Water use and yield of canola under dryland conditions in the central Great Plains

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Water Use and Yield of Canola under Dryland Conditions in the Central Great Plains

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Research Question

Canola is an oil seed crop that may have production potential in the central Great Plains as production systems incorporate reduced tillage methods that increase noncrop precipitation storage efficiency. Growing season precipitation timing and amounts vary widely from year to year, causing variations in timing and severity of water stress. This study was conducted to determine the effects of water stress timing and amount on canola yield and yield components, and to combine those results with long-term precipitation records to assess the production potential of canola as a dryland crop in northeastern Colorado. An additional objective was to determine whether the potential exists to use infrared thermometry to quantify water stress for future studies of its effects on canola yield.

Literature Summary

Water use/yield functions for canola grown under central Great Plains conditions are not available. Yields from Kansas ranged from 1045 to 1384 lb/acre. Canola production in Alberta was about 900 lb/acre with 8 in. of water use, and increased by 135 lb/acre for each additional inch of water used. Environmental stresses are reported to cause pod abortion and seed loss in rapeseed, but no reports are available regarding water stress timing effects on specific yield components. A non-water-stressed baseline for calculating the Crop Water Stress Index from infrared thermometer measurements of canola canopy temperature has not been reported.

Study Description

Two field experiments were conducted in both 1993 and 1994 at Akron, CO. In both experiments water use was calculated by the water balance method using measurements of soil water content made with a neutron probe and a time-domain reflectometry system. The first experiment consisted of three replications of four water treatments applied to canola. All plots received the long-term average precipitation for the canola growing season, but at differing times. Water treatments consisted of severe water stress during one of the three major growth stages (vegetative, reproductive, and grain-filling) or mild water stress throughout the entire growing season. The second experiment used a line-source gradient irrigation system to apply varying amounts of water to generate data for a water use/yield function. Fully irrigated areas were also used to determine a non-water-stressed baseline from infrared thermometer measurements of canopy temperature.

Applied Questions

Is canola yield more sensitive to water stress at any one growth stage.

Canola yield was not significantly reduced by water stress at any particular growth stage. Trends in data indicate lower numbers of pods and seeds with water stress during reproductive development, and lower seed weight with stress during grain-filling.

To what depth will canola extract soil water?

Water extraction was measured from all depths down to 65 in., but most of the water used by canola was extracted from the 0 to 47 in. soil layer.

Full scientific article from which this summary was written begins on page 307 of this issue.

What is the water use/yield function for canola?

The water use/yield function for canola is:
Yield (lb/acre) = 175.2 (lb/acre per in.) × water use (in.) – 1090 (lb/acre)

Can canola be grown profitably in northeastern Colorado?

Seed yield predicted from long-term precipitation records averages 1020 lb/acre. At current market prices, canola production in a wheat-canola-fallow rotation would be profitable, but would produce less profit than winter wheat-fallow. A 10% increase in the market price of canola and a 10% decrease in the market price of wheat would make the two systems roughly equivalent in profitability. Producers experiencing wheat yield reductions due to winter annual grass weeds could probably reduce weed pressure and increase profits by going to a wheat-canola-fallow rotation.

Can infrared thermometry be used to quantify water stress in canola?

Canola has a well-defined non-water-stressed baseline of:

$$T_{canopy} - T_{air}\ (^{\circ}C) = 2.152 - 2.52 \times \text{Vapor Pressure Deficit (kPa)}$$

Therefore, water stress in canola can be quantified with measurements of canopy temperature made with an infrared thermometer.

Water Use and Yield of Canola under Dryland Conditions in the Central Great Plains

David C. Nielsen

Reduced tillage systems, compared with conventional tillage methods, have increased precipitation storage efficiencies and increased the amount of available water for crop production in the central Great Plains. Increased available water affords producers the opportunity to diversify and intensify their production systems from the traditional wheat (*Triticum aestivum* L.)-fallow system. This study was conducted to determine canola (*Brassica napus* L.) production potential under the limited and variable precipitation patterns found in dryland agricultural systems in northeastern Colorado. Water stress timing effects on canola yield components were determined under a rainout shelter in 1993 and 1994, with water withheld during either the vegetative, reproductive, or grain-filling growth stage. All treatments received the same total water application, equal to the long-term average growing season precipitation. Rooting depth was determined from water extraction patterns monitored with a neutron probe. A water use-yield function was determined for canola grown under a line-source gradient irrigation system. A non-water-stressed baseline was determined for future water stress research using an infrared thermometer in canola. Timing of water stress did not significantly affect yield. Canola can extract water from soil depths of 65 in., but 92 to 95% of total seasonal water use comes from growing season precipitation and water extracted from soil depths above 47 in. An examination of the growing season precipitation records indicates that canola yields could range from 284 to 2358 lb/acre (averaging 1020 lb/acre), assuming 4 in. of stored soil water use in addition to precipitation. Dryland canola production may not be economically viable for northeastern Colorado at current market prices and yields.

