Reduction in Primary Tillage Depth and Secondary Tillage Intensity for Irrigated Canola Production in a Loam Soil in Central Iran

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ABSTRACT

The introduction of canola (oilseed rape; *Brassica napus* L.) as a new source of vegetable oil production in Iran prompts evaluation of the performance of this crop under different tillage systems. A field experiment was conducted to determine the impact of depth and intensity of tillage on soil physical properties, crop establishment and yield of irrigated winter canola in a loam soil (Typic Haplargids) near Isfahan in central Iran. In a split-plot design, three primary tillage treatments consisted of moldboard plowing to 20 cm (MP20), two passes of a cultivator first to 10 and then to 15 cm (2TC15), and one single pass of cultivator to 10 cm (TC10), were combined with two seedbed preparation treatments (four passes with a disk harrow as opposed to a single pass with a rotary tiller). Results showed that the soil bulk density in the 0-5 and 5-10 cm layers were not significantly affected by primary tillage treatments. Soil penetration resistance (PR) in the 0-10 cm layer was significantly higher in 2TC15 compared to moldboard plowed soil; however, no significant effect of primary tillage was detected on PR in the 10-20 cm depth. A single pass by a rotary tiller was as effective in seedbed preparation as four passes of a disk harrow, as assessed by bulk density, penetration resistance and the percentage of emergence. The number of plants per square meter at final emergence and at harvest was statistically similar for both the seedbed preparation methods. Mean canola total dry matter biomass was 10,020, 9,860 and 10,410, kg ha^{-1} and dry grain yield was 2,340, 2,410 and 2,880 kg ha^{-1} under MP20, 2TC15 and TC10, respectively. However, the effects on mean crop yield were non-significant (P> 0.05). The mean oil content of the 2TC15 (40.1%) was significantly lower than the MP20 and TC10 treatments, 43.7 and 42.3%, respectively. Lack of yield response to tillage treatment may have been the result of achieving a good seedbed (aggregate mean diameter of less than 15 mm) under all tillage methods, which help to obtain sufficient plant establishment. These results indicate that the yield of irrigated winter canola is not sensitive to reduction in the depth of primary tillage or intensity of secondary tillage. With reduced tillage, an optimum plant per unit area can also be achieved. Overall, TC10 combined with a single pass of a rotary tiller was considered to be agronomically desirable, due to the absence of grain yield difference compared with both the MP20 or 2TC15 systems and reduced tilling depth.

Keywords: Disk harrow, Grain yield, Non-inversion tillage, Oilseed rape, Rapeseed, Rotary tiller.

INTRODUCTION

The suitability of minimum-tillage systems for annual crop production is dependent on soil and agronomic factors. Soil tillage requirement is an important aspect of minimum-tillage systems since some soils are structurally unstable and subject to compaction, and have limited ability for regeneration of soil structure without the input of some form of tillage (Ball, 1986; Carter, 1987). Furthermore, climatic factors as well as soil topography and drainage characteristics (Ball, 1986) can influence the tillage requirement of any one soil type. In addition to soil factors, agronomic aspects such as: crop-residue amounts, plant disease and pests, and peren-

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nial weeds can modify soil tillage require-ment and affect the choice of tillage imple-ments for a specific farming system (Carter *et al*., 1990).

The depth of tillage is soil- and crop-specific. Extensive research in Ontario and throughout western Canada for rainfed canola production has failed to show any improve-ments in water storage or yield for tillage depths beyond 10 to 15 cm in most soils. Deep cultivation may bring up large-sized clods which is problematic for seedbed prepa-ration. It also brings dormant weed seeds to the soil surface where they germinate and grow (Thomas, 1984). Many experiments in England have been carried out aimed at de-termining the best method for rainfed canola establishment, and the results suggest that, under uncompacted, weed-free conditions and with sufficient seedbed moisture, there is very little difference between plowing, culti-vating to various depths and direct drilling (Ward *et al*., 1985).

Minimum tillage due to its minimum soil disturbance, lower cost and less fuel con-sumption should be considered as long as there is no general compaction in the topsoil to be removed. In this case, the principle of tilling the soil from the top down should be adopted to produce fine seedbeds. In the first pass, a shallow cultivation is performed; then, in the second pass, the working depth of the tillage implement is increased. This is ex-pected significantly to reduce the size of clods and also produce a firmer seedbed when compared with plowing since the shal-low depth of tilled soil reacts well to consoli-dation (Ward *et al*., 1985). Bonari *et al*. (1995) compared conventional (25 cm deep plowing) and minimum (10-15 cm deep disk harrowing) tillage for winter oilseed rape production on a very sandy soil and con-cluded that rapeseed grain and biomass yields under both systems never differed signifi-cantly. They also reported work done by other Italian researchers on heavier soils and their results demonstrated that, in many cases, the deployment of no-tillage or minimum-tillage produces crop yields that are not sig-nificantly different from those obtained using conventional plowing. In a cold semi-arid

climate, Arshad *et al*. (1995) found that spring canola under reduced tillage (soil tilled with a cultivator to a depth of 8-10 cm once in the spring just prior to seeding) tended to be higher than either conventional tillage (soil tilled with a cultivator to a depth of 8-10 cm once in the preceding fall and twice prior to seeding in the spring) or no-tillage, although the mean differences were usually non-significant.

