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Research Paper

Wheat (*Triticum aestivum*) productivity, profitability, irrigation water-use efficiency and energetics under different irrigation levels and sowing methods

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ABSTRACT

A field experiment was carried out during the winter (*rabi*) seasons of 2009–10 and 2010–11 at Pantnagar, Uttarakhand, on a loamy sand soil to assess the impact of irrigation levels and crop-establishment methods on crop productivity, irrigation water-use efficiency (WUE), net monetary returns and energetics of wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.]. Irrigation at an irrigation water: cumulative pan evaporation (IW : CPE) of 1.0 resulted in the maximum mean wheat grain yield (3.89 t/ha), while, critical stage-wise irrigation treatment was superior to 0.75 and 1.00 IW : CPE for mean straw yield. An IW : CPE of 1.0 ratio fetched the maximum mean gross returns (₹46,513), net returns (₹24,964) and benefit: cost ratio (1.17). Crop irrigated at critical growth stages, in spite of consuming the maximum input energy, recorded the maximum output energy, net energy gain and energy-use efficiency (EUE). Crop raised under zero-till condition exhibited the highest mean grain (3.86 t/ha) and straw (6.67 t/ha) yields, while these were found to be the lowest in conventional tillage treatment. It also generated ₹5,742 and ₹3,797 higher net returns and also gave 51.6 and 36.9% higher benefit: cost ratio over the conventional tillage and raised bed treatments respectively. The minimum energy for raising wheat crop was spent in zero-tillage and the maximum in conventional tillage. Former treatment also recorded 25.7 and 18.1% higher EUE than conventional and raised bed treatments respectively. Irrigation water-use efficiency was found to be the highest with an IW : CPE of 0.75 and raised bed treatments.

Key words : Benefit: cost ratio, Energy, Irrigation water-use efficiency, IW : CPE ratio, Sowing method, Wheat

Conventionally, wheat is sown on fine seedbed obtained through repeated land preparations, which results in extra cost and energy consumption. Accelerated decomposition of organic matter and degradation of soil heath have also raised a question mark on the conventional practice of farming and, thus, has become a major concern for the farmers and researchers. Availability of irrigation water is also showing the declining trend as both surface and groundwater are being over-exploited for various purposes. The grimness of situation has further aggravated due to changing climate, especially declining rainfall during the winter (*rabi*) season. Thus, there is a need to find out alternate crop-establishment methods to enhance and sustain the crop and water productivity.

It is well established that wheat sowing with zero-tillage and raised bed methods not only saves the 15–30% irrigation water but also reduces the cost of cultivation. Zero-tillage has been proved as one of the important components of low-cost sustainable production system. Presence of residues in zero-tillage system can be beneficial in conserving moisture, suppressing weeds, and reducing soil losses besides lowering the cost of cultivation. Zero-tillage is advantageous for saving of time and energy in addition to increase in yield (Kumar *et al.,* 2013) besides savings of 14% production cost (Krishna and Veettil, 2014). Elimination of the tillage operations slow down the mineralization of soil organic matter resulting in better soil structure. Zero-tillage also resulted in water saving and improved water-use efficiency (WUE), since the soil is not exposed through tillage, the unproductive evaporation of water is reduced while water infiltration is facilitated.

In raised bed system, water applied in furrows reaches the crop root zone through lateral movement. Furrows are also useful in trapping the rain water for soil-moisture augmentation besides reducing the crust formation on the soil surface. Piling up of fertile top-soil in the form of beds also helps in vigorous root-system, enabling the plant to explore more soil volume and resist against lodging.

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Ahmad *et al.* (2010) reported that bed-furrow method consumes about 35.6% less water as compared to the conventional row planting in flat beds with flood irrigation. Waraich *et al*. (2010) found 50% water saving in raised bed and furrow system of wheat as compared to flat sowing system.

Irrigation water is one of the most crucial inputs for wheat growth, development and yield expression. Maintaining adequate soil-moisture regime in the crop root zone is the prime aim of irrigation. However, the time of irrigation application is governed by type of the soil, stage of the crop and evaporative demand of the atmosphere. Improper scheduling of irrigation results not only in wastage of water but also decreases the crop yield. Therefore, crop is likely to respond differently to variable irrigation applications under different establishment methods. The scheduling of irrigation on the basis of climatological approach (IW : CPE ratio) is considered to be more scientific and practical, as it takes care of both rainfall and evaporation. Performance of zero-tillage and Furrow irrigated raised bed system (FIRBS) is specific to growing situation, particularly the soil texture. The performance of wheat under these systems has been found variable across the situations. Thus, objective of present study was to evaluate the wheat under different planting methods and irrigation levels.