REDUCED TILLAGE systems have increased precipitation storage efficiencies and increased the amount of available water for crop production in the central Great Plains (Greb et al., 1970; Smika and Unger, 1986; Nielsen and Anderson, 1993). Increased available water affords producers the opportunity to diversify and intensify their agricultural production systems from the traditional wheat-fallow system (Halvorson and Reule, 1994; Peterson et al., 1994; Halvorson et al., 1994). Precipitation timing and amounts exhibit wide year-to-year variation, producing variations in timing and severity of crop water stress. The production potential for any alternative crop grown under dryland agricultural production systems has to be evaluated with regard to this variable water availability.

Canola is an oil seed crop that may have production potential in the central Great Plains. A market is readily available due to the existence of processing facilities that handle sunflower (*Helianthus annuus* L.) oil production and consumer demand for low saturated fat oil. Producers would be able to use their existing wheat production equipment for tillage, spraying, planting, and harvesting of canola.

Sims et al. (1993) reported that canola yields in Montana increased greatly with increased availability of water, but that increased water lowered mean oil content. In Alberta, canola produced seed yields of about 900 lb/acre with 8 in. of water use, and seed yield increased by 135 lb/acre for each additional inch of water used (Anonymous, 1985). Stoker and Carter (1984) reported that irrigation following flowering was the most critical factor affecting seed yield of

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Table 1. Irrigation treatments to determine effect of water stress timing on canola production.

Treatment	Water withheld during:	Water applied during:	No. irrigations	Weekly irrigation amount	Total water applied
				in.	
1	--	V, R, GF†	15	0.62	9.20
2	GF	V, R	10	0.92	9.20
3	R	V, GF	10	0.92	9.20
4	V	R, GF	10	0.92	9.20

† V= vegetative stage, R=reproductive stage, GF = grain-filling stage.

oil seed rape. Nutall et al. (1992) found canola yields were reduced 363 lb/acre for every 5° F increase in mean maximum daily temperature during July and August. Johnson et al. (1995) noted greatly reduced canola yields under high temperatures and severe drought stress during July in eastern North Dakota. Wright et al. (1988) reported that severe environmental stresses during the rapeseed growing season caused intense competition for assimilates, pod abortion, and seed loss.

Shafii et al. (1992) reported that four winter canola cultivars grown in 1988 in Kansas yielded from 1045 to 1384 lb/acre with oil contents ranging from 37.7 to 40.0%. They provided no precipitation or water use data. Francois (1994) reported that the oil content of irrigated canola (cv. Westar) grown in Brawley, CA, averaged 40% in a 2-yr study. He also reported that the long-term average oil content for Westar grown in Canada was 43%.

Future studies of canola adaptability to dryland agriculture environments may require detailed analysis of canola development and yield response to water deficits. Evaluations of crop response to varying water availability and water stress can easily be accomplished by calculating the Crop Water Stress Index from crop temperatures obtained with an infrared thermometer (Gardner et al., 1992a, b). This calculation requires knowledge of the relationship between crop temperature, air temperature, and vapor pressure deficit for a non-water-stressed crop (the non-water-stressed baseline). This relationship has not been determined for canola.

The objectives of this study were to determine: (i) the sensitivity of yield components, oil content, and leaf area development to water deficits at various growth stages; (ii) canola rooting depth; (iii) a water use/seed yield production function for spring canola; (iv) canola production potential from the long-term precipitation record at Akron, CO; and (v) a non-water-stressed baseline for future water stress evaluations using an infrared thermometer in canola.

MATERIALS AND METHODS

Two studies using Westar canola were conducted during both the 1993 and 1994 growing seasons at the USDA Central Great Plains Research Station, 4 mi east of Akron, CO (45° 09'N, 103° 09'W, 4540 ft). The soil type is a Rago silt loam (fine, montmorillonitic, mesic Pachic Argiustoll). In both studies, water use (evapotranspiration) was calculated by the water balance method using soil water content measurements and assuming runoff and deep percolation were negligible. The soil water content measurements in the 0 to 12 in. layer were made by time-domain reflectometry. Soil water content measurements at 18, 30, 41, 53, and 65 in. were made with a neutron probe.

