Comparison of Three Alternative Oilseed Crops for the Central Great Plains

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David C. Nielsen

Research Question

The traditional wheat-fallow cropping system of the central Great Plains is subject to the production problems of monoculture systems. Diversification through crop rotation could lead to a more sustainable and profitable production system. Selection of suitable crops to rotate with winter wheat requires knowledge of productivity under a range of water use. Crop water use varies widely due to year-to-year variability in precipitation and starting soil water content. Canola, crambe, and sunflower are oilseed crops that may have dryland production potential for the central Great Plains. The objectives of this study were to determine water use/yield relationships and likely average production levels for spring canola, crambe, and sunflower, and to determine differences in oil concentration and soil water extraction patterns among these three crops.

Literature Summary

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. Canola yields in North Dakota have ranged from 200 to 2900 lb/acre. Reported oil concentrations for canola range from 28 to 44%. Crambe has been considered to be more drought tolerant than canola, with reported yields in North Dakota of 400 to nearly 3000 lb/acre and oil concentrations ranging from 24 to 32%. Sunflower yields in both Texas and Nebraska increased by about 155 lb/acre for every additional inch of seasonal water use. Sunflower oil concentrations reportedly range from 41 to 56%, and increase with water use. Sunflower has a deep root system capable of extracting water from as deep as 117 in., but most of the soil water extraction probably occurs above 78 in.

Study Description

Canola, crambe, and sunflower were grown near Akron, CO, under a line-source, gradient irrigation system to determine seed yield and oil concentration under a range of water use. Sunflower was also grown in several dryland rotations following a variety of crops, which resulted in a range of starting soil water conditions. Water use was calculated by the water balance method using measurements of soil water extraction made with a neutron probe and time-domain reflectometry. Seed yield and oil concentration were measured. Water use/yield production functions were developed by linear regression. Long-term precipitation records were used with these production functions to determine long-term yield distributions.

Applied Questions

What are the water use/yield production functions for spring canola, crambe, and sunflower for the central Great Plains?

The water use/yield production functions are:

canola	Yield (lb/acre) = 175.2 × water use (in.) – 1090
crambe	Yield (lb/acre) = 172.0 × water use (in.) – 1001
sunflower	Yield (lb/acre) = 134.1 × water use (in.) – 628

What are the oil concentrations for canola, crambe, and sunflower, and does oil concentration change with water use?

Oil concentrations generally increased with increased water use, and ranged from 37 to 44% for canola, 22 to 32% for crambe, and 43 to 49% for sunflower.

Full scientific article from which this summary was written begins on page 336 of this issue.

Are there differences among the three crops in soil water extraction?

Sunflower extracted more water from deeper in the soil profile than canola and crambe, which were similar to each other. Canola and crambe extracted 4 to 6.5 in. of soil water, while sunflower extracted nearly 8 in. Most of the soil water used by canola and crambe came from the 0 to 47 in. soil layer, compared with sunflower soil water extraction down to 71 in.

What range of yields could be expected for canola, crambe, and sunflower production under dryland conditions in the central Great Plains?

Using Akron long-term precipitation data and the water use/yield production functions, median yields (and ranges) for canola, crambe, and sunflower in the central Great Plains would be 1130 lb/acre (510–2390), 1180 lb/acre (570–2420), and 1520 lb/acre (860–2200), respectively (Fig. 1).

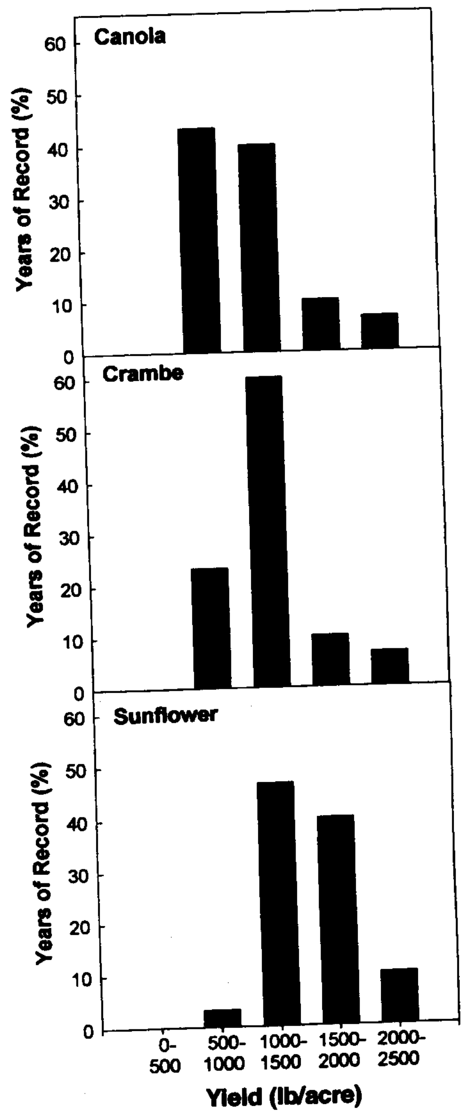

Fig. 1. Frequency distributions of canola, crambe, and sunflower yields predicted from water use/yield production functions and growing season precipitation record (1965–1997) at Akron, CO.

