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IMPACT OF LAND CONFIGURATIONS AND IRRIGATION SYSTEMS ON GROWTH AND YIELD OF WHEAT (*TRITICUM AESTIVUM* L.)

S.H. Parmar*, D.D. Vadalia, G.V. Prajapati and P.A. Pandya

Centre of Excellence on Soil and Water Management, Office of Research Scientist (Agril. Engg.),
Junagadh Agriculture University, Junagadh, Gujarat, India
*****Corresponding author E-mail : sanjayparmar5151@gmail.com

ABSTRACT

A field experiment was conducted at the Research cum Demonstration Farm, RTTC, Junagadh Agricultural University during 2017-18 to evaluate the impact of land configurations, irrigation systems, and irrigation levels on the growth, yield, water use efficiency, and economic returns of wheat (*Triticum aestivum* L., variety GW-366). The study involved two land configurations: broad bed furrow (BBF) (L_1) and flat land(L_2), two irrigation systems: drip irrigation(S_1) and surface irrigation(S_2) and two irrigation levels: 1.0 ET_c(I_1) and 0.8 ET_c(I_2). Results revealed that BBF land configuration with drip irrigation scheduled at 1.0 ET_c recorded the highest plant height (95.77 cm), productive tillers (300.67), grains per spike (39.33) and test weight (53.53), which was statistically at par with flat land configuration with drip irrigation at 0.8 ET_c. Maximum grain yield (4124.35 kg/ha), straw yield (7715.02 kg/ha), and water use efficiency (15.74 kg/ha.mm) were obtained under flat land configuration with drip irrigation at 0.8 ET_c. The highest water saving (51.36%) was achieved under BBF with drip irrigation at 0.8 ET_c, followed closely by flat land with drip irrigation at 0.8 ET_c (50.53%). Drip irrigation under BBF and flat land configurations significantly reduced irrigation water usage by 32.29% to 46.09% compared to surface irrigation. The highest benefit-cost ratio (2.32) was recorded under BBF with drip irrigation at 1.0 ET_c, while the lowest (1.23) was observed under BBF with surface irrigation at 0.8 ET_c. The study highlights that adopting drip irrigation with appropriate land configuration can enhance wheat productivity, save water, and improve economic returns under limited water conditions.

Key words : Broad Bed Furrow, Irrigation systems, Land configurations, Wheat.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important staple food grains for the human race. India produced approximately 112.5 million tons of wheat during the year 2023-24, accounting for about 14% of the world production. India ranks as the second-largest producer of wheat globally and is also the second-largest consumer after China. Wheat holds the position of the second most important cereal in India after rice, contributing significantly to national food security by supplying more than 50% of the calories to people who rely on it as a dietary staple.

Availability of irrigation water is the major limiting factor for improving wheat productivity in India. Two decades ago, more than 60% of wheat in India was cultivated under rainfed conditions. At present, over 60% of wheat area is irrigated; however, about 50% of this irrigated area receives only one or two irrigations (Chouhan and Yadav, 2012). A key reason for the low coverage and efficiency of irrigation is the predominant use of the flood (conventional) method of irrigation, where water use efficiency remains extremely low (35-40%).

In the traditional surface irrigation systems, the irrigation cycle comprises a short period of infiltration followed by a long period of simultaneous redistribution, evaporation, and water extraction by the crop. This method incurs a fixed cost per water application, necessitating the minimization of irrigation frequency by maximizing soil water storage before the next irrigation cycle without causing significant yield loss. However, this approach often results in large fluctuations in soil-water potential, as observed by Bresler and Yaron (1972).

The advent of drip irrigation systems has addressed this limitation by enabling precise and frequent water delivery to the soil at no additional operational cost (Rawlins, 1973). Drip irrigation is widely recognized as the most efficient irrigation method and has been successfully implemented for vegetables, orchards, flowers, and plantation crops. However, limited studies have been conducted to evaluate its effectiveness for field crops like wheat.

Crop productivity is a complex phenomenon influenced by several factors, including improved varieties, appropriate sowing methods, timely sowing, optimal spacing, judicious water and nutrient management and effective weed, pest and disease control. Among these, the sowing method or land configuration plays a pivotal role in achieving the crop's yield potential.

