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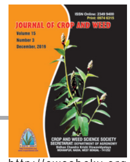

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Evaluation of bed planted wheat (*Triticum aestivum* L.) in relation to row orientation and intercropping systems

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ABSTRACT

Manipulation of radiant energy within a crop field by an appropriate adoption of crop geometry like intercropping and row orientation can provide a means to create light saturated condition for crop canopy for the purpose of efficient harvest of solar energy for agricultural production. So, a field experiment was conducted to investigate the effect of row orientation on the growth and yield of wheat and intercrops and to obtain information regarding highly productive and economically viable bed planted wheat based intercropping system. The experiment was carried out during rabi seasons of 2013-14 and 2014-15 at the research farm of the Department of Agronomy, Punjab Agricultural University, Ludhiana. The experiment was laid out in a split-plot design with two directions of sowing (i.e. north-south and east- west) in the main plot, and eleven different spatial crop arrangements (i.e. intercropping of wheat + spinach, wheat + fenugreek, wheat + fodder oat, wheat + canola and wheat + linseed along with sole planting of wheat in bed system and five different component crops in flat system) in the subplot, replicated four times. Raising the wheat in east-west row orientation resulted in higher grain yield (55.1 q ha^{-1}), wheat equivalent yield (55.7 q ha^{-1}), system productivity (35.0 kg ha^{-1}day^{-1}) and net return (₹ 58,000 ha^{-1}) as compared to north-south row orientation. Wheat + fodder oat system produced significantly higher wheat equivalent yield (70.3 q ha^{-1}), system productivity (44.2 kg ha^{-1}day^{-1}) and the economic returns (₹ 110,680 gross and ₹ 76,340 net returns ha^{-1}) than the other wheat based intercropping systems.

Key words: Bed planted wheat, equivalent yield, intercropping systems, land equivalent ratio (LER), net returns, row orientation

The population of the developing countries like India is increasing but the food production remains stagnant due to decreased crop productivity and limited natural resources. So, there is a need to increase food grain production per unit of available resource. Intercropping is a viable option for increasing the productivity on small farms as it provides security against potential losses in monoculture (Ghosh, 2004). Intercropping is simple and inexpensive method which has an advantage over sole cropping (Awal *et al*., 2006). Intercropping increases diversity in the cropping system and results in higher yield on a piece of land by making more effective usage of the existing growth resources such as light, space, nutrient and water (Lithourgidis *et al*., 2011). So, in modern agriculture, it can help to increase crop productivity particularly at small farms as it satisfies the diversified demands of the farm people (Imran *et al*., 2011).

Solar radiation is a major resource determining growth and yield of component crops in intercropping, particularly when other resources (e.g. water and nutrients) are not severely limiting the crop growth. Rows orientation, due to its effect on interception of solar radiation in the crop canopy, also affects photosynthetic efficiency and canopy temperature (Drews *et al*., 2009). A uniform distribution and proper orientation of plants over a cropped area are needed for greater light interception throughout the crop profile and maximum photosynthetic efficiency by all the leaves of a plant (Evers *et al*., 2009). Crops must be sown on a suitable pattern to make the best use of solar radiation through higher light interception which is non-monetary, non-pollutant and natural sources of energy. Presently, wheat is grown as a sole crop in most part of the country. In bed planted wheat, there is scope for growing some intercrops in furrows during early stages of crop growth. The production potential of bed planted wheat and different intercrops may also vary in relation to the direction of sowing in the intercropping system. Thus, wheat production can be increased by improving the efficient use of solar energy with some innovation in agronomic management. The objective of this study was to investigate the effects of row orientation on the growth and yield of wheat and intercrops and to find highly productive and economically viable bed planted wheat based intercropping system.

MATERIALS AND METHODS

The experiment was carried out during *rabi* seasons of 2013-14 and 2014-15 at the research farm of the Department of Agronomy, Punjab Agricultural University (PAU), Ludhiana situated at 30º 54' N latitude

