Journal of Oilseed Brassica, 5(1) : 40-54, Jan 2014

Effect of plant density variations at different growth stages on yield and phenological and morphological traits of rapeseed

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(Received: 16 June 2013; Revised: August 2013; Accepted: Sep 2013)

Abstract

The effect of plant density at different growth stages of rapeseed on yield and phenological and morphological traits was investigated at Natural Resources Nursery of Bam, Iran during 2010-2011. A factorial study was devoted to the time of plants removal including seedling emergence, stemming, and flowering, and the second factor was devoted to the intensity of plants removal at three levels of 25, 50 and 75%. It was found that rapeseed is more sensitive to the intensity of plants removal than to its stage. The effect of plants removal intensity was significant on seed dry weight, seed yield per plant, total dry weight, oil yield per unit area at 5% probability level, and on pod dry weight, seed dry weight per unit area and finally, total yield per unit area at 1% probability level, so that the removal of 25 and 50% of plants was compensated by greater growth and single-plant yield (by 34.2%), and only the removal of 75% of plants decreased seed yield per unit area by 30.7 and 19.9% as compared to the removal of 25 and 50% of plants, respectively. The effect of plants removal time was significant only on stem dry weight per unit area at 5% probability level. The interactions between the time and intensity of plants removal was significant for stem dry weight and total dry weight per unit area at 1%, and for pod dry weight, seed dry weight, oil yield, and seed yield at 5% probability level. The lowest seed yield (2668 kg ha^{-1}) was obtained by the removal of the plants at flowering and stemming which differed with control by 26.34%. Other evaluated traits were not affected by the treatments. The evaluation of the response of different seed yield components to the variations of plant density showed that the removal of plants had the highest effect on pod number per unit area followed by seed number per plant and single-seed weight. As plants removal was reduced from vegetative growth to reproductive growth stage, the ability of plants in compensating the loss of plants by increasing pod number per plant was decreased. It can be recommended that the maximum seed yield can be realized in Bam, Iran by decreasing plant density by 15% (57 plants m^{-2}).

Key words: *Oil yield, plants removal method, , plants removal time, rapeseed, seed yield*

Introduction

There are over 250 oilseed plants in the world (Pazaki, 2000). Oilseeds are the second most important nutrient of the world after grains. Rapeseed is one of the most important oilseeds throughout the world (Nazardad, 2001). Total dry matter yield is the result of plant population efficiency in using solar radiation in growing season to produce adequate uniformly-distributed leaves for covering the ground. This target is allowed by changing plant density and appropriate distribution of plants on the ground (Ganjali *et al*., 2000). The number of plants per unit area is called density. The effect of uniform distribution of plants per unit area on appropriate distribution of intercepted radiation is reflected inside plant canopy. Therefore, the main effect of planting arrangement and plant density on yield is mainly caused by the difference in the manner of solar radiation distribution (Fathi, 2005). Special distribution of plants in a population is associated with radiation absorption which plays a decisive role in photosynthesis capacity (Wells, 1991). In a study on three densities of 33, 67 and 133 plants m^{-2} in Rasht, Iran, Ozoonidooji *et al*. (2007) reported that 67 plants m^{-2} resulted in the highest dry matter and consequently, the highest seed yield due to the adequate use of space and other resources by plants, lower competition between plants, and higher leaf area index and crop growth rate. The results of another study have revealed that oil yield is not influenced by row spacing or plant density (Morrison *et al*., 1990). Sajedi *et al*. (2009) reported that lower seeding rate (4 kg ha^{-1}) maximized seed oil production (1157.2 kg ha^{-1}). Ahmadi (2010) reported that higher density per unit area resulted in lower number of pods per plant. Modafebehzadi (2001) stated that the effect of density was significant on pod number. Rapeseed branching rate depends on cultivar, environment, plants nourishment, agronomic practices, etc. Plant density considerably impacts branching rate and the height of plant out of which the main branch emerges (Agriculture Research and Education Organization, 2010). Rapeseed mostly enjoys a good restoring potential and can compensate the effects of low plant number by producing numerous auxiliary branches if the plant density is lower (Khajehpour, 2007). Studies have indicated the loss of branch number per plant with the increase in plant density (Fathi, 2008; Ahmadi, 2010; Chapman *et al*., 1984; Ganjali, 2000; Ilkayi and Imam, 2003). Thurling (1974) related the loss of branch number per plant under high density to increase the distance between crown to the emergence of the first auxiliary branch per plant. Chegini *et al*. (2006) showed that the increase in density from 30 to 70 plants m^{-2} significantly reduced plant height. Modafebehzadi (2001) stated that the increase in density from 50 to 80 plants m^{-2} increased stem length by about 10 cm. In a study on rapeseed at three densities (40, 80 and 120 plants m^{-2}), Shirani Rad *et al*. (1996) reported that 40 and 80 plants m^{-2} produced the highest and lowest total dry weight, respectively. Also, Chegini *et al*. (2006) indicated that the increase in plant density from 30 to 70 plants m^{-2} increased plant dry weight. Fathi (2008) reported the impact of plant density on biological yield at maturity time as to be significant and the highest and lowest biological yields were obtained at 110 and 50 plants m^{-2} (14.6 and 10.8 t ha^{-1}), respectively. Kandil *et al*. (1996) stated that the increase in density from 50 to 90 plants m^{-2} increased biological yield from 11049.9 to 14046.1 kg ha^{-1}. Abadian *et al*. (2008) reported that the effect of density was significant on biological yield and that the highest biological yield was obtained at 80 plants m^{-2}. The slight variations of harvest index showed the greater dependence of this trait to plant genetic structure (Imam and Nicknejad, 1994). According to the findings of Appelquist and Ohlson (1972), Kimber and McGregor (1999), and Ilkayi and Imam (2003), it seems that the self-regulatory mechanism of the balance between vegetative and reproductive organs is the reason for the variations of harvest index at different densities.