Crop establishment largely depends on the methods of seedbed preparation and sowing (Håkansson *et al*., 2002). Few field opera-tions are more closely related to success or failure in canola production than is seedbed preparation. For canola, the seedbed should be reasonably level, uniform, well packed, weed-free, warm, slightly lumpy on the sur-face and moist throughout its whole depth. A firm, well-packed seedbed provides excellent soil moisture and oxygen supply to seeds (Thomas, 1984).

In recent years, more than 90% of the vege-table oil consumed in Iran has been imported from foreign countries. In 2005, Iran im-ported 850,000 metric tons of vegetable oil (Fars News Agency, 2005). The Iranian gov-ernment is planning to achieve self-sufficiency in vegetable oil production in the long term. Canola with its high oil content has been introduced as a new oilseed crop to farmers. Canola cropping in central Iran raised questions about many basic production practices including optimum cultivation depth, and seedbed preparation methods. This study was conducted to determine the effect of decreasing the depth of primary tillage and intensity of secondary tillage on irrigated winter canola establishment and yield in cen-tral Iran.

MATERIALS AND METHODS

Site and Soil

The field experiment was conducted in 2002-2003 at the Research Station farm of Isfahan University of Technology (32°32´N; 51°23´E; 1630 m a.s.l.) in Isfahan (central Iran). The mean annual precipitation and

temperature at the station are 140 mm and 14.5°C, respectively. The soil (fine-loamy, mixed, thermic Typic Haplargids, USDA system; Calcairc Cambisols, FAO system) is formed by the alluvial sediments of the Zayandeh Roud Rriver (Lakzian, 1989). It is initially low in OM and has a history of intensive conventional cultivation and cropping of cereals, hay, and silage corn (*Zea mays* L.) in rotation. The field had been under clover (*Trifolium resupinatum* L.) in the previous year. The growing season usually extends from October to late June of the next year. The values of some physical and chemical properties of the soil are given in Table 1.

Experimental Design and Treatments

The experimental design was a split-plot, randomized complete block, with primary tillage as the main plots and secondary tillage as subplots. Treatments were replicated three times. Individual plots were 4 m wide and 22 m long with a main border 5 m wide between each two blocks. The primary tillage treatments were as follows: (1) moldboard plowing to 20 cm (MP20), (2) cultivation with a rigid cultivator in the first pass to 10 cm and in the second pass to 15 cm (2TC15), and (3) cultivation with a rigid cultivator in a single pass to 10 cm (TC10). The secondary tillage treatments consisted of (1) four passes with a disk harrow, and (2) a single pass with a rotary tiller. Rolling with a Cambridge roller was done immediately after secondary tillage in all treatments. The number of disk harrow passes was determined by visual examination of seedbed structure by the farm manager who has experience in production of oilseed crops. A pre-tillage irrigation was applied to the soil; then, the primary tillage was performed when the soil moisture content in the 0-20 cm soil layer was optimum. The description of the tillage and planting implements are given in Table 2.

Canola Sowing

The seeding was done using the dry flatland system. In each plot 9 rows were sown using a Hassia grain drill. The canola (S-L-M046 cultivar) was sown at the rate of 15 kg per hectare with a row spacing of 32 cm. All plots were rolled with a Cambridge roller immediately after sowing. The 1,000-kernel weight and germination percentage of the seed were 3.8 g and 69%, respectively. However, when the seed was passed through the drill, its germination reduced significantly to 55%.

Crop Management

The crop received 180 kg N ha^{-1} as urea, 40 kg P ha^{-1} as ammonium phosphate and 40 kg K ha^{-1} as potassium sulphate. Full applications of P and K and a one-third application of N were broadcast before secondary tillage operation. The remaining N was applied in all treatments in two split applications at stem elongation stage (4 March 2004) and at the beginning of flowering stage (29 March 2004). Weeds were controlled by hand-weeding in April. Canola was treated once (30 March 2004) with 0.5 kg ha^{-1} Pirimor® (Pirimicarb) for cabbage aphid (*Brevicoryne brassicae* L.) control. Canola was sown on 30 September 2003 and harvested on 25 June 2004. The experiment was sown in dry soil and then irrigated to bring the soil moisture content to field capacity. Irrigation consisted of flooding level basins and the first one was on 2 October 2003. The field was irrigated 14 times from seeding to harvest time.

