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Effects of Late-Season Nitrogen Fertilizer on Irrigated Soybean Yield And Composition

T. L. Wesley, R. E. Lamond,* V. L. Martin, and S. R. Duncan

Even though soybean [*Glycine max* (L.) Merr.] fixes N from the air, N demand at the R4 to R6 (pod-fill) growth stages of high-yielding, high-protein soybean may be greater than the amount of available N with normal farming practices. In Kansas, supplemental N has not been recommended on soybean regardless of yield level. Research was conducted at eight sites over a 2-yr period on irrigated soybean to evaluate effects of N rates (0, 20, 40 lb/acre) and sources (urea-ammonium nitrate solution [UAN], ammonium nitrate, urea, urea + N-[n-butyl] thiophosphoric triamide NBPT]) on leaf N concentrations, grain yield, and grain protein, and oil concentrations. The NBPT used is a commercially available urease inhibitor. Most N was broadcast but UAN was applied over the top of the canopy through flat-fan nozzles. All applications were made at the R3 growth stage. Nitrogen concentrations in leaf samples taken 2 to 3 wk after N application were unaffected by N fertilization. Soybean yields were increased significantly by late-season N application at six of eight sites; the average increase was 6.9 bu/acre or 11.8 %. Both of the nonresponsive sites had yields averaging under 50 bu/acre, whereas responsive sites yielded 56 bu/acre or more. Soybean plants at all locations were well nodulated. In most cases, 20 lb N/acre provided positive responses. Late-season N fertilization increased grain protein and oil concentrations at some sites, but overall combined analysis indicated nonsignificant effects. Nitrogen sources performed similarly. Application of UAN resulted in leaf burn, which probably reduced yields at the 40 lb N/acre rate. However, this would not be a problem for producers applying UAN through irrigation systems where the UAN would be much more diluted. Even when well nodulated, soybean with high yield potential may not be able to take in enough N to achieve maximum yield of high quality grain. Public and private soil test labs and crop consultants may have to reevaluate N recommendations for soybean with high yield potential. Supplemental N application at the R3 growth stage can provide positive economic returns for producers growing irrigated soybean with high yield potential.

Dep. of Agronomy, Throckmorton Hall, Kansas State Univ., Manhattan, KS 66506. Kansas Agric. Exp. Stn. Contribution no. 98-141-J. Received 31 Oct. 1997. *Corresponding author.

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NITROGEN REQUIREMENT of soybean is high because of the high protein seed produced. Symbiotic N_2 fixation supplies N for soybean, but Harper (1974) reported that only 25 to 60% of the N in a mature soybean plant comes from N fixation and the other 40 to 75% comes from the soil. However, application of N fertilizer to soybean remains a very controversial issue because of mixed results of previous research. Past research on N fertilization of soybean indicated positive responses (Sorenson and Penas, 1978; Al-Ithawi et al., 1980; Eaglesham et al., 1983; Touchton and Rickerl, 1986; Gascho, 1991; Cooper et al., 1991).

Abbreviations: NBPT, N- (n-butyl) thiophosphoric triamide; UAN, urea-ammonium nitrate solution.

Table 1. Location and cultural practices for research sites.

Location	Site	Row spacing	Cultivar	Seeding rate
		in.		Seeds/acre
Johnson Co.	JO94	30	Asgrow A4138	160 000
Brunker Farm	JO95	30	Asgrow A 4138	160 000
Shawnee Co.	SN94	36	Asgrow A3935	180 000
Parr Farm	SN95	36	Asgrow A3935	180 000
Reno Co.	RN94	7.5	Asgrow A3935	200 000
Seck Farm	RN 95	7.5	Asgrow A3834	200 000
Stafford Co.	SF94	30	Resnick	150 000
Sandyland Field	SF 95	30	KS3494	125 000

Table 2. Selected soil characteristics of research sites.

				Organic matter	Profile N	
Site	pH	Bray-1 P	K	0–6 in.	0–6 in.	6–24 in.
		ppm		%	ppm	
JO94	6.9	41	125	0.7	4.1	--
JO95	6.8	44	165	0.8	3.0	5.5
SN94	7.3	65	305	2.8	6.7	--
SN95	7.7	67	240	3.1	7.9	6.3
RN94	6.8	50	210	1.2	2.7	--
RN95	6.8	48	190	1.7	3.0	2.2
SF94	6.9	31	140	0.9	3.1	--
SF95	6.7	52	130	1.3	7.8	4.5

However, other research indicated no response (Beard and Hoover, 1971; Welch et al., 1973; Ham et al., 1975; Deibert et al., 1979). Most of this research was conducted on nonirrigated soybean fields, and involved preplant or early-season N application.

