available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/agwat

Methods of planting and irrigation at various levels of nitrogen affect the seed yield and water use efficiency in transplanted oilseed rape (*Brassica napus* L.)

*G.S. Buttar, H.S. Thind *, M.S. Aujla*

Punjab Agricultural University Regional Station, Dabwali Road, Bathinda 151001, Punjab, India

ARTICLE INFO

Article history:
Accepted 4 May 2006
Published on line 14 June 2006

Keywords:
Brassica napus
Irrigation
Methods of planting
Nitrogen
WUE

ABSTRACT

The ridge planting of cotton at row spacing of 67.5 cm is widely used in the southwest region of Indian Punjab. Generally, transplanted oilseed rape (*Brassica napus*) fits well to grow after the harvest of cotton. Transplanting reduces days to maturity and results in higher seed yield. The present study was undertaken to determine if rape could be transplanted onto the cotton ridges thereby saving time and resources. The field experiments were conducted for 3 years with four methods of planting, three methods of irrigation and three levels of N (100, 125 and 150 kg/ha). The four methods for transplanting were: flat with 45 cm row spacing, flat with 67.5 cm row spacing, 67.5 cm ridge and bed planting. The three methods of irrigation were: flooding for flat with 45 and 67.5 cm row spacing; each furrow and each bed irrigation for ridge and bed planting; ridge with alternate furrow irrigation. The results revealed that increase in N from 100 to 150 kg/ha increased the seed yield significantly during 2 years. For 3 years, ridge transplanting reduced, on average, water applied by 30% for each furrow and 47% for alternate furrow irrigation as compared to 45 cm row spacing in flat method without any loss in seed yield. The corresponding increase in WUE was 27 and 34%. In bed planting, there was a 35% saving in water resulting in 32% increase in WUE. It is concluded that after harvest of cotton that the same ridges can be used for transplanting oilseed rape thereby reducing the quantity of irrigation water applied as well as the energy otherwise required for preparing the seed bed.

1. Introduction

Enhancing water use efficiency, both under rain fed and irrigated agriculture, is a high priority for agricultural improvement in developing countries. Although renewable fresh water resources are severely limited, current practices of flood irrigation and soil-water management are inefficient, wasteful and harmful to the environment. Groundwater is being depleted in many situations and the water table is rising too rapidly and bringing high concentration of soluble salts into the root zone in other areas. The wasteful and harmful system of flood irrigation practiced widely in South Asia must be replaced with furrow, drip or sub-irrigation systems (Lal, 2000). In future, water will become increasingly scarce particularly in semi-arid regions. Therefore, global climate change may lead to higher potential evapotranspiration, decreasing precipitation and increasing frequency of high intensity rains. At the same time, water demand is most likely to grow due to higher population density and expanding areas of irrigation. Hence, there is an urgent need to use water more

* *Corresponding author at*: House No. 109-C, Rajguru Nagar, Ludhiana 141 012, India. Tel.: +91 161 2464947.
E-mail address: harmit_thind@yahoo.co.in (H.S. Thind).
0378-3774/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2006.05.008

efficiently in these regions (Gaiser et al., 2004; Tennakoon and Milroy, 2003). Efficiency is a term that creates a mental picture of a system in which we can twist dials, tweak the components and ultimately influence the efficiency of the system. Unfortunately, the crop production system is much more complex than a factory analogy. Water use efficiency is estimated using total water use from a crop surface, which includes evaporation from soil and transpiration from plant components. However, total water use is difficult to measure, thus, alternately total water expense (irrigation water applied + precipitation + profile water used) during the growing season can be used (Hatfield et al., 2001). Although there are many places where we can manipulate the components, the effect on WUE is often not achieved and the results are not consistent among locations or experiments. A comprehensive survey of the literature revealed a large variation in measured WUE across a range of climates, crops and soil management practices (Hatfield et al., 2001). This survey further revealed that it is possible to increase WUE by 25–40% through soil management practices and 15–25% by modifying nutrient management practices.

In Indo-Gangetic plains of India a large region is under cotton–wheat cropping sequence, where soils are light in texture and underground water is brackish. There is a great need for judicious use of limited available canal water (Aujla et al., 2005) because the excess usage causes high percolation resulting in rising water table and secondary salinization. The water logging and secondary salinization has already caused degradation of land resources in large tracks of Indo-Gangetic plains (Datta and de Jong, 2002). The production potential of wheat, which is the major crop of the winter season, is drastically reduced owing to delay in sowing caused by late picking of cotton and erratic and inadequate canal water supply. Therefore, the diversification of cropping pattern having lower water requirements and suitable for delayed sowing has great promise in the region. Rapeseed–mustard group of crops seem good substitute as they require less inputs of fertilizers, irrigation, labour and has shorter duration than the wheat. Oilseed rape (*Brassica napus*) has been adopted by farmers of the region to replace wheat especially under the area giving lower yields of wheat owing to late sowing. Plant breeding efforts in *B. napus* have resulted in improvements in the fatty acid composition of the oil (reduction of erucic acid) and a marked reduction in the level of glucosinolates have made it world's third most important vegetable oil after soybean and palm oil (Downey and Rimmer, 1993). The other favourable feature of the *B. napus* is its ability to grow by transplanting, after raising nursery in the other field. The transplanted oilseed rape gave significantly higher seed yield than direct sown crop and the relative increase in seed yield was higher under delayed conditions (Gupta, 1994). Transplanting also reduces days to maturity by about one fortnight thus making it specially suitable for the late sowing conditions.