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and 75º 51' E longitude at a height of 247 meters above the mean sea level in the central plain region of Punjab under Trans-Gangetic agro-climatic zone of India. The soil of the experimental field was loamy sand with pH 7.2. It was moderately fertile being low in organic carbon (0.21%), available nitrogen (63.5 kg ha^{-1}) and, available potassium (122.1 kg ha^{-1}), and medium in available phosphorus (19.5 kg ha^{-1}). The experiment was laid out in a split-plot design with two directions of sowing (*i.e.* north-south and east-west) in the main plot, and eleven different spatial crop arrangements (*i.e.* intercropping of wheat + spinach, wheat + fenugreek, wheat + fodder oat, wheat + canola and wheat + linseed along with sole planting of wheat in bed system and five different component crops in flat system) in subplot, replicated four times. Sowing of wheat on beds was done with the help of a bed planter, which enables two wheat rows 20 cm apart on 37.5 cm wide bed and makes 30 cm wide furrow between two beds and intercrops were sown in consecutive furrows. In sole plots, wheat and intercrops (spinach, fenugreek, fodder oat, canola and linseed) were sown at recommended row spacing. The recommended dose of N, P and K fertilizer was applied to wheat and intercrops on area basis. The control of weeds on both beds and furrow was done by two hand weedings at 30 and 65 days after sowing (DAS). Other package of practices for wheat and intercrops were followed as per PAU recommendations. The varieties taken for sowing were PBW 621 of wheat, Punjab Green of spinach, ML 150 of fenugreek, Kent of fodder oat, GSC 6 of canola and LC 2063 of linseed.

The intercropping systems were evaluated in terms of wheat equivalent yield (WEY) (q ha^{-1}), system productivity (kg $ha^{-1}day^{-1}$) and economic returns. Economic returns (₹ ha^{-1}) for individual crop in intercropping systems were calculated on the basis of prevailing market rates of inputs and selling price of the produce.

The system productivity was calculated by converting the yield of all crops grown in intercropping system in terms of wheat equivalent yield (WEY) and dividing it with the duration of intercropping system. It was expressed as kg $ha^{-1}day^{-1}$. Yield of individual crop was converted into wheat equivalent yield (q ha^{-1}) on the basis of prevailing market price of the crop (Anjaneyulu *et al.*, 1982). It was calculated by the following formula :

$$\text{WEY} = \text{Grain yield of wheat} + \frac{\text{Yield of intercrops} \times \text{Selling price of intercrops}}{\text{Selling price of wheat}}$$

Land Equivalent Ratio (LER) indicates the efficiency of intercrops in using the resources of the environment compared with sole cropping. LER indicates the total land area required by sole crops to achieve the same yield as the intercrops. When the LER is >1, intercropping favours the growth and yield of the species. By contrast, when LER <1, intercropping negatively affects the growth and yield of the plants grown in mixtures (Caballero *et al.*, 1995). LER was calculated as following:

$$\text{LER} = \text{LER}_a + \text{LER}_b$$

$$\text{LER}_a = \frac{Y_{ab}}{Y_{aa}} \;;\; \text{LER}_b = \frac{Y_{ba}}{Y_{bb}}$$

Where, LER_a and LER_b are the partial LER of intercrops 'a' and 'b' respectively. Y_{ab} is yield of crop 'a' when grown with crop 'b' and Y_{ba} is yield of crop 'b' when grown with crop 'a'; Y_{aa} and Y_{bb} are the yields of crops 'a' and 'b' grown as sole crops under those conditions with which comparison are to be made.

Analysis of variance method was used for pooled statistical analysis of both the crop growing seasons of 2013-14 and 2014-15 and for drawing conclusions. The significance of various sources of variation was tested by error mean square by Fisher-Snedecor's "F" Test at probability level 0.05 (Cochran and Cox, 1955, Panse and Sukhatme, 1967). For comparison of 'F' tables and for computation of critical differences, Fisher and Yates table was consulted.

RESULTS AND DISCUSSION

Yield attributing characters

There were significant effects of row orientation and intercropping systems on the number of ears m^{-1} row length and number of grains ear^{-1} in wheat (Table 1). In pooled analysis of two years data both the number of ears m^{-1} row length (84.3) and number of grains ear^{-1} (63.2) were significantly higher in east-west row orientation as compared to the number of ears m^{-1} row length (77.8) and number of grains ear^{-1} (57.1) in north-south row orientation. Among the intercropping systems maximum (83.9) number of ears m^{-1} row length were observed in wheat + spinach intercropping system which was statistically at par with wheat + fenugreek (82.5), wheat + fodder oat (80.9) and wheat + linseed (79.4) but significantly higher than wheat + canola (75.2) intercropping system (pooled analysis of two years data). Highest number of grains ear^{-1} were recorded in sole bed planted wheat (62.7) which was statistically at par with wheat + spinach (61.5), wheat + fenugreek (60.9), wheat + fodder oat (60.3) but significantly higher than wheat + linseed (58.7) and wheat + canola (54.8) intercropping systems (pooled analysis of two years data). In pooled analysis of two year data, wheat + canola intercropping system resulted in significantly lower number of ears m^{-1} row length (75.2) and grains ear^{-1} (54.8) as compared to sole bed planted wheat and other wheat based intercropping systems. Kumar (2008) and Khan *et al*., (2005) reported similar findings. They observed that wheat intercropped with Indian mustard resulted in significantly lower grain yield and yield attributes. Row orientations and the intercropping systems did not significantly influence the 1000-seed weight.