Measurement of Soil Parameters

After secondary tillage, soil samples were taken from each plot. A 0.5×0.5 m frame was used to surround the soil sample; then the surface layer of soil was removed by hand to the working depth to prevent soil aggregate break-up. All the soil aggregate samples were dried prior to sieving. A set of sieves of 125, 75, 50, 38.1, 25, 22.4, 19, 16, 12.5, 8, 6.3, 4.75, 2, 0.85, 0.45, 0.25, 0.15, and 0.075 mm mesh openings was selected. Each soil sample was passed through the set of sieves, and the soil retained on each was weighed, as

Table 1. Soil physical and chemical properties at the Isfahan University of Technology Research Station farm, Isfahan, Iran

Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Texture	Saturation percentage (kg kg^{-1})	Field capacity (kg kg^{-1})	Permanent wilting point (kg kg^{-1})	Electrical conductivity (mS cm^{-1})	Organic carbon (g kg^{-1})	pH	Total N[a] (g kg^{-1})	Available P[b] (mg kg^{-1})	Available K[c] (mg kg^{-1})	CaCO$_3$ (TNV) (g kg^{-1})
0-30	390	400	210	Loam	0.486	0.265	0.127	1.2	8.9	7.1	0.7	16.5	390	275
30-60	420	360	220	Loam	0.428	0.253	0.126	0.9	6.1	7.3	0.5	10.8	295	298

[a] Kjeldahl method.
[b] Sodium bicarbonate extractable P (Olsen procedure).
[c] Ammonium acetate extractable K.

Table 2. Tillage implements and drill specifications.

Equipment	Width (m)	Description
Moldboard plow	0.90	Mounted, general purpose, 3-bottom, 30 cm bottom spacing.
Field cultivator	1.95	Mounted, 15 straight rigid shanks, fixed on a 2-row chassis at a spacing of 14 cm with a vertical clearance of 35 cm, a triangular 5-cm wide point with a rake angle of 44° attached at the end of each vertical shank.
Tandem disk harrow	2.41	Mounted, 7 disks in each gang, diameter of front gang notched disk 46 cm, rear gang plain disk 46 cm, 18-cm disk spacing.
Rotary tiller	1.50	Mounted, horizontal rotor, with 36 L-shaped blades arranged on 7 flanges of its rotor, with three right-hand and three left-hand blades per flange.
Cambridge roll	1.93	Trailed, with alternate serrated rings (43 cm in diameter) and sprocket-tooth rings (41 cm in diameter).
Drill	3.00	Mounted, 19 sowing rows with 16 cm spacing, with fluted-roll metering device, single disk furrow opener, without covering device (Hassia brand).

well as the soil that passed through the sieve with the smallest aperture. The aggregate mean weight diameter of the individual sample was calculated by the following equation (Adam and Erbach, 1992):

$$MWD = \sum X_i W_i$$

where MWD is the aggregate mean weight diameter, mm; X_i is the average aggregate diameter in a particular sieve in mm and W_i the weight of aggregates in the size range i, as a function of total dry weight of sample analyzed.

Three days after the first irrigation (5 October 2003), the soil bulk density (BD) for the 0–5 and 5–10 cm layers in each plot was estimated using the core method. Intact soil cores with a 5.4 cm diameter by 4 cm length were obtained using a core sampler (Blake and Hartage, 1986).

Cone penetration resistance (PR) was measured using a digital cone penetrometer (Model Rimik CP20, Agridry Rimik Ltd, Queensland, Australia). Estimates of PR to a depth of 20 cm in 2 cm measurements were made three days after the third irrigation on 15 October 2003 and 10 insertions per plot were made. Soil samples at a 0-20 cm depth were collected for gravimetric water content determination. At the time of PR measurement, the mean gravimetric moisture content at the 0-20 cm depth was 17%.

Plant and Yield Measurements

Weed density was assessed subjectively by three persons on 22 Oct 2003. The criterion was based on how much of the area between the plant rows was covered in weeds. Weed density was rated on a scale of 0 to 3, where 0 would indicate no weeds present and 3 would indicate a large part of the plot covered by weeds.

The number of plants at full emergence was determined on 12 November 2003 by counting the number of seedlings in two 1 m rows per plot. Emergence for each plot was also subjectively assessed as a percentage of the plot area with canola plants. Following the winter, plant stand was estimated on 4 March 2004. Seedling establishment for each plot was expressed as a percentage of the plot area with canola plants. Canopy ground cover and plant height score were assessed subjectively by three persons on 22 April 2004. Canopy ground cover for each plot was determined as a percentage of the plot area covered by canola plants. Plant height was rated from a scale of 1 to 4, where 1 would indicate short plants and 4 would indicate tall plants.