MATERIALS AND METHODS

A field experiment was carried out at the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand during the winter seasons of 2009–10 and 2010–11. The site is located at 29°N, 79.5°E at 243.8 m above the mean sea-level under the foot-hills of Shivalik range of Himalayas, representing the *tarai* region of Uttarakhand. Soil was loamy sand, low in available nitrogen (230 kg/ha), medium in available phosphorus (21.8 kg/ha) and potassium (213 kg/ha) high in organic carbon (0.87%) with neutral in reaction *p*H (7.2). The bulk density of top 0–15 cm soil was 1.39 Mg/m^3. The soil-moisture content at field capacity and permanent wilting point in the upper 0–30 cm surface was 22.9 and 7.4%, respectively, with basic infiltration rate of 1.12 cm/hr. The water table during study period remained below 2 m. The study comprised 9 treatments having 3-irrigation schedules, viz. irrigation at irrigation water : cumulative pan evaporation (IW : CPE) ratio 0.75, 1.00 and at critical growth stages, in main plots and 3 sowing methods, viz. conventional, zero-tillage and raised bed, in sub-plot were laid-out in a split-plot design and replicated thrice. Wheat variety 'UP 2526' was seeded on 27 November and 1 December in 2009–10 and 2010–11, respectively, following the recommended practices. Conventional plots were prepared after giving pre-sowing irrigation and seeds were drilled by tractor-mounted seed drill @ 100 kg/ha in rows 20 cm apart, whereas in zero- tilled plots, crop was sown by tractor-mounted zero-till-cum-ferti-seed drill after soybean. Raised beds were prepared with the help of tractor-mounted bed-maker (bed top 40 cm and furrow 20 cm) and 2 rows of wheat were sown on it, thus, having average row spacing of 30 cm. The recommended dose of fertilizers,120 kg N + 60 kg P_2O_5 + 40 kg K_2O was applied to the crop through NPK mixture (12 : 32 : 16), urea and muriate of potash. Full dose of phosphorus and potassium was applied basal, while nitrogen was applied in 3 equal splits as basal, at crown-root-imitation (CRI) and heading stages. A common irrigation was applied at CRI stage and variable irrigations as per treatments were given thereafter. The irrigation depth for conventional flat method was of 6 cm maintained through Parshall flume. In zero-tillage system, the depth of first irrigation was 5 cm, while in subsequent irrigation it was 6 cm. In raised bed system, irrigation water was applied only in furrows and depth was maintained at 4.2 cm. The rainfall received during the crop period was 36.2 and 111.6 mm during the first and second year respectively. The number of irrigations applied in IW : CPE of 0.75, 1.00 and growth stage-wise irrigation was 3, 4 and 4 and 2, 3 and 4 during 2009–10 and 2010–11 respectively. The crop was harvested on 8 and 18 April during respective years. Irrigation water-use efficiency (IWUE) was computed as:

$$\text{Irrigation WUE (kg/m}^3\text{)} = \frac{\text{Grain yield (kg)}}{\text{Total irrigation depth (m}^3\text{)}}$$

Economics was worked out as per prevailing market prices of input and output. To calculate the input energy, all inputs in the form of labour, seed, water, chemical fertilizers, herbicides and pesticides used were taken into consideration using the energy-conversion factors. The energy requirement for the different field operations was calculated by using the energy-conversion factors as given in Table 1. Energy equivalents for all the inputs were summed up to provide an estimate for total energy input. The farm produce (grain yield + straw yield) was also converted into energy in terms of energy output (MJ) by using 2 year's average yield. Output energy from the product (grain and straw) was calculated by multiplying the amount of produce and its corresponding energy equivalent. Energy-use efficiency, net energy gain and energy intensity for wheat production were calculated using the following formulae of Canakci *et al.,* (2005).

$$\text{Energy–use efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

Net energy = Energy output (MJ/ha^{-})–Energy input (MJ/ha)

$$\text{Energy intensity} = \frac{\text{Energy input (MJ/ ha)}}{\text{Grain yield (kg/ ha)}}$$