Comparison of Three Alternative Oilseed Crops for the Central Great Plains

David C. Nielsen*

Diversification of the traditional dryland cropping system in the central Great Plains (winter wheat [*Triticum aestivum* L.]-fallow) could lead to a more sustainable production system. Selection of suitable crops to rotate with winter wheat requires knowledge of productivity under a widely varying precipitation regime. The objectives of this study were to determine water use/yield relationships and likely average production levels for spring canola (*Brassica napus* L.), crambe (*Crambe abyssinicia* Hochst), and sunflower (*Helianthus annuus* L.), and to determine differences in oil concentration and soil water extraction patterns among these three crops. Canola, crambe, and sunflower were grown under a line-source, gradient irrigation (GI) system to determine seed yield and oil concentration under a range of water use. Sunflower was also grown in several dryland rotations following a variety of crops, which resulted in a range of starting soil water conditions. Soil water extraction was monitored with a neutron probe and time-domain reflectometry. All three crops exhibited linear responses of yield to water use. Sunflower was less responsive than canola and crambe, which had nearly identical water use/yield functions. Oil concentrations showed a trend for increasing oil content with increasing water use. Sunflower extracted water from lower soil depths than canola and crambe, which were similar in soil water extraction. Median yield levels predicted from long-term precipitation records at Akron, CO, were 1130, 1180, and 1520 lb/acre for canola, crambe, and sunflower, respectively. All three crops are agronomically feasible oilseed crops for dryland rotations with winter wheat in the central Great Plains.

THE TRADITIONAL WHEAT-FALLOW cropping system of the central Great Plains is subject to production problems of monoculture systems, e.g., insect, weed, and pathogen infestations (Anderson, 1994; Elliot and Lynch, 1995; Norris, 1982). Infestation cycles can be broken with crop rotations. Reduced tillage systems lead to more effective precipitation storage and greater soil water availability (Greb et al., 1970; Smika and Unger, 1986; Nielsen and Anderson, 1993). Increased available water permits a reduction in fallow frequency and production of other crops in rotation with winter wheat (Halvorson and Reule, 1994). Consequently, there is a need for alternative summer crops to be grown in rotation with winter wheat. Three oilseed crops that may have production potential in the central Great Plains are canola, crambe, and sunflower.

Canola is the world's third-most important edible oil source, following soybean [*Glycine max* (L.) Merr.] and palm (*Elaeis guineenis*) (Downey, 1990), based on worldwide production. Sovero (1993) reported canola seed contains 40 to 44% oil, while Johnson et al. (1995) reported canola seed oil concentrations ranging from 28 to 34% in North Dakota. Sims et al. (1993) found greater canola yields with greater available water, but lower oil concentration with increased water. In Alberta, Canada, canola produced seed yields of about 900 lb/acre with 8 in. of water, and seed yield increased by 135 lb/acre for each additional inch of water used (Anonymous, 1985). Johnson et al. (1995) reported canola yields in North Dakota ranging from 200 to 2900 lb/acre for canola planted in the first 2 wk of May. Yield differences were largely attributable to differences in growing season rainfall. Nutall et al. (1992) found that canola yield in Saskatchewan, Canada, increased by 134 lb/acre for every additional inch of precipitation in July and August. Winter-type canola varieties generally have greater yield potential than spring-type varieties, but winter-type varieties that can survive the winter and early spring conditions of the central Great Plains are only recently being developed (Rife and Salgado, 1996).

Crambe is one of the richest known sources of erucic acid (cis-13-docosonoic) (Lessman, 1990). Erucic acid is used to produce erucimide, a preferred slip and antiblock agent for polyolefin films (Carlson et al., 1996). The defatted seed meal left after oil extraction can be fed to cattle. Johnson et al. (1995) stated that crambe cultivars are more drought tol-

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Abbreviations: ACR, alternative crop rotation; GI, gradient irrigation

Table 1. Cultural practices information for water use/yield experiments with canola, crambe, and sunflower.

