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Research Article

Yield and Water Use Efficiency of Oilseed *Brassica* Species as Influenced by Irrigation Levels under Normal and Late Sown Conditions in Central Punjab

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ABSTRACT

A field study was conducted during three consecutive *rabi* seasons of 2003-04, 2004-05 and 2005-06 to characterize the water use efficiency (WUE) of oilseed *Brassica* species, viz, *Brassica juncea* (V_1:cv. RL-1359) and *Brassica napus* (V_2: cv.PGSH-51; V_3: cv.PAC-401) sown on two dates (D_1-1st week of November and D_2 – 1st week of December). Three water application treatments were marked with progressively increasing amount of irrigation (I_1, I_2 and I_3 with one, two and three post-sowing irrigations, respectively). Soil water extraction was found minimum under I_1 treatment with minimum number of irrigations and maximum under I_3 treatment with maximum number of irrigations for all the cultivars. Dry matter production and seed yield were also maximum in I_3 followed by I_2 and I_1 in the decreasing order. Delayed sowing reduced the yield and yield contributing characters in all the cultivars under all the irrigation levels. Hence, delayed sowing increased the consumptive water use but decreased the water use efficiency of all the cultivars.

Key words: Water use efficiency, *Brassica juncea*, *Brassica napus*, Irrigation, Sowing time

Introduction

With an increasing population and decreasing water availability for agricultural production, the food security for future generations is at stake. The agricultural sector faces the challenge to produce more food with less water by increasing crop water productivity. A higher crop water productivity results in either the same production from less water resources or a higher production from the same water resources (Zwart and Bastiaanssen, 2004). With good management and adoption of appropriate practices, improved agricultural water conservation and subsequent use of that water, more efficient crop production are possible under both dryland and irrigated conditions (Wang *et al.*, 2004).

Efficient and sustainable agricultural production requires that we continue to strive for systems that are efficient in the use of water and nutrients (Hatfield, 2001). Water deficit is a major limiting factor for crop production in the world. Under such constraints, emphasis needs to be focused on increasing water use efficiency (WUE) of the crops. This can be possible through proper irrigation scheduling, i.e., by providing the water as per the crop evapo-transpiration requirements and at critical growth stages (Wang *et al.*, 2001; Norwood and Dumler, 2002 and Kar *et al.*, 2005). Oweis *et al. (*2000) observed that in the Mediterranean rainfed environment, WUE could be substantially improved by adopting deficit

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supplemental irrigation to satisfy upto 2/3 of irrigation requirements alongwith early sowing and appropriate nitrogen levels. Kar *et al.* (2007) observed a significant increase in water use efficiency of mustard by increasing irrigations from two to three.

In last few decades there has been continuous lowering of water table in Punjab and as a result the water for irrigation is becoming both scarce and expensive. Oilseed crops are next to cereals in the agricultural economy of India being less water requiring and important source of fats and proteins. In Punjab, rapeseed and mustard were grown on 27 thousand ha during 2008-09 with a production of 33 thousand tons and an average yield of 12.04 q/ha (Annonymous, 2010). These crops grow well on well drained light to medium textured soils in areas having 25 to 40 cm rainfall. Thus, crop diversification alternatives are required to be explored under limited water conditions in Punjab. The present study was, therefore, undertaken to evaluate the water productivity of oilseed *Brassica* species under different sowing dates and irrigation levels.

Material and Methods

Experimental Site

The field experiments were conducted at the research farm, Department of Agricultural Meteorology, Punjab Agricultural University, Ludhiana during *Rabi* 2003-04, 2004-05 and 2005-06. Ludhiana is situated at 30°54′ N latitude, 75°48′ E longitude and at an elevation of 247m above m.s.l. and has semi-arid climate with hot summer and mild winter seasons. The maximum and minimum temperature during the crop season are 24.5 and 9.7 °C, respectively and the rainfall is 127 mm. The actual weekly meteorological parameters are presented in Fig. 1. The soil of the experimental field was sandy loam in texture.