Proper land configuration enhances water use efficiency, reduces soil erosion, and ensures uniform germination, plant growth, and nutrient availability. Broad Bed Furrow (BBF) land configuration has proven to be a more efficient alternative to the traditional flatbed method. BBF improves water use efficiency (Chiroma *et al.*, 2008), increases crop yields and reduces seed usage. It also facilitates better drainage during wet monsoons, enhances fertilizer efficiency through targeted placement, and promotes better tillering, longer ear lengths, and bolder grains (Sayre, 2001). Furthermore, BBF supports in-situ rainwater conservation, proper aeration in the root zone, and pre-sowing irrigation, which allows for effective weed control prior to planting.

In regions with high evaporative demand, groundwater scarcity, deficient rainfall, and poor on-farm water management, irrigation scheduling plays a crucial role in improving crop productivity while conserving water resources. The predominant challenges include a lack of knowledge about irrigation frequency under water-scarce conditions, low water application efficiency in surface irrigation practices, and the adverse impacts of irregular rainfall.

Effective irrigation scheduling requires the accurate estimation of crop evapotranspiration (ETc), which varies based on crop canopy and climatic conditions. Efficient water management practices can address the constraints associated with traditional irrigation systems, particularly under limited water resources (Farahani *et al.*, 2008).

Considering these factors, a field study was conducted to explore strategies for improving wheat productivity through the optimization of land configurations and irrigation systems.

Materials and Methods

Field Experimental details

The field experiment was conducted during 2017-18 at the Research cum Demonstration Farm, Research Testing & Training Center, Junagadh Agricultural University, Junagadh to evaluate the conjunctive impact of two land configurations; broad bed furrow(L_1) and flat land(L_2), two irrigation systems; drip irrigation(S_1) and surface irrigation(S_2) and two irrigation levels; 1.0 ET_c (I_1) and 0.8 ET_c (I_2) on productivity of wheat (GW-366). Each of eight treatments was replicated thrice. Large plot design was adopted and datas were analyzed using factoral randomized block design.

Field was ploughed using tractor operated cultivator and blade harrow. Clods were broken and field was leveled with the help of plank. Raised beds (15 cm high and 210 cm wide with 100 cm tops and 55 cm furrows) with provision of irrigation channels was made with tropiculture.

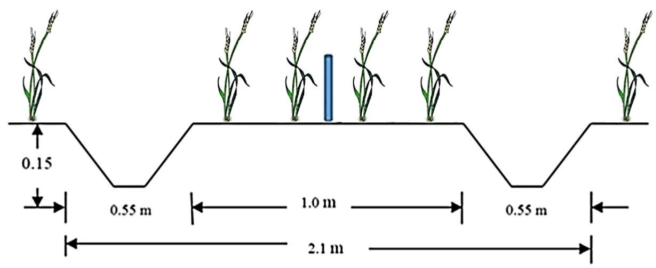

Fig. 1 : Dimensions of broad bed furrow.

Sowing of wheat seed was done on 3rd week of November by tractor mounted seed cum fertilizer drill. Seed rate was maintained as 100 kg/ha. Recommended dose of fertilizer N:P:K (120: 60: 60) was given to wheat crop. First 60 kg nitrogen and whole quantity of phosphorus and potash were applied as basal dose. Another 60 kg nitrogen were applied 21 days after sowing. The crop was kept free from weeds for proper growth and development of plants. Spraying of pendimethalin 30 % EC (Stomp) after common surface irrigation to whole treatments to keep the weeds under check.

Irrigation Scheduling

Irrigation scheduling was done based on actual evapotranspiration measured with the help of soil moisture sensors installed at 15 cm and 30 cm from top of soil near the root zone of wheat crop in different treatments. Two set of sensors with data loggers were installed in different treatments at irrigation level 1.0 ET_c and 0.8 ET_c. The sensors were calibrated for local condition and moisture content calculated based on calibrated soil moisture characteristic curve. Actual crop evapotranspiration was calculated by subtracting moisture content before and after irrigation, multiplied with bulk density of soil and depth of root zone. The rooting depth of wheat was calculated using model developed by Fereres *et al.* (1981). Irrigation water was applied as per actual evapotranspiration at 1.0 ET_c and 0.8 ET_c.