Crop biomass and seed yield were estimated on 29 June 2004 by cutting all the above-ground crop biomass on three sub-sampling areas of 3 m of a row in the central area of each plot. Each sub-sampling had 0.96 m^{-2} (i.e. a total of 2.88 m^{-2} was harvested in each plot). The number of plant cut in each 3 m of row and the distance between plants in each row were determined and the vegetative material harvested was separated from the seed for each of the three sub-samples in each plot and was weighed and dried. The straw

and seed samples were dried for 48 and 4 hours at 70 and 130°C, respectively. Crop Harvest Index (HI) was calculated by dividing the dry grain yield by Total plant aboveground Dry Matter (TDM). The thousand-kernel weight was estimated by counting and weighing two 250-kernel samples taken from the harvested grain of each plot. Plant height, measured in centimeters, was determined by measuring at harvest from the base of the plant to the top pod on the main stem. In one-pass harvesting of the canola with a combine, the plant height can prove important. Therefore, the plant height was measured on two sub-samples of 10 plants selected randomly along the two middle rows of each plot. Grain sample was analyzed for oil contents and ash. Grain samples were dried for 4 hours at 130°C and then cooled overnight in desiccators before determination of oil content. Oil content was determined by ether extraction and ash by muffle furnace (Pages *et al*., 1982).

Statistical Analysis

All data were subjected to analysis of variance using SAS Proc GLM of (SAS Institute, 1990). When the analysis of variance was significant at P< 0.05 probability level, treatment means were separated by Least Significant Difference (LSD$_{0.05}$) test. Correlation analysis was used to examine the association between parameters (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Soil Physical Properties

Aggregate Mean Weight Diameter

Mean MWD was significantly higher under TC10 than either MP20 or 2TC15 (Table 3). However, two passes of the tined implement (2TC15) was as effective as moldboard plowing (MP20) in soil fragmentation. The results of aggregate distribution analysis showed that all tillage methods created a fine soil structure in which more than 50% of aggregates by weight were in the class of < 5 mm in diameter (Table 3). It is reported that a good seedbed is obtained when 50% of the aggregates by weight are in the range of 0.5-6.0 mm. This corresponds to a MWD of 12 mm (Berntsen and Berre, 2000). Russell (1973) also indicated that it is generally accepted that soil particle sizes in the range of 1 to 5 mm are required for seedbeds. Table 3 shows that one pass of rotary tiller was as efficient as four passes of disk harrow at creating an ideal seedbed.

Bulk Density

The dry soil Bulk Density (BD) in primary and secondary tillage treatments is presented in Table 4. BD was not affected by either primary or secondary tillage. The average values of the BD at 0-5 and 5-10 cm were 1.17 and 1.31 g cm^{-3}, respectively. Similar

Table 3. Effect of primary and secondary tillage on mean weight diameter (MWD) of the aggregates and the percentage of aggregates < 5 mm in the seedbed [a].

Treatment	MWD (mm)	Aggregates< 5 mm (%)
Primary tillage, maximum depth		
Cultivation, 10 cm (TC10)	13.6 a	53.6 b
Cultivation, 15 cm (2TC15)	9.6 b	61.4 a
Plowing, 20 cm (MP20)	9.6 b	67.7 a
Secondary tillage		
Disking (4 passes)	10.8	60.5
Rotary tilling (single pass)	11.0	61.3

[a] Mean values followed by the same letter or with no letters in each column within treatment category are not significantly different at the 5% level of probability by LSD.

BD for chiseling and moldboard plowing were obtained also by Benjamin and Cruse (1987) and Comia *et al*. (1994).

Penetration Resistance

Cone penetrometer measurements showed no differences in soil strength among primary tillage treatments in the 10-20 cm layer while, at the 0-10 cm depth, 2TC15 had significantly higher soil strength than the moldboard plowing treatment (Table 4). The penetration resistance in the 0-10 cm layer was 17 and 26% higher for TC10 (one pass) and 2TC15 (two passes), respectively, when compared with moldboard plowed soil. Contrary to the results for BD, this indicated that the moldboard plow was more efficient than a tined implement in soil loosening. Similar results were obtained by Carter (1996) and Arvidsson (1998). No differences in penetration resistance were found between secondary tillage treatments for both depths. The penetration resistance of 0-10 and 10-20 cm layers were positively correlated (r= 0.68, P= 0.002).

Canola Establishment and Yield

Weed Density

The weed density score was significantly (P= 0.0015) lower under MP20 than either 2TC15 or TC10 (Table 5). There was no sig-

nificant effect of secondary tillage on the weed density score. The lesser degree of soil disturbance under tined cultivation (chisel plowing) as compared with moldboard plowing generally results in an increase in the occurrence of perennial weeds in many cropping systems (Froud-Williams *et al*., 1984; Buhler *et al*., 1994). Børresen and Njøs (1994) stated that deep plowing and deep and intense seedbed preparation reduced weed infestation. The weed density score had a negative correlation with the number of plants per square meter that approached significance (r= -0.41, P= 0.087).

Plant Density

The canola plant population at full emergence was not significantly affected by the primary or secondary tillage operations (Table 5). This was the result of relatively high emergence resulting from a fine, firm and well-packed seedbed under all treatments (Tables 3 and 4). Rolling before sowing crushed the large aggregates, leveled the soil surface, and facilitated a uniform shallow seeding depth. Rolling immediately after sowing provided good soil-seed contact for moisture absorption during germination (Håkansson *et al*., 2002). von Polgár (1984)

Table 4. Effect of primary and secondary tillage on soil bulk density and penetration resistance [a].