Experimental Treatments

The experiment consisted of a combination of oilseed *Brassica* species namely *Brassica juncea* (V_1:cv. RL-1359) and *Brassica napus* (V_2: cv.PGSH-51; V_3: cv.PAC-401) sown on two dates (D_1-1st week of November and D_2 – 1st week of December) and three irrigation levels namely I_1 (pre-sowing irrigation + irrigation at flowering), I_2 (pre-sowing irrigation + 30 DAS + irrigation at flowering) and I_3 (pre-sowing irrigation + 30 DAS + at flowering + irrigation at pod development). The crop received nutrients @40 kg N/ha and 12 kg P_2O_5/ha. Half of nitrogen and full amount of phosphorus was applied as a basal dose while the remaining half of nitrogen was applied 30 days after sowing.

Data Recorded

Soil Water Extraction

Soil water retention in the 120 cm root zone was monitored by using neutron probe regularly from sowing to crop maturity at 15 days interval, and in addition immediately before as well as 24-48 hrs after each irrigation. Total water use during growth season of the crop was obtained by adding depletion of root zone soil moisture between successive sampling intervals. Soil moisture retention at soil moisture sampling is given by:

$$\text{Root zone water retention} = \sum_{i=1}^{n} D_j \qquad \ldots(1)$$

where "i" is soil depth interval (0-15, 15-30, 30-60, 60-90 and 90-120 cm) and D_j is the depth of water retained in the respective soil depth intervals.

To compute soil water use by the crop, the difference in soil water retention for the two successive samplings was taken as soil water use by the crop, assuming that no deep drainage (or percolation) occurred below the root zone. From the date of each irrigation to the day of next soil moisture sampling, the daily rate of actual pan evaporation was considered.

Biometric Parameters

Dry matter accumulation was recorded at periodic intervals starting at 35 DAS. Plant samples were collected periodically at 15-day intervals and dry matter accumulation was