Table 1. Energy equivalents of inputs and outputs used in the study

Particulars	Unit	Energy equivalent (MJ/unit)
Input		
Human labor	hr	1.96
Machinery	hr	62.7
Diesel fuel	l	56.31
Chemical fertilizers	kg	
Nitrogen (N)		66.14
Phosphate (P_2O_5)		12.44
Potassium (K_2O)		11.15
Chemicals	kg	120
Water for irrigation	m^3	1.02
Output		
Wheat grain	kg	14.7
Wheat straw	kg	12.5

Source: Shahan *et al.* (2008)

RESULTS AND DISCUSSION

Yield attributes

Number of spikes/m^2 exhibited significant variations due to irrigation levels only. Irrigation given at an IW : CPE of 0.75 produced the maximum number of spikes/m^2, followed by an IW : CPE of 1.0 (Table 2). Wheat irrigated at critical growth stages recorded the lowest number of spikes/m^2, being lowered by 12.1 and 6.0% against IW : CPE of 0.75 and 1.0 respectively. Number of spikes/m^2 did not vary due to sowing methods. Both conventional and zero-tillage treatments produced the maximum identical number of spikes. It was higher by 9.1% than raised bed method. The grain weight/spike did not differ significantly both due to irrigation levels and sowing methods. Wheat irrigated at an IW : CPE of 1.0 exhibited the maximum grain weight/spike. Among the sowing methods, raised bed-sown wheat recorded the maximum grain weight/spike (Table 2). Higher grain weight/spike in raised bed system might be owing to diversion of photosynthates towards less number of effective tillers and healthy tillers owing to more space availability. Thousand-grain weight did not show significant variation due to any of tested factors. However, wheat irrigated at an IW : CPE of 1.0 revealed the maximum 1,000-grain weight. It was higher by 9.5 and 11.3% than IW : CPE of 0.75 and critical growth stages based treatment respectively. Among different sowing methods, its values were marginally higher under zero-tillage treatment.

Yield

Wheat under zero-till condition gave the maximum grain yield, followed by raised bed and conventional tillage methods (Table 2). Higher grain yield under zero-tillage method was owing to higher 1,000-grain weight and higher number of effective tillers (Table 2). This might have resulted from greater photosynthesis and better translocation of photosynthates, besides larger sink and stronger reproductive phase as reflected in the greater number of effective spikes/m^2 and 1,000-grain weight. Medium-textured soil favours the better establishment and root system under zero-tillage system owing to less shear strength. Our results confirm the findings of Susha *et al*. (2014). Kumar *et al.* (2013) reported 10% higher grain yield in zero-tillage system as compared to flat planting. Raised bed method also resulted in 5.8% higher grain yield than

Table 2. Yield attributes and yields of wheat as influenced by irrigation levels and sowing methods (pooled data of 2 years)

Treatment	Spikes/m^2	Grain weight/ spike (g)	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Irrigation level					
IW : CPE of 0.75	556	1.38	38.9	3.67	6.41
IW : CPE of 1.00	526	1.46	42.6	3.85	6.45
Critical growth stages-based irrigation	496	1.37	38.3	3.82	6.84
SEm±	17.3	0.42	0.92	0.84	1.23
CD (P=0.05)	51.9	NS	2.76	NS	NS
Sowing method					
Conventional	541	1.36	39.9	3.62	6.49
Zero-tillage	541	1.39	40.2	3.89	6.66
Raised bed	496	1.46	39.6	3.83	6.54
SEm±	17.3	0.42	0.92	0.84	1.23
CD (P=0.05)	NS	NS	2.76	2.52	NS

IW : CPE, Irrigation water : cumulative pan evaporation

conventional planting. Although number of effective spikes/m^2 were more in conventional planting, raised bed method resulted in higher wheat grain yield due to heavier spikes. Higher grain yield of wheat on raised bed over conventional planting could be attributed to better soil rhizosphere environment owing to piling of top soil along with fertilizer and border effect on above-ground parts. Mollah *et al.* (2009) and Majeed *et al.* (2015) observed 21 and 15.1% higher wheat grain yield respectively, in bed planting compared to flat planting. Meena *et al.* (2013) also observed 11.3% higher wheat grain yield in furrow irrigated raised bed system (FIRBS) than conventional planting of wheat.

The mean wheat grain yield was found to be the maximum when it was provided irrigation at an IW : CPE of 1.0, followed by critical stages-based irrigation and IW : CPE of 0.75. Stimulated vegetative growth of wheat on account of frequent supply of water in IW : CPE of 1.0 treatment maintained adequate available soil moisture in the root zone throughout the crop-growth period which, in turns, got reflected in increased number of effective tillers, grain weight/ear and 1,000-grain weight and higher grain yield. These findings are in accordance with the findings of Saren *et al.* (2004).