Experiment 1

This experiment was used to determine the water stress timing effects on canola yield components. Canola was hand-planted in rows 12 in. apart on 20 Apr. 1993 and 7 Apr. 1994 into 12 small plots (9 ft by 8.73 ft). An automated rainout shelter covered the plots during precipitation. The 12 in. row spacing was selected to accomodate the water application manifold in the rainout shelter, although there are some reports of increased yields with narrower row spacing in canola (Anonymous, 1985). Three replications of four water treatments were arranged in a randomized complete block design (Table 1). Prior to planting, all plots received 60 lb N/acre. Trifluralin was applied at 1 lb ai/acre and incorporated with a small garden tiller. No crop residues remained on the soil surface after planting. All plots received the same amount of water over the growing season, but at different times. The 15-wk growing season was divided into a 5-wk vegetative period, a 5-wk reproductive period, and a 5-wk grain-filling period, as determined by visual observations of canola development at Akron from previous years (unpublished data). Long-term average precipitation during the 15-wk growing season is 9.2 in. This amount of water was applied in equal weekly amounts as shown in Table 1.

Following emergence, plots were thinned to a stand of about 442 000 plants/acre. Leaf area was measured periodically during the growing season with the LAI-2000 Plant Canopy Analyzer (Li-Cor, Inc., Lincoln, NE). Plots were hand-weeded as needed throughout the experiment. A four-row by 6.5-ft area around each access tube was hand-harvested on 29 July and 4 Aug. 1993 and 11 July 1994. Two harvest dates were needed in 1993 due to differences in maturity associated with the stress timing treatments. The earlier harvest date in 1994 was the result of the earlier planting date.

Experiment 2

This experiment was used to determine a water use/seed production function for canola. Canola was planted on 3 May 1993 and 22 Apr. 1994 using a grain drill with double disk openers. Seeding rate was approximately 900 000 seeds/acre (about 7 lb/acre) in rows spaced 8 in. apart. Final population was approximately 420 000 plants/acre. Prior to planting, crop residues (corn in 1993, black lentil [*Lens culinaris* Medikus] in 1994) were disked and the plot area (40 ft by 180 ft) was fertilized with 62 lb N/acre and 30 lb P_2O_5/acre in 1993 and 84 lb N/acre and 35 lb P_2O_5/acre in 1994. Trifluralin was applied at 1.5 lb ai/acre and disk-incorporated prior to planting.

The plot area (40 ft by 180 ft) was comprised of a center section (40 ft by 60 ft) bordered by two solid set, gradient irrigation lines. This center section was the fully irrigated area; irrigations were applied weekly to replace evapotranspiration losses as measured by changes in soil water at four neutron probe measurement sites. An irrigation catch gauge was located at each soil water measurement site. The irrigation system applied water to the fully irrigated plots at 0.13

Table 2. Total irrigation amounts applied and precipitation falling on solid set, gradient irrigation plots.

Gradient position	Total irrigation (SE)† 1993	Total irrigation (SE)† 1994
	in.	
1	1.67 (0.13)	1.41 (0.28)
2	4.45 (0.27)	4.63 (0.21)
3	7.94 (0.24)	8.68 (0.53)
4	10.38 (0.41)	10.36 (0.30)
	Precipitation	
	in.	
Growth stage		
Vegetative	1.95	1.80
Reproductive	1.59	0.23
Grain-filling	4.10	2.83
Total	7.64	4.86

† Average of four sites, standard error in parentheses.

in./h. On either side of the center section were the gradient irrigation areas (40 ft by 60 ft), with linearly declining water applications as distance from the irrigation lines increased (Table 2). Three irrigation levels were located in each of the two gradient irrigation areas, with two soil water measurement sites and two irrigation catch gauges at each irrigation level (four replications of each gradient irrigation level). Each irrigation level was separated by 20 ft along the irrigation gradient. Irrigations were generally applied in the evening when wind speeds were low to minimize differences in water application across the two gradient irrigation areas.

Canopy temperatures were measured on six dates from 21 June to 27 July 1993 and five dates from 9 June to 5 July 1994. Measurements were taken every 45 min from 1000 to 1700 h MDT on the fully irrigated plots (center section of irrigation area) from the southeast and southwest corners (so that mainly sunlit leaves were viewed by the infrared thermometer) following the methods of Gardner et al. (1992a, b) and fully described by Nielsen (1994). These data provided a range of temperature and vapor pressure deficit conditions from which to construct the non-water-stressed baseline for canola. These data were recorded and are presented in °C (temperature) and kPa (vapor pressure deficit), as is the customary method for non-water-stressed baseline determinations (Gardner et al., 1992a).