Grain, straw yield and harvest index of wheat

Grain and straw yield of wheat was significantly influenced by row orientation and intercropping systems (Table 2). The data showed that grain and straw yield of wheat was significantly higher in east-west row orientation and they varied from 53.6 to 56.7 and 69.0 to 69.8 q ha^{-1}, respectively. In general, selection of east-west row orientation was better for grain yield (Table 2). This might be due to more number of ears m^{-1} row length, grains ear^{-1} and higher biomass production in this planting condition. Wheat grown on beds with an east-west orientation has been reported to produce more number of ears $area^{-1}$, grains ear^{-1} and higher grain yields than wheat planted on beds with a north-south orientation (Day *et al*., 1976). These results are also confirmed by Hozayn *et al*., (2012) and Borger *et al*., (2010). However, some authors have reported north-south direction as the best option for wheat sowing (Lyon *et al*., 2006). Flat sowing of wheat cultivars (PBW-12, HD-2009 and WL-1562) had higher average yield in north-south row orientation than in east-west row orientation (Dhingra *et al*., 1986). No effect of row orientation was observed on the fraction of radiation intercepted (F), radiation use efficiency (RUE) and the harvest index (HI). Effect of row orientation on intercrop and sole crop efficiency was negligible (Tsubo *et al*., 2003).

Wheat + canola intercropping system recorded the significantly lower grain yield as compared to the sole bed planted wheat and other intercropping system during the growing seasons of 2013-14 and 2014-15. It is because in intercropping system, canola was more exposed to the sun and wheat suffered more as it was growing under the canola canopy. Similar findings were also reported by Kumar (2008) and Khan *et al*., (2005). The data showed that higher value of straw yield of wheat was observed in sole bed panted wheat (70.6 and 69.5 q ha^{-1}) which was on par with the wheat + spinach (70.2 and 69.3 q ha^{-1}), wheat + fenugreek (69.5 and 66.6 q ha^{-1}) but significantly higher than wheat + fodder oat (64.4 and 65.7 q ha^{-1}), wheat + linseed (60.4 and 60.1 q ha^{-1}) and wheat + canola (59.4, 59.3 q ha^{-1}) intercropping systems. Significantly lower straw yield were observed in wheat + linseed and wheat + canola intercropping systems than the rest of the intercropping systems during both the years. Harvest index was not affected significantly in relation to row orientation and the intercropping systems.

Intercrop yield, wheat equivalent yield and system productivity

Yield of intercrops was not affected in relation to row orientation during both the growing seasons. Sole planting of the component crops resulted higher yield than planting as intercrops (Table 3). All these intercrops possess different nature of growth habit, duration, rooting pattern and canopy structure. Therefore, these crops differ in yield potential and possess differential competitive ability in intercropping systems. Yield potential of the intercrops was significantly higher in fodder oat and canola as compared to linseed, spinach and fenugreek in intercropping systems irrespective of their sole planting. WEY and system productivity were significantly higher in east-west row orientation (55.7 q ha^{-1}, 35.0 kg ha^{-1} day^{-1}) as compared to north-south (49.9 q $ha^{-1}$and 31.4 kg ha^{-1} day^{-1}) row orientation (pooled data of two years). Wheat + fodder oat intercropping system produced significantly higher wheat equivalent yield (70.3 q ha^{-1}) and the system productivity (44.2 kg ha^{-1} day^{-1}) than the other wheat based intercropping systems and their respective sole planting of wheat and the component crops (Table 3).

Economic returns

Crop raised in east-west row orientation resulted insignificantly higher values of gross returns (₹ 85,870 ha^{-1}), net returns (₹ 58,000 ha^{-1}) and benefit cost ratio (2.20) as compared gross returns (₹ 77,070 ha^{-1}), net returns (₹ 49,200 ha^{-1}) and benefit cost ratio (1.91) of the crop raised in north-south row orientation (Table 3). Wheat + fodder oat intercropping system produced significantly higher value of gross returns (₹ 110,680 ha^{-1}) and net returns (₹ 76,340 ha^{-1}) than the other wheat based intercropping systems and their respective sole planting. Wheat +fodder oat and wheat + spinach intercropping systems showed significantly higher value of net returns than the sole bed planted wheat, whereas, wheat + fenugreek and wheat + canola intercropping systems resulted in statistically at par but lower value of net returns than the sole bed planted wheat. Wheat + linseed intercropping system recorded significantly lower value of net returns than the sole bed planted wheat. Among the intercropping systems wheat + fodder oat (2.22) showed significantly higher value of benefit cost ratio as compared to other intercropping system and sole planting of wheat.