Actual Evapotranspiration (ET_a) was calculated using following equation

$$ET_a = 1000 \times (M_1 - M_2) \times Z_r \times BD \quad (1)$$

Where,

ET_a = Actual evapotranspiration (mm),

M_1 = Moisture content after irrigation ($m^3\ m^{-3}$),

M_2 = Moisture content before irrigation ($m^3\ m^{-3}$),

Z_r = Rooting depth (m),

BD = Bulk density (g/cc)

Irrigation was given based on the equation (1) considering the application efficiency of drip irrigation as 90%, furrow irrigation as 60% and flood irrigation as 50% as suggested by Kurre (2016) at 1.0 ET_c and 0.8 ET_c.

Data collection

Samples of crop yield parameters like; plant height at harvest, productive tillers per m^2, number of grains per spike, grain yield, straw yield, test weight were collected from each treatment and statistically analysed. Water use efficiency was calculated considering grain yield and total water irrigation water used.

Total cost of cultivation, net seasonal income, total net income was calculated considering additional area to be irrigated by saving of irrigation water compared to flat land configuration with surface irrigation at 1.0 ET_c irrigation level, Benefit cost ratio was calculated for each treatment.

Results and Discussion

Determination of Actual Evapotranspiration and Kc Values

Evapotranspiration (ET) can be conceptually expressed either in the form of potential or actual evapotranspiration. Potential evapotranspiration (PET) describes the maximum loss of water under specific climatic conditions when unlimited water is available. The actual evapotranspiration (AET) is the rate at which water is actually removed to the atmosphere from a surface due to the evapotranspiration process. The influence of soil moisture on the AET has made its physical modeling more complicated than the PET. Complexity of AET has also imposed some limitations on the previously developed estimation models. Although the AET is the preferred form of ET in the hydrological analysis, vast majority of the previous studies have investigated the modeling of PET. As a result, there is a vital need for modeling and analysis of AET mechanism. Complexity of the AET physics, limitations of the currently available AET estimation approaches, such as requirement of extensive information and reasonable estimation of models parameters has led to the investigation of some techniques/tools that can model/analyze such complicated mechanism without having a complete understanding of it.

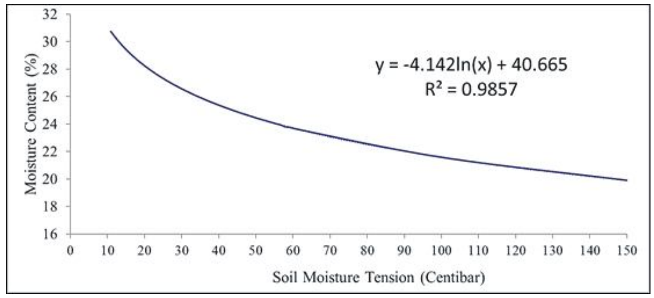

Fig. 2 : Calibrated soil moisture characteristic curve.

Table 1 : Total depth of water applied in different treatments.

Irrigation level	Total depth of water applied (mm)			
	L_1		L_2	
	S_1	S_2	S_1	S_2
I_1	277.39	418.22	294.14	529.71
I_2	257.62	380.47	262.07	486.12

Actual evapotranspiration ET_a was estimated using soil moisture sensors with data loggers installed at 15 cm and 30 cm depth from top of the soil (Lynch and Tai, 1989; Taylor *et al.*, 1959) in different treatments. The daily fluctuation of soil moisture tension was recorded at 9:00 AM. Average value of these two depths was considered. The local calibration of soil sensors is shown in Fig. 2.

Daily actual evapotranspiration was calculated using equation (1). The temporal variation of root depth was determined using equation 3.4. Depth of sowing, days to attain physiological maturity and maximum depth of root zone for wheat was 5 cm, 90 days and 30cm. The crop period is 120 days. Application efficiency in drip irrigation was taken as 90%, furrow irrigation as 60% and flood irrigation as 50%. Daily weather data received from Department of Agro-meteorology, Junagadh Agricultural University, Junagadh, during the experimental run.

Irrigation Water requirement

Irrigation was applied based on ET_a (sensor-based values) for different irrigation levels. The depth of water to be applied for replenishment was calculated using equation (1). Total depth of water applied in different treatments are given in Table 1. The depth of water applied ranged from 257.62 mm to 529.71 mm. Broad bed furrow consumed less water. Savings of irrigation water by bed planting of wheat ranged from 18% to 50% were also reported by Gupta (2003) and Mollah *et al.* (2009).