Treatment	Bulk density (g cm^{-3})		Penetration resistance (kPa)	
	0-5 cm	5-10 cm	0-10 cm	10-20 cm
Primary tillage, maximum depth				
Cultivation, 10 cm (TC10)	1.18	1.32	790 ab	1057
Cultivation, 15 cm (2TC15)	1.16	1.27	854 a	1127
Plowing, 20 cm (MP20)	1.18	1.33	677 b	1069
Secondary tillage				
Disking (4 passes)	1.18	1.33	783	1072
Rotary tilling (single pass)	1.16	1.28	764	1079

[a] Mean values followed by the same letter or with no letters in each column within treatment category are not significantly different at the 5% level of probability by LSD.

Table 5. Effect of primary and secondary tillage on weed density score, number of plants per square meter and percentage of seedlings at full emergence, stand establishment after winter and canopy cover and plant height index measured in spring [a].

	Date of sampling					
	22 Oct. 2003	12 Nov. 2003		4 Mar. 2004	22 Apr. 2004	
Treatment	Weed density score	Plants per square meter	Emergence (%)	Plant estab-lishment after winter (%)	Canopy ground cover (%)	Plant height score
Primary tillage, maximum depth						
Cultivation, 10 cm (TC10)	1.92 a	74	81	77	79	2.9 b
Cultivation, 15 cm (2TC15)	1.75 a	104	80	81	84	3.5 ab
Plowing, 20 cm (MP20)	0.83 b	125	88	88	93	3.8 a
Secondary tillage						
Disking (4 passes)	1.33	103	85	89	87	3.5
Rotary tilling (sin-gle pass)	1.67	99	81	81	84	3.3

[a] Mean values followed by the same letter or with no letters in each column within treatment category are not significantly different at the 5% level of probability by LSD.

reported an extensive series of trials with rolling after spring sowing of barley, oats and wheat on soils with clay contents of between 3 and 56%. On average, rolling immediately after sowing increased early crop emergence by 9%, final emergence by 4% and yield by 2% irrespective of crop and harrowing or sowing depths. Seedling losses and uniformity of establishment are especially influenced by seedbed conditions of the time of sowing (Daniels *et al*., 1986) and during establishment (Taylor and Smith, 1992).

Plant establishment after the winter was not influenced by tillage treatments. Its trend was similar to the percentage of emergence (Table 5) and they were significantly correlated (r= 0.75, P= 0.0003). It was also correlated with the number of plants per square meter (r= 0.56, P= 0.015) measured at full emergence. The effect of tillage on canopy ground cover measured in spring was not significant (Table 5). Canopy ground cover and plant density were significantly correlated (r= 0.61, P= 0.0072) and their correlation with the percentage of emergence approached significance (r= 0.45, P= 0.062). Canopy ground cover and plant establishment after the winter also strongly correlated (r= 0.82, P= 0.0001). The negative correlation between canopy

ground cover and the penetration resistance of 0-10 and 10-20 cm layers approached significance (r= -0.45, P= 0.06; r= -0.40, P= 0.097, respectively).

The plant height score estimated in the spring was significantly affected by primary tillage, but not by secondary tillage. The plant height under TC10 and MP20 had the lowest and highest scores, respectively (Table 5). A positive correlation was found between plant density and plant height score (r= 0.54, P= 0.012).

Seed Yield and Biomass

No significant differences in grain yield of canola were found among MP20, 2TC15 and TC10, even though the absolute mean yields increased with a decrease in tillage depth (Table 6). High variability between the replications of the reduced tillage (TC10) did not permit the difference between treatments turned to become significant. More replications could increase the precision of the experiment. However, the results agree with the findings of Bonari *et al*. (1995) who stated that, under rainfed conditions, grain and biomass yields of winter rapeseed under conven-

tional and minimum tillage never differed significantly. Hocking *et al*. (2003) studied the responses of canola cultivars to tillage (one-pass cultivation and no-tillage) in both high and low rainfall environments and found that tillage had little effect on seed yields. Arshad *et al*. (1995) studied the effects of decreasing tillage intensity (conventional to zero tillage) on the growth of canola (*Brassica campestris* L.) on a clay soil under a cold, semi-arid climate of the northern Canadian Prairies. They reported that, in most cases, tillage effects on mean crop yields were non-significant and a reduced tillage system (tilling once just prior to seeding with a cultivator to depth of 8-10 cm) was recommended.

Non-significant effects of tillage on plant establishment after winter could cause similar grain yields under different tillage treatments. The positive and significant correlation (r= 0.48, P= 0.044) of plant establishment after winter with the grain yield is in agreement with the above conclusion.