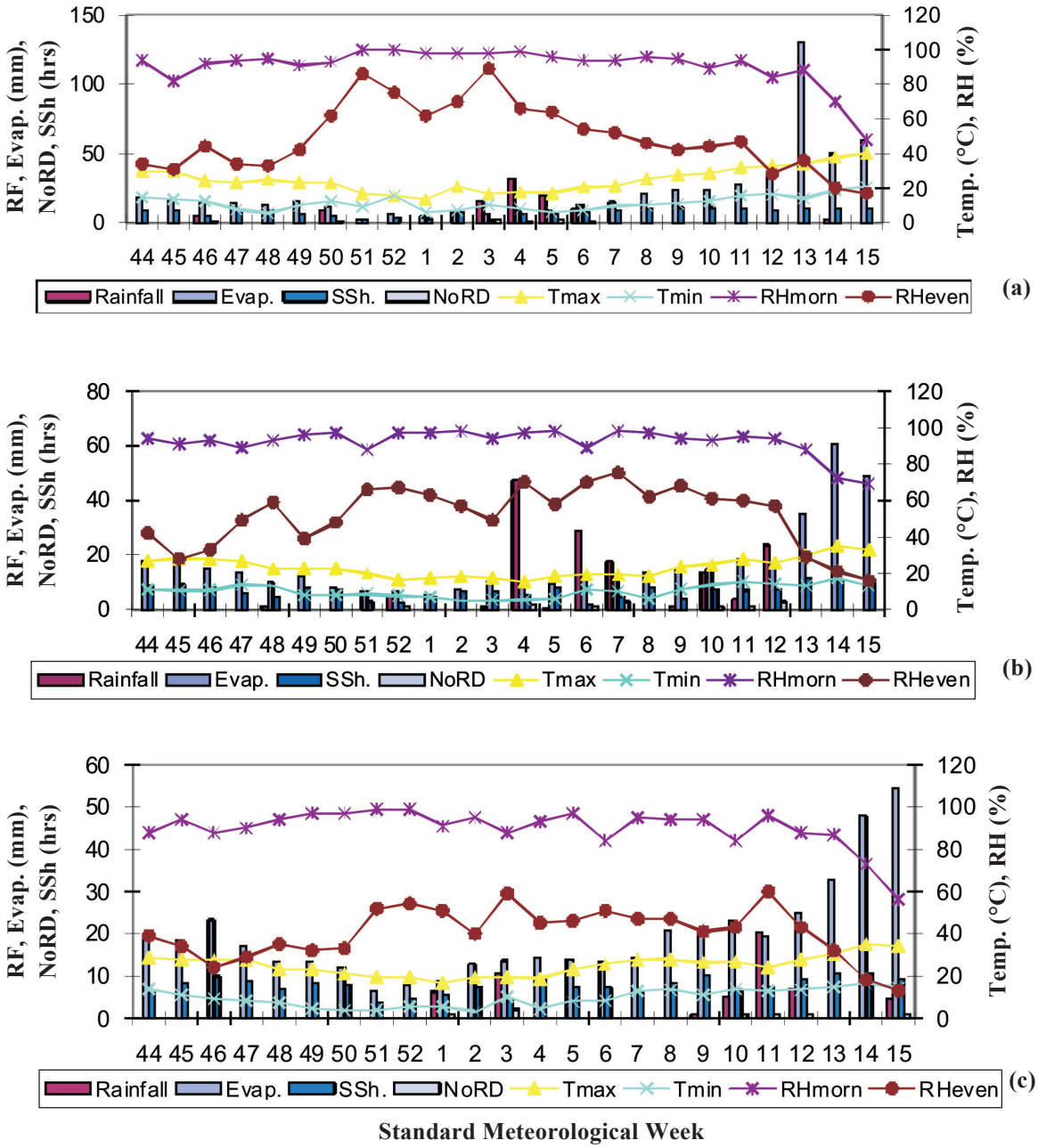

Fig. 1. Weekly meteorological conditions during the three crop seasons of oilseed brassica species (a) *rabi* 2003-04 (b) *rabi* 2004-05 (c) *rabi* 2005-06

recorded. Grain yield and straw yields were recorded at the time of harvesting of the crop. Yield attributing characters namely, number of primary branches (#/m^2), number of secondary branches (#/m^2), number of seeds per pod and 1000-seed weight etc., were also recorded at the time of harvesting.

Water use efficiency

Water use efficiency (WUE) for seed and straw yield was calculated by using the relationship:

$$\text{WUE (kg/ha/mm)} = \frac{\text{Seed or Straw Yield (kg/ha)}}{\text{Total water use (mm)}} \quad \ldots(2)$$

Results and Discussion

Soil Water Extraction by Oilseed Brassica species

Amongst the three irrigation levels, soil moisture extraction was found to be highest under I_3 i.e. the maximum water application treatment and minimum under I_1 i.e. minimum water application treatment. Not much differences were found amongst the species regarding the soil moisture extraction. During 2003-04, I_1 treatment extracted 276mm, I_2 352mm and I_3 446mm of water in first date of sowing irrespective of the varieties, whereas in the second date of sowing I_1 extracted 313mm, I_2 389mm and I_3 437mm of water during the entire growing season of the crop (Table 1).

Similarly during 2004-05, I_1, I_2 and I_3 treatments extracted 295, 367 and 413mm water, respectively under first date of sowing and 249, 336 and 403mm, respectively during second date of sowing; whereas during 2005-06, the corresponding irrigation treatments extracted 247, 320 and 406mm water under first date of sowing and 280, 374 and 448mm under second date of sowing. The data indicated that there was not much variation in soil water extraction among the cultivars as well as dates of sowing. But irrigation treatments showed a significant impact on moisture extraction pattern of the crop.