Saving of irrigation water under different treatments was ranged from 8.2% to 51.36%. Highest water saving (51.36%) was observed under $L_1S_1I_2$, which was at par with $L_2S_1I_2$ (50.53%) as compared to $L_2S_2I_1$. Treatment $L_2S_2I_2$ recorded lower water saving (8.23%) as compared to $L_2S_2I_1$. Water saving in case of drip irrigation were also reported by Bhella (1988), Bafna *et al.* (1993), Yasser *et al.* (2009) and Chouhan *et al.* (2015).

L_1S_1 saved 140.83mm (33.67%) and 122.85mm (32.29%) irrigation water as compared to L_1S_2 at I_1 and I_2 respectively. Whereas, 235.57mm (44.47%) and 224.05mm (46.09%) water saving was observed under L_2S_1 as compared to L_2S_2 at I_1 and I_2, respectively. More water saved under raised bed system than flat bed planting system because irrigation water advances faster between two beds, less percolation loss due to untilled furrow and compacted furrow bottom, as well as furrow side causes two wheeler passing at sowing time, less percolation loss occurred in raised bed soil than flat bed soil (Mollah *et al.*, 2009; Parihar *et al.*, 2017).

Effect of land configurations, irrigation systems and irrigation levels on yield attributes of wheat

The yield attributes of wheat like plant height, productive tillers (per m²), grains per spike, and test weight, were significantly influenced by different land configurations, irrigation systems, and irrigation levels during the experimental study.

Among the land configurations, the results showed that L_2 (Broad Bed Furrow) recorded comparatively higher values for all yield attributes, including plant height (80.51 cm), productive tillers (256.25 m²), grains per spike (30.25) and test weight (51.00 g), as compared to L_1 (Flat Land). However, the differences were statistically non-significant (NS) for all these parameters.

The higher values observed under BBF land configuration may be attributed to improved moisture retention, better aeration and enhanced nutrient availability in the root zone, which facilitated better crop growth and development. Similar observations were reported by Sayre (2001) and Chiroma *et al.* (2008), highlighting the efficiency of BBF in optimizing plant growth conditions.

The irrigation levels had a non-significant effect on all the yield attributes, namely plant height, productive tillers, grains per spike and test weight. The higher irrigation level (I_1: 1.0 ET_c) recorded slightly superior values for plant height (80.21 cm), productive tillers (249.42 m²), grains per spike (30.58) and test weight (50.81 g), compared to the lower irrigation level (I_2: 0.8 ET_c).

The slight improvement in growth and yield attributes at I_1 can be attributed to the sufficient availability of water for plant processes such as cell expansion, nutrient uptake, and photosynthesis. Conversely, at I_2, reduced water availability might have caused mild stress, leading to slightly lower values. However, the non-significant effect indicates the ability of wheat to perform reasonably well even under limited irrigation conditions, suggesting the potential for water savings without significant yield losses.

The irrigation systems significantly influenced all yield attributes. Drip irrigation (S_1) resulted in higher values for plant height (88.58 cm), productive tillers (280.83 m²), grains per spike (33.83) and test weight (52.95 g), compared to surface irrigation (S_2), which recorded lower values of 70.52 cm, 207.33 m², 26.08, and 48.29 g, respectively.

The significant improvement under drip irrigation can be attributed to its higher water use efficiency, precise water delivery and reduced evaporation losses, leading to better moisture availability in the root zone. These findings are in agreement with earlier reports by Mostafa *et al.* (2017), where drip irrigation enhanced crop performance by maintaining favourable soil-water potential.

Interaction effect of land configuration and irrigation level showed significant difference in plant height, productive tillers, and grains per spike, suggesting that irrigation levels had a notable impact under different land configurations. Interaction of land configurations and irrigation systems showed significant difference in number of productive tillers of wheat and highly significant ($P<0.01$) for grains per spike, indicating a strong interactive influence on these parameters. While Interaction of irrigation systems and Irrigation Level showed Non-significant for all the yield attributes, indicating that the irrigation levels did not interact significantly with the irrigation systems.