Irrigated soybean yields in Kansas can be exceptional. Many producers average 65 to 80 bu/acre. For example, the average yield (five locations) of all irrigated soybean cultivars in the 1994 Kansas soybean performance test was 63.6 bu/acre (Schapaugh et al., 1995). A soybean crop that yields 70 bu/acre must translocate 242 lb N/acre into the seeds during pod fill. This period of high N requirement for soybean is from the R3 to the R6 growth stages (Harper and Cooper, 1971; Harper, 1974; Herman 1982). With the high yield potential of irrigated soybean, can N fixation supply enough N to meet demand? Can late-season supplemental N fertilization increase yields? Harper (1974) reported that both soil and fixed N were needed for maximum soybean yield, and other research has shown that most of the N used by soybean during pod fill is supplied by the soils (Brevedan et al., 1978, Deibert et al., 1979). Gascho (1991), Flannery (1986), Oplinger (1991), and Wood et al. (1993) reported that fertilizer N applied at the R1 to R5 growth stages increased soybean yield. Little of this work, however, was conducted in the Midwest.

In addition to potential increases in soybean yield, changes in soybean marketing strategies have renewed interest in N fertilization to increase grain protein and oil concentrations (Helms and Watt, 1991). The USDA Federal Grain Inspection Service (1989) has discussed implementation of oil and protein testing as official soybean marketing criteria. Soybean pricing structures in the future may well be influenced by these parameters. Limited research has been conducted on the effects of N fertilization of protein and oil

Table 3. Statistical significance of late-season N treatments on soybean for leaf N, grain yield, grain protein, and oil concentrations for all locations.

Site	Leaf N	Yield	Protein	Oil
JO94	NS	†	†	†
JO95	NS	**	NS	*
SN94	NS	†	†	†
SN95	NS	**	NS	NS
RN94	NS	*	NS	NS
RN95	NS	†	NS	NS
SF94	NS	NS	†	NA
SF95	NS	NS	†	NS
Avg.	NS	†	NS	NS

†, *, ** Significant at $P = 0.10, 0.05, 0.01$, respectively; NS = nonsignificant; NA = not available.

contents of irrigated soybean seed. However, Gascho (1991) reported that late-season N applications increased protein.

Many research studies have evaluated response of soybean to N fertilizer, yet very little work has evaluated late-season N fertilization on high-yielding, irrigated soybean in Kansas or adjacent areas in the Midwest. Limited information exists on how later season N fertilization affects soybean grain protein and oil concentrations. The objective of this research was to evaluate the effects of late-season N fertilization on the yield and protein and oil contents of irrigated soybean with high yield potential.

MATERIALS AND METHODS

Field studies were initiated at four locations in Kansas in 1994 and repeated in 1995. Studies were located in Shawnee (SN) County (Muir silt loam, fine-silty, mixed, superactive, mesic Cumulic Haplustalls); Johnson (JO) County (Eudora silt loam, coarse-silty, mixed, superactive, mesic Fluventic Hapludolls); Reno (RN) County (Naron fine sandy loam, fine-loamy, mixed, mesic Udic Arguistolls); and Stafford (SF) County (Pratt loamy fine sand, sandy, mixed, mesic Psammentic Haplustalfs). Cultural practices used at each location are summarized in Table 1. All sites were irrigated and managed for top production. Each site included four replications and nine treatments arranged in a randomized complete block design. Individual plots usually measured 10 by 20 ft, but when 36-in. rows were used, plots measured 12 by 20 ft. Treatments included four N sources: UAN, urea, urea + NBPT, and ammonium nitrate, each applied at rates of 20 and 40 lb N/acre. The NBPT used is a commercially available urease inhibitor sold under the trade name Agrotain®. The UAN was applied with a backpack sprayer through flat-fan nozzles over the top of the canopy in 40 gal/acre total volume. Other N sources were broadcast. Nitrogen was applied between the R3 and R4 growth stages (Herman, 1982) of the soybean plant. The R3 growth stage is when the first pods are approximately 0.25 in. long at one of the four uppermost nodes. The R4 growth stage is when the pods are 0.75 in. long at one of the four uppermost nodes. A no-N check treatment was included.

Soil samples were taken at each site and analyzed for pH, P, K, and organic matter. Profile N (nitrate N) was determined to a depth of 24 in. in 1995 and to a depth of 6 in. in 1994. Soil test information is reported in Table 2. At all sites, soybean followed corn (*Zea mays* L.), and cooperators applied needed P and K in the corn year of the rotation. Soil

Table 4. Effect of late-season N rate and source on irrigated soybean yield.