Year	Exp.†	Crop	Variety	Seeding rate		Fertilizer N	Fertilizer P_2O_5	Planting date	Harvest date	Row spacing
				seeds/acre		lb/acre				in.
1993	GI	canola	Westar	900 000	7	76	30	3 May	2 Aug	8
1994	GI	canola	Westar	900 000	7	85	35	22 April	19 July	8
1986	GI	crambe	Meyer	2 100 000	30	--	--	15 April	24 July	8
1993	GI	crambe	Meyer	2 100 000	30	70	--	20 April	12 Aug	8
1994	GI	crambe	Meyer	2 100 000	30	78	--	22 April	14 July	8
1993	GI	sunflower	Triumph 546	18 000	--	70	--	1 June	21 Oct	30
1994	GI	sunflower	Triumph 546	18 000	--	78	--	27 May	21 Oct	30
1993	ACR	sunflower	Triumph 546	16 600	--	60	--	26 May	14 Oct	30
1994	ACR	sunflower	Triumph 546	16 600	--	80	--	27 May	27 Oct	30
1995	ACR	sunflower	Triumph 546	16 600	--	variable‡	--	16 June	18 Oct	30
1996	ACR	sunflower	Triumph 546	20 300	--	variable		5 June	23 Sep	30
1997	ACR	sunflower	Triumph 546	20 300	--	variable	variable	6 June	28 Sep	30

† Experiment code: GI = gradient irrigation; ACR = alternative crop rotation
‡ Variable N fertilization rates based on soil test results

erant and higher yielding than canola, but seeds are lower in oil concentration. They reported crambe yields in North Dakota ranging from about 400 lb/acre to nearly 3000 lb/acre, with the lowest yields occurring in response to below-normal precipitation in June and July and above-normal temperature in July. Oil concentration ranged from 28 to 32% when yields were high, and 24 to 29% when yields were low.

Sunflower is a deep-rooted species capable of extracting large amounts of available water from deep in the soil profile. In a detailed study of sunflower root development and soil water use in Kansas, Jaafar et al. (1993) found 87 to 96% of observed roots in the sampled soil profile were above 65 in., although some roots were found as deep as 106 in. They noted measurable soil water depletion at the 79 in. depth, as did Bremner et al. (1986) in Australia. Jones (1984) reported soil water extraction down to 71 in. by dryland sunflower in Texas. Soil water depletion was noted down to the lowest sampling depth of 65 in. by d'Andria et al. (1995) in Italy. Hattendorf et al. (1988) also confirmed deep rooting of sunflower in Kansas, with soil water being extracted down to a depth 117 in., but with most of the observed extraction coming from the surface to 78 in. soil depth. Sunflower can extract soil water to a lower matric potential than corn (*Zea mays* L.), proso millet (*Panicum miliaceum* L.), and winter wheat, although this may not be true for all soil types (Unger, 1990; Nielsen, 1997a).

From sunflower yield and water use data reported previously, the following water use/yield functions were generated:

yield (lb/acre) = 156.1 × growing season water use (in) – 1104.1; Jones (1984; Texas),

yield (lb/acre) = 152.4 × growing season water use (in) + 315.9; Lyon et al. (1995; Nebraska),

yield (lb/acre) = 230.5 × growing season water use (in) – 500.9; d'Andria et al. (1995; Italy),

yield (lb/acre) = 78.8 × growing season water use (in) + 381.8; Unger (1982; Texas).

Jones (1984) found a yield response of 159 lb/acre per in. of available soil water at seeding. Seed yield over a 5-yr period ranged from 0 to 1785 lb/acre. Highest yields were reported when greater than 5.5 in. of soil water was available at seeding, and timely rainfall occurred at flowering and the early stages of seed-filling. Lyon et al. (1995) in Nebraska reported a much lower sunflower yield response of 95 lb/acre per in. of available water at seeding. Hattendorf et al. (1988) reported the average sunflower yield and water use for three site-years in Kansas was 2031 lb/acre and 21.5 in., respectively.

Jones (1984) found sunflower oil concentrations ranged from 41 to 45%. D'Andria et al. (1995) reported oil concentration increased with increasing water use and ranged from 48 to 56%. Oil concentrations reported by Unger (1982) were affected by timing of irrigation, but not by total seasonal water use. Unger (1990) stated that, generally, oil concentration increased with increased levels of soil water maintained throughout the growing season. Connor and Sadras (1992) similarly reported increased sunflower oil concentration with increased plant transpiration.

Evaluation of suitability of any crop introduced into a new area requires knowledge of water use/yield relationships and soil water extraction patterns for that crop. This type of data for these three oil seed crops is lacking in the high evaporative demand and variable rainfall environment of the central Great Plains.

The objectives of this investigation were to: (i) determine water use/yield relationships for spring canola, crambe, and sunflower grown under central Great Plains environmental conditions; (ii) determine changes in seed oil concentration that occur with varying water use; (iii) identify differences in soil water extraction patterns among the three oilseed crops; (iv) determine likely average production levels and variability based on long-term precipitation records.

MATERIALS AND METHODS

Studies were conducted during 1986 and from 1993 to 1997 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, smectitic, mesic Pachic Argiustoll). Results are reported for two different experiments: (i) GI experiment, and (ii) alternative crop rotation (ACR) experiment. Details of cultural practices are given in Table 1. Spring canola was chosen for these studies because winter types have frequently winter-killed at this location.