Materials and Methods

The study was carried out at Natural Resources Nursery of Bam, Iran (Long. 58°18’ E., Lat. 29°05’ N.) in 2009-2010. Mean precipitation was 37 mm, mean maximum annual temperature was 24C, and mean minimum temperature was 12 C. The soil texture was loam-sandy. Soil analysis showed that the soil was deficient in organic matter, absorbable N, and absorbable P (0.47%, 0.025 mg kg^{-1}, 8.63 mg kg^{-1}, respectively), but the field was in a better status in terms of absorbable K (200 mg kg^{-1}).

The study was a factorial experiment on the basis of a Randomized Complete Block Design with three replications in which the first factor was devoted to plants removal time including seedling emergence, stemming and flowering, and the second factor was devoted to plants removal intensity including the removal of 25, 50 and 75% of plants. Each replication was composed of nine plots and each plot included a control. Each sub-plot was composed of six rows with inter-row spacing of 30 cm. The rows were 6 m long. The soil was fertilized according to fertilizer recommendations of regional research center. The weeds were controlled by Terfelan which was applied as prerequisite of hand weeding. The field was weeded by hand during growing season, too. The seeds were sown on November 22, 2010 by hand. Two seeds were sown in each sowing space. One plant was thinned at 2-4-leaf stage. The first irrigation was carried out after sowing followed by another one three days later. Then, it was repeated once every seven days. To study the phenological stages (days to germination, stemming and flowering), the plants were counted once every three days from the beginning of each stage to the 50% of maturity. The plants were harvested from rows 3, 4 and 5 after eliminating two marginal rows and 0.5 meter from both ends of the rows on April 27. The traits separately measured for each plot included branch number per plant, plant height, stem dry weight, pod dry weight, single-seed dry weight, and total dry weight. To measure dry weight of plant organs, they were oven-dried at 70°C in laboratory for 24 hours. Then, the dried samples were precisely weighed by a scale. The length of the tallest stem was measured by a scaled string to measure plant height and then, total length of other plants was measured. The branches of the plants were separately counted to determine the number of branches per plant. To measure yield and oil, the plants were harvested from rows 3, 4 and 5 after eliminating marginal rows, the rows from which the previous samples had been taken and 0.5 m from both ends of the rows. Then, total yield was determined for each plot and the samples were prepared according to guideline for measuring oil percentage in Seed Research Laboratory of Karaj, Iran. The collected data were statistically analyzed by SAS and MS-TATC software and the means were compared by Duncan's Multiple Range Test at 5% probability level.

Results and Discussion

Seed Yield

Plants removal (time and intensity combination) influenced seed yield per unit area significantly at 5% probability level (Table 1a). The lowest seed yield (2689.6 and 2688.0 kg ha^{-1}) was obtained under the removal of 75% of plants at seedling emergence and stemming, respectively (26.4% lower than that of control; Table 1b) showing more sensitivity of rapeseed canopy to the removal of plants during vegetative growth period (seedling emergence and stemming). Plant removal time did not affect seed yield per unit area significantly. The effect of plants removal intensity was significant on seed yield per unit area at 1% probability level. Given the trend of the response of rapeseed seed yield per unit area, it was found that the removal of 25 and 50% of plants was compensated with the increase in single-plant growth and yield (by 34.2%) and only the removal of 75% of plants significantly decreased seed yield per unit area as compared with the removal of 25 (3916 kg ha^{-1}) and 50% (3389 kg ha^{-1}) of plants by 30.7 and 19.9%, respectively (Table 1d). In a study on three densities of 33, 67 and 133 plants m^{-2} in Rasht, Iran, Ozoonidooji *et al.* (2007) reported that the highest studied density produced the highest dry matter and by which the highest seed yield due to the adequate utilization of space and other resources, lower inter-plant competition, higher leaf area index, and increased plant growth. Abadian *et al.* (2008) reported that the effect of density was significant on seed yield and that the highest seed yield was obtained at 80 plants m^{-2} and the increase in density resulted in significant loss of yield. Yazdpour *et al.* (2008) revealed that density only affected seed yield significantly and that the highest seed yield was produced at 60 plants m^{-2}.

Oil Yield

Plants removal time and intensity combinations impacted oil yield significantly at 5% probability level (Table 1a). The non-significant effect of the removal of 25 and 50% of plants at seedling emergence and stemming and the removal of 25% of plants at flowering on oil yield (Table 1b) indicated that the density of control (67 plants m^{-2}) was in excess of the density required for realizing maximum oil yield. The removal of 25% of plants at stemming and the decrease in density from 67 to 50 plants m^{-2} gave rise to the highest oil yield (2056 kg ha^{-1}) which was in the same statistical group with control, too (Table 1b, Fig. 2a). Among different combinations of plants removal time and intensity, the removal of 75% of plants at seedling emergence and stemming as well as the removal of 50 and 75% of plants at flowering resulted in significant loss of oil yield as compared to control (1701 kg ha^{-1}; Table 1b, Fig. 2a) indicating that rapeseed is less sensitive to plants removal at vegetative growth stages than at reproductive growth period. In other words, rapeseed plant population has more opportunity to compensate the loss of plant number by increasing the yield of the remaining plants if the plants are removed during vegetative growth.

