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Corn Growth and Nitrogen Uptake with Furrow Irrigation and Fertilizer Bands

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ABSTRACT

Furrow irrigation is commonly used to provide supplemental water to row crops. Alternate-furrow irrigation has been proposed as a method to decrease deep percolation water losses as well as the leaching of fertilizer and pesticides. A study was conducted on a Ulm clay loam (fine, smectitic, mesic Ustic Haplargids) in 1994 and 1995 near Fort Collins, CO. Corn (*Zea mays* L.) growth and N uptake were measured under alternate-furrow and every-furrow irrigation water applications, each with fertilizer bands placed either in the row or in the furrow. Nitrogen-15-depleted $(NH_4)_2SO_4$ fertilizer was used to distinguish plant uptake of fertilizer N from uptake of naturally occurring N. There were no differences in plant response to alternate-furrow or every-furrow irrigation water placement for the same amount of water applied. Greater fertilizer-N uptake occurred with row placement than with furrow placement of N fertilizer. Early in the growing season, fertilizer-N uptake from row placement was from 2 to 10 times the fertilizer-N uptake from furrow placement. By the end of the growing season, the average total-N uptake from row placement was 12% greater than for furrow placement. Placing the fertilizer in the nonirrigated furrow of the alternate-furrow irrigation treatment decreased N availability by 20% compared with the average of the other treatments. If alternate-furrow irrigation is used to increase water use efficiency in furrow-irrigated fields, placing the N fertilizer in the nonirrigated furrow of the alternate