Table 1: Effect of row orientations and intercropping systems on yield attributing characters of bed planted wheat

Treatment	Ears m^{-1} row length (No.)			Grains ear^{-1} (No.)			1000-seed weight (g)		
	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled
Row orientation									
N-S	75.50	80.20	77.80	54.50	59.60	57.10	39.50	42.70	41.10
E-W	81.30	87.40	84.30	61.40	64.90	63.20	41.10	44.10	42.60
SEM	**1.10**	**1.40**	**0.90**	**0.80**	**1.00**	**0.70**	**0.78**	**0.77**	**0.74**
CD (p=0.05)	**5.10**	**6.40**	**3.10**	**3.60**	**3.90**	**2.10**	**ns**	**ns**	**Ns**
Intercropping system									
W+S	80.50	87.30	83.90	59.50	63.50	61.50	42.00	44.20	43.10
W+F	79.70	85.30	82.50	59.00	62.70	60.90	40.80	43.70	42.30
W+FO	78.10	83.80	80.90	58.00	62.40	60.30	39.70	43.10	41.40
W+C	73.60	76.80	75.20	52.70	56.80	54.80	38.10	41.60	40.00
W+L	77.40	81.50	79.40	56.30	61.00	58.70	38.40	42.90	40.70
SW	81.10	88.30	84.70	60.40	65.00	62.70	42.70	44.80	43.70
SEM	**1.60**	**3.50**	**1.40**	**1.00**	**0.90**	**0.80**	**1.54**	**1.26**	**1.23**
CD (p=0.05)	**4.50**	**7.10**	**4.70**	**3.40**	**2.70**	**3.10**	**ns**	**ns**	**ns**

N-S = North-south; E-W = East-west; W+S = Wheat+spinach; W+F = Wheat+fenugreek; W+FO = Wheat+fodder oat; W+C = Wheat+canola; W+L = Wheat+linseed; SW = Sole wheat; ns = Non-significant

Table 2: Effect of row orientations and intercropping systems on grain yield, straw yield and harvest index of bed planted wheat

Treatment	Grain yield (q ha^{-1})			Straw yield (q ha^{-1})			Harvest index
	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled	
Row orientation							
N-S	46.80	49.40	48.10	62.90	60.50	61.70	44.20
E-W	53.60	56.70	55.10	69.00	69.80	69.40	44.60
SEM	**0.60**	**0.50**	**0.40**	**1.10**	**1.30**	**0.80**	**1.20**
CD (p=0.05)	**2.80**	**2.50**	**1.40**	**5.10**	**5.90**	**3.00**	**ns**
Intercropping system							
W+S	52.80	56.90	54.90	70.20	69.30	69.90	44.10
W+F	51.80	55.60	53.70	69.50	66.60	68.00	44.50
W+FO	50.10	52.90	51.50	64.40	65.70	65.20	44.40
W+C	43.60	43.10	43.30	59.40	59.30	59.40	43.00
W+L	49.70	52.00	50.80	60.40	60.10	60.30	46.00
SW	53.60	57.70	55.70	70.60	69.50	70.00	44.40
SEM	**1.50**	**2.30**	**1.40**	**1.10**	**1.20**	**1.10**	**2.20**
CD (p=0.05)	**4.50**	**6.80**	**4.70**	**3.30**	**3.50**	**3.70**	**ns**

N-S = North-south; E-W = East-west; W+S = Wheat+spinach; W+F = Wheat+fenugreek; W+FO = Wheat+fodder oat; W+C = Wheat+canola; W+L = Wheat+linseed; SW = Sole wheat; ns = Non-significant

Land equivalent ratio (LER)

Intercropping advantage in terms of LER indicated that there was no significant effect of row orientation in LER of wheat and other component crops (Table 4). The data on LER of different intercropping systems showed that LER values were greater than one in all the intercropping systems and it indicated yield advantage over monocropping due to the better utilization of environmental resources in both the growing seasons. Mengping and Zhangjinsong, (2004) also reported that intercropping system showed higher LER than the sole planting of crops. Values of partial LER of wheat were higher than the partial LER of intercrops. Partial LER of any of the intercrops was not more than 0.5, so none

Table 3: Effect of row orientations and intercropping systems on yield and economic viability of bed planted wheat based intercropping systems expressed in terms of wheat equivalent yield, system productivity and economic returns (pooled data of two years)