The growth stage at which the plants were removed did not significantly affect oil yield. But the intensity of plants removal influenced this trait significantly

Table 1. Summary of (a) analysis of variance and (b) means comparison for the traits related to seed and oil yield of rapeseed on the basis of a randomized complete block design and summary of results of (c) analysis of variance and (d) means comparison for these traits in Bam, Iran in 2010

(a) Analysis of variance of the effect of treatment combinations[(a)]

Sources of variations	df	Means of squares		
		Seed yield/plant	Seed yield/unit area	Oil yield
Replication	2	0.13ns	333025.39ns	125383.42ns
Treatment	9	0.83ns	1057203.41*	226101.80*
Experimental error	18	0.43	445713.70	105720.46
Coefficient of variations (%)		**29.14**	**19.80**	**21.21**

(b) Means comparison for treatment combinations[(b)]

Treatment combinations	g plant^{-1}	kg ha^{-1}	
Control	1.53 a	3653.34 abc	1700.85 ab
Removal of 25% of plants at seedling emergence	1.95 a	4055.53 ab	1782.96 ab
Removal of 50% of plants at seedling emergence	2.72 a	3648.59 abc	1633.34 ab
Removal of 75% of plants at seedling emergence	2.54 a	2689.63 c	1213.30 b
Removal of 25% of plants at stemming	1.81 a	4436.52 a	2055.71 a
Removal of 50% of plants at stemming	2.37 a	3448.48 abc	1556.24 ab
Removal of 75% of plants at stemming	2.51 a	2687.99 c	1195.08 b
Removal of 25% of plants at flowering	1.69 a	3254.50 abc	1521.82 ab
Removal of 50% of plants at flowering	2.22 a	3071.12 bc	1399.24 b
Removal of 75% of plants at flowering	3.25 a	2763.58 bc	1269.56 b

(c) Analysis of variance of the effect of time and intensity of plants removal[(a)]

Sources of variations	df	Seed yield/plant	Seed yield/unit area	Oil yield
Replication	2	0.10 ns	115994.19 ns	58252.04 ns
Plants removal time (A)	2	0.09 ns	655937.06 ns	100687.60 ns
Plants removal intensity (B)	2	2.09 *	3266390.41 **	709359.84 **
A x B	4	0.35 ns	349803.11 ns	80173.39 ns
Experimental error	16	0.49	447923.26	107748.89
Coefficient of variations (%)		**29.80**	**20.04**	**21.68**

(d) Means comparison for the effect of time and intensity of plants removal[(b)]

Time of plants removal	g plant^{-1}	kg ha^{-1}	
50% seedling emergence	2.40 a	3464.59 a	1543.20 a
50% stemming	2.23 a	3524.33 a	1602.34 a
50% flowering	2.38 a	3029.73 a	1396.88 a

Intensity of plants removal	g plant^{-1}	kg ha^{-1}	
Removal of 25% of plants	1.82 b	3915.52 a	1786.83 a
Removal of 50% of plants	2.44 ab	3389.39 a	1529.61 ab
Removal of 75% of plants	2.76 a	2713.74 b	1225.98 b

(a) ns, * and ** show non-significance and significance at 5 and 1% probability level.
(b) Figures in the columns with similar letter(s) did not have significant differences at 5% probability level.

at 1% probability level (Table 1c). Although the increase in plants removal intensity decreased oil yield per unit area, only the removal of 75% of plants resulted in significant loss of oil yield (1226.0 kg ha^{-1}) as compared to that under the removal of 25% of plants (1786.8 kg ha^{-1}; Table 1d). Oil yield from the removal of 50% of plants (1529.6 kg ha^{-1}) significantly differed with oil yield under the removal of 25 and 75% of plants (Table 1d). Oil yield increases with plant density (Danesh Shahraki *et al*., 2008). Also, oil yield is not affected by row spacing or plant density (Morrison *et al*., 1990).

Plant Phenological Traits

Different treatments of plants removal time and intensity did not significantly influence phenological traits of rapeseed including days from sowing to 50% germination, stemming, flowering and pod formation (Table 2a). Therefore, it can be concluded that the phenology of rapeseed was not related to

Table 2. Summary of (a) analysis of variance and (b) means comparison for the traits related to growth phenology of rapeseed plants on the basis of a randomized complete block design and summary of results of (c) analysis of variance of these traits in Bam, Iran in 2010