For both studies, soil water content measurements were made at planting and at physiological maturity. Time-domain reflectometry was used to measure water content in the 0 to 12 in. layer. Soil water content measurements at 18, 30, 41, 53, and 65 in. were made with a neutron probe. Neutron probe readings were converted to volumetric soil water content using a calibration curve for the experimental site soil type. Soil water use was calculated as the difference between soil water measurements at planting and physiological maturity. Growing season water use (planting to physiological maturity) was calculated by the water balance method by adding precipitation to soil water content change and assuming runoff and deep percolation were negligible.

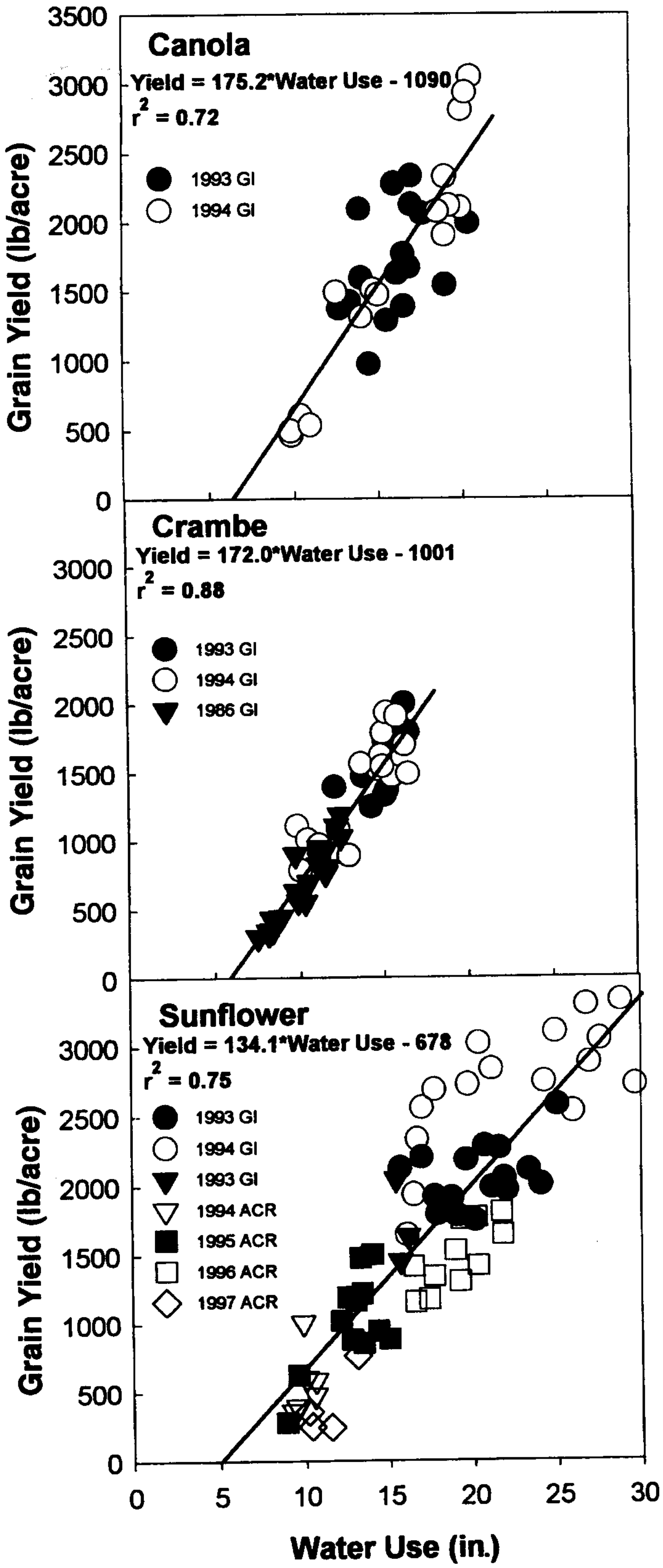

Fig. 1. Water use/seed yield production functions for canola, crambe, and sunflower grown at Akron, CO.

Gradient Irrigation Experiment

Canola, crambe, and sunflower were grown under a gradient line-source solid-set irrigation system, with full irrigation next to the irrigation line, and linearly declining water application as distance increased away from the line (Nielsen, 1997b). Four replications of four irrigation levels existed along the line-source system, with a soil water measurement site and irrigation catch gage at each of the 16 locations for each crop. Irrigations were applied weekly to replace evapotranspiration losses from the measurement sites closest to the irrigation line. These were considered the fully irrigated, non-water-stressed plots. The area was treated with trifluralin at a rate of 1.5 lb ai/acre and disk-incorporated prior to planting. Canola plots were hand-harvested in 1993 and 1994 (harvest area = 26.7 sq ft). Crambe plots were direct combined in 1986 (harvest area = 172.5 sq ft); swathed and combined in 1993 (harvest area = 252 sq ft); and hand-harvested in 1994 (harvest area = 26.7 sq ft). Sunflower plots were hand-harvested in 1993 and 1994 (harvest area = 100 sq ft). Hand-harvested samples were threshed with the same plot combine used for machine harvesting in other years.