Interaction of land configurations, irrigation systems and irrigation levels was significant for productive tillers ($P<0.05$) and grains per spike ($P<0.01$), demonstrating a combined influence of the three factors on these parameters. The significant interactions, particularly for productive tillers and grains per spike, suggest that the

Table 2 : Effect of land configurations, irrigation systems and irrigation levels on yield attributes of wheat.

Treatments	Plant height (cm)	Productive tillers (per m^2)	Grains per spike (nos.)	Test weight (gm)
Land configurations				
L_1	78.59	231.92	29.67	50.25
L_2	80.51	256.25	30.25	51.00
S.Em. ±	1.88	9.67	0.84	0.62
C.D. at (5%)	NS	NS	NS	NS
Irrigation levels				
I_1	80.21	249.42	30.58	50.81
I_2	78.89	238.75	29.33	50.44
S.Em. ±	1.88	9.67	0.84	0.62
C.D. at (5%)	NS	NS	NS	NS
Irrigation systems				
S_1	88.58	280.83	33.83	52.95
S_2	70.52	207.33	26.08	48.29
S.Em. ±	1.88	9.67	0.84	0.62
C.D. at (5%)	5.65	28.99	2.51	1.85
Interaction				
L X S	NS	*	**	NS
L X I	*	*	*	NS
S X I	NS	NS	NS	NS
L X S X I	*	NS	**	NS
C.V. (%)	8.21	13.72	9.68	4.23

Level of Significance: * P<0.05, **P<0.01, NS: non-significant.

growth and yield attributes.

Effect of land configurations, irrigation systems and irrigation levels on grain and Straw yield of wheat

The interaction effects of land configurations, irrigation systems, and irrigation levels on grain yield of wheat are presented in Table 3. Under Broad Bed Furrow (L_2) configuration, drip irrigation (S_1) with the higher irrigation level (I_1: 1.0 ET_c) recorded the maximum grain yield (4124.35 kg/ha), followed closely by the lower irrigation level (I_2: 0.8 ET_c) with 3890.27 kg/ha. The mean grain yield under S_1 (drip irrigation) in L_2 was 4007.31 kg/ha, which was significantly higher than the yields obtained under surface irrigation (S_2). In contrast, under Flat Land (L_1), the combination of drip irrigation (S_1) and the higher irrigation level (I_1) produced a grain yield of 3868.63 kg/ha, which was substantially higher than other treatments. However, the yields under surface irrigation (S_2) were comparatively lower across both irrigation levels. These results are in conformity with the findings of Bilalis *et al.* (2011), Naresh *et al.* (2015) and Singh *et al.* (2017).

The interaction effect between land configurations, irrigation systems, and irrigation levels was found to be significant (C.D. = 528.87), indicating the combined influence of these factors on grain yield. The superiority of BBF land configuration combined with drip irrigation can be attributed to improved soil moisture availability, reduced evaporation losses and enhanced water use efficiency. Drip irrigation ensures precise water application, which avoids waterlogging and provides optimum soil-water conditions for root development and

Table 3 : Interaction effect land configurations, irrigation systems and irrigation levels on grain yield of wheat.

Grain yield (kg/ha)						
	L_1			L_2		
Irrigation systems	Irrigation Levels			Irrigation Levels		
	I_1	I_2	Mean	I_1	I_2	Mean
S_1	3868.63	3357.96	3613.30	3890.27	4124.35	4007.31
S_2	2588.79	2349.15	2468.97	3751.54	3035.23	3393.39
Mean	3228.71	2853.56		3820.91	3579.79	
S.Em. ±	124.74					
C.D. at (5%)	528.87					
C.V. (%)	9.06					

Broad Bed Furrow land configuration in combination with drip irrigation and appropriate irrigation levels (1.0 ET_c or 0.8 ET_c) has a synergistic effect, leading to improved

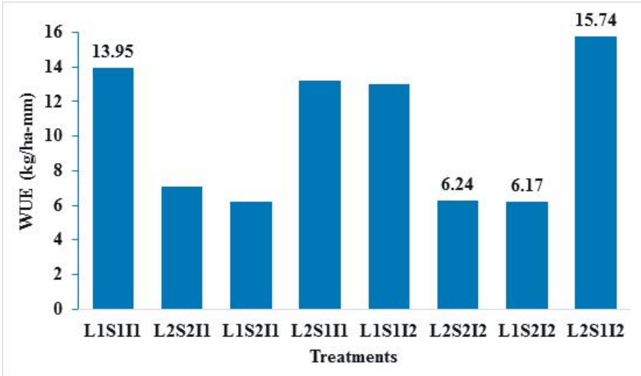

Fig. 3 : Impact of land configurations, irrigation systems and irrigation levels on water use efficiency of wheat.

significant (C.D. = 677.45), demonstrating that the combination of land configurations, irrigation systems, and irrigation levels significantly influenced straw yield. Similar results were recorded by Mostafa *et al.* (2017).