A four-row by 10 ft area around each access tube was hand-harvested for seed yield on 6 Aug. 1993, and 18 and 27 July 1994. Two harvest dates were used in 1994 due to differences in development rate associated with the water gradient application. The effect of water use on seed yield was determined by linear regression, and significant differ-

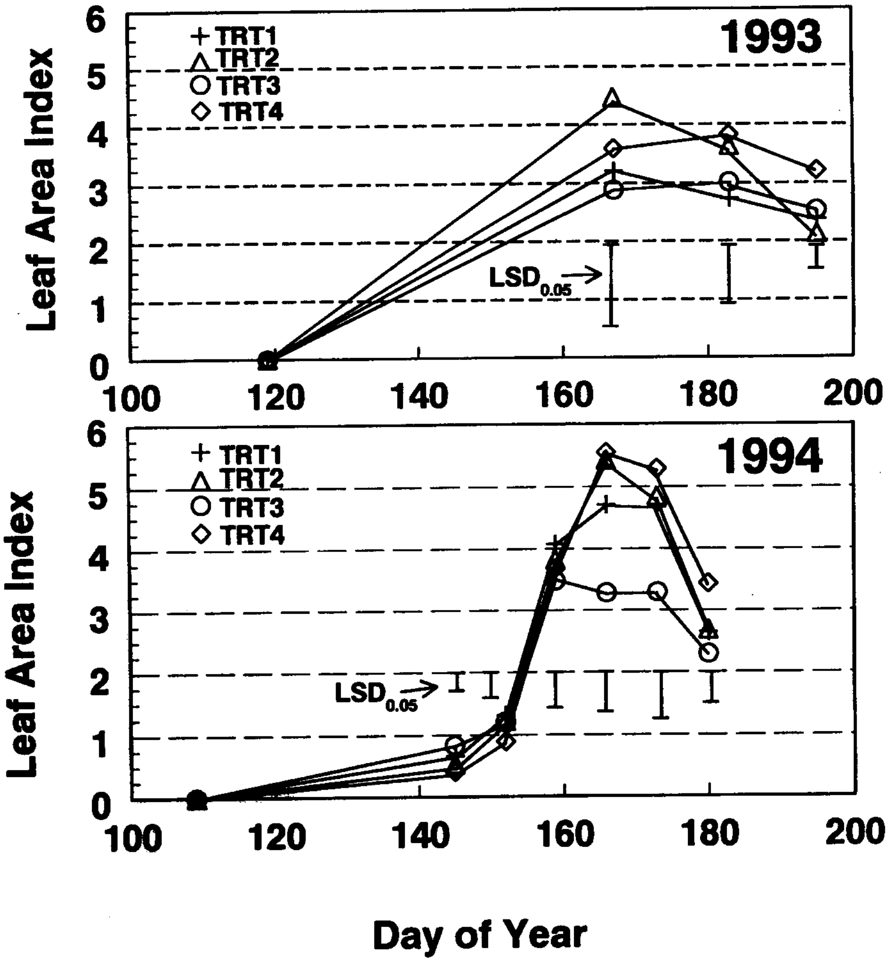

Fig. 1. Seasonal development of canola leaf area index.

Table 3. Yield component analysis for water stress timing treatments imposed in Exp. 1 (rainout shelter).

Irrigation treatment	Branches/plant	Pods/branch	Seeds/pod	1000 seed wt	Seed yield	Evapotranspiration	Water use efficiency
				g	lb/acre	in.	lb/acre per in.
				1993			
1	4.55	6.65	10.0	3.19	841	14.1	60.6
2	3.51	5.61	10.6	2.70	562	15.7	35.6
3	4.61	6.01	8.9	3.44	830	11.9	70.2
4	4.69	8.68	7.7	2.90	909	13.1	69.7
†	0.058	0.009	0.374	0.145	0.343	0.001	0.179
LSD (0.10)	0.73	1.18	NS‡	0.55	NS	0.9	29.5
				1994			
1	2.95	8.34	3.9	2.93	368	15.6	23.7
2	2.78	8.34	5.1	2.67	331	18.1	18.3
3	2.20	7.44	3.8	3.00	227	14.1	20.0
4	3.45	7.68	4.2	3.22	350	16.5	26.5
†	0.093	0.597	0.391	0.134	0.490	0.010	0.400
LSD (0.10)	0.76	NS	NS	0.37	NS	1.8	NS

† Probability level of rejecting the null hypothesis of no difference in yield component due to water stress timing treatments.
‡ NS = not significant.

ences in oil content due to water use were determined by inspection of the standard deviation of the four repeated measurements at a given water gradient application area.