Alternative Crop Rotation Experiment

An ACR experiment was initiated in 1990 (Bowman and Halvorson, 1997). Several rotations that included sunflowers were added in 1993. Data from 1993 are from sunflower following winter wheat; data from 1994 are from sunflower following winter wheat or triticale [*xTriticosecale* (Wittmack)]; data from 1995 are from sunflower following winter wheat, proso millet, foxtail millet (*Setaria italica* L.), or fallow; data from 1996 and 1997 are from sunflower following winter wheat, corn, proso millet, or triticale. Plots were treated with trifluralin at a rate of 2.1 lb ai/acre in 1993 and 1.5 lb ai/acre in 1994. In 1995, 1996, and 1997, plots were treated with ethalfluralin at a rate of 1.0 lb ai/acre. Herbicides were disk-incorporated prior to planting. Plots were combine-harvested in all 3 yr (harvest area = 750 sq ft in 1993, 500 sq ft in 1994 and 1995, and 400 sq ft in 1996 and 1997.

RESULTS AND DISCUSSION

Water use/yield relationships for canola, crambe, and sunflower are shown in Fig. 1. All three crops exhibited linear responses of yield to water use over the range observed, with coefficients of determination ranging from 0.72 for canola to 0.88 for crambe. Sunflower yield appeared to be slightly less responsive to water use than canola and crambe yields, while crambe and canola were very similar in yield response to water use. The average yield response of canola in its 2 yr was 175.2 lb/acre per in. of water use after 6.2 in. of water use. The average yield response of crambe in its 3 yr was 172.0 lb/acre per in. of water use after 5.8 in. of water use. The average yield response of sunflower in its five years was 134.1 lb/a per in. of water use after 5.1 in. of water use. The regression equations predict slightly higher yields of sunflower at low water use (<11 in.) compared with canola and crambe, and slightly lower yields of sunflower at high water use (>15 in.) compared with canola and crambe. Predicted yields of the three crops in the most likely dryland water use range (10 to 17 in.) do not differ greatly between the three crops (about 680 to 1800 lb/acre). The water use/yield relationship constructed from data reported for sunflowers in Bushland, TX (Jones, 1984), predicts very similar yields in the 10 to 17 in. water use range compared with the sunflower relationship shown in Fig. 1.

Oil concentrations ranged from 36.6 to 44.2% for canola, 22.4 to 31.6% for crambe, and 42.6 to 48.6% for sunflower (Fig. 2). There was a trend for higher oil concentrations with

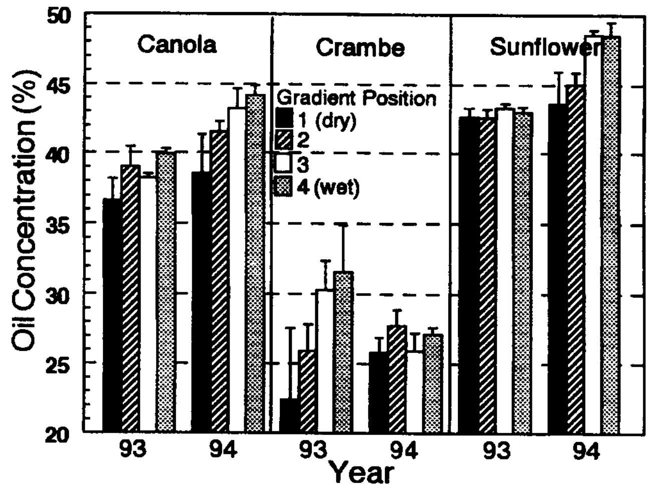

Fig. 2. Effect of irrigation gradient on oil concentration of canola, crambe, and sunflower (bars are one standard deviation).