N rate	N source	Grain yield								
		JO 94	JO 95	SN 94	SN 95	RN 94	RN 95	SF 94	SF 95	Avg.
lb/acre		bu/acre								
0	--	64	58	72	57	56	58	35	43	55
20	UAN	70	62	76	62	75	66	39	47	62
40	UAN	65	56	73	60	59	73	37	41	58
20	AN	64	66	78	64	61	71	38	47	61
40	AN	69	66	76	69	61	66	35	44	61
20	Urea	67	63	76	65	69	76	37	48	63
40	Urea	70	69	74	68	67	68	43	51	64
20	Urea + NBPT	64	63	79	65	82	72	41	46	64
40	Urea + NBPT	70	70	83	70	67	67	42	48	65
LSD (0.10)		5	5	7	4	11	9	NS	NS	6
		N rate means								
20		66	64	77	64	72	71	38	47	62
40		69	65	77	67	63	69	39	46	62
LSD (0.10)		2	NS	NS	2	7	NS	NS	NS	NS
		N source means								
	UAN	67	59	75	61	67	70	38	44	60
	AN	66	66	77	66	61	69	37	46	61
	Urea	69	66	75	66	68	72	40	49	63
	Urea + NBPT	67	67	81	67	74	69	41	47	64
LSD (0.10)		NS	3	NS	3	8	NS	NS	NS	NS

NS = nonsignificant.

pHs at all sites were near neutral, and P and K levels were adequate for optimum production of irrigated soybean. Soil analyses were performed at the Kansas State University Soil Testing Lab. Plant tissue samples were taken 2 to 3 wk after N application by collecting the last fully developed trifoliate leaf from 10 to 12 plants in each plot. Grain yields were determined by either hand harvest (20-ft row) and threshing with a plot thresher or by direct machine harvest (40-ft row) depending on location. Grain samples were retained to determine test weight and moisture, protein, and oil contents.

All plant tissue and seed samples were dried at 149°F (65°C), ground to pass a 0.04-in. (1-mm) screen, and analyzed for N. Leaf and grain samples were subjected to an acid digestion consisting of sulfuric acid and hydrogen peroxide (Isaac, 1977). Nitrogen concentrations were determined on the digests with a Technicon Autoanalyzer using the method 334-74 W/B (Technicon Industrial System, 1977). Protein content was calculated by multiplying percentage N by 6.25. Seed samples were analyzed for oil content using official Method Ac 3-44 (AOCS, 1995). Grain test weight and moisture content were determined using a Dickey-John ® grain analyzer. Grain yields are reported at 13% moisture. Data were analyzed using ANOVA and GLM procedures of Statistical Analysis System (SAS Institute, 1988). Each location was analyzed separately and all statistical tests were performed at the = 0.10 level of significance.

RESULTS AND DISCUSSION

Table 3 summarizes analysis of variance for leaf N concentrations, grain yield, and protein and oil contents as affected by N application. Nitrogen rate × source interactions were not significant for any measured parameter except for grain yield in Johnson County in both 1994 and 1995 and Reno County in 1994.

Nitrogen Fertilization Effects on Leaf N

Soybean leaf N concentrations at 2 to 3 wk after N application were not affected significantly by N fertilization (data not shown). The fact that late-season N application had no impact on leaf N concentration suggests that the fertilizer N taken up by the plant was translocated directly to the forming soybean seed and not stored in the leaf.

Nitrogen Fertilization Effects on Yield

During the 2 yr of this research, late-season N fertilization significantly increased soybean grain yield at six of eight sites (Tables 3, 4). Visual inspection of soybean root systems at all locations revealed excellent nodulation at the time of N fertilizer application. Leaf N concentrations of the check treatments ranging from 4.96 to 5.70% verify that soybean plants were not severely N stressed and suggest that the nodules were effectively fixing N for the plant. The two nonresponsive sites were at the Stafford County location, which was also the lowest yielding location. The soybean there would have had a lower N demand than at the other three locations because of lower yields (below 50 bu/acre). The six responsive sites showed an average yield increase of 6.9 bu/acre or 11.8 % with N fertilization. Yields at these six sites ranged from a low of 56 bu/acre to a high of 83 bu/acre.

Even though soybean grain yields were increased by N application, differences between the 20 and 40 lb N/acre rates were minimal. When averaged across all site years, the 20 lb/acre rate produced a yield of 62.4 bu/acre, whereas the 40 lb N/acre produced a yield of 61.9 bu/acre. The 40 lb/acre rate produced significantly higher yields than the 20 lb N/acre rate at two of the eight sites, JO94 and SN95, but significantly lower yield at one site, RN94 (Table 4). The 40 lb N/acre rate sometimes produced lower yield (5 bu/acre less) than the 20 lb/acre rate when UAN was the N source. This yield decrease can be attributed to leaf burn from UAN,

Table 5. Effect of late-season N rate and source on irrigated soybean protein concentration.