RESULTS AND DISCUSSION

Water stress during the vegetative growth stage (treatment 4) limited early leaf area development, but plants recovered and produced more leaf area as water became available later in the growing season (Fig. 1). Water stress during the grain-filling stage (treatment 2) resulted in a more rapid loss of leaf area than water stress occurring during other growth stages. Water stress during the reproductive growth stage (treatment 3) was the most restrictive to leaf area development, with maximum leaf area development 64 to 68% of that observed when water stress did not occur until the grain-filling period (treatment 2). The overall greater leaf area in 1994 compared with 1993 is probably the result of greater available soil water at planting in 1994 (Fig. 2). The lower beginning water content in the 1993 rainout shelter plots was a result of failure to adequately preirrigate the plots to field capacity.

Water stress timing did not significantly affect ($P < 0.05$) seed yield in either 1993 or 1994, although the trend in 1993 was for the lowest yield to occur when water stress occurred during the grain-filling period (treatment 2) (Table 3). The lower yield was the result of fewer branches per plant, pods per branch, and smaller seeds. Seed yields in 1993 ranged from 562 lb/acre when water stress occurred during grain-filling to 909 lb/acre when water stress occurred during the vegetative period. Yields were much lower for all four treatments in 1994. Plants showed no visual signs of insect or disease problems. A partial explanation for the lower yields in 1994 may be the greater heat stress during that year. During 1994, 34 d occurred with maximum temperatures greater than 90° F, compared with only 17 d in 1993. There was no trend for any one particular treatment to result in higher or lower yields than the other treatments. Water stress during the reproductive stage (treatment 3) did result in fewer branches per plant than the other treatments.

Highest water use in both years occurred with water stress during grain-filling (treatment 2) (Table 3). The larger leaf area that developed early in the growing season and maintained itself during the reproductive stage was the

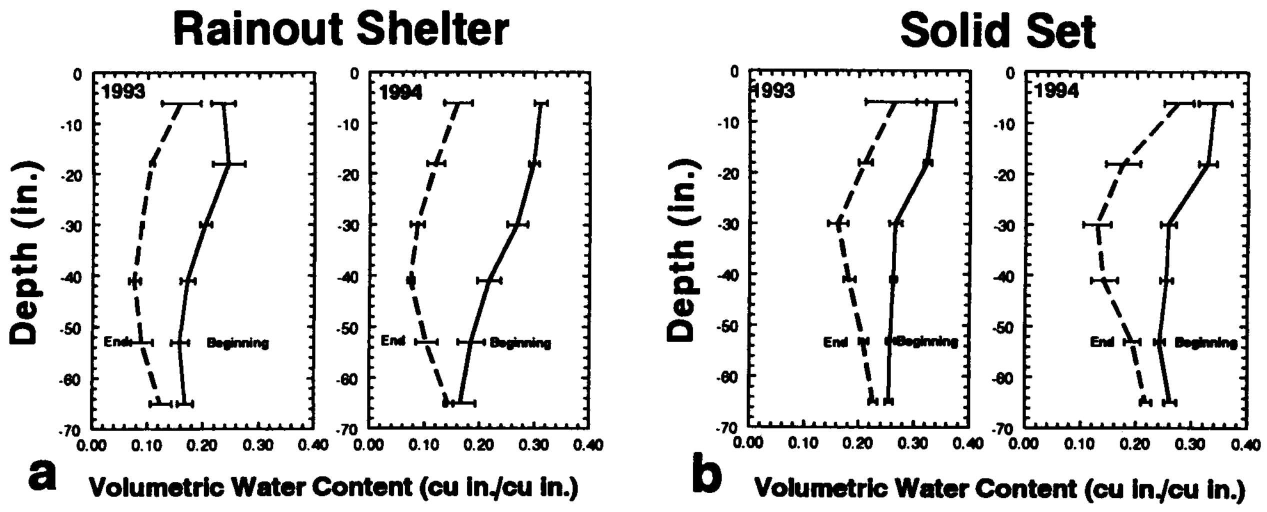

Fig. 2. Soil profile volumetric water content at the beginning and end of the canola growing season in (a) the rainout shelter and (b) the solid set irrigation area. Bars are ± 1 standard deviation about the mean.

probable cause of higher water use. Although significant water use differences were observed, water use efficiency was not affected by water stress timing treatment.