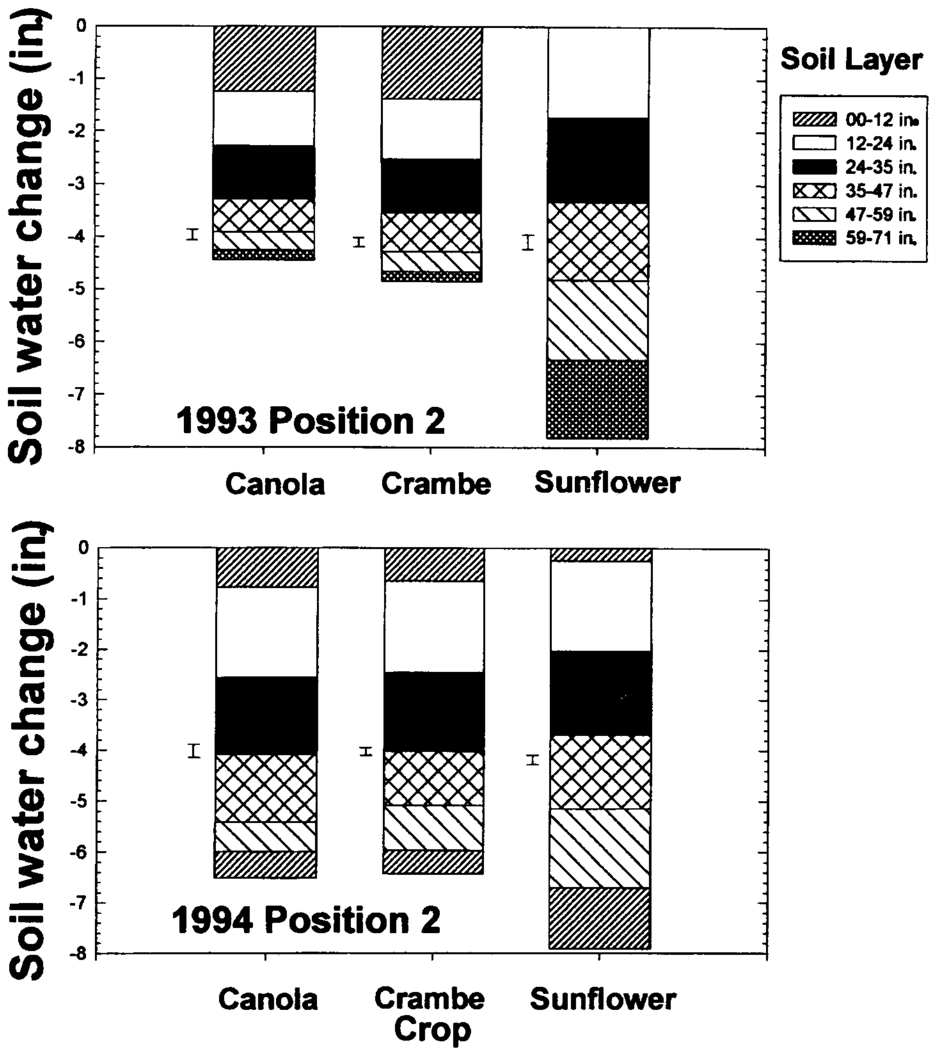

Fig. 3. Change in soil water content (by depth) between beginning and ending soil water readings for canola, crambe, and sunflower (bars are one standard deviation averaged across depths).

Table 2. Irrigation amounts (averaged by gradient position) and growing season precipitation amounts (planting to physiological maturity). (Gradient irrigation studies only conducted in 1986, 1993, and 1994.)

Species	Year	Gradient Position 1	2	3	4	Precipitation
		in.				
canola	1993	1.67	4.45	7.94	10.28	5.71
	1994	1.41	4.63	8.68	10.36	2.97
	avg(1965–1997)					6.07
crambe	1986	0.11	1.20	2.94	4.41	7.31
	1993	1.51	4.29	7.66	9.48	6.89
	1994	1.16	4.41	8.25	9.78	2.54
	avg(1965–1997)					6.35
sunflower	1993	0.96	3.34	6.44	7.39	8.90
	1994	0.93	4.55	12.12	15.08	7.32
	1995					5.88
	1996					11.48
	1997					8.22
	avg(1965–1997)					8.33

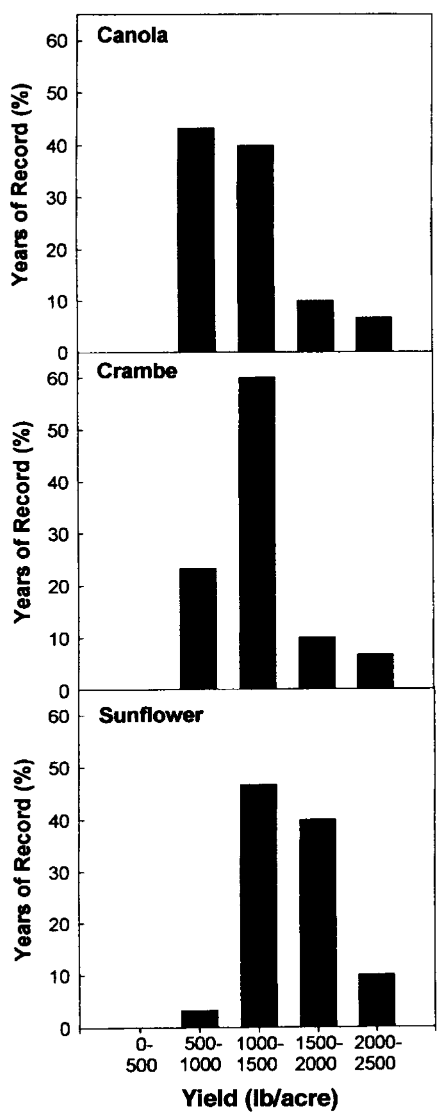

Fig. 4. Frequency distributions of canola, crambe, and sunflower yields predicted from water use/yield production functions and growing season precipitation record (1965–1997) at Akron, CO.

increasing irrigation amount and greater water use, although crambe in 1994 and sunflower in 1993 did not have oil concentrations that changed with greater water use. Unger (1982) and Talha and Osman (1975) also reported increased sunflower oil concentration with increases in water use.