Yield Attributing Characters of Oilseed Brassica species

The data on yield attributing characters of the oilseed brassica species namely *Brassica juncea* (V_1:cv. RL-1359), *Brassica napus* (V_2: cv.PGSH-51; V_3: cv.PAC-401) under different sowing and irrigation treatments and crop years are presented in Table 2, 3 and 4, respectively. The perusal of the data revealed that the November sown crop yielded higher yield attributing characters, namely number of primary and secondary branches per unit area, number of seeds per pod and 1000-seed weight. Yadav *et al.* (1999) also reported significant increase in crop growth parameters in

Table 1. Soil water extraction by oilseed *Brassica* species under different dates of sowing and irrigation levels

Cultivar	D_1: 1st week November			Mean	D_2: 1st week December			Mean
	I_1	I_2	I_3		I_1	I_2	I_3	
				***Rabi* 2003-04**				
RL-1359	270.4	333.2	433.0	345.5	315.9	389.7	434.6	380.1
PGSH-51	271.4	346.2	444.6	354.1	307.9	389.7	441.6	379.7
PAC-401	286.4	377.2	461.0	374.9	313.9	386.7	434.6	378.4
Mean	276.1	352.2	446.2		312.6	388.7	436.9	
				***Rabi* 2004-05**				
RL-1359	334.1	369.9	392.6	365.5	270.6	331.6	388.6	330.3
PGSH-51	273.1	352.9	420.9	349.0	227.6	358.5	398.6	328.2
PAC-401	276.6	377.2	423.9	359.2	248.6	316.6	420.9	328.7
Mean	294.6	366.7	412.5		248.9	335.6	402.7	
				***Rabi* 2005-06**				
RL-1359	264.4	312.4	388.0	321.6	305.1	392.7	424.9	374.2
PGSH-51	239.9	354.9	434.5	343.1	286.5	389.1	464.3	380.0
PAC-401	236.4	293.4	395.0	308.3	248.9	339.5	453.7	347.4
Mean	246.9	320.2	405.8		280.2	373.8	447.6	

I_1: Pre-sowing irrigation + irrigation at flowering

I_2: Pre-sowing irrigation + irrigation at 30DAS + irrigation at flowering

I_3: I_2 + irrigation at pod development

Table 2. Effect of time of sowing and irrigation levels on the yield attributing characters of *Brassica juncea* (cv. RL-1359)

Yield attributes	D_1: I[st] week of Nov.			Mean	D_2: I[st] week of Dec.			Mean
	I_1	I_2	I_3		I_1	I_2	I_3	
				***Rabi* 2003-04**				
Primary branches (#/m^2)	41	45	47	44	39	42	42	41
Secondary branches (#/m^2)	75	89	93	86	60	56	69	62
No. of seeds/pod (#)	9	11	11	10	10	10	11	10
1000-seed weight (g)	3.1	3.2	3.3	3.2	3.0	3.1	3.3	3.1
				***Rabi* 2004-05**				
Primary branches(#/m^2)	37	39	40	39	33	34	34	34
Secondary branches(#/m^2)	48	65	67	60	61	66	70	66
No. of seeds/pod (#)	15	16	16	16	11	13	13	12
1000-seed weight (g)	2.9	3.0	3.1	3.0	3.1	3.1	3.3	3.2
				***Rabi* 2005-06**				
Primary branches(#/m^2)	34	33	35	34	39	33	32	35
Secondary branches(#/m^2)	59	62	63	61	74	80	82	79
No. of seeds/pod (#)	15	16	16	16	14	15	16	15
1000-seed weight (g)	3.0	3.2	3.5	3.2	3.5	3.8	3.9	4.0

I_1: Pre-sowing irrigation + irrigation at flowering

I_2: Pre-sowing irrigation + irrigation at 30DAS + irrigation at flowering

I_3: I_2 + irrigation at pod development

Table 3. Effect of time of sowing and irrigation levels on the yield attributing characters of *Brassica napus* (cv. PGSH-51)

