244	39	175	113.3	17.0
Integrated	7.48	0.48	4.0	240	38	171	99.5	15.7
Natural	7.70	0.55	3.9	227	30	152	99.7	14.2
SEM±	0.15	0.05	0.4	5.0	3.5	8.3	6.7	1.2
LSD (*p*=0.05)	NS	NS	0.8	8.0	NS	10	13.8	2.4

(Table 3) showed that discounted BCR in different treatments tested ranged from 1.29–1.55 in maize, 1.06–1.65 in wheat and 1.18–1.60 in maize–wheat system. Due to reduced cost of cultivation in natural farming The BCR in maize raised in natural farming, chemical and integrated nutrient management options was statically equal (1.49–15.0) under and but significantly higher than in the organic nutrient management option (1.35). Different schedules and methods of irrigation along with their interactions had no effect on BCR. The BCR in conventional farmer's practice, was also comparable with treatments having SSDI or SDI with 0.8 or 1.0 ETc under chemical, integrated and natural nutrient methods. Maize–wheat system also followed the above similar trends in BCR with changing nutrient options, irrigation schedules and methods of irrigation.

Chemical and integrated nutrient management practices in maize and wheat yielded comparable net income and BCR because of similar crop productivity and meagre differences in expenses on cultivation. However, integrated management in the long run may offer additional benefits in terms of soil fertility improvement, reduced greenhouse gas emissions, and less groundwater pollution from nutrient leaching. It also promotes agri-waste recycling, contributing to a circular agricultural economy (Pretty *et al.* 2018). The

Table 3 Effect of nutrient management options, irrigation schedules and methods on net income (NI) and discounted benefit-cost ratio (BCR) of drip fertigated maize-wheat cropping system (pooled data of 2022–24)

Nutrient management options	Methods of irrigation*											
	SSDI		SDI		Mean	Conv.	SSDI		SDI		Mean	Conv.
	0.8 ETc	1.0 ETc	0.8 ETc	1.0 ETc			0.8 ETc	1.0 ETc	0.8 ETc	1.0 ETc		
	Irrigation schedules						Irrigation schedules					
	Net income						Benefit-cost ratio					
						Maize						
Chemical	53954	59038	47483	56593	54267^{a}		1.50	1.55	1.43	1.52	1.50^{a}	
Organic	41645	38487	35771	51578	41870^{b}		1.35	1.32	1.29	1.43	1.35^{b}	
Integrated	57176	57166	49231	56376	54987^{a}		1.51	1.51	1.43	1.50	1.49^{a}	
Natural	49883	39740	50905	50249	47694^{a}		1.53	1.42	1.54	1.53	1.50^{a}	
Mean	50664	48608	45848	53699		50814	1.47	1.45	1.42	1.50		1.42
Overall mean	SSDI= 49636^{a}, SDI= 49773^{a}, 0.8 ETc = 48256^{a}, 1.0 ETc= 51153^{a}						SSDI= 1.46^{a}, SDI = 1.46^{a}, 0.8 ETc = 1.45^{a}, 1.0 ETc = 1.47^{a}					
LSD (p=0.05)	MI- NS, IS- NS, NMO- 10608, MI × IS × NMO vs Conv.- 20646						MI- NS, IS- NS, NMO- 0.10, MI × IS × NMO vs Conv.- 0.10					
						Wheat						
Chemical	49587	65421	34775	48406	49547^{a}	49587	1.49	1.65	1.33	1.47	1.48^{a}	
Organic	25310	33572	10523	28656	24515^{b}	25310	1.20	1.28	1.06	1.23	1.20^{c}	
Integrated	46663	49156	33444	40483	42437^{a}	46663	1.42	1.44	1.29	1.36	1.38^{ab}	
Natural	25943	28512	26928	31624	28252^{b}	25943	1.27	1.30	1.28	1.34	1.30^{bc}	
Mean	36876	44165	26418	37292		36876	1.35	1.42	1.24	1.35		1.31
Overall mean	SSDI=40520^{a}, SDI=31855^{a}, 0.8 ETc =31646^{b}, 1.0 ETc =40729^{a}						SSDI=1.38^{a}, SDI=1.29^{a}, 0.8 ETc =1.29^{a}, 1.0 ETc =1.38^{a}					
LSD (p=0.05)	MI - NS, IS - 8810, NMO - 12461, MI × IS × NMO vs Conv.- 24317						MI - NS, IS - NS, NMO - 0.13, MI × IS × NMO vs Conv.- 0.12					
						Maize–wheat system						
Chemical	103541	124460	82259	104999	103815^{a}		1.49	1.60	1.38	1.50	1.49^{a}	
Organic	66955	72059	46294	80234	66385^{b}		1.28	1.30	1.18	1.33	1.27^{c}	
Integrated	103839	106322	82675	96859	97424^{a}		1.47	1.48	1.36	1.43	1.43^{ab}	
Natural	75826	68252	77834	81873	75946^{b}		1.41	1.36	1.41	1.43	1.40^{b}	
Mean	87540	92773	72265	90991		85095	1.41	1.43	1.33	1.42		1.37
Overall mean	SSDI=90157^{a}, SDI=81628^{a}, 0.8 ETc =79903^{a}, 1.0 ETc = 91882^{a}						SSDI=1.42^{a}, SDI= 1.38^{a}, 0.8 ETc = 1.37^{a}, 1.0 ETc = 1.43^{a}					
LSD (p=0.05)	MI - NS, IS - NS, NMO - 17171, MI × IS × NMO vs Conv.- 33326						MI - NS, IS - NS, NMO - 0.10, MI × IS × NMO vs Conv.- 0.16					