For increasing the production potential which lead to greater water use efficiency, Choudhury et al. (1990) observed an increase in seed yield of seeded *B. napus* with increase in N from 0 to 90 kg/ha in a sandy loam soil of Assam, India. The positive impact of N on the seed yield of *B. napus* has been reported from many regions of the world (Asare and Scarisbrick, 1995; Hocking et al., 1997; Diepenbrock, 2000; Jackson, 2000; Rathke et al., 2005). Thakur et al. (2003) reported that seeded *B. napus* responded to applied N up to 80 or 120 kg/ha in different cropping sequences. Bishnoi et al. (1991) observed that the sowing of two rows in furrows and ridges spaced 90 cm produced 24% higher seed yield whereas paired sowing (30 cm:60 cm) produced 20% higher seed yield than 45 cm spaced row sowing of *B. napus*. They observed that radiation interception, accumulation and partitioning of dry matter and leaf area in this system were beneficial for exploiting the input resources. The root growth parameters increased with increase in N level from early vegetative phase, sizeable early build up of above ground plant infrastructure and ultimately high seed yield and N uptake was observed in *B. napus* (Narang and Gill, 1992).

The significant interaction of N $\times$ irrigation for seed yield of direct seeded *B. napus* (Narang et al., 1993; Gill and Narang, 1993) emphasized the presence of adequate moisture supply and high N fertilization for high efficiency of applied N and irrigation water. About 50% of applied N is recovered in the harvested seed under proper irrigation conditions, however, moisture stress reduced the N recovery considerably (Wright et al., 1988; Schjoerring, 1995). Under deficient water conditions the effectiveness of mineral N-fertilizer is reduced due to reduced mineralization of soil organic N as well as impaired N-transport to roots. As root growth, physiological activity of roots and shoot growth are constrained, shortage of water indirectly leads to N-deficiency in plants (Schjoerring, 1995). Stoker and Carter (1984) have observed that in *B. napus* the irrigation following flowering was the most critical factor affecting seed yield. Water deficiency in late vegetative and early reproductive growth stages reduces photosynthetic rate in leaves and, in particular, siliques of medium and high N plants but not of low N plants (Gammelvind et al., 1996). In a 16 year long term study, Nuttal et al. (1992) have observed that seed yield was positively correlated to total precipitation and negatively correlated to mean maximum daily temperature. While comparing the ridge and furrow sowing with flat sowing of *B. napus* (45 cm spaced rows) for water use, Aujla et al. (1992) observed 18 and 41% irrigation water saving while irrigating each and alternate furrow, respectively. Consequently an increase of 10 and 36% in WUE than flat sowing was recorded. While working on furrow irrigation methods on transplanted *B. napus* at row spacing of 45 cm, Aujla et al. (2003) reported a saving in irrigation water of 26 and 41% by irrigating each and alternate furrow, respectively, than flat method of transplanting. It is evident that the application of N and modified furrow methods have the potential to improve yield and WUE.

In recent years, the ridge planting of cotton at row spacing of 67.5 cm is widely followed in this cotton growing region for economizing the irrigation water use. It is pertinent to elucidate the effect of wider spaced (67.5 cm) ridges for the transplanting *B. napus* so that same ridges may be used after cotton harvest to economize time and resources. The objectives of the present investigation are to determine the independent and interactive effects of methods of planting and irrigation, and levels of N on seed yield and WUE of transplanted *B. napus*.

Table 1 – Monthly mean of temperature, relative humidity, pan evaporation and rainfall during the growing seasons

Month	Temperature (°C)		Relative humidity (%)		Pan evaporation (mm/day)	Rainfall (mm)
	Maximum	Minimum	Maximum	Minimum		
2001–2002						
November	29.9	10.1	79.0	30.2	3.6	0
December	22.2	6.4	86.4	40.9	3.3	0
January	22.6	8.1	84.0	53.5	2.1	0
February	19.3	3.3	87.6	50.2	1.9	0
March	29.7	12.0	77.9	36.1	2.7	0
April	38.5	19.1	62.3	25.3	5.7	0
2002–2003						
November	29.4	12.6	82.5	49.3	3.9	0
December	23.5	8.4	87.1	43.0	2.6	10.0
January	17.3	5.7	97.1	68.9	1.3	4.2
February	22.2	7.7	65.5	47.2	1.8	40.0
March	24.7	12.0	83.2	37.2	4.1	5.0
April	36.1	20.7	53.7	24.4	4.4	0
2003–2004						
November	23.3	9.4	80.0	34.9	3.3	0
December	20.0	7.0	96.2	50.3	2.4	0
January	17.0	6.3	94.5	69.8	2.2	17.5
February	24.4	10.8	86.6	55.0	2.5	10.0
March	31.1	13.9	78.7	31.9	4.5	3.8
April	37.3	19.5	55.5	22.9	5.6	2.0