(a) Analysis of variance of the effect of treatment combinations[a]					
Sources of variations	df	Means of squares			
		Days from sowing to 50%			
		Germination	Seedling emergence	Stemming	Flowering
Replication	2	2.26 ns	3.81 ns	0.22 ns	8.15 ns
Treatment	9	3.50 ns	11.07 ns	17.86 ns	4.21 ns
Experimental error	18	2.72	6.69	13.33	9.83
Coefficient of variations (%)		**9.41**	**3.30**	**4.50**	**3.12**
(b) Means comparison for treatment combinations[b]					
Treatment combinations		days			
Control		16.66 a	77.44 a	89.36 a	100.09 a
Removal of 25% of plants at seedling emergence		19.63 a	79.93 a	91.41 a	100.85 a
Removal of 50% of plants at seedling emergence		16.87 a	81.05 a	89.78 a	101.31 a
Removal of 75% of plants at seedling emergence		16.69 a	75.49 a	85.74 a	98.77 a
Removal of 25% of plants at stemming		16.72 a	79.97 a	89.78 a	99.50 a
Removal of 50% of plants at stemming		17.79 a	79.22 a	91.86 a	101.76 a
Removal of 75% of plants at stemming		18.39 a	76.48 a	94.06 a	101.51 a
Removal of 25% of plants at flowering		17.36 a	77.84 a	89.46 a	101.25 a
Removal of 50% of plants at flowering		16.65 a	76.43 a	87.17 a	98.70 a
Removal of 75% of plants at flowering		18.31 a	80.25 a	92.18 a	101.64 a
(c) Analysis of variance of the effect of time and intensity of plants removal[a]					
Replication	2	2.55 ns	3.13 ns	1.33 ns	8.55 ns
Plants removal time (A)	2	0.19 ns	0.96 ns	21.37 ns	0.86 ns
Plants removal intensity (B)	2	1.69 ns	8.59 ns	2.54 ns	0.03 ns
A x B	4	5.33 ns	19.35 *	27.81 ns	8.85 ns
Experimental error	16	3.01	6.82	14.10	10.76
Coefficient of variations (%)		**9.86**	**3.33**	**4.17**	**3.26**

(a) ns, * and ** show non-significance and significance at 5 and 1% probability level.
(b) Figures in the columns with similar letter(s) did not have significant differences at 5% probability level.

the plant density during growing season. In total, days to 50% germination, stemming, flowering and pod formation under different treatment varied in the ranges of 16.7-19.6, 75.5-81.1, 85.7-94.1 and 98.7-101.8 days (Table 2b). Also, the growth stage and intensity of plants removal did not significantly influence the growth phenology of canola (Table 2c).

Plant Morphological Traits

Number of Branches per Plant

Various levels of plants removal time and intensity did not affect branch number per plant significantly (Table 3a). Although the decrease in plant density increased branch number per plant as compared to control (6.37 branches per plant), this effect was not statistically significant (Table 3a,b). The study on the effect of plants removal stage and intensity on branch number per plant showed that they did not affect this trait significantly (Table 3c). In total, the number of branches per plant varied in the range of 6.37-7.97 branches per plant (Table 3b), whereas most studies show the decrease in branch number per plant with the increase in plant density (Fathi, 2008; Chapman *et al*., 1984; Ilikayi and Imam, 2003). Thurling (1974) related the loss of branch number per plant under high densities to the increase in the

Table 3 - Summary of (a) analysis of variance and (b) means comparison for the morphological traits of rapeseed on the basis of a randomized complete block design and summary of results of (c) analysis of variance of these traits in Bam, Iran in 2010

(a) Analysis of variance of the effect of treatment combinations[(a)]			
Sources of variations	df	Means of squares	
		Branch number/plant	Plant height
Replication	2	0.01 ns	0.74 ns
Treatment	9	0.93	181.11 ns
Experimental error	18	71.45 ns	122.23
Coefficient of variations (%)		**13.27**	**8.09**
(b) Means comparison for treatment combinations[(b)]			
Treatment combinations		/plant	cm
Control		6.37 a	133.33 a
Removal of 25% of plants at seedling emergence		6.87 a	138.00 a
Removal of 50% of plants at seedling emergence		7.70 a	132.67 a
Removal of 75% of plants at seedling emergence		7.97 a	134.67 a
Removal of 25% of plants at stemming		7.27 a	147.00 a
Removal of 50% of plants at stemming		7.40 a	142.33 a
Removal of 75% of plants at stemming		7.63 a	133.00 a
Removal of 25% of plants at flowering		7.10 a	139.50 a
Removal of 50% of plants at flowering		6.80 a	133.50 a
Removal of 75% of plants at flowering		7.70 a	133.33 a
(c) Analysis of variance of the effect of time and intensity of plants removal[(a)]			
Replication	2	0.04 ns	164.58 ns
Plants removal time (A)	2	0.24 ns	91.00 ns
Plants removal intensity (B)	2	1.11 ns	144.08 ns
A x B	4	0.30 ns	33.58 ns
Experimental error	16	0.99	130.53
Coefficient of variations (%)		**13.47**	**8.33**

(a) ns, * and ** show non-significance and significance at 5 and 1% probability level.

(b) Figures in the columns with similar letter(s) did not have significant differences at 5% probability level.

distance from crown to the emergence of the first auxiliary branch in plant.

Plant Height

Different treatments of plants removal time and intensity significantly affected plant height (Table 3a), but the effect of stage and intensity of plants removal was not significant on this trait (Table 3c). In total, plant height was in the range of 132.67-147.0 cm under different treatments (Table 3b). Chegini *et al*. (2006) revealed that the increase in density from 30 to 70 plants m^{-2} resulted in significant loss of plant height. Modafebehzadi (2001) stated that the increase in density from 50 to 80 plants m^{-2} reduced stem length by 10 cm. Khajeh Hosseini (1991) concluded that the increase in plant height was induced by the growth of internodes caused by gibberellin hormone under light deficiency conditions.

Aerial Organs Dry Weight
Stem Dry Weight

Stem dry weight per unit area was significantly influenced by plants removal time and intensity at 1% probability level (Table 4a), so that the removal of 25% of plants at seedling emergence (1327.9 g m^{-2}), and at stemming (1290.5 g m^{-2}) were ranked in the same statistical group with control (1427.5 g m^{-2}), and the removal of 75% of plants at stemming (482.8 g m^{-2}), and at flowering (517.5 g m^{-2}) produced the lowest stem dry weight (Table 4b).