The superior straw yield under BBF with drip irrigation can be attributed to the efficient utilization of water and nutrients, which promoted better vegetative growth and biomass accumulation. Conversely, the lower straw yields under surface irrigation on flat land may be due to inefficient water distribution, waterlogging, and moisture stress during critical growth stages, which adversely affected plant biomass production. It was also found that with sufficient moisture in the soil profile under higher irrigation frequency with drip irrigation, plant nutrient particularly nitrogen, phosphorus and potash were more available and might have translocated to produce more dry matter (Barkha *et al.*, 2017).

Table 4 : Interaction effect land configurations, irrigation systems and irrigation levels on straw yield of wheat.

Straw yield (kg/ha)						
	L_1			L_2		
Irrigation systems	**Irrigation Levels**			**Irrigation Levels**		
	I_1	I_2	**Mean**	I_1	I_2	**Mean**
S_1	6398.75	5226.18	5812.47	6473.75	7715.02	7094.39
S_2	6835.19	4140.71	5487.95	6105.36	4347.00	5226.18
Mean	5410.38	5019.89		6616.97	4683.45	
S.Em. ±	225.97					
C.D. at (5%)	677.45					
C.V. (%)	9.80					

nutrient uptake, thereby enhancing yield performance. The lower yields under surface irrigation (S_2), particularly on flat land (L_1), could be due to uneven water distribution, greater evaporation losses and reduced water use efficiency. These findings are consistent with the results reported by Liao *et al.* (2008) and Wang *et al.* (2011). Thus, the combination of BBF land configuration with drip irrigation emerged as the most promising practice for maximizing wheat grain yield under limited water resources.

The interaction effects on straw yield of wheat are presented in Table 4. Similar to grain yield, the Broad Bed Furrow (L_2) configuration in combination with drip irrigation (S_1) at the higher irrigation level (I_1: 1.0 ET_c) recorded the maximum straw yield (7715.02 kg/ha). The mean straw yield under S_1 in L_2 was 7094.39 kg/ha, significantly higher than under surface irrigation (S_2) at both irrigation levels. Under the Flat Land (L_1) configuration, straw yield was higher under surface irrigation (S_2) at the higher irrigation level (I_1: 1.0 ET_c), recording 6835.19 kg/ha. However, the mean straw yield under drip irrigation (S_1) was comparatively lower (5812.47 kg/ha). The interaction effect was found to be

Water Use Efficiency

Water use efficiency is the yield of harvested crop produce achieved form the available water to the crop from rainfall, irrigation and soil water storage (Singh *et al.*, 2010). Water use efficiency under different land configuration, irrigation system and irrigation levels are depicted in Fig 3.

Water use efficiency under different treatment varied from 6.17 kg/ha.mm to 15.74 kg/ha.mm. Highest water use efficiency (15.74 kg/ha.mm) was observed under treatment $L_2S_1I_2$ and lowest was observed at $L_1S_2I_2$ (6.17 kg/ha.mm). Treatment $L_1S_1I_1$ at par with $L_2S_1I_1$ and $L_1S_1I_2$. Treatment $L_1S_2I_1$ at par with $L_2S_2I_2$ and $L_1S_2I_2$. Treatment $L_2S_1I_2$ has higher water use efficiency because flat land with drip irrigation system having higher grain yield as compared to broad bed furrow with drip irrigation system. Similarly, broad bed furrow with drip irrigation

Table 5 : Cost economics of wheat cultivation.