2. Materials and methods

2.1. Experimental site

A 3-year field study was conducted at Research Farm of Punjab Agricultural University Regional Station, Bathinda, India, during the winter seasons of 2001–2002, 2002–2003 and 2003–2004. The farm is located at an altitude of 211 m above mean sea level and is intersected by 30°9′N latitude 74°56′E longitude. Geologically the farm area forms a part of the Indo-Gangetic alluvial plains. The whole expanse of these plains is formed, with varying monotony of Pleistocene and recent alluvial deposits of the rivers of Indo-Gengetic system, which have completely shrouded the old land surface. The climatic parameters were recorded at a meteorological observatory at a distance of 500 m from the experimental field. The mean monthly maximum air temperature, minimum air temperature, maximum and minimum relative humidity, pan evaporation and rainfall during the three cropping seasons are presented in Table 1. The area was characterized as arid (dry), and mean annual rainfall is 401 mm. Rainfall being monsoonal in nature, approximately 70–80% of rainfall is received during the months of July–September.

2.2. Soil of experimental field

The soil of the experimental field was loamy sand in texture and belongs to Ghahri Bhagi series (mixed, hyperthermic, Ustochreptic Camborthid). Some physico-chemical properties of the soil are presented in Table 2. The organic carbon content of the surface layer (0–15 cm) was 0.18%. The available nitrogen, phosphorus and potash in surface layer was 114, 14.4 and 449 kg/ha, respectively. The soils have no salinity and drainage problem, and water table was more than 7 m deep.

2.3. Experimental treatments and procedures

The treatments comprised of three levels of nitrogen, four methods of planting and three methods of irrigation. The three levels of N were 100, 125 and 150 kg/ha which were

Table 2 – Physico-chemical characteristics of soil profile of experimental field

Soil depth (cm)	pH	EC[a] (dS/m)	Volumetric moisture (%)		Available soil moisture (cm)	Bulk density (g/cm^3)
			1/3 bar	15 bar		
0–15	8.1	0.37	26.1	7.6	2.9	1.49
15–30	8.3	0.31	27.8	8.3	3.0	1.53
30–60	8.7	0.32	26.9	9.5	5.1	1.39
60–90	8.3	0.29	28.3	9.7	5.5	1.44
90–120	8.2	0.34	27.6	9.3	5.2	1.50
120–150	8.3	0.33	28.3	8.0	5.5	1.50
150–180	8.4	0.35	27.9	8.3	5.4	1.52

[a] EC: electrical conductivity.

Table 3 – Treatment details regarding various methods of transplanting cum irrigation

Serial number	Method of planting	Row spacing (cm)	Method of irrigation	Treatment designation
1	Flat	45.0	Flooding	F_{45}FL
2	Flat	67.5	Flooding	$F_{67.5}$FL
3	Ridge	67.5	Each furrow	$R_{67.5}$EF
4	Ridge	67.5	Alternate furrow	$R_{67.5}$AF
5	Bed	37.5:30[a]	Each bed	B_{pair}EB

[a] 37.5 cm bed and 30 cm furrow for planting two rows on bed.

designated as N_1, N_2 and N_3, respectively. In case of different methods of cultivation, there were various combinations regarding methods of planting, irrigation and row spacing as detailed in Table 3. The experiment was conducted in a split plot design having three levels of N in main-plot while methods of cultivation in sub-plot having three replications. The plot size for each plot was 4.05 m × 7.80 m. The oilseed rape (*B. napus* cv. PGSH-51) was transplanted on 12 and 19 December and 20 November during 2001–2003, respectively. The crop was harvested on 8 and 10 April and 29 March during the year 2002–2004, respectively. Plant to plant spacing was 15 cm in F_{45}FL, 20 cm in B_{pair}EB and 10 cm in remaining treatments to have equal number of plants per unit area (148 148 ha^{-1}). A 30 kg/ha P_2O_5 was applied as basal dose. Every year, half of N as urea was applied at the time of transplanting and remaining half N was applied after 4 weeks of transplanting after second irrigation. Four irrigations were applied during dry years of experimentation; immediately after transplanting, 3 weeks after transplanting, at flowering and at seed filling. Only three irrigations were required during second year of experimentation owing to higher rainwater. In flat planting treatments about 7.5 cm irrigation water was applied and actually irrigation water applied was measured through Parshall Flume (Hensen et al., 1980) in all the plots at each irrigation. All other recommended packages of practices relating to weed and plant protection measures were followed. Different plant parameters such as plant height, primary branches, secondary branches and pods/plant were recorded. Seed yield was recorded for all the treatment combinations.

2.4. *Water use efficiency*

For calculating the WUE, the water expense was calculated for different treatment combinations. The water expense is sum total of irrigation water applied, profile water used and rainfall during the growing season of oilseed rape. Profile water was measured in 0–180 cm soil profile by gravimetric method. For soil moisture determination soil samples were collected from 0 to 15, 15 to 30, 30 to 60, 60 to 90, 90 to 120, 120 to 150 and 150 to 180. The rainfall received during the entire cropping season was 0, 5.9 and 3.3 cm in 2001–2002, 2002–2003 and 2003–2004, respectively. For computation of WUE, seed yields per hectare were divided by the water expense and expressed as kg/ha/cm.