N rate	N source	JO 94	JO 95	SN 94	SN 95	RN 94	RN 95	SF 94	SF 95	Avg.
		Grain protein concentration								
		%								
0	--	35.9	37.7	34.9	36.7	36.1	35.2	34.9	35.7	35.9
20	UAN	36.5	37.6	35.8	37.2	35.3	35.3	35.9	36.4	36.3
40	UAN	35.8	37.3	35.7	36.1	35.3	34.7	35.5	36.3	35.9
20	AN	37.1	37.2	35.6	37.1	35.9	34.9	35.7	36.2	36.2
40	AN	35.9	37.5	35.3	36.9	35.9	35.4	35.1	36.6	36.1
20	Urea	36.3	37.2	36.0	36.1	35.8	35.2	35.8	36.2	36.1
40	Urea	36.1	37.0	36.1	36.8	35.8	35.2	36.0	36.6	36.2
20	Urea + NBPT	37.0	37.0	34.7	37.1	35.9	35.4	36.2	36.8	36.3
40	Urea + NBPT	36.2	37.2	36.5	36.4	36.0	34.8	35.1	37.0	36.2
LSD (0.10)		1.1	NS	1.0	NS	NS	NS	0.8	0.7	NS
		N rate means								
20		36.7	37.3	35.5	36.9	35.8	35.2	35.9	36.4	36.2
40		36.0	37.2	35.9	36.5	35.8	35.0	35.4	36.6	36.1
LSD (0.10)		NS	NS	NS	NS	NS	NS	NS	NS	NS
		N source means								
	UAN	36.1	37.5	35.8	36.7	35.3	35.0	35.7	36.3	36.1
	AN	35.5	37.3	35.5	36.9	35.9	35.1	35.4	36.4	36.1
	Urea	36.2	37.1	36.1	36.4	35.8	35.1	35.9	36.4	36.1
	Urea + NBPT	36.6	37.1	35.6	36.7	36.0	35.1	35.6	36.9	36.2
LSD (0.10)		NS	NS	NS	NS	0.6	NS	NS	0.4	NS

NS = nonsignificant

which was quite noticeable at all sites shortly after application. Leaf burn was apparent at both N rates, but it was much more pronounced at the 40 lb/acre N rate. The leaf burn problem would not occur when UAN is applied through irrigation systems, which is recommended, because it probably would be applied in an inch of water, which would dilute it to a 27 000 gal/acre total volume. With the exception of the leaf burn, N source effects overall were minimal (Table 4). Results indicate that all of the sources evaluated would be viable choices for supplying late-season N to soybean under irrigated conditions. The lack of difference between N sources is not surprising since all sites were irrigated shortly after N application, which would move the N into the root zone for immediate uptake. These results corroborate the work of Deibert et al. (1979), who suggested that soil N is crucial during periods of peak N demand such as pod fill.

In summary, significant increases in yield were recorded at six of the eight sites when N was applied to soybean (Table 3). Generally, 20 lb N/acre was adequate to produce the increase in yields. With the exception of UAN, N source effects on soybean yield were minimal. Producers of high yielding soybean (greater than 55 bu/acre), would benefit from a late-season application of N at the 20 lb N/acre rate. Assuming a $7/bu soybean price, the 6.9 bu/acre yield increase would bring an added return of $48.30/acre. Assuming a N cost of $0.30/lb, applying 20 lb N/acre would cost $6/acre, which would result in a net economic benefit of $42.30/acre.

Nitrogen Fertilization Effects on Grain Quality

Although soybean protein content was increased significantly by N fertilization at four of the eight sites, combined analysis indicated nonsignificant effects (Tables 3 and 5). At the responsive sites, protein increases were about 1%. Over the course of this research, N rate had no significant effect on soybean seed protein at any of the eight sites. Nitrogen source had minimal effect on soybean seed protein levels.

Late-season N fertilization significantly increased soybean oil content at three sites, but combined analysis indicated overall effects were nonsignificant (Tables 3 and 6). At responsive sites, oil content was increased by 0.3 to 0.5%. This contrasts with work by Lyons and Earley (1952) and Ham et al. (1975), who found that N fertilization tended to result in lower oil levels. At JO94 and JO95, the 40 lb N/acre rate produced significantly higher oil content than the 20 lb N/acre rate. Nitrogen rate effects on oil content were not significant at any of the other sites. Nitrogen source effects on soybean oil content were minimal. At JO95, urea + NBPT produced significantly higher oil content than UAN (Table 6). Nitrogen source resulted in no significant differences in oil contents at the other six sites.