Yield attributes	D_1: I[st] week of Nov.			Mean	D_2: I[st] week of Dec.			Mean
	I_1	I_2	I_3		I_1	I_2	I_3	
				***Rabi* 2003-04**				
Primary branches(#/m^2)	44	50	57	50	44	38	38	40
Secondary branches(#/m^2)	77	82	99	86	45	22	35	34
No. of seeds/pod (#)	17	18	20	18	17	19	20	19
1000-seed weight (g)	3.1	3.3	3.6	3.3	2.9	2.9	3.1	3.0
				***Rabi* 2004-05**				
Primary branches(#/m^2)	40	41	41	41	35	36	36	36
Secondary branches(#/m^2)	77	79	79	78	70	77	80	76
No. of seeds/pod (#)	19	21	22	21	15	16	16	15
1000-seed weight (g)	3.2	3.2	3.3	3.2	3.4	3.6	3.6	3.5
				***Rabi* 2005-06**				
Primary branches(#/m^2)	38	37	38	37	37	33	35	35
Secondary branches(#/m^2)	75	60	66	67	71	72	81	75
No. of seeds/pod (#)	18	19	20	19	17	17	17	17
1000-seed weight (g)	3.4	3.2	3.3	3.3	3.4	3.4	3.7	3.5

I_1: Pre-sowing irrigation + irrigation at flowering

I_2: Pre-sowing irrigation + irrigation at 30DAS + irrigation at flowering

I_3: I_2 + irrigation at pod development

Table 4. Effect of time of sowing and irrigation levels on the yield attributing characters of *Brassica napus* (cv. PAC-401)

Yield attributes	D_1: Ist week of Nov.			Mean	D_2: Ist week of Dec.			Mean
	I_1	I_2	I_3		I_1	I_2	I_3	
				***Rabi* 2003-04**				
Primary branches(#/m^2)	41	39	46	42	41	45	41	42
Secondary branches(#/m^2)	55	46	80	60	45	41	45	44
No. of seeds/pod (#)	15	14	17	15	17	14	17	16
1000-seed weight (g)	3.1	3.0	3.2	3.1	2.9	2.8	3.0	2.9
				***Rabi* 2004-05**				
Primary branches(#/m^2)	41	48	48	46	39	39	40	40
Secondary branches(#/m^2)	86	105	145	112	81	81	103	88
No. of seeds/pod (#)	23	25	26	25	16	17	17	17
1000-seed weight (g)	3.4	3.4	3.6	3.5	3.7	3.7	4.1	3.8
				***Rabi* 2005-06**				
Primary branches(#/m^2)	45	47	46	46	36	38	37	37
Secondary branches(#/m^2)	93	99	100	97	63	70	71	68
No. of seeds/pod (#)	22	23	25	23	16	17	19	17
1000-seed weight (g)	3.6	3.5	3.5	3.5	3.3	3.3	3.4	3.3

I_1: Pre-sowing irrigation + irrigation at flowering

I_2: Pre-sowing irrigation + irrigation at 30DAS + irrigation at flowering

I_3: I_2 + irrigation at pod development

timely sown mustard crop. Amongst the three irrigation levels, highest value of yield attributing characters were found under I_3 (maximum water application) followed by I_2 and I_1 (minimum water application) treatment in the decreasing order. Although, the yield attributing characters increased with increase in irrigation application, but delayed sowing decreased the value of most of the yield attributing characters (Table 2).

Amongst the three cultivars, cv. PAC-401 gave higher yield contributing attributes under second date of sowing. However, under early sowing, *Brassica juncea* cv. RL-1359 invariably performed better and *Brassica napus* cv. PGSH-51 and cv. PAC-401 performed better under late sowing environment. This may be attributed to longer and prolonged vegetative growth period of *Brassica napus* cultivars as compared to *Brassica juncea* cultivars.