2.5. *Agronomic efficiency of nitrogen*

For calculation of agronomic efficiency of nitrogen (AEN), grain yields per hectare were divided by the amount of N in kg/ha applied in different treatments. This AEN has been reported as kg seed/kg N.

2.6. *Statistical analysis*

Analysis of variance was performed to determine the effects of nitrogen levels, methods of cultivation and their interactions using IRRISTAT version 1992 (IRRI, Manila, Philippines). Means were compared using least significant differences (LSD) at 5% probability level.

3. Results and discussion

3.1. *Yield response*

The perusal of the data revealed that bed transplanting, irrespective of N rates, increased the seed yield significantly during first and third year of experimentation (Table 4). However, during the second year of investigation, all the methods tried were not significantly different from each other. The increase in N application from N_1 to N_3 (100–150 kg/ha), irrespective of methods of planting, increased the seed yield significantly during first and third year but during second year increased N failed to effect the seed yield significantly. The data elucidated that superiority of bed planting during first and third year was owing to significant increase in grain yield at N_1 as compared with all other methods of planting. On the other hand, ridge planting with alternate furrow irrigation ($R_{67.5}$AF), during first year, produced significantly lower seed yield at N_3 as compared to flat planting. On an average of 3 years, bed planting gave the highest grain yield of 873 kg/ha as compared to 811 kg/ha in flat transplanting and flood irrigation method (F_{45}FL). The other three methods designated as $F_{67.5}$FL, $R_{67.5}$EF and $R_{67.5}$AF produced 828, 837 and 794 kg/ha, respectively. Higher seed yield in ridge and bed planting in spite of lower amount of water applied can be explained because transplanted *B. napus* is an effective root forager, placing its roots selectively in the wet parts of the soil (Wang et al., 2005). They confirmed that in transplanted *B. napus* fixed spot water supply, causing partial root drying, produced significantly higher biomass than uniform supply of the same amount of water. The higher seed yield during the third year was mainly contributed to early transplanting resulting in favourable climatic conditions specially temperature at the time of flowering and seed filling. Treatments of flat transplanting and flood irrigation (F_{45}FL and $F_{67.5}$FL) produced same quantity of seed yield although the row spacing was 45 and 67.5 cm can be explained owing to total number of plants per unit area were same (plant to plant distance was 15 and 10 cm, respectively). Plant density has been observed to have a huge influence on growth, development and seed yield of *B. napus* (Leach et al., 1999; Momoh and Zhou, 2001). On the other

Table 4 – Seed yield (kg/ha) as influenced by nitrogen and different methods of planting

Methods of transplanting	Nitrogen levels			Mean
	N_1	N_2	N_3	
2001–2002				
$F_{45}FL$	603.9	620.1	732.4	652.1
$F_{67.5}FL$	602.8	618.5	729.9	650.4
$R_{67.5}EF$	602.9	614.3	709.1	642.1
$R_{67.5}AF$	581.6	596.6	654.0	610.5
$B_{pair}EB$	672.7	677.1	764.6	704.8
Mean	612.8	625.2	718.0	
2002–2003				
$F_{45}FL$	623.9	647.6	653.9	641.8
$F_{67.5}FL$	646.7	696.5	649.0	664.0
$R_{67.5}EF$	714.7	710.6	688.3	704.5
$R_{67.5}AF$	692.9	692.9	671.6	685.8
$B_{pair}EB$	669.0	681.7	675.5	675.4
Mean	669.4	685.8	667.6	
2003–2004				
$F_{45}FL$	1111.2	1135.7	1167.4	1138.1
$F_{67.5}FL$	1171.3	1178.7	1158.8	1169.6
$R_{67.5}EF$	1088.8	1203.6	1198.7	1163.7
$R_{67.5}AF$	1078.9	1056.7	1119.5	1085.1
$B_{pair}EB$	1235.3	1232.0	1246.9	1238.1
Mean	1137.1	1161.3	1178.3	

LSD (0.05)	2001–2002	2002–2003	2003–2004
Methods	38.3	NS	59.6
Nitrogen	42.9	NS	30.6
Interaction	66.3	NS	NS

hand, the application of N, irrespective of methods of planting, produced 806, 824 and 855 kg/ha at N_1, N_2 and N_3, respectively. The average increase was 2.2 and 6.3% at N_2 and N_3 as compared to N_1. Under similar conditions, Gill and Narang (1993) have observed the response of direct sown oilseed rape up to 150 kg/ha and significant positive interaction with N and quantity of irrigation water applied (Gill and Narang, 1993; Narang et al., 1993).

The various methods of rape plant cultivation, irrespective of N application, affected plant height, primary branches, secondary branches and number of pods/plant but the differences were not significant except in number of secondary branches/plant during first year and number of pods/plant during third year (Table 5). However, all these parameters were highest in bed method of planting. In bed planting the plant height was 3.0% higher, primary branches were 6.0% higher, secondary branches were 4.3% higher and number of pods/plant were 6.1% higher than conventional method ($F_{45}FL$) of planting and irrigation. On the other hand, although there was consistent increase in these parameters with increase in levels of N applied but the differences were significant only in number of pods/plant during third year.