Water use efficiencies from Exp. 2 (line source) ranged from 50 to 100 lb/acre per in. between the evapotranspiration range of 10 to 15 in., similar to the values obtained from Exp. 1 (rainout shelter) in 1993 (35.6 to 70.2 lb/acre per in.). The low yields in Exp. 1 in 1994 resulted in extremely low water use efficiencies (18.3 to 26.6 lb/acre per in.).

No significant effect of water stress timing on oil content was observed (Fig 3a). Oil contents in Exp. 1 in the rainout shelter ranged from 34 to 39%, with higher contents in 1994. Oil contents in Exp. 2 under the solid set gradient irrigation were also higher in 1994 than in 1993 (Fig, 2b). These data showed a strong trend for increasing oil content with increasing level of irrigation, with values ranging from 37% for the low irrigation level in 1993 to 44% for the high irrigation level in 1994.

Gradient irrigation treatment results are shown in Fig. 4. The linear regression fit to the combined data for the 2 yr indicates that 175.2 lb seed/acre are produced for every inch of water used after the first 6.2 in. of water use. Yields ranged from 480 lb/acre with 9.8 in. of water use to 3050 lb/acre with 20.5 in. of water use. A similar yield function for winter wheat grown in northeastern Colorado shows a much higher water use efficiency, with 390.4 lb/acre of wheat produced for every inch of water use after the first 6.8 in. of water use (Nielsen, 1995).

The change in soil water content between the beginning and ending soil water readings is shown in Fig. 2a (rainout