Soil water extraction data from position 2 (second driest position) in the GI area show species differences in depth and amount of water extraction (Fig. 3). Water extraction from this position was essentially the same as from position 1 (driest) and not greatly affected in the upper soil depths by the small amount of irrigation applied. Sunflower extracted more water from deeper in the soil profile than canola and crambe, which were similar to each other. Water extraction by sunflower was similar between years, while a distinct difference appeared between years for both canola and crambe. This was probably a response to differences between years in growing season precipitation (Table 2). For all three species, growing season precipitation was greater in 1993 than in 1994. Evaporative demand was also greater in 1994 than in 1993, as indicated by 24% higher pan evaporation for May, June, and July (31.4 in. in 1993; 38.9 in. in 1994). The drier conditions in 1994 apparently stimulated canola and crambe to produce deeper and more prolific root systems capable of extracting water from deeper in the profile than in 1993.

Based on the growing season precipitation at Akron from 1965 to 1994, and assuming 5 in. of soil water use for canola and crambe and 7.5 in. of soil water use for sunflower (Fig. 3), the water use/yield relationships shown in Fig. 1 predict the distributions of yields shown in Fig. 4. About 83% of the years of record would have had canola and crambe yields in the 500 to 1500 lb/acre range, but the distribution of crambe yields is shifted more to the higher end of that range (1000–1500 lb/acre). Approximately 47% of the years of record would have had sunflower yields in the 1000 to 1500 lb/acre range, with 40% of the years yielding 1500 to 2000 lb/acre. None of the three crops had predicted yields less than 500 lb/acre. This yield result would probably be true if the assumed level of soil water extraction (5 in. for canola and crambe, 7.5 in. for sunflower) occurred. Predicted median yield levels and ranges were 1130 lb/acre (510–2390), 1180 lb/acre (570–2420), and 1520 lb/acre (860–2200) for canola, crambe, and sunflower, respectively.

Break-even yields to pay direct costs of production for sunflower are reported as 925 lb/acre in Colorado (Peairs et al., 1993), 865 lb/acre in western Minnesota (H. Kandel, University of Minnesota, 1998, personal communication), and 573 lb/acre in southwest North Dakota (Swensen and Haugen, 1997). Break-even yields for canola and crambe for eastern Colorado are not available because no market exists. However, Swensen and Haugen (1997) report break-even yields to pay direct costs in southwest North Dakota as 551 lb/acre for canola and 384 lb/acre for crambe. Currently, premiums are paid for sunflower oil concentrations above 40%, but no premiums are paid for canola or crambe oil over a given concentration.

Producers should be aware that timing of water stress can affect seed yield. Sunflower and canola yields, for example, are reduced more by water stress occurring during flowering and seed development than during vegetative development (Unger, 1990; Nielsen, 1997b). Water stress during these growth stages could lower yields below what the water use/yield relationship predicts.

Because of the greater amounts of water extracted from the soil by sunflower compared with other crops, producers may want to consider the effect of sunflower on subsequent winter wheat yields. For example, wheat yields following sunflower in northeast Colorado average 7 to 15 bu/acre lower than wheat yields in wheat-fallow or wheat-corn-fallow systems (D.C. Nielsen, unpublished data). But producers should always consider the yield of the total rotation, not just the yield of an individual crop in the rotation.

The median yield levels reported here suggest that all three crops could be feasible alternative oilseed crops for dryland rotations with winter wheat in the central Great Plains. If current breeding efforts to increase winter hardiness of winter-type canola (Rife and Salgado, 1996) are successful, then yield of canola for a given amount of water use probably will increase, making dryland canola production in the central Great Plains more favorable.

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REFERENCES

Anderson, R.L. 1994. Management strategies for winter annual grasses in winter wheat. p. 114–122. *In* L.S. Murphy (ed.) Proc. National Intensive Wheat Manage. Conf., Denver, CO. 10–11 Mar. Potash and Phosphate Inst., Manhattan, KS.

Anonymous. 1985. Canola production in Alberta. Alberta Agric. Field Crops Branch AGDEX 149/20-1.

Bowman, R.A., and A.D. Halvorson. 1997. Crop rotation and tillage effects on phosphorus distribution in the central Great Plains. Soil Sci. Soc. Am. J. 61:1418–1422.

Bremner, P.M., G.K. Presto, and C.F. de St. Groth. 1986. A field comparison of sunflower (*Helianthus annuus*) and sorghum (*Sorghum bicolor*) in a long drying cycle. I. Water extraction. Aust. J. Agric. Res. 37:483–493.

Carlson, K.D., J.C. Gardner, V.L. Anderson, and J.J. Hanzel. 1996. Crambe: New crop success. p. 306–322. *In* J. Janick (ed.) Progress in new crops. ASHS Press, Alexandria, VA.