Table 5 – Effect of nitrogen and methods of transplanting on mean yield attributing parameters

Treatments	Year			Mean
	2001–2002	2002–2003	2003–2004	
Plant height (cm)				
N_{100}	122	103	173	133
N_{125}	122	104	174	134
N_{150}	125	104	175	135
LSD (0.05)	NS	NS	NS	
$F_{45}FL$	121	104	171	132
$F_{67.5}FL$	123	103	172	133
$R_{67.5}EF$	127	102	175	134
$R_{67.5}AF$	122	102	176	133
$B_{pair}EB$	123	107	177	136
LSD (0.05)	NS	NS	NS	
Secondary branches/plant				
N_{100}	7.4	14.9	33.6	18.6
N_{125}	6.9	15.4	35.2	19.2
N_{150}	6.8	15.8	35.2	20.0
LSD (0.05)	NS	NS	NS	
$F_{45}FL$	6.1	15.9	34.0	18.7
$F_{67.5}FL$	8.4	14.5	36.1	19.0
$R_{67.5}EF$	5.8	15.2	35.8	18.9
$R_{67.5}AF$	6.4	15.2	34.3	18.6
$B_{pair}EB$	8.6	15.2	36.7	19.5
LSD (0.05)	2.1	NS	NS	
Primary branches/plant				
N_{100}	6.6	5.3	8.3	6.7
N_{125}	6.7	5.0	8.7	6.8
N_{150}	6.5	5.4	8.9	6.9
LSD (0.05)	NS	NS	NS	
$F_{45}FL$	6.9	5.3	7.9	6.7
$F_{67.5}FL$	6.9	5.7	8.2	6.9
$R_{67.5}EF$	6.2	5.2	9.0	6.8
$R_{67.5}AF$	6.5	4.6	9.1	6.7
$B_{pair}EB$	6.6	5.3	9.5	7.1
LSD (0.05)	NS	NS	NS	
Number of pods/plant				
N_{100}	174	198	328	233
N_{125}	175	210	330	238
N_{150}	180	203	344	242
LSD (0.05)	NS	NS	10.8	
$F_{45}FL$	178	209	309	231
$F_{67.5}FL$	166	198	334	233
$R_{67.5}EF$	171	213	338	241
$R_{67.5}AF$	164	205	318	229
$B_{pair}EB$	180	209	346	245
LSD (0.05)	NS	NS	32	

3.2. *Irrigation water applied*

It is revealed from the data that there was wide variation in irrigation water applied in different methods in the present study (Table 6). The minimum applied water was in ridge planting with alternate furrow irrigation ($R_{67.5}AF$) followed by $B_{pair}EB$, $R_{67.5}EF$, $F_{67.5}FL$ and $F_{45}FL$ during all the 3 years of investigation. On an average of 3 years, the irrigation water applied by different methods of rape plant cultivation was 15.2, 18.8, 20.1, 28.5 and 28.9 cm in $R_{67.5}AF$, $B_{pair}EB$, $R_{67.5}EF$, $F_{67.5}FL$ and $F_{45}FL$, respectively. However, the irrigation water applied did not vary under different levels of N. It is further revealed that adopting proper method of rape plant cultivation considerable irrigation water can be saved without any loss in seed yield. Forty-seven percent water is saved in $R_{67.5}AF$ and 35% in $B_{pair}EF$ and 30% in $R_{67.5}EF$ than conventional method ($F_{45}FL$) of planting and irrigation. In an earlier study, Aujla et al. (2003) reported 26 and 41% saving of irrigation water applied to

Table 6 – Quantity of irrigation water applied (cm) under different treatments

Methods of transplanting	Nitrogen levels			Mean
	N_1	N_2	N_3	
2001–2002				
F_{45}FL	30.0	29.4	30.4	29.9
$F_{67.5}$FL	30.4	30.4	29.8	30.2
$R_{67.5}$EF	22.4	19.2	19.2	20.3
$R_{67.5}$AF	18.0	16.8	16.0	16.9
B_{pair}EB	18.4	19.2	19.2	18.9
Mean	23.9	23.0	22.9	
2002–2003				
F_{45}FL	24.2	25.4	25.5	25.0
$F_{67.5}$FL	23.8	23.9	23.3	23.7
$R_{67.5}$EF	17.9	17.3	17.2	17.5
$R_{67.5}$AF	13.4	13.8	13.5	13.6
B_{pair}EB	15.7	16.1	15.9	15.9
Mean	19.0	19.3	19.1	
2003–2004				
F_{45}FL	31.6	31.6	31.6	31.6
$F_{67.5}$FL	31.6	31.6	31.6	31.6
$R_{67.5}$EF	22.4	22.4	22.4	22.4
$R_{67.5}$AF	16.0	13.5	16.6	15.2
B_{pair}EB	21.6	21.6	21.6	21.6
Mean	24.6	24.1	24.6	

each furrow and alternate furrow, respectively, but the ridges were spaced at 45 cm as compared to 67.5 cm in the present study. These results revealed that ridges at wider space saved more water (30 and 47%).