Straw yield did not differ significantly due to any tested factor during both the years of study (Table 2). However, crop irrigated at critical growth stages recorded 6.7 and 6.0% higher straw yield at IW: CPE of 0.75 and 1.0, respectively. Among different sowing methods, zero-tilled wheat provided the maximum straw yield.

Water-use parameters

Irrigation applied at an IW : CPE of 0.75 recorded the maximum irrigation water-use efficiency (IWUE), being higher by 32.7 and 58.7% than the IW: CPE of 1.00 and critical stages-wise irrigation treatments respectively (Table 3). Crop subjected to irrigation at IW : CPE of 0.75 consumed less amount of water. It received 40.6 and 60.9% less irrigation water than IW : CPE of 1.0 and critical growth stages based irrigation treatments respectively (Table 3). This ratio recorded at par grain yield, but consumed less irrigation water thus resulted in the maximum IWUE.

Among the sowing methods, IWUE was found to be the maximum in raised bed method and the minimum in conventional sowing method. It was higher by 33.8 and 46.8% over the zero-and conventional-tillage treatments respectively. The decrease in water consumption in the bed-planted wheat was due to application of water to limited area (furrows) which decreased irrigation water amount and lowered the evaporation from the top soil. Idnani and Kumar (2012) also reported higher water-use efficiency in bed planting as compared to flat planting. Irrigation water-use efficiency in zero-tillage system was also higher by 9.7% than conventional wheat due to 5.8% higher grain yield and also on account of 4.4% less irrigation water application in the former treatment (Table 3).

Economics

The mean values of economic parameters revealed that crop irrigated as per IW : CPE of 1.00 earned the maximum gross and net returns, followed by critical stages-based irrigation and IW : CPE of 0.75 due to producing higher grain yield. The benefit: cost ratio was also maximum (1.17) with the former treatment. Crop irrigated according to IW: CPE of 0.75 resulted in 10.7 and 6.7% less net return than IW : CPE of 1.0 and critical growth stages based treatment respectively (Table 3). The benefit: cost ratio of 1.1 was identically received in both IW : CPE of 0.75 and critical growth stages based treatments that was 6.4% lower to IW : CPE of 1.0.

Among the crop-establishment methods, zero-tilled wheat fetched the maximum gross and net returns and the benefit: cost ratio. It gave ₹5,742 and ₹3,797/ha higher

Table 3. Economics and water-use parameters of wheat as influenced by irrigation levels and sowing methods (pooled data of 2 years)

Treatment	Irrigation water used (m^3)	Irrigation WUE (kg/m^3)	Gross returns (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio
Irrigation level					
IW : CPE of 0.75	1,300	2.84	43.3	22.5	1.10
IW : CPE of 1.00	1,870	2.14	46.5	24.9	1.17
Critical growth stages based irrigation	2,140	1.79	46.2	24.0	1.10
Sowing method					
Conventional	2,000	1.86	44.2	21.3	0.93
Zero-tillage	1,915	2.04	46.1	27.0	1.41
Raised bed	1,420	2.73	45.7	23.2	1.03

IW : CPE, Irrigation water : cumulative pan evaporation

net return than that of conventional and raised bed treatments respectively. Zero-tilled wheat also exhibited the maximum benefit: cost ratio which was higher by 51.6% and 36.9% over the conventional tillage and raised bed treatments respectively. The higher net returns and benefit: cost ratio in zero-tillage treatment was largely due to lowering cost of production by reducing the tillage operations. Higher grain yield under this treatment further supported the economics. Gupta *et al.* (2007) also observed 6.8 and 9.3% increase in net return and benefit: cost ratio under zero-tillage over conventional tillage respectively.

Kumar *et al.* (2013) also observed higher benefit: cost ratio in zero-tilled wheat crop against the 1.71 in conventionally tilled wheat crop. Raised bed method also earned 3.4 and 8.9% higher gross and net returns, respectively, than conventional flat planting. The benefit: cost ratio was also higher by 6.2% in bed planting than conventional planting. These results confirm findings of Mazeed *et al*. (2015), who observed 29% higher economic return in bed planting as compared to flat planting.