Yield and Water Use Efficiency of Oilseed Brassica species

The data on seed and straw yield and water use efficiency (WUE) of the oilseed brassica species namely *Brassica juncea* (V_1:cv. RL-1359), *Brassica napus* (V_2: cv.PGSH-51; V_3: cv.PAC-401) under different sowing and irrigation treatments and crop years are presented in Table 5, 6 and 7, respectively. Seed as well as straw yield increased with irrigation application in all the cultivars. Timely sown crop yielded higher as compared to late sown crop. Saikia *et al.* (2009) also reported that early sown crop is exposed to such meteorological conditions that better yield is obtained. In general, the WUE for straw and seed yield decreased with increased water application for the three oilseed *Brassica* cultivars. Singh *et al.* (2001) also observed that higher number of irrigations increased the

Table 5. Water use efficiency of *Brassica juncea* (cv. RL-1359) under different dates of sowing and irrigation levels

Date of sowing	Irrigation level	Water use (mm)	Yield (Kg/ha)		Water use efficiency (Kg/ha/mm)	
			Straw	Seed	Straw	Seed
			***Rabi* 2003-04**			
D_1 : 1st week November	I_1	270.4	3571.4	725.4	13.21	2.68
	I_2	333.2	4427.1	954.2	13.29	2.86
	I_3	433.0	5487.4	1068.6	12.67	2.47
D_2: 1st week December	I_1	315.9	1971.7	372.0	6.24	1.18
	I_2	389.7	2529.8	455.7	6.49	1.17
	I_3	434.7	2250.7	583.6	5.18	1.34
			***Rabi* 2004-05**			
D_1 : 1st week November	I_1	334.1	3638.0	731.9	10.89	2.19
	I_2	369.9	3946.0	751.8	10.67	2.03
	I_3	392.6	4167.0	853.2	10.61	2.17
D_2: 1st week December	I_1	270.6	1367.0	196.2	5.05	0.72
	I_2	331.6	1389.0	242.5	4.19	0.73
	I_3	388.6	1940.0	246.9	4.99	0.63
			***Rabi* 2005-06**			
D_1 : 1st week November	I_1	264.4	4409.0	859.0	16.67	3.25
	I_2	312.4	4459.0	985.0	14.27	3.15
	I_3	388.0	4504.0	1118.0	11.61	2.88
D_2: 1st week December	I_1	305.1	878.0	224.0	2.88	0.73
	I_2	392.7	1074.0	337.0	2.73	0.86
	I_3	424.9	1571.0	391.0	3.70	0.92

I_1: Pre-sowing irrigation + irrigation at flowering

I_2: Pre-sowing irrigation + irrigation at 30DAS + irrigation at flowering

I_3: I_2 + irrigation at pod development

consumptive use of water but decreased the water use efficiency of Indian mustard. Water use efficiency was higher under normal sown crop and it decreased under late sown conditions. Amongst the three cultivars, highest WUE for straw and seed was noted for oilseed *Brassica napus* cv. PAC-401 under early (November) sown environments. But under late (December) sown environment, higher WUE for straw and seed was noted for *Brassica juncea* cv. RL-1359.

In *Brassica juncea* cv. RL-1359, the WUE for straw and seed yield was maximum during crop year 2005-06 followed by crop year 2003-04 and 2004-05 in decreasing order for November sown crop (Table 5). For December sown crop, the WUE for straw was maximum during crop year 2003-04, followed by crop year 2004-05 and 2005-06 in decreasing order. But the WUE for seed was maximum during crop year 2005-06, followed by crop year 2004-05 and 2003-04 in decreasing order.