3.3. *Water use efficiency*

The total water expense under different treatments was calculated from profile water use (Table 7), irrigation water applied (Table 6) and rainfall received (0, 5.9 and 3.3 cm in first, second and third year, respectively) during the cropping season for all the 3 years. The WUE was calculated from seed yield per hectare divided by the water expense and expressed as kg/ha/cm as presented in Table 8. There was a spectacular increase in WUE in the treatments with lower irrigation water expense (bed and ridge methods of planting). The WUE was not affected at various levels of N owing to small changes in seed yield due to increase in rate of N application. On an average of 3 years, the highest WUE of 22.0 kg/ha/cm was observed with $R_{67.5}$AF which represent an increase of 34% over conventional method of planting and irrigation (F_{45}FL). The WUE was 32% higher in B_{pair}EB and 27% in $R_{67.5}$EF. It is evident that considerable higher WUE can be achieved by following bed or ridge methods. *B. napus* has a tap root system giving the crop access to deep water and nutrients (Downey et al., 1974). Numerous field assessments of *B. napus* indicate that it is capable of extracting water from depths of 114 to 165 cm (Johnston et al., 2002). Nielsen (1997) reported that while neutron scatter measurements found that *B. napus* extracted water to depths of 165 cm, 92–95% of the growing season water use of the crop came from the surface 119 cm of soil profile. Tillage studies with *B. napus* have found that the crop is well suited to no-till seeding as it produced 1–14% higher seed yield than conventional tillage (Lindwell et al., 1994). Higher WUE in ridge transplanting of *B. napus* on ridges spaced at 45 cm was reported earlier (Aujla et al., 2003).

Table 7 – Profile water use and total water expense as influenced by nitrogen and different methods of planting

Methods of transplanting	Nitrogen levels			Mean
	N_1	N_2	N_3	
Profile water use (cm)				
2001–2002				
F_{45}FL	18.5	17.2	19.0	18.2
$F_{67.5}$FL	16.6	17.8	19.9	18.1
$R_{67.5}$EF	19.2	18.3	19.1	18.9
$R_{67.5}$AF	17.3	18.9	19.5	18.6
B_{pair}EB	17.0	18.9	18.6	18.1
Mean	17.7	18.2	19.2	
2002–2003				
F45FL	16.9	17.6	16.8	17.1
$F_{67.5}$FL	17.5	18.2	16.0	17.2
$R_{67.5}$EF	17.3	18.4	19.1	18.3
$R_{67.5}$AF	15.0	18.5	18.5	17.3
B_{pair}EB	16.8	17.8	16.3	17.0
Mean	16.7	18.1	17.5	
2003–2004				
F_{45}FL	16.3	13.0	19.2	16.2
$F_{67.5}$FL	14.4	11.3	13.5	13.1
$R_{67.5}$EF	14.6	13.7	18.4	15.6
$R_{67.5}$AF	16.4	15.9	16.7	16.3
B_{pair}EB	17.4	19.7	16.2	17.8
Mean	15.8	14.7	16.8	
Water expense (cm)				
2001–2002				
F_{45}FL	48.5	46.6	49.4	48.2
$F_{67.5}$FL	47.0	48.2	48.7	48.0
$R_{67.5}$EF	41.6	37.5	38.3	39.1
$R_{67.5}$AF	35.3	35.7	35.5	35.5
B_{pair}EB	35.4	38.1	37.8	37.1
Mean	41.5	41.2	41.9	
2002–2003				
F_{45}FL	47.0	47.4	48.2	47.5
$F_{67.5}$FL	47.6	49.5	47.4	48.2
$R_{67.5}$EF	41.1	41.6	42.2	41.6
$R_{67.5}$AF	34.3	34.3	37.9	35.5
B_{pair}EB	38.4	39.8	38.1	38.8
Mean	41.6	42.5	42.8	
2003–2004				
F_{45}FL	51.2	47.9	54.1	51.1
$F_{67.5}$FL	49.3	46.2	48.4	48.0
$R_{67.5}$EF	40.3	39.4	44.1	41.3
$R_{67.5}$AF	35.7	35.2	36.0	36.6
B_{pair}EB	42.3	44.6	41.1	42.7
Mean	43.8	42.7	44.7	

3.4. *Agronomic efficiency of N*

The agronomic efficiency of N (AEN) under different methods of transplanting and various levels of N applied varied widely as presented in Table 9. With increase in quantity of N applied, there was consistent decrease in AEN during all the 3 years and under all the methods of rape plant cultivation. On an average of 3 years, the maximum AEN, irrespective of rate of N application, was observed in B_{pair}EB which was 8% higher than

Table 8 – Water use efficiency (kg/ha/cm) as influenced by nitrogen and methods of planting