Connor, D.J., and V.O. Sadras. 1992. Physiology and yield expression in sunflower. Field Crops Res. 30:333–389.

d'Andria, R., F.Q. Chiarondà, V. Magliulo, and M. Mori. 1995. Yield and soil water uptake of sunflower sown in spring and summer. Agron. J. 87:1122–1128.

Downey, R.K. 1990. Canola: A quality brassica oilseed. p. 211–217. *In* J. Janick and J.E. Simon (ed.) Advances in new crops. Timber Press, Portland, OR.

Elliot, L.R., and J.M. Lynch. 1995. The international workshop on establishment of microbial inocula in soil. Am. J. Altern. Agric. 10:50–73.

Greb, B.W., D.E. Smika, and A.L. Black. 1970. Water conservation with stubble mulch fallow. J. Soil Water Conserv. 25:58–62.

Halvorson, A.D., and C.A. Reule. 1994. Nitrogen fertilizer requirements in an annual dryland cropping system. Agron. J. 86:315–318.

Hattendorf, M.J., M.S. Redelfs, B. Amos, L.R. Stone, and R.E. Gwin, Jr. 1988. Comparative water use characteristics of six row crops. Agron. J. 80:80–85.

Jaafar, M.N., L.R. Stone, and D.E. Goodrum. 1993. Rooting depth and dry matter development of sunflower. Agron. J. 85:281–286.

Johnson, B.L., K.R. McKay, A.A. Schneiter, B.K. Hanson, and B.G. Shatz. 1995. Influence of planting date on canola and crambe production. J. Prod. Agric. 8:594–599.

Jones, O.R. 1984. Yield, water-use efficiency, and oil concentration and quality of dryland sunflower grown in the southern High Plains. Agron. J. 76:229–235.

Lessman, K.J. 1990. Crambe: A new industrial crop in limbo. p. 217–222. *In* J. Janick and J.E. Simon (ed.) Advances in new crops. Timber Press, Portland, OR.

Lyon, D.J., F. Boa, and T.J. Arkebauer. 1995. Water-yield relations of several spring-planted dryland crops following winter wheat. J. Prod. Agric. 8:281–286.

Nielsen, D.C. 1997a. Water use and rooting differences among various crops. p. 37–40 *In* R.L. Anderson (ed.) Diversity as a management strategy. Proc. Ninth Annu. Conf. of the Colorado Conservation Tillage Assoc., Sterling, CO. 4–5 Feb. Colorado Conservation Tillage Assoc., Ault, CO.

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

Nielsen, D.C., and R.L. Anderson. 1993. Managing residue and storing precipitation. Conserv. Tillage Fact Sheet no. 2-93. Cent. Great Plains Res. Stn., Akron, CO.

Norris, R.F. 1982. Interactions between weeds and other pests in the agroecosystem. p. 343–406. *In* J.L. Hatfield and I.J. Thomason (ed.) Biometeorology and integrated pest management. Academic Press, New York.

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

Peairs, F.B., B.C. Kondratieff, R.F. Meyer, H.F. Schwartz, R.L. Croissant, D.D. Baltensperger, M.J. VanGessel, and J.M. Krall. 1993. High Plains sunflower production and IPM. Colorado State Univ. Coop. Ext. Bull. 556A.

Rife, C.L., and J.P. Salgado. 1996. Selecting winter hardy oilseed rape for the Great Plains. p. 272–278. *In* J. Janick (ed.) Progress in new cops. ASHS Press, Alexandria, VA.

Sims, J.R., D.J. Solum, D.M. Wichman, G.D. Kushnak, L.W. Welty, G.D. Jackson, G.F. Stallknecht, M.P. Westcott, and G.R. Carlson. 1993. Canola variety trials. Montana AgRes. 10:15–20.

Smika, D.E., and P.W. Unger. 1986. Effect of surface residues on soil water storage. p. 111–138. *In* B.A. Stewart (ed.) Advances in soil science. Vol. 5. Springer-Verlag, New York.

Sovero, M. 1993. Rapeseed, a new oilseed crop for the United States. p. 302–307. *In* J. Janick and J.E. Simon (ed.) New crops. John Wiley and Sons, New York.

Swensen, A., and R. Haugen. 1997. Projected 1998 crop budgets, southwest North Dakota. North Dakota State Univ. Coop. Ext. Farm Manage. Plan. Guide, Sect. 4, Region 4.

Talha, M., and F. Osman. 1975. Effect of soil water stress on water economy and oil composition in sunflower (*Helianthus annuus* L.). J. Agric. Sci. (Cambridge) 84:49–56.

Unger, P.W. 1982. Time and frequency of irrigation effects on sunflower production and water use. Soil Sci. Soc. Am. J. 46:1072–1076.

Unger, P.W. 1990. Sunflower. p. 775–794. *In* B.A. Stewart and D.R. Nielsen (ed.) Irrigation of agricultural crops. Agron. Monogr. 30. ASA, CSSA, and SSSA, Madison, WI.