Plants removal stage and intensity and their interaction significantly impacted stem dry weight at 1% probability level (Table 5a). The removal of plants at seedling emergence and stemming did not bring about any significant changes in this trait (914.0 and 923.9 g m^{-2}), but decreasing plants removal to flowering significantly reduced stem dry weight to 697.8 g m^{-2} (Table 5b). The effect of plants removal intensity on stem dry weight was such that the increase in the intensity from 25 to 50 and 75% of plants reduced the stem dry weight by 17.7 and 55.2% from 1116.6 to 918.8 and 500.2 g m^{-2}, respectively (Table 5b). As can be seen in Fig. 5, stem dry weight decreased gradually with the increase in the intensity of plants removal during seedling emergence and stemming, while the removal of 50% of plants at flowering did not significantly increase plant dry weight as compared to the removal of 25% of plants. For the same reason, the interaction between plants removal stage and intensity was significant for this trait (Table 5a).

Pod Dry Weight

Plants removal time and intensity significantly impacted pod dry weight at 5% probability level (Table 4a). The highest pod dry weight (1733.8 g m^{-2}) was observed under the removal of 25% of plants at stemming which was 22.8% higher than the control (1412.3 g m^{-2}; Table 4b). Taking pod dry weight of control as the baseline, the highest loss of pod dry weight happened with the removal of 75% of plants at seedling emergence (51.3%), followed by the removal of 75% of plants at stemming (42.9%), the removal of 75% of plants at flowering (37.8%), the removal of 25% of plants at flowering (28.4%) and the remaining treatments were ranked in the same statistical group as the control (Table 4b).

The influence of plants removal stage and intensity was not significant on pod dry weight per unit area, but the intensity of plants removal significantly affected pod dry weight per unit area at 1% probability level (Table 5a). When the intensity of plants removal was increased to 75% of plants, pod dry weight per unit area was significantly lower than that under the removal of 25 and 50% of plants (Table 5b).

Seed Dry Weight

Seed dry weight per unit area was significantly affected by the treatments at 5% probability level (Table 4a). The removal of 75% of plants at seedling emergence and stemming resulted in significantly lower seed dry weight (351.4 and 362.6 g m^{-2}) than that of control (781.2 g m^{-2}; Table 4b). The stage of plants removal did not significantly impact this trait, but the effect of plants removal intensity was significant on it at 1% probability level (Table 5a). The increase of plants removal from 25 to 50% did not significantly change seed dry weight, but the removal of 75% of plants increased seed dry weight per plant by 42.7%, and decreased seed dry weight per plant (17.8 g $plant^{-1}$) and per unit

Table 4. Summary of (a) analysis of variance and (b) means comparison for the traits related to dry weight (DW) of plant parts of rapeseed in Bam, Iran in 2010

(a) Analysis of variance of the effect of treatment combinations[(a)]

Sources of variations	df	Means of squares								
		Stem DW		Pod DW		Seed DW		Total DW		Harvest
		/plant	/m^2	/plant	/m^2	/plant	/m^2	/plant	/m^2	index
Replication	2	23.69 ns	45339.99 ns	47.73 ns	125194.97 ns	6.80 ns	3835.68 ns	0.33 ns	213257.40 ns	9.07 ns
Treatment	9	16.05 ns	378368.48**	209.57 ns	390422.52*	62.01 ns	85208.96*	643.29 ns	2234116.36**	8.17 ns
Experimental error	18	10.18	10507.34	119.93	118143.69	34.99	24936.77	320.49	284499.37	7.57
Coefficient of variations (%)		**10.60**	**11.35**	**25.76**	**28.14**	**28.02**	**26.21**	**19.11**	**19.56**	**12.36**

(b) Means comparison for treatment combinations[(b)]

Treatment combinations	/plant	/m^2	/plant	/m^2	/plant	/m^2	/plant	/m^2	%
Control	25.67 a	1427.45 a	25.49 a	1412.33 a..b	14.09 a	781.18 a	65.25 a	3620.95 a	21.55 a
Removal of 25% of plants at seedling emergence	30.22 a	1327.88 a	37.19 a	1603.61 ab	17.94 a	782.17 a	85.35 a	3713.66 a	21.04 a
Removal of 50% of plants at seedling emergence	31.05 a	913.65 bc	47.71 a	1405.02 a..b	25.01 a	735.30 a	103.78 a	3053.98 ab	24.08 a
Removal of 75% of plants at seedling emergence	33.19 a	500.35 d	45.36 a	688.17 e	23.33 a	351.38 b	101.88 a	1539.89 d	22.91 a
Removal of 25% of plants at stemming	28.98 a	1290.54 a	37.80 a	1733.77 a	16.68 a	753.65 a	83.46 a	3777.96 a	19.98 a
Removal of 50% of plants at stemming	32.45 a	998.46 b	47.29 a	1492.02 abc	21.83 a	675.97 a	102.57 a	3166.44 ab	21.06 a
Removal of 75% of plants at stemming	30.92 a	482.81 d	50.89 a	807.14 de	23.07 a	362.64 b	104.88 a	1652.60 cd	21.49 a
Removal of 25% of plants at flowering	27.78 a	731.49 c	38.43 a	1011.20 b..e	18.84 a	494.40 ab	85.04 a	2237.08 bcd	22.14 a
Removal of 50% of plants at flowering	28.72 a	844.37 bc	40.13 a	1180.79 a..e	20.40 a	601.05 ab	89.24 a	2626.21 bc	22.68 a
Removal of 75% of plants at flowering	31.91 a	517.54 d	53.80 a	878.65 cde	29.88 a	487.36 ab	115.59 a	1883.55 cd	25.63 a

(a) ns, * and ** show non-significance and significance at 5 and 1% probability level.