No significant effect of tillage could be detected on canola biomass (Table 6). A statistically similar plant population and biomass per plant (Table 7) was responsible in part for the lack of significant differences between tillage treatments.

The primary×secondary tillage interactions for the number of plants, and the amount of straw and biomass production per square meter were significant (Table 8). Among treatments, the lowest number of plants per square meter was counted at harvest for the TC10+single pass of a rotary tiller. Under TC10, the number of plants, and the amount of straw and biomass production per square meter in four passes of disking were significantly higher than those of a single pass of rotary tilling. Whereas, under MP20 and 2TC15, the values of these parameters were statistically similar for both seedbed preparation methods.

Grain yield was strongly correlated with biomass (r= 0.87, P= 0.0001). This finding agrees with the results reported by Rabiee *et al*. (2004) for canola grown as a second crop after rice in a high rainfall region in the North of Iran and for canola under irrigation in Southeastern Australia (Taylor and Smith, 1992). Taylor and Smith (1992) stated that high yields were related to a large biomass capable of supporting a large number of pods per square meter. This shows that dry matter yield in canola plants is indicative of grain yield potential. Biomass also had a positive correlation with the grain yield per plant that approached significance (r= 0.43, P= 0.07).

The number of plants per square meter and the grain yield per plant at harvest for MP20, 2TC15 and TC10 were not statistically different (Table 7). The average plant density at harvest in all treatments was higher than 50 (Table 8). Therefore, due to sufficient plant density and a non-significant grain yield per plant in all tillage treatments, a similar canola grain yield under all treatments is to be expected. Yield per area is the product of plant population density and grain yield per plant. Plant density has the greatest effect on grain

Table 6. Effect of primary and secondary tillage on canola dry grain yield, straw and biomass (g m^{-2}) and harvest index (%) ^{a}.

Treatment	Grain yield g m^{-2}	Straw g m^{-2}	Biomass g m^{-2}	Harvest index (%)
Primary tillage , maximum depth				
Cultivation, 10 cm (TC10)	288	753	1041	27.8 a
Cultivation, 15 cm (2TC15)	241	745	986	24.5 b
Plowing, 20 cm (MP20)	234	768	1002	23.7 b
Secondary tillage				
Disking (4 passes)	267	749	1015	26.1
Rotary tilling (single pass)	242	762	1004	24.6

^{a} Mean values followed by the same letter or with no letters in each column within treatment category are not significantly different at the 5% level of probability by LSD.

Table 7. Effect of primary and secondary tillage on plant density, spacing and height at harvest, 1000-kernel weight, and grain yield and biomass of a single plant [a].

Treatment	Plants per square meter	Plant spacing (cm)	Plant height (cm)	1000-kernel weight (g)	Grain yield (g)	Biomass (g)
Primary tillage, maximum depth						
Cultivation, 10 cm (TC10)	76	4.8	116	4.1	4.2	14.1
Cultivation, 15 cm (2TC15)	84	4.2	114	4.1	3.1	12.2
Plowing, 20 cm (MP20)	98	3.5	118	4.0	2.5	10.4
Secondary tillage						
Disking (4 passes)	92	3.7	114	4.1	3.0	11.0
Rotary tilling (single pass)	80	4.6	118	4.0	3.5	13.4

[a] Mean values with no letters in each column within treatment category are not significantly different at the 5% level of probability by LSD.

yield and the yield components of individual plants (Diepenbrock, 2000). Bunting (1969) reported 60 plants per square meter was the minimum density required to eliminate a yield response, whereas others (Hodgsons, 1970; Bowerman and Rogers-Lewis, 1980) considered 50 plants per square meter to be the minimum density. Canola stands of between 40 to 200 plants per square meter have been shown to provide similar crop performance in Canada. However, very low or high densities also carry a risk of significantly lower yield (Canadian Canola Grower Council, 2005). McGregor (1987) reported a 20% yield reduction when comparing rapeseed (*Brassica napus*) stands of 40 plants per square meter to full stands of 200 plants per square meter.

Grain yield per plant was negatively correlated with the number of plants per square meter ($r= -0.66$, $P= 0.0028$) and positively correlated with the distance between plants in a row ($r= 0.77$, $P= 0.0002$). Plant density governs yield components and, hence the yield of individual plants (Diepenbrock, 2000). The grain and straw yield per plant were strongly correlated ($r= 0.93$, $P= 0.0001$).

The number of plants per square meter at harvest was significantly correlated ($r= 0.80$, $P= 0.0001$) with the number of plants per square meter as measured at the final stage of emergence, the percentage of emergence ($r= 0.62$, $P= 0.0064$), stand establishment after winter ($r= 0.69$, $P= 0.0017$) and the canopy cover ($r= 0.64$, $P= 0.004$) measured in spring.