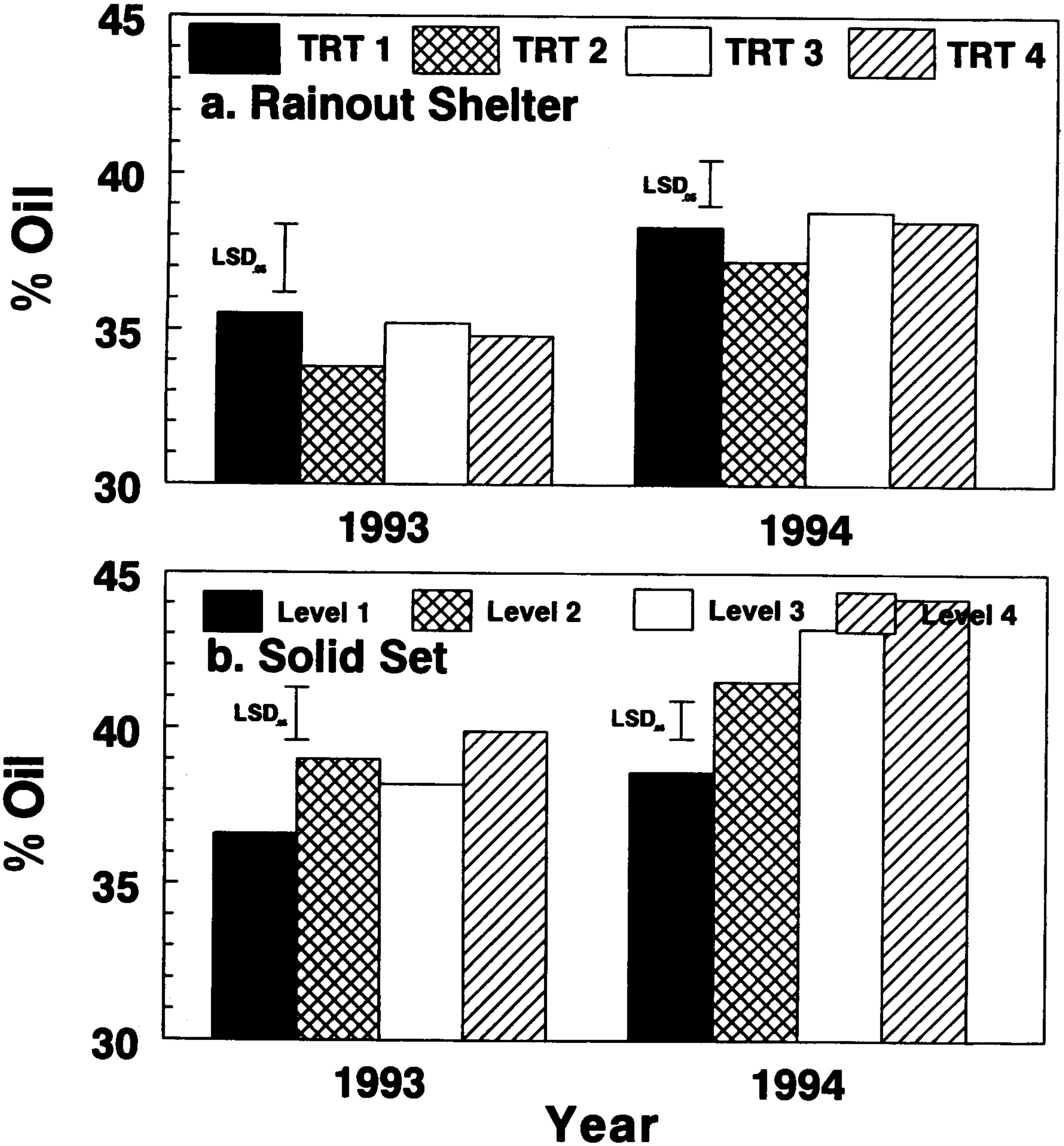

Fig. 3. Percentage oil content for canola grown under four water stress timing treatments (a. rainout shelter) and four irrigation application levels (b. solid set).

Table 4. Economics ($/acre) of a wheat-canola-fallow rotation compared with a wheat-fallow rotation.

Operation	Wheat-canola-fallow	Wheat-fallow
	$/acre	
Wheat phase		
Plant wheat	6.00	6.00
seed	6.00	6.00
Fertilizer		
N	10.00	10.00
P_2O_5	9.00	9.00
Herbicide	8.00	8.00
Harvest	21.00	21.00
Fall tillage with sweeps		
2 operations @ $4 each	8.00	
Canola phase		
Spring tillage	4.00	
trifluralin granules	12.00	
Plant canola	6.00	
seed	8.00	
Fertilizer		
N	10.00	
P_2O_5	9.00	
Harvest		
Swath	7.00	
Combine	21.00	
Fallow phase		
Tillage		
6 operations @ $4 each	24.00	24.00
Total Costs	169.00	84.00
Harvest receipts		
wheat 40 bu/acre @ $4/bu	160.00	160.00
canola 1020 lb/acre @ $0.10/lb	102.00	
Total receipts	262.00	160.00
Rotation profit	93.00	76.00
Annual profit	$31.00	$38.00

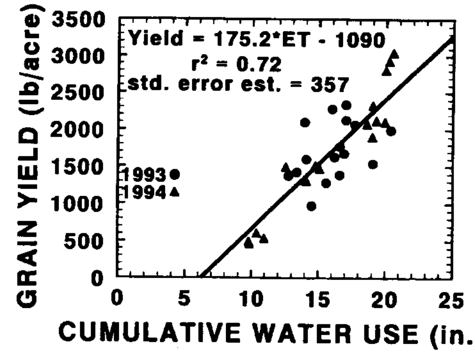

Fig. 4. Water use/seed yield production function for canola grown at Akron, CO, during 1993 and 1994 growing seasons.

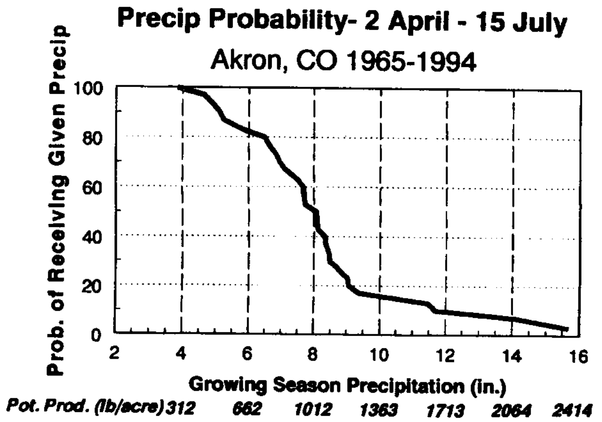

Fig. 5. Probability of receiving at least a given amount of precipitation (x-axis) during the period of 2 April through 15 July at Akron, CO.

shelter plots, treatment 2) and Fig. 2b (solid set irrigation plots, low end of the irrigation gradient). Water extraction by canola occurred from depths down to 65 in., but 92 to 95% of growing season water use came from growing season precipitation and water extracted from the 0 to 47 in. soil layer. Greater water extraction in the middle soil depths occurred from the solid set plots in 1994 than in 1993, probably a result of the lower amount of precipitation received by the plots in 1994 (Table 2), although irrigations brought the total water received by the plots in the 2 yr to nearly the same level (9.31 in. in 1993, 9.49 in. in 1994, which was similar to the 9.2 in. applied to the rainout shelter plots). Under the water deficit conditions of treatment 2 in the rainout shelter (no water applied during the last 5 wk of development), canola was able to extract soil water down to a volumetric water content of 0.08 cu in/cu in (Fig. 2a). This is similar to the water extraction patterns noted for winter wheat in this area (D.C. Nielsen, 1996, unpublished data).