(b) Figures in the columns with similar letter(s) did not have significant differences at 5% probability level.

Table 5. Summary of analysis of variance of traits related to the effect of time and intensity of plants removal on dry weight of plant parts of rapeseed in Bam, Iran in 2010

(a) Analysis of variance of the effect of treatment combinations(a)

Sources of variations	df	Means of squares								
		Stem DW		Pod DW		Seed DW		Total DW		Harvest
		/plant	/m^2	/plant	/m^2	/plant	/m^2	/plant	/m^2	index
Replication	2	26.34 ns	37885.81 ns	60.09 ns	177330.77 ns	5.14 ns	5195.13 ns	6.62 ns	299950.05 ns	8.54 ns
Plants removal time (A)	2	9.47 ns	146948.97 **	11.82 ns	238509.71 ns	14.50 ns	21926.88 ns	0.40 ns	990445.01 *	16.49 ns
Plants removal intensity (B)	2	20.63 ns	891451.99 **	341.81 ns	1145930.00 **	132.04 *	224154.81 **	1191.41 *	6107121.41 **	12.30 ns
A x B	4	4.78 ns	103318.32 **	53.36 ns	155811.25 ns	25.25 ns	42078.01 ns	176.80 ns	812363.68 *	3.58 ns
Experimental error	16	11.08	11490.13	131.90	123746.31	39.12	27023.23	355.43	300060.80	8.48
Coefficient of variations (%)		**10.89**	**12.68**	**25.87**	**29.31**	**28.58**	**28.21**	**19.46**	**20.84**	**13.04**

(b) Means comparison for treatment combinations

Plants removal time	g/plant	g/m^2	g/plant	g/m^2	g/plant	g/m^2	g/plant	g/m^2	%
50% seedling emergence	31.49 a	913.96 a	43.42 a	1232.27 a	22.09 a	622.95 a	97.00 a	2769.18 ab	22.68 a
50% stemming	30.79 a	923.94 a	45.66 a	1344.31 a	20.53 a	597.42 a	96.97 a	2865.67 a	20.84 a
50% flowering	29.47 a	697.80 b	44.12 a	1023.55 a	23.04 a	527.60 a	96.62 a	2248.94 b	23.48 a
Plants removal intensity	g/plant	g/m^2	g/plant	g/m^2	g/plant	g/m^2	g/plant	g/m^2	%
Removal of 25% of plants	28.99 a	1116.64 a	37.81 a	1449.52 a	17.82 b	676.74 a	84.62 b	3242.90 a	21.05 a
Removal of 50% of plants	30.74 a	918.83 b	45.38 a	1359.28 a	22.42 ab	670.77 a	98.53 ab	2948.87 a	22.60 a
Removal of 75% of plants	32.01 a	500.23 c	50.02 a	791.32 b	25.43 a	400.46 b	107.45 a	1692.01 b	23.34 b

(a) ns, * and ** show non-significance and significance at 5 and 1% probability level.

(b) Figures in the columns with similar letter(s) did not have significant differences at 5% probability level.

area (676.7 g m^{-2}) as compared to that under the removal of 25% of plants (Table 5b).

Total Dry Weight

Total dry weight per unit area was significantly affected by different treatments of plants removal time and intensity at 1% probability level (Table 4a), so that the removal of 25 and 50% of plants at seedling emergence (with total dry weights of 3713.7 and 3054.0 g m^{-2}, respectively) and stemming (3778.0 and 3166.4 g m^{-2}, respectively) ranked in the same statistical group as that of control (3621.0 g m^{-2}) and the removal of 75% of plants at seedling emergence (1539.9 g m^{-2}), stemming (1652.6 g m^{-2}) and flowering (1883.6 g m^{-2}) resulted in the lowest total dry weight per unit area (Table 4b).

Plants removal stage and intensity and their interaction influenced total dry weight significantly at 1% probability level (Table 5a). Total dry weight of the treatments of the removal of 25% of plants at seedling emergence (2769.2 g m^{-2}) and stemming (2865.7 g m^{-2}) did not show significant differences, but retarding the time of plants removal at flowering resulted in 18.8% loss of total dry weight to 2248.9 g m^{-2} (Table 5b). The increase in the intensity of removal from 25 to 50% of plants significantly decreased total dry weight, but as the intensity was increased to a total dry weight to only 75% of plants, total dry weight significantly reduced by 47.8% to 1692.0 g m^{-2} (Table 5b). As can be seen in Fig. 6d, the increase in the intensity of plants removal at seedling emergence and stemming, caused gradually decreased in the total dry weight per unit area; the removal of 50% of plants at flowering although did not, bring about significant increase in total dry weight as compared to the removal of 25% of plants but resulted in a significant interaction between the stage and intensity of plants removal (Table 5a). In a study on rapeseed at three densities of 40, 80 and 120 plants m^{-2}, Shirani Rad *et al.* (1996) reported that the highest and lowest total dry weights were produced at 40 and 80 plants m^{-2}, respectively. Also, Chegini *et al*. (2006) showed that the increase in density from 30 to 70 plants m^{-2} resulted in higher crop dry weight. Fathi (2008) reported the effect of plant density on biological yield at maturity as to be significant and that the highest and lowest biological yields were produced at 110 and 50 plants m^{-2} (14.6 and 10.8 t ha^{-1}), respectively. Kandil *et al*. (1996) observed the increase in biological yield with the increase in density from 50 to 90 plants m^{-2} (11049.9 and 14046.1 kg ha^{-1}, respectively). Abadian *et al*. (2008) reported that biological yield was significantly related to the density, and that the highest biological yield was obtained at 80 plants m^{-2}.