Methods of transplanting	Nitrogen levels			Mean
	N_1	N_2	N_3	
2001–2002				
$F_{45}FL$	12.5	13.3	14.8	13.5
$F_{67.5}FL$	12.8	12.7	15.0	13.5
$R_{67.5}EF$	14.5	16.4	18.5	16.5
$R_{67.5}AF$	16.5	16.7	18.4	17.2
$B_{pair}EB$	19.0	17.8	20.2	19.0
Mean	14.8	15.3	17.4	
2002–2003				
$F_{45}FL$	13.3	13.2	13.6	13.4
$F_{67.5}FL$	13.6	14.1	13.7	13.8
$R_{67.5}EF$	17.4	17.1	18.5	17.7
$R_{67.5}AF$	20.2	17.6	17.3	18.4
$B_{pair}EB$	17.4	17.1	17.4	17.3
Mean	16.4	15.8	16.1	
2003–2004				
$F_{45}FL$	21.7	23.7	21.6	22.3
$F_{67.5}FL$	23.8	25.5	23.9	24.4
$R_{67.5}EF$	27.0	30.6	27.2	28.3
$R_{67.5}AF$	30.2	30.0	31.4	30.5
$B_{pair}EB$	29.2	27.6	29.0	28.6
Mean	26.4	27.5	26.6	

in conventional method ($F_{45}FL$). Irrespective of methods of planting, AEN decreased from 8.06 to 6.59 kg/kg of applied N (18%), when N level was increased from 100 to 125 kg/ha. When N rate was increased to 150 kg/ha, AEN further decreased to 5.70 kg/kg of N applied resulting an decrease of 29% as compared to the lowest level of N (100 kg/ha).

Table 9 – Agronomic efficiency of nitrogen (kg seed/kg of N applied) as influenced by nitrogen and methods of planting

Methods of transplanting	Nitrogen levels			Mean
	N_1	N_2	N_3	
2001–2002				
$F_{45}FL$	6.04	4.96	4.88	5.29
$F_{67.5}FL$	6.03	4.96	4.87	5.28
$R_{67.5}EF$	6.03	4.91	4.73	5.22
$R_{67.5}AF$	5.82	4.77	4.36	4.98
$B_{pair}EB$	6.73	5.42	5.10	5.75
Mean	6.13	5.00	4.79	
2002–2003				
$F_{45}FL$	6.24	5.18	4.36	5.26
$F_{67.5}FL$	6.47	5.57	4.33	5.45
$R_{67.5}EF$	7.15	5.68	4.59	5.81
$R_{67.5}AF$	6.93	5.54	4.48	5.65
$B_{pair}EB$	6.69	5.45	4.50	5.55
Mean	6.69	5.49	4.45	
2003–2004				
$F_{45}FL$	11.11	9.09	7.78	9.33
$F_{67.5}FL$	11.71	9.43	7.73	9.62
$R_{67.5}EF$	10.89	9.63	7.99	9.50
$R_{67.5}AF$	10.79	8.45	7.46	8.90
$B_{pair}EB$	12.35	9.86	8.31	10.17
Mean	11.37	9.31	7.86	

4. Conclusions

The results of present investigation revealed that ridge transplanting and subsequent furrow irrigation of *B. napus* saved 30% of irrigation water without affecting the seed yield of oilseed rape. The saving of water can further be increased to 47% by irrigating alternate furrows without any loss in seed yield. Although bed rape plant cultivation gave highest seed yield but it needs special preparation of beds before transplanting but in the case of ridge planting same ridges used for planting cotton can be used for transplanting. Under such conditions ridge transplanting will save large quantity of energy required for ploughing the field and other operations required for preparing seed bed for direct sown crops. By reusing the ridges, used for cotton planting, for transplanting oilseed rape large quantity of energy and irrigation can be saved without any loss in yield.

REFERENCES

Asare, E., Scarisbrick, D.H., 1995. Rate of nitrogen and sulphur fertilizers on yield, yield components and seed quality of oilseed rape (*Brassica napus* L.). Field Crops Res. 44, 41–46.

Aujla, M.S., Singh, C.J., Buttar, G.S., Saini, K.S., 2003. Effect of modified irrigation on water use and yield of transplanted *gobi sarson* (*Brassica napus* subsp. *oleifera* var. *annua*). Indian J. Agric. Sci. 73, 661–663.

Aujla, M.S., Singh, C.J., Kumar, K., Sandhu, B.S., 1992. Efficiency of different methods of irrigation in Indian rape (*Brassica napus*). J. Arid Environ. 22, 369–374.

Aujla, M.S., Thind, H.S., Buttar, G.S., 2005. Cotton yield and water use efficiency at various levels of water and N through drip irrigation under two methods of planting. Agric. Water Mange. 71, 167–179.

Bishnoi, O.P., Taneja, K.D., Rao, V.U.M., Singh, R., Niwas, R., 1991. Influence of different planting systems on the microclimate and seed yield of *Raya* (*Brassica napus* var. *glauca*). Indian J. Agron. 36, 368–375.

Choudhury, A.K., Saikia, M., Dutta, K., 1990. Response of rapeseed (*Brassica napus*) to irrigation and nitrogen levels under sandy loam soils of Assam. Indian J. Agric. Sci. 60, 347–349.

Datta, K.K., de Jong, C., 2002. Adverse effect of water logging and soil salinity on crop and land productivity in southwest region of Haryana, India. Agric. Water Manage. 57, 223–238.

Diepenbrock, W., 2000. Yield analysis of winter oilseed rape (*Brassica napus* L.): a review. Field Crops Res. 67, 35–49.

Downey, R.K., Klassen, A.J., McAnsh, J., 1974. Rapeseed: Canola's "Cinderella" crop. Publ. 33. Rapeseed Assoc. of Canada, Winsterg, Man.