Treatments	CCC (`/ha)	FCI (`/ha)	VCI (`/ha)	TCC (`/ha)	Net seasonal income (`/ha)	Total net income(`/ha)	B:C Ratio
$L_1S_1I_1$	21078.70	8015.42	4211.58	33305.69	77186.60	147396.93	2.32
$L_2S_2I_1$	26728.70	5095.61	8274.19	40098.50	74809.99	74809.99	1.87
$L_1S_2I_1$	27028.70	5095.61	6532.80	38657.11	51824.33	65638.70	1.34
$L_2S_1I_1$	19578.70	15883.18	4465.91	39927.79	77790.35	140090.13	1.95
$L_1S_1I_2$	21078.70	8015.42	3911.50	33005.61	67697.40	139194.05	2.05
$L_2S_2I_2$	26728.70	5095.61	7593.34	39417.65	59637.09	64984.38	1.51
$L_1S_2I_2$	27028.70	5095.61	5943.06	38067.37	47011.82	65451.90	1.23
$L_2S_1I_2$	19578.70	15883.18	3978.98	39440.86	83748.71	169277.09	2.12

system having higher water use efficiency as compared to boarder irrigation system (Ram *et al.,* 2013; Waraich *et al.,* 2010).

Economics

The cost economics of wheat cultivation as influenced by land configurations, irrigation systems and irrigation levels are presented in Table 5. The analysis includes Cost of Crop Cultivation (CCC), Fixed Cost of Irrigation (FCI), Variable Cost of Irrigation (VCI), Total Cost of Cultivation (TCC), Net Seasonal Income, Total Net Income, and the Benefit-Cost (B:C) Ratio.

The highest B:C ratio (2.32) and total net income (` 147396.93/ha) were obtained under the combination $L_1S_1I_1$ (Flat Land, Drip Irrigation, 1.0 $ET_c$), followed closely by $L_2S_1I_2$ (BBF, Drip Irrigation, 0.8 $ET_c$) with a B:C ratio of 2.12 and total net income of ` 169277.09/ha. The $L_2S_1I_1$ (BBF, Drip Irrigation, 1.0 ET_c) treatment also performed well, recording a B:C ratio of 1.95 and total net income of ` 140090.13/ha. This highlights the economic advantage of adopting drip irrigation systems in both land configurations (flat and BBF) at the higher irrigation level (1.0 ET_c).

Under surface irrigation, the combinations $L_2S_2I_1$ (BBF, Surface Irrigation, 1.0 ET_c) and $L_1S_2I_1$ (Flat Land, Surface Irrigation, 1.0 ET_c) recorded lower B:C ratios of 1.87 and 1.34, respectively. The net seasonal income was also comparatively lower under these treatments. Similarly, the lowest B:C ratio (1.23) was observed in $L_1S_2I_2$ (Flat Land, Surface Irrigation, 0.8 ET_c), indicating the economic disadvantage of surface irrigation under deficit water availability (0.8 ET_c). The Broad Bed Furrow (L_2) land configuration in combination with drip irrigation (S_1) showed better economic performance compared to flat land (L_1) with surface irrigation. This can be attributed to improved water use efficiency, better aeration and *in-situ* moisture conservation in the BBF system.

Conclusion

The study revealed that land configuration, irrigation systems, and irrigation levels significantly influence the growth, yield and economic returns of wheat cultivation. broad bed furrow (BBF) land configuration with drip irrigation at 1.0 ET_c recorded the highest plant height (95.77 cm), productive tillers (300.67), grains per spike (39.33) and test weight (53.53), which was statistically at par with flat land configuration with drip irrigation at 0.8 ET_c. The highest water saving (51.36%) was observed under BBF with drip irrigation at 0.8 ETc, followed closely by flat land with drip irrigation at 0.8 ETc (50.53%). Treatments with drip irrigation at 1.0 ET_c or optimized levels of 0.8 ETc outperformed surface irrigation by maximizing productivity while conserving water. Among all treatments, the highest benefit-cost ratio (2.32) was obtained under BBF with drip irrigation at 1.0 ET_c, while the lowest (1.23) was recorded under BBF with surface irrigation at 0.8 ET_c. Flat land configuration with drip irrigation at 0.8 ET_c achieved the highest grain yield (4124.35 kg/ha), straw yield (7715.02 kg/ha), and water use efficiency (15.74 kg/ha.mm). The results emphasize the importance of adopting efficient irrigation systems like drip irrigation and improved land configurations such as BBF to achieve higher yields, better resource utilization and greater economic sustainability in wheat cultivation under limited water availability.

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