In *Brassica napus* cv. PGSH-51, the WUE for straw and seed yield was maximum during crop year 2003-04 followed by crop year 2004-05 and 2005-06 in decreasing order for December sown crop (Table 6). For November sown crop,

Table 6. Water use efficiency of *Brassica napus* (cv. PGSH-51) under different dates of sowing and irrigation levels

Date of sowing	Irrigation level	Water use (mm)	Yield (Kg/ha)		Water use efficiency (Kg/ha/mm)	
			Straw	Seed	Straw	Seed
			***Rabi* 2003-04**			
D_1 : 1st week November	I_1	271.4	4278.3	645.5	15.76	2.38
	I_2	346.2	5013.0	757.1	14.48	2.19
	I_3	444.6	5124.6	868.2	11.52	1.95
D_2: 1st week December	I_1	307.9	2613.5	390.6	8.49	1.26
	I_2	389.7	3143.6	388.8	8.07	1.00
	I_3	441.6	3571.4	442.7	8.09	1.00
			***Rabi* 2004-05**			
D_1 : 1st week November	I_1	273.1	4255.0	687.8	15.58	2.52
	I_2	352.9	4387.0	637.1	12.43	1.80
	I_3	420.9	4608.0	941.4	10.95	2.23
D_2: 1st week December	I_1	227.6	1984.0	343.9	8.72	1.51
	I_2	358.5	2006.0	366.0	5.59	1.02
	I_3	420.6	2447.0	606.3	5.82	1.44
			***Rabi* 2005-06**			
D_1 : 1st week November	I_1	239.9	2069.0	620.0	8.62	2.58
	I_2	354.9	2479.0	849.0	9.98	2.39
	I_3	434.5	2686.0	907.0	6.18	2.09
D_2: 1st week December	I_1	286.5	1629.0	244.0	5.68	0.85
	I_2	389.1	1894.0	311.0	4.87	0.80
	I_3	464.3	2422.0	378.0	5.22	0.81

I_1: Pre-sowing irrigation + irrigation at flowering

I_2: Pre-sowing irrigation + irrigation at 30DAS + irrigation at flowering

I_3: I_2 + irrigation at pod development

the WUE for straw was maximum during crop year 2003-04, followed by crop year 2004-05 and 2005-06 in decreasing order. But the WUE for seed was maximum during crop year 2005-06, followed by crop year 2004-05 and 2003-04 in decreasing order.

In *Brassica napus* cv. PAC-401, the WUE for straw and seed yield was maximum during crop year 2005-06 followed by crop year 2004-05 and 2003-04 in decreasing order for November sown crop (Table 7). For December sown crop, the WUE for straw was maximum during crop year 2003-04, followed by crop year 2004-05 and 2005-06 in decreasing order. But the WUE for seed was maximum during crop year 2004-05, followed by crop year 2005-06 and 2003-04 in decreasing order. Tesfamariam *et al.* (2010) also observed that well watered control gave highest value of water use and seed yield; whereas water stress at flowering stage gave the lowest values of water use and seed yield in case of *Brassica napus*. They further suggested that in areas with sufficient water supply it would be advisable to irrigate canola according to crop demand throughout the growing season to ensure highest seed yield, but in areas where water scarcity is the crucial issue, high water use efficiency at the expense of some seed and oil yield can be achieved by stressing the crop during the vegetative or grain-filling stages.

Table 7. Water use efficiency of *Brassica napus* (cv. PAC-401) under different dates of sowing and irrigation levels

Date of sowing	Irrigation level	Water use (mm)	Yield (Kg/ha)		Water use efficiency (Kg/ha/mm)	
			Straw	Seed	Straw	Seed
		***Rabi* 2003-04**				
D_1 : 1st week November	I_1	286.4	3683.0	613.3	12.86	2.14
	I_2	377.2	3999.3	711.5	10.61	1.88
	I_3	461.0	4371.3	897.0	9.48	1.94
D_2: 1st week December	I_1	313.9	2576.3	420.8	8.21	1.34
	I_2	386.7	3301.7	488.0	8.54	1.26
	I_3	434.6	3236.6	514.3	7.45	1.18
		***Rabi* 2004-05**				
D_1 : 1st week November	I_1	276.6	4630.0	754.0	16.74	2.72
	I_2	377.2	4850.0	822.3	12.86	2.18
	I_3	423.9	4916.0	725.3	11.60	1.71
D_2: 1st week December	I_1	248.6	2116.0	429.9	8.51	1.73
	I_2	316.6	2293.0	551.1	7.25	1.74
	I_3	420.6	2447.0	606.3	5.82	1.44
		***Rabi* 2005-06**				
D_1 : 1st week November	I_1	236.4	4236.0	1151.0	17.92	4.87
	I_2	293.4	4657.0	1303.0	15.87	4.44
	I_3	395.0	4922.0	1435.0	12.46	3.63
D_2: 1st week December	I_1	248.9	1938.0	376.0	7.78	1.51
	I_2	339.5	3079.0	558.0	9.07	1.64
	I_3	453.7	2473.0	657.0	5.45	1.45