There were no significant effects of primary or secondary tillage on the Thousand Kernel Weight (TKS) of canola. Bonari *et al.* (1995) found similar values for TKS under conventional and minimum tillage for the years in which the rainfall and temperature in May were normal. The mean TKS values obtained here are higher than other reported values for canola, such as those by Abdoli *et al.* (2004) and Rabiee *et al.* (2004). A negative correlation was found between plant density and TKS ($r= -0.42$, $P= 0.084$). Apparently, winter canola plants have a highly plastic yield structure and the ability to adjust its yield components when plant density is reduced. Seed weight depends to a lesser extent on environmental conditions than on other yield components (Diepenbrock, 2000).

The straw yield was not significantly influenced by tillage treatments (Table 6). The mean straw per square meter was 755 g m^{-2}. The straw per plant was negatively correlated with plant density at harvest ($r= -0.63$, $P= 0.0048$) and positively correlated with the distance between plants ($r= 0.70$, $P= 0.0011$).

Harvest Index (HI) did change significantly with primary tillage. Mean canola HI was significantly higher under TC10 than either MP20 or 2TC15. These values of HI agree with the results reported by Bonari *et al.* (1995) for winter rapeseed under rainfed conditions and for the same variety under dryland conditions (Abdoli *et al.*, 2004). HI was positively correlated with the grain yield per plant ($r= 0.48$, $P= 0.0044$).

Table 8. Primary×secondary tillage interaction effect on plant, straw and biomass production per square meter at harvest.

Primary tillage, maximum depth	Secondary tillage	
	Disking (4 passes)	Rotary tilling (single pass)
	------------------------Plants per square meter------------------	
Cultivation, 10 cm (TC10)	97	56
Cultivation, 15 cm (2TC15)	89	79
Plowing, 20 cm (MP20)	91	105
$LSD_{0.05}$= 28		
	------------------------------Straw (g m^{-2})------------------------	
Cultivation, 10 cm (TC10)	911	595
Cultivation, 15 cm (2TC15)	667	823
Plowing, 20 cm (MP20)	668	868
$LSD_{0.05}$= 297		
	---------------------------Biomass (g m^{-2})-----------------------	
Cultivation, 10 cm (TC10)	1253	826
Cultivation, 15 cm (2TC15)	908	1064
Plowing, 20 cm (MP20)	886	1118
$LSD_{0.05}$= 367		

Based on linear regression analysis, the correlation between grain yield and yield components was highly significant (*Grain yield= -7393.4+35.7 (plants m^{-2})+615.5 (grain yield plant^{-1})+1196.3 (1,000-kernel weight)*; R^2= 0.93).

Plant height measured at harvest was not significantly affected by primary or secondary tillage treatments (Table 7). The mean of plant height over all tillage treatments was 116 cm. However, the values for plant height obtained in this study were lower than 135-153 cm as observed for canola cultivars grown as a second crop after rice in a high rainfall region in the North of Iran (Rabiee *et al*., 2004)

Oil Content and Ash

The effect of primary tillage on oil content was significant, but no significant secondary tillage effect was observed (Table 9). No significant oil content differences were observed between TC10 and MP20. These results indicate that by decreasing the tilling depth to half of conventional tillage, no reduction in oil

production was observed. These grain oil contents are in the same range as reported by Abdoli *et al*. (2004) for the same cultivar grown under dryland conditions. However, the values of oil content obtained in this study were higher than 37.7% as observed for canola cultivars grown as a second crop after rice in a high rainfall region of northern Iran (Rabiee *et al*., 2004) and for a later-than-optimum seeding date of canola in the northern Great Plains, USA (Lamb *et al*., 2004). The difference in oil content between these studies could be attributed to differences in the climatic conditions between the experimental locations, genotype and cultural practices.

The results indicated that the ash content was not significantly affected by the primary tillage treatments, while the ash contents for four passes of the disk harrow was significantly higher than that for a single pass of the rotary tiller. The values of ash contents obtained in this experiment are comparable with the findings of Al-Jaloud *et al*. (1996) who reported ash seed contents from 3.46-4.16%.

CONCLUSIONS

No significant differences in the yield of

Table 9. Effect of primary and secondary tillage on composition of canola seed [a].

Treatment	Dry matter (%)	Oil content (%)	Ash (%)
Primary tillage, maximum depth			
Cultivation, 10 cm (TC10)	95.7	42.3 a	3.4
Cultivation, 15 cm (2TC15)	95.8	40.1 b	3.5
Plowing, 20 cm (MP20)	95.7	43.7 a	3.7
Secondary tillage			
Disking (4 passes)	95.7	41.5	3.7 a
Rotary tilling (single pass)	95.8	42.6	3.4 b

[a] Mean values with no letters in each column within treatment category are not significantly different at the 5% level of probability by LSD.

canola were found among MP20, 2TC15 and TC10 even though canola yield after minimum tillage (TC10) was 23% greater than after moldboard plowing. Thus, this experiment showed that canola yield did not respond to changes in the depth and intensity of tillage provided that a good seedbed (aggregate mean diameter of less than 15 mm) for sufficient plant establishment could be achieved. These results demonstrate that tillage intensity could be reduced to the level of TC10 combined with a single pass of a rotary tiller, without any negative influence on the plant establishment and with a likelihood of crop yield improvement for irrigated canola production in central Iran.