In order to assess long-term yield potentials for canola in the central Great Plains, precipitation records at Akron, CO, were examined for the 15-wk growing season of 2 April to 15 July over the 30-yr period from 1965 to 1994 (Fig. 5). These data show that 50% of the years have growing season precipitation of less than 8 in. Assuming, conservatively, that canola could extract 4 in. of soil water from the profile during the growing season, and applying the water use/seed yield production function given in Fig.4, 50% of the years would have seed production less than 1012 lb/acre. The predicted range of seed production over the past 30 yr was 280 to 2360 lb/acre, averaging 1020 lb/acre.

Table 4 shows the economics of a wheat-canola-fallow rotation, assuming an average wheat yield of 40 bu/acre and an average canola yield of 1020 lb/acre, compared with the economics of a winter wheat-fallow system with an average yield of 40 bu/acre. Operational costs are typical of custom rates in northeastern Colorado. Profit from canola production is fairly low, resulting in a rotation profit that is $7/acre per year lower than the profit for the winter wheat-fallow system. With the level of anticipated yield derived from these experiments and the current market price of canola, canola would probably not be considered an economically viable dryland crop for northeastern Colorado. However, only a 10% increase in canola price and a 10% decrease in wheat price would bring the annualized profits of the two systems to within $1/acre of each other ($29/acre for wheat-canola-fallow and $30/acre for wheat-fallow). Field evalua-

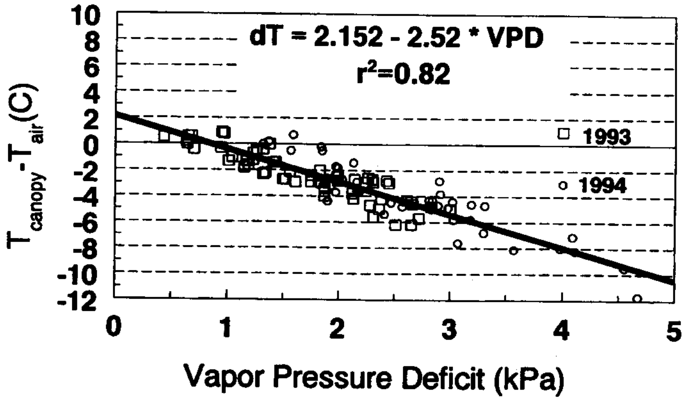

Fig. 6. Non-water-stressed baseline for canola.

tions should be conducted to determine the actual canola and winter wheat yields grown in rotation, as well as to determine beneficial effects of the rotation on reducing winter annual grass weeds in winter wheat (Lyon and Baltensperger, 1995). If a winter annual grass infestation reduced wheat yields to 30 bu/acre, then the annualized profit for the wheat-fallow system would drop to $18/acre, thereby giving the profit advantage to the wheat-canola-fallow rotation, if it is able to reduce or eliminate the weed problem.

Data from the two growing seasons resulted in a linear response between vapor pressure deficit and canopy temperature minus air temperature (the non-water-stressed baseline) over the vapor pressure deficit range of 0.5 to 4.6 kPa (Fig. 6). Infrared thermometry can be used with the non-water-stressed baseline to reliably quantify water stress in canola in future studies of water stress effects on canola production.

SUMMARY

Canola yield is not significantly affected by water stress at any particular growth stage. Oil contents ranged from 34 to 44% for the various water treatments in the 2 yr of this study, with water deficits decreasing oil percentage. Soil water extraction comes primarily from the top 4 ft of the soil profile. Canola exhibits a linear response of seed yield to water use, with approximately 175 lb/acre of seed produced for every inch of water used after the first 6 in. of water use. Average canola production under the dryland conditions of the central Great Plains probably would average about 1020 lb/acre with a range of 280 to 2360 lb/acre. This average seed production level may not make canola a competitively profitable dryland crop at current market prices (about $0.10/lb). Water stress effects on canola development can be quantified with infrared thermometry measurements of canopy temperature.

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