Downey, R.K., Rimmer, S.R., 1993. Agronomic improvement in rapeseed Brassicas. Adv. Agron. 50, 1–66.

Gaiser, T., de Barros, I., Lange, F.M., Williams, J.R., 2004. Water use efficiency of a maize/cowpea intercrop on a highly acidic tropical soil as affected by liming and fertilizer application. Plant Soil 263, 165–171.

Gammelvind, L.H., Schjoerring, J.K., Mogensen, V.O., Jenson, C.R., Bock, J.G.H., 1996. Photosynthesis in leaves and siliques of winter oilseed rape (*Brassica napus* L.). Plant Soil 186, 227–236.

Gill, M.S., Narang, R.S., 1993. Yield analysis in *gobhi sarson* (*Brassica napus* subsp. *Oleifera* var. *annua*) to irrigation and nitrogen. Indian J. Agron. 38, 257–265.

Gupta, T.R., 1994. Effect of transplanting on *gobhi sarson* (*Brassica napus* subsp. *Oleifera* var. *annua*). Indian J. Agron. 39, 146–147.

Hatfield, J.L., Sauer, T.J., Prueger, J.H., 2001. Managing soils to achieve greater water use efficiency: a review. Agron. J. 93, 271–280.

Hensen, V.E., Israelson, O.W., Stringham, G.E., 1980. Irrigation Principals and Practices. Wiley, New York, pp. 333–338.

Hocking, P.J., Randall, P.J., Demarco, D., Bamforth, I., 1997. Assessment of the nitrogen status of field grown canola (*Brassica napus* L.) by plant analysis. Aust. J. Exp. Agric. 37, 83–92.

Jackson, G.D., 2000. Effect of nitrogen and sulphur on canola yield and nutrient uptake. Agron. J. 92, 644–649.

Johnston, A.M., Tanaka, D.L., Miller, P.R., Brandt, S.A., Niesen, D.C., Lafond, G.P., Riverland, N.R., 2002. Oilseed crops for semiarid cropping systems in the northern Great Plains. Agron. J. 94, 231–240.

Lal, R., 2000. Soil management in the developing countries. Soil Sci. 165, 57–72.

Leach, J.E., Stevenson, H.L., Rainbow, A.J., Mullen, L.A., 1999. Efects of high populations on the growth and yield of winter oilseed rape (*Brassica napus*). J. Agric. Sci. 132, 173–180.

Lindwell, C.W., Larney, F.J., Johnston, A.M., Moyer, J.R., 1994. Crop management in conservation tillage systems. In: Unger, P.W. (Ed.), Managing Agricultural Residues. Lewis Publ, Boca Raton, FL, pp. 185–209.

Momoh, E.J.J., Zhou, W., 2001. Growth and yield responses to plant density and stage of transplanting in winter oilseed rape (*Brassica napus* L.). J. Agron. Crop Sci. 186, 253–259.

Narang, R.S., Gill, M.S., 1992. Effect of irrigation and nitrogen management on root growth parameters, N use and seed yield response of gobhi sarson (*Brassica napus* subsp. *Oleifera* var. *annua*). Indian J. Agric. Sci. 62, 179–186.

Narang, R.S., Mahal, S.S., Gill, M.S., 1993. Response of rapeseed (*Brassica napus*) to fertilizers and irrigation in Punjab. Indian J. Agric. Sci. 63, 790–794.

Nielsen, D.C., 1997. Water use and yield of canola under dryland conditions in the central Great Plains. J. Prod. Agric. 10, 307–313.

Nuttal, W.F., Moulin, A.P., Townley-Smith, L.J., 1992. Yield response of canola to nitrogen, phosphorus, precipitation and temperature. Agron. J. 84, 765–768.

Rathke, G.W., Christen, O., Diepenbrock, W., 2005. Effects of nitrogen source and rate on productivity and quality of winter oilseed rape (*Brassica napus* L.) grown in different crop rotations. Field Crops Res. 94, 103–113.

Schjoerring, J.K., 1995. Nitrogen incorporation and remobilization in different shoot components of field-grown winter oilseed rape (*Brassica napus* L.) as affected by rate of nitrogen application and irrigation. Plant Soil 177, 255–264.

Stoker, R., Carter, K.E., 1984. Effect of irrigation and nitrogen on yield and quality of oilseed rape. N.Z. J. Exp. Agric. 12, 219–224.

Tennakoon, S.B., Milroy, S.P., 2003. Crop water use and water use efficiency on irrigated farms in Australia. Agric. Water Manage. 61, 179–194.

Thakur, K.S., Kumar, A., Manuja, S., 2003. Effect of nitrogen on productivity and nitrogen balance in soil in *gobhi sarson* (*Brassica napus*)-based crop sequences. Indian J. Agron. 48, 160–163.

Wang, L., de Kroon, H., Boggemann, G.M., Smits, A.J.M., 2005. Partial root drying effects on biomass production in *Brassica napus* and the significance of root responses. Plant Soil 276, 313–326.

Wright, G.C., Smith, C.J., Woodroofe, M.R., 1988. The effect of irrigation and nitrogen fertilizer on rapeseed (*Brassica napus*) production in south-eastern Australia. 1. Growth and seed yield. Irrig. Sci. 9, 1–13.