In summary, even though protein and oil contents were increased significantly with N application at some sites, overall effects were inconsistent and nonsignificant (Table 3). In general, application of 20 lb N/acre was sufficient to achieve the noted increase in protein or oil. Nitrogen source effects on protein and oil were minimal. With the average 6.9 bu/acre yield increase achieved, protein and oil production would be increased by 149 and 83 lb/acre, respectively (assuming 36% protein and 20% oil). If soybean marketing eventually requires a minimum protein plus oil level, later season N fertilization may have to be further evaluated. Currently, significant premiums are not offered for increased protein or oil in soybean.

SUMMARY AND CONCLUSIONS

Soybean yields were increased at six of eight sites when supplemental N was applied at the R3 growth stage. Differences between N rates were minimal, and N sources performed similarly. In nearly all cases, 20 lb N/acre was enough to achieve the positive responses noted in this work. The two nonresponsive sites had yields below 50 bu/acre. Results suggest that soybean with high yield potential (greater than 55 bu/acre) may not be able to supply the

Table 6. Effect of late-season N rate and source on irrigated soybean oil concentration.

N rate	N source	Grain oil concentration								
		JO 94	JO 95	SN 94	SN 95	RN 94	RN 95	SF 94	SF 95	Avg.
		%								
0	--	19.3	19.6	19.5	20.0	20.4	19.0	--	21.4	19.9
20	UAN	19.4	19.6	19.6	20.0	20.1	18.7	--	21.9	19.9
40	UAN	19.7	19.5	19.9	20.0	20.4	18.9	--	21.7	20.0
20	AN	19.6	19.4	19.7	20.0	20.5	19.1	--	21.5	20.0
40	AN	19.4	20.0	19.7	20.3	20.4	18.9	--	21.4	20.0
20	Urea	19.7	19.4	19.7	20.3	20.7	18.9	--	21.7	20.1
40	Urea	19.6	20.0	19.7	20.0	20.5	19.1	--	21.5	20.1
20	Urea + NBPT	19.3	19.5	19.9	20.0	20.9	19.2	--	21.7	20.1
40	Urea + NBPT	19.7	20.1	19.6	20.3	20.3	19.5	--	21.9	20.2
LSD (0.10)		0.4	0.3	0.4	NS	NS	NS	NA	NS	NS
		N rate means								
20		19.4	19.5	19.7	20.1	20.5	19.0	--	21.7	20.0
40		19.6	19.9	19.8	20.2	20.4	19.1	--	21.6	20.1
LSD (0.10)		0.2	0.2	NS	NS	NS	NS	NA	NS	NS
		N source means								
	UAN	19.5	19.5	19.7	20.0	20.3	18.8	--	21.8	19.9
	AN	19.5	19.7	19.7	20.2	20.4	19.0	--	21.5	20.0
	Urea	19.6	19.7	19.7	20.2	20.6	19.0	--	21.6	20.1
	Urea + NBPT	19.5	19.8	19.7	20.2	20.6	19.3	--	21.8	20.1
LSD (0.10)		NS	0.2	NS	NS	NS	NS	NA	NS	NS

NS = nonsignificant; NA = not available

heavy N demand that occurs at pod fill through the N fixation process. The 11.8 % average increase in yield is large enough to make this practice economically viable for producers of high-yielding irrigated soybean. Assuming prices of \$7/bu for soybean, \$0.30/lb N, and a \$5/acre application cost, these results would show a return of \$48.30/acre for an \$11/acre investment (at 20 lb N/acre).

Leaf N concentrations in samples taken 2 to 3 wk after N application were not affected by N fertilization. Likewise, combined analysis of all sites revealed that soybean grain protein and oil concentrations were not consistently affected by late season N fertilization. Soybean protein and oil concentrations were significantly increased at some sites, though increases were small. Nitrogen application consistently increased protein and oil production per acre due to yield increases.

Results from this work show that application of N at the R3 growth stage will increase soybean yields. These results, coupled with similar results in other states (Flannery, 1986; Gascho et al., 1991), suggest that public and private labs and consultants who make fertilizer recommendations should reconsider N recommendations for irrigated soybean with high yield potential.

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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-

USDA-ARS, Central Great Plains Res. Stn., P.O. Box 400, Akron, CO 80720. Received 15 Nov. 1997. *Corresponding author (dnielsen@lamar.colostate.edu).

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