Harvest Index

The effect of plants removal time and intensity was not significant on harvest index (Table 4a). Also, the effect of plants removal stage and intensity was not significant on this trait (Table 5a). In total, harvest index varied in the range of 20.0-25.6% (Table 4b). The slight variations of harvest index show its dependence on plant genetic structure (Imam and Nicknejad, 1994). According to the studies of Appelquist and Ohlson (1972), Kimber and McGregor (1999) and Ilikayi and Imam (2003), it seems that self-regulatory mechanism of the balance between vegetative and reproductive organs is the reason for the variations of harvest index at different densities.

Conclusion

Seed Yield

The response of seed yield per plant and per unit area to the time and intensity of plants removal indicated that the decrease in plant number per unit area resulted in higher seed yield per plant (Table 5). In other words, the removal of 25% of plants at seedling emergence, stemming and flowering increased seed yield per plant by 27.0, 18.3 and 10.0%, respectively. Furthermore, the removal of 50% of plants at seedling emergence, stemming and flowering increased seed yield per plant by 77.6, 54.6 and 44.6%, respectively, and finally, the removal of 75% of plants at seedling emergence, stemming and flowering resulted in 65.5, 63.5 and 44.6% higher seed yield per plant, respectively (Table 5). Given the balance between the increase in seed yield per plant and the decrease in plant number per unit area, it can be seen that the removal of 50% of plants at seedling emergence and stemming increased seed yield by 77.6 and 54.6%, respectively but the removal of 75% of plants resulted in 65.5 and 63.5%

Table 6. Response of seed yield per plant and unit area and oil yield to the intensity of plants removal at different growth stages of rapeseed in Bam region, Iran in 2010

Trait	Seed yield per plant (g/plant)			Seed yield per unit area (kg/ha)			Oil yield per unit area (kg/ha)		
Control	1.53			3656.34			1700.85		
	Time of plants removal								
Plants removal intensity	Seedling emergence	Stemming	flowering	Seedling emergence	Stemming	flowering	Seedling emergence	Stemming	flowering
	Percentage of variations as compared to control								
25%	+27.0	+18.3	+10.0	+10.9	+21.3	-11.0	+4.8	+20.9	-10.5
50%	+77.6	+54.6	+44.6	-0.2	-5.7	-16.0	-4.0	-8.5	-17.7
75%	+65.5	+63.5	+46.6	-26.4	-26.5	-24.4	-28.7	-29.7	-25.4

Table 7. Response of dry weight of different plant parts to the intensity of plants removal at different growth stages of rapeseed in Bam region, Iran in 2010

Trait	Stem dry weight (g/m^2)			Pod dry weight (g/m^2)			Seed dry weight (g/m^2)		
Control	1427.45			1412.33			781.18		
	Time of plants removal								
Plants removal intensity	Seedling emergence	Stemming	flowering	Seedling emergence	Stemming	flowering	Seedling emergence	Stemming	flowering
	Percentage of variations as compared to control								
25%	-7.0	-9.6	-48.8	+13.5	+22.8	-28.4	+0.1	-3.5	-36.7
50%	-36.0	-30.1	-40.8	-0.5	+5.6	-16.4	-5.9	-13.5	-23.1
75%	-64.9	-66.2	-63.7	-51.3	-42.9	-37.8	-55.0	-53.6	-37.6

higher seed yield per plant, respectively (Table 5). The removal of 25, 50 and 75% of plants at flowering caused the seed yield per plant to be much lower than the number of removed plants, and to increase by 10.0, 44.6 and 46.6%, respectively (Table 5). Therefore, as plants removal was retarded, the plants had less opportunity to compensate the removal of plants by increasing seed yield per plant (Table 5). Accordingly the diagram of plant density and seed yield per plant by seed yield per unit area, the variations of the later versus the decrease in plant density, showed that plants removal at flowering decreased seed yield, whereas the removal of 25 and 50% of plants at seedling emergence and the removal of 25% of plants at stemming not only did not decrease seed yield, but also increased it by 10.9-21.3% (Table 5). The fitting of the model for determining the response of seed yield to the loss of plant density revealed that the increase in plants removal increased seed yield per plant, but decreased seed yield per unit area (Fig. 1). The intersection between these two graphs was when the increase in seed yield per plant (20.7%) under the removal of 15% of plants (the decrease in density from 67 to 57 plants m^{-2}) was equal to the decrease in seed yield per unit area (20.8%; Fig. 1). Hence, it can be concluded that the maximum seed yield in Bam, Iran can be realized by using the density of up to 57 plants m^{-2} (the inter-plant spacing can be adjusted to 5.0-5.8 cm). Ogilvy (1984) showed that although the optimum seeding rate for winter cultivation in the UK was 4-8 kg ha^{-1}, the seeding rate of 3-12 kg ha^{-1} resulted in similar yield with the differences of no more than 10%. Also, he believed that the density of 80-100 plants m^{-2} was desirable in spring, and the lower densities resulted in sparse state which increased the risk of pests and lodging.