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تأثیر کاهش عمق خاک‌ورزی اولیه و شدت خاک ورزی ثانویه بر تولید کلزای آبی در یک خاک لوم در ایران مرکزی

ع. همت

چکیده

معرفی کلزا (.Brassica napus L) به عنوان منبع جدید تولید روغن نباتی در ایران، ارزیابی عملکرد این گیاه تحت روشهای مختلف خاک ورزی را طلب می نماید. در یک آزمایش مزرعه‌ای، اثر کاهش عمق عملیات خاک ورزی اولیه و شدت خاک ورزی ثانویه بر خواص فیزیکی خاک، استقرار گیاه و عملکرد دانه کلزای پاییزه آبی در یک خاک لوم (Typic Haplargids)در اصفهان مورد بررسی قرار گرفت. سه تیمار خاک ورزی اولیه به ترتیب تحت نامهای خاک ورزی کامل برگردان (شخم با گاوآهن برگرداندار به عمق ۲۰ سانتی‌متر، MP20)، بی برگردان ورزی به عمق ۱۵سانتی‌متر (دو بار عبور با یک کولتیواتور ساقه صلب به ترتیب تا عمق ۱۰ و ۱۵ سانتی متر، 2TC15) و بی برگردان ورزی به عمق ۱۰سانتی متر (فقط یک بار عبور با یک کولتیواتور ساقه صلب تا عمق ۱۰سانتی متر، TC10) با دو روش تهیه بستر بذر (چهار بار عبور با هرس بشقابی در مقابل یک بار عبور با روتیواتور)، با به کارگیری طرح کرت های خردشده در قالب بلوکهای کامل تصادفی در سه تکرار ارزیابی شد. نتایج نشان داد که جرم مخصوص ظاهری خاک در لایه‌های ۵-۰ و ۱۰-۵ سانتی‌متر تحت‌تأثیر تیمارهای خاک ورزی اولیه قرار نگرفت. میانگین مقاومت خاک (شاخص مخروطی) در لایه ۱۰-۰ سانتی‌متر در تیمار بی برگردان ورزی (2TC15) بطور معنی داری بیشتر از خاک ورزی مرسوم بود، ولی اثر خاک ورزی اولیه بر مقاومت خاک لایه ۲۰-۱۰ سانتی‌متر معنی دار نبود. مقایسه جرم مخصوص ظاهری، مقاومت خاک و درصد سبز دو روش تهیه بستر بذر نشان داد که یک بار عبور روتیواتور تقریباً به اندازه چهار بار عبور با هرس بشقابی در تهیه بستر بذر مؤثر بود. تعداد بوته در واحد سطح اندازه‌گیری شده در زمان سبز کامل و در زمان برداشت برای هر دو روش تهیه بستر بذر، از نظر آماری مشابه بود. مقدار بیوماس و عملکرد دانه خشک تحت تیمارهای MP20، 2TC15 و TC10 به‌ترتیب ۱۰۰۲۰، ۹۸۶۰ و ۱۰۴۱۰ کیلوگرم در هکتار و ۲۳۴۰، ۲۴۱۰ و ۲۸۸۰ کیلوگرم در هکتار بود. ولی، اثر تیمارهای خاک ورزی اولیه بر بیوماس و عملکرد دانه معنی دار نبود. مقدار روغن برای تیمارهای MP، 2TC15 و TC10 به ترتیب ۴۳/۷، ۴۰/۱ و ۴۲/۳ درصد بود. کاهش عملیات خاک ورزی به سطح 2TC15، درصد روغن را در مقایسه به خاک ورزی مرسوم بطور معنی‌داری کاهش نداد. عدم پاسخ عملکرد دانه به تیمارهای خاک ورزی ممکن است به علت دستیابی به بستر مناسب (قطر متوسط وزنی خاک دانه کمتر از ۱۵ میلی متر) تحت تمام تیمارهای خاک ورزی بوده که به تبع آن موجب دستیابی به استقرار تعداد بوته کافی در واحد سطح باشد. نتایج نشان داد که عملکرد کلزای پاییزه آبی حساس به کاهش عمق و شدت خاک ورزی نبود. با تیمار کم خاک ورزی نیز تعداد بوته بهینه در واحد سطح می تواند بدست آید. بر اساس نتایج حاصله، روش بی برگردان ورزی به عمق ۱۰ سانتی‌متر همراه با یک بار عبور با روتیواتور (سیستم کمینه خاک ورزی)، ممکن است مطلوب‌تر از بقیه سیستم‌های خاک ورزی (MP و2TC15) از نظر زراعی و حفاظت خاک به علت عملکرد دانه بیشتر و کاهش عمق شخم، در شرایط مشابه با آزمایش حاضر باشد.