Treatment	Intercrop yield (q ha^{-1})	Wheat equivalent yield (q ha^{-1})	System productivity (kg ha^{-1}day^{-1})	Gross returns [₹] (x 10^3 ϕ ha^{-1})	Net returns [₹] (x 10^3 ϕ ha^{-1})	Benefit Cost ratio
Row orientation						
N-S	101.40	49.90	31.40	77.07	49.20	1.91
E-W	101.50	55.70	35.00	85.87	58.00	2.20
SEM		**0.41**	**0.27**	**0.51**	**0.51**	**0.01**
CD (p=0.05)	**-**	**1.25**	**0.71**	**1.71**	**1.58**	**0.04**
Intercropping system						
W+S	32.90	62.50	39.30	101.49	67.43	2.04
W+F	12.80	57.90	36.40	93.97	59.78	1.75
W+FO	168.60	70.30	44.20	110.68	76.34	2.22
W+C	8.00	59.80	37.60	97.92	59.56	1.55
W+L	2.30	56.70	35.80	90.90	55.30	1.55
SS	229.50	57.90	36.50	80.33	63.75	3.85
SF	156.70	50.90	32.00	70.52	53.74	3.21
SFO	373.10	41.60	26.10	57.89	39.79	2.19
SC	19.90	40.90	25.70	64.17	40.32	1.67
SL	10.60	26.60	16.80	37.01	12.48	0.51
SW	-	55.70	34.90	91.30	61.11	2.02
SEM		**1.61**	**1.22**	**2.04**	**2.01**	**0.06**
CD (p=0.05)	**-**	**4.20**	**2.60**	**5.40**	**5.35**	**0.16**

N-S=North-south; E-W=East-west; W+S=Wheat+spinach; W+F=Wheat+fenugreek; W+FO=Wheat+fodder oat; W+C=Wheat+canola; W+L=Wheat+linseed; SS= Sole spinach; SF= Sole fenugreek; SFO= Sole fodder oat; SC= Sole canola; SL= Sole linseed; SW= Sole wheat

Table 4: Land equivalent ratio (LER) of bed planted wheat based intercropping systems in relation to row orientations and intercrops

Treatment	2012-13			2013-14		
	Wheat	Intercrop	System (W+IC)	Wheat	Inter-crop	System (W+IC)
Row orientation						
N-S	0.92	0.25	1.17	0.91	0.26	1.15
E-W	0.93	0.27	1.20	0.91	0.28	1.18
SEM	**0.03**	**0.01**	**0.03**	**0.03**	**0.01**	**0.04**
CD (p=0.05)	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
Intercropping system						
W+S	0.98	0.15	1.13	0.99	0.14	1.11
W+F	0.97	0.09	1.05	0.98	0.07	1.06
W+FO	0.94	0.46	1.39	0.92	0.46	1.37
W+C	0.82	0.39	1.20	0.75	0.42	1.18
W+L	0.93	0.23	1.15	0.91	0.21	1.11
SEM	**0.03**	**0.01**	**0.04**	**0.02**	**0.01**	**0.04**
CD (p=0.05)	**0.09**	**0.02**	**0.11**	**0.09**	**0.03**	**0.12**

N-S=North-south; E-W=East-west; W+S=Wheat+spinach; W+F=Wheat+fenugreek; W+FO=Wheat+ fodder oat; W+C=Wheat + canola; W+L=Wheat + linseed; IC= Intercrop; ns=Non-significant of the intercropping systems had negative effect on partial LER of wheat (Chen *et al.,* 2004). Value from Table 4 showed that partial LER of wheat was significantly lower in wheat + canola intercropping system than other intercropping systems in both the growing seasons of 2013-14 and 2014-15. Values of partial LER of intercrops were significantly higher in fodder oat, followed by canola> linseed> spinach> fenugreek in both the growing seasons. Wheat + fodder oat intercropping system showed the significantly higher value of LER as compared to other intercropping systems.

From the study, it is concluded that there were higher yield advantage (grain and straw), wheat equivalent yield, system productivity and economic returns (gross, net returns and benefit cost ratio) by raising the wheat crop in east-west row orientation as compared to north-south row orientation. Yield of intercrops was not affected in relation to row orientation. Wheat + fodder oat intercropping system produced significantly higher wheat equivalent yield, system productivity and the economic returns than the other wheat based intercropping systems and sole planting of wheat and the component crops. Wheat + fodder oat intercropping system showed the significantly higher value of benefit cost ratio and LER as compared to sole bed planted wheat and the rest of the intercropping systems.

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