Oil Yield

As can be seen in Table 4, the removal of 25% of plants at seedling emergence and stemming increased oil yield by 4.8 and 20.9%, respectively, while oil yield showed negative response to the removal of 50 and 75% of plants at seedling emergence and stemming, and all levels of the plants removal at flowering (Table 5). To fit the response

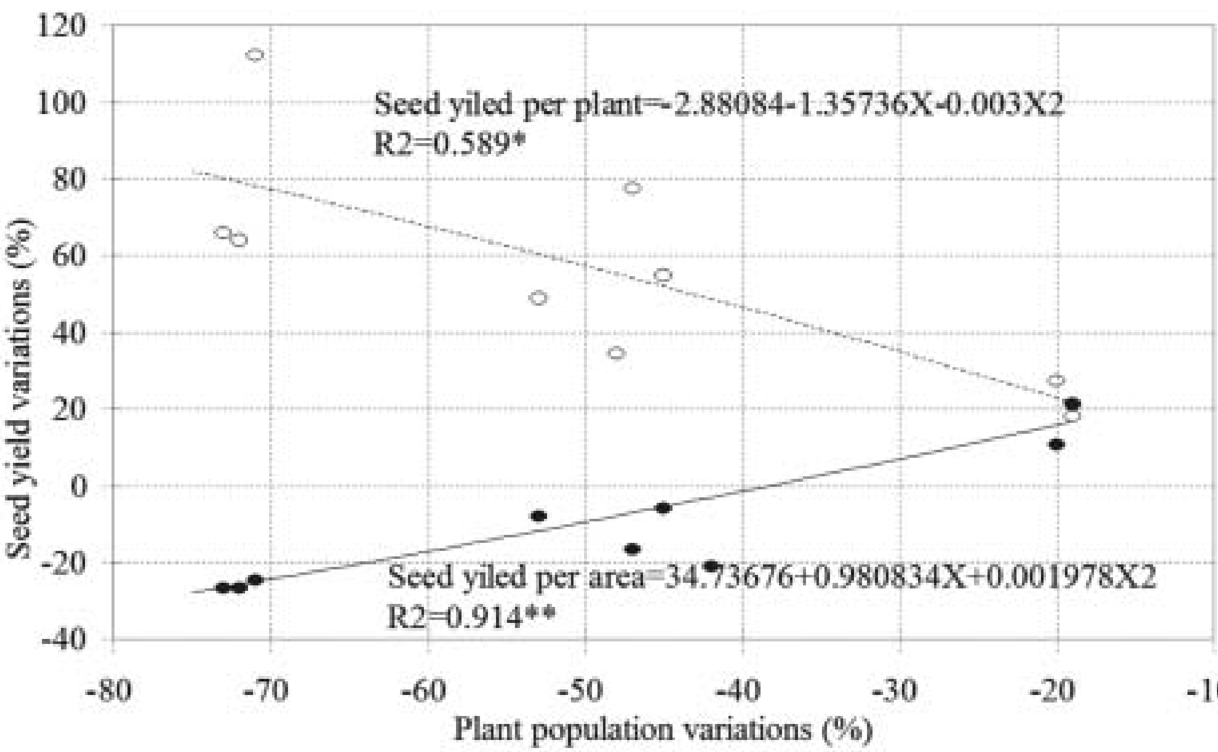

Fig 1. Response of canola seed yield per area and plant variations to the final plant population variations in Bam region, Iran in 2010

of oil yield to the variations of plant density, quadratic equation explained the variations well (Fig. 2). This equation indicated that the removal of up to 34% of platns increased oil yield per unit area. In other words, the highest oil yield (= the lowest loss of yield) was obtained at the density of 45 plants m^{-2} (Fig. 2). Fanaye *et al*. (2008) reported that oil yield was positively correlated with seed yield and oil percentage and as seed yield was increased, oil extraction rate was increased. But they reported the effect of seeding rate on oil percentage to be non-significant.

Dry Weight

The response of dry weight of different parts of the plant to the variations of plant density showed that the removal of plants at flowering had the highest negative effect on the dry weight of vegetative parts (Table 7). As 25, 50 and 75% of plants were removed at flowering, stem dry weight was decreased by 48.8, 40.8 and 63.7%, pod dry weight was decreased by 28.4, 16.4 and 37.8%, and seed dry weight was decreased by 36.7, 23.1 and 37.6%, respectively (Table 7).

Fig 2. Response of canola oil yield variations to the final plant population variations in Bam region, Iran in 2010

We concluded from the present study that rapeseed is more sensitive to the intensity of plants removal than to its stage. The evaluation of the response of different components of seed yield to the variations of plant density showed that plants removal had the highest effect on pod number per unit area followed by seed number per plant, and single-seed weight. As plants removal was retarded from vegetative growth to reproductive growth stage, the plants lost their capability in compensating the loss of plants by increasing pod number per plant.

Bam has a distinguished soil texture, and we recommend that these kind of studies should be to conducted in other regions. Other agro-technique parameters including irrigation interval and planting arrangement should also be included in the studies. Since the present study was conducted under the most optimum conditions, the effect of water stress and fertilization requirement needs to be included too. No similar study has been conducted in other rape-producing regions of Iran. So, it is recommended to repeat the study in those regions. The study needs to be conducted on other cultivars. It needs to be conducted on other crops as well.

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