I_1: Pre-sowing irrigation + irrigation at flowering

I_2: Pre-sowing irrigation + irrigation at 30DAS + irrigation at flowering

I_3: I_2 + irrigation at pod development

Conclusions

It was observed that delayed sowing reduced the yield and yield contributing characters in all the cultivars under all the irrigation levels. Hence, delayed sowing increased the consumptive water use but decreased the water use efficiency of all the cultivars. Under normal sowing, water use efficiency with lower water application was higher or comparable than that at higher water application, whereas under delayed sowing, water use efficiency was found higher for higher irrigation application. Hence, it can be concluded that timely sowing with good irrigation management of the crop can help to enhance its water use efficiency.

References

Anonymous. 2010. Package of practices for crops of Punjab – *Rabi* 2010-11, PAU, Ludhiana, pp. 36-48.

Hatfield, J.L., Thomas, S.J., Prueger J.H. 2001. Managing soils to achieve greater water use efficiency: A Review. *Agron J*. **93**: 271-280.

Kar, G., Kumar, A., Marthe, M. 2007. Water use efficiency and crop coefficients of dry season oilseed crops. *Agric. Water Manage.* **87**: 73-82.

Kar, G., Singh, R. and Verma, H.N. 2005. Phenological based irrigation scheduling and determination of crop coefficient of winter maize in rice fallow of eastern India. *Agric. Water Manage.* **75**: 169-183.

Norwood, C.A., Dumler, T.J. 2002. Transition to dryland agriculture: Limited irrigation vs. dryland corn. *Agron. J*. **94**: 310-320.

Oweis, T., Zhang, H., Papa, M. 2000. Water use efficiency of rainfed and irrigated bread wheat in a Mediterranean environment. *Agron. J*. **92**: 231-238.

Saikia, B., Banerjee, S. and Sarkar, S.S. 2009. Crop weather relationship in *Brassica Campestris* var. yellow Sarson grown in gangetic West Bengal. *Journal of Agrometeorology* **11** (Special issue): 67-69.

Singh, J., Singh, B. and Yadav, J.S. 2001. Effect of irrigation on Indian mustard (*Brassica juncea*) sown on conserved moisture. *Indian Journal of Agronomy* **46**(4): 721-726.

Tesfamarium, E. H., J. G. Annandale and J. M. Steyn. 2010. Water stress effects on winter canola growth and yield. *Agron J.* **102**(2): 658-666.

Wang, F.H., Wang, X.Q., Sayre, K. 2004. Conventional flood irrigated flat planting with furrow irrigated raised bed planting for winter wheat in China. *Field Crop Res*. **87**: 35-42.

Wang, H, Zhang, L., Dawes, W.R., Liu, C. 2001. Improving water use efficiency of irrigated crops in north China planis – measurements and modeling. *Agric. Water Manage*. **48**: 151-167.

Yadav, K.S., Rajput, R.L. and Agarkar, M.S. 1999. Effect of sowing dates and irrigation schedules on yield and water use efficiency of Indian mustard (Brassica juncea). *Indian Journal of Agronomy* **44**(1): 148-150.

Zwart, S.J., Bastiaanssen, W.G.M. 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agric. Water Manage.* **69**: 115-133.

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