Energy-use parameters

Comparison of energy-use pattern in different irrigation schedules revealed that crop irrigated at critical growth stages consumed the maximum input energy owing to more energy used in irrigation water and labours used for applying the irrigation (Table 4). It was higher by 5.5 and 1.3% over the IW : CPE of 0.75 and 1.0 respectively. Among the crop-establishment methods, the minimum energy for raising wheat crop was used in zero-tillage treatment and the maximum in conventional tillage treatment. Zero-tilled wheat saved 2,834.3 and 2,143.8 MJ input energy compared to conventional and raised bed treatments respectively. The higher energy consumption in conventionally tilled wheat was due to more energy consumed in fuels and labours for land preparation. The results confirm the findings of Jha *et al.* (2011). They observed 6,227 MJ/ha more input-energy consumption under conventional tillage system compared to zero-till sowing of wheat owing to more tillage operations

The output energy which is a function of grain and straw yields and their energy equivalents was found to be the maximum with critical growth stages based irrigation treatment (Table 4). It recorded 6.3% and 2.8% higher output energy than IW : CPE of 0.75 and 1.0, respectively, with non-significant differences. Higher output energy in critical growth stages based irrigation treatment was owing to higher grain and straw yields. Although its grain yield was lower than IW: CPE of 1.0, resulted in the maximum output energy due to having higher straw yield. Wheat raised under zero-tilled condition recorded the maximum output energy followed by raised bed and conventional treatments (Table 4). Higher output energy in zero-tillage treatment was owing to its higher grain and straw yields.

Energy-use efficiency, was higher in the critical stages-based irrigation treatment due to relatively higher grain and straw yields which in turn resulted in higher output energy and finally the EUE. It was higher by 3.4% and 1.4% than IW : CPE of 0.75 and 1.00 treatments, respectively, the differences were found to be non-significant. Although, EUE was influenced significantly by sowing methods. Wheat raised under zero-tilled condition also recorded 25.7% and 18.1% higher EUE than conventional and raised bed treatments respectively. Jha *et al.* (2011) also observed 17.3% higher energy-use efficiency in zero-

Table 4. Energy-use parameters of wheat as influenced by irrigation levels and sowing methods (pooled data of 2 years)

Treatment	Energy input ($\times 10^3$MJ/ha)	Energy output ($\times 10^3$MJ/ha)	Energy-use efficiency (output/input ratio)	Net energy ($\times 10^3$MJ/ha)	Energy intensity (MJ/kg)
Irrigation level					
IW: CPE of 0.75	14.5	133.4	9.15	118.8	4.02
IW: CPE of 1.00	15.1	137.9	9.12	122.8	3.89
Critical growth stages-based irrigation	15.3	141.8	9.26	126.5	4.00
SEm±	-	2.2	0.14	2.2	0.09
CD (P=0.05)	-	NS	NS	NS	NS
Sowing method					
Conventional	16.2	135.1	8.35	118.9	4.41
Zero-tillage	13.3	140.1	10.50	126.8	3.46
Raised bed	15.5	137.7	8.89	122.2	4.05
SEm±	-	2.2	0.14	2.2	0.09
CD (P=0.05)	-	NS	0.43	6.6	0.26

IW : CPE, Irrigation water : cumulative pan evaporation

tilled system of wheat than that of the conventional system. Kumar *et al*. (2013) found that due to lesser energy input and higher output energy, zero-tilled wheat had 20% higher energy-use efficiency than conventionally tilled wheat crop.

Net energy gain which is worked out by deducting the input energy from output energy was also found to be the maximum in critical growth stages-based treatment. Among the crop- establishment methods, zero-tilled wheat showed superiority to the remaining treatments. However, from energy intensity point of view, which shows the amount of energy spent to produce a unit of marketable produce, IW : CPE of 1.0 was least intensive to produce per unit wheat yields compared to the remaining treatments (Table 4). An IW : CPE of 0.75 spent the maximum energy to produce/unit grain yield. It was due to relatively less grain yield and higher input energy. Among different sowing methods, zero-tilled wheat treatment was the lowest-energy intensive, as it required 21.5% and 8.9% less energy compared to conventional and raised bed treatments, respectively, and also resulted in higher grain yield. Raised bed wheat also spent 8.9% less energy than conventional treatment.

Our findings indicate that IW : CPE of 0.75 is optimum for wheat in loamy sand soil requiring 2–3 irrigations depending on the rainfall. For productivity, energy conservation and economic returns, zero-tillage method was found more effective, can be advocated. Since raised bed method gave 33.8% and 46.8% higher WUE than the zero-and conventional tillage treatments, respectively, it can be adopted in water-scarce area.

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