MI, Methods of irrigation; SSDI; Sub-surface drip irrigation, SDI; Surface drip irrigation; ETc, Crop evapotranspiration; Conv., Conventional flood irrigation and soil application of chemical fertilisers.

BCR in natural farming matched with that in chemical and integrated methods, possibly due to lower production costs, as also reported by Umar *et al.* (2019). The lower net income and BCR in organic nutrient management could mainly be assigned to the reduced maize and wheat productivity and higher input cost of vermicompost and FYM. Hazarika *et al.* (2023) suggested that on-farm production of organic inputs might further increase profitability from organic farming.

Higher net returns and BCR at higher irrigation schedule of 1.0 ETc in wheat were due to the favourable soil moisture conditions and higher crop yields with minimal additional costs on irrigation. The effects were not conspicuous in maize due to fulfilling most of its water requirement from rainfall. Brar *et al.* (2021) also reported higher returns and BCR in drip-irrigated wheat at 1.0 ETc compared to other lower irrigation schedules. The longer lifespan (15 years) and reduced maintenance cost in of SSDI compared to SDI (10 years) offset the higher installation costs, resulting in equal cash inflows and net returns for both systems. Compared to conventional system plots, net returns obtained from crops fertigated with integrated or chemical nutrient sources and irrigated at 0.8 ETc, either through SSDI or SDI was higher mainly due to improved crop productivity. Similar findings were reported by previous workers (Liu *et al.* 2023). Reduced the labour costs by 10–15% and easy cultivation using drip fertigation system found investment on drip economically viable even without subsidy (Narayanamoorthy 2010).

In conclusion, integrated nutrient management proved to be a financially attractive alternative to chemical nutrient management, particularly under the 1.0 ETc irrigation schedule. Although yields were comparable with conventional surface flood irrigation, SDI and SSDI achieved 35–55% irrigation water savings along with higher water use efficiency, thereby enhancing overall resource-use efficiency. Profitability may be further improved with increased farmer expertise and on-farm production of FYM and vermicompost. Owing to its lower cost of cultivation, natural farming emerged as a viable alternative to chemical methods in terms of benefit-cost ratio, particularly for subsistence agriculture, while also enhancing soil biological properties. However, as the present investigation was confined to a two-year period, the long-term benefits of this approach are likely to be more pronounced in terms of soil sustainability. Although productivity was relatively lower, performance under natural farming can be improved by integrating additional organic manure applications to adequately meet the nutrient requirements of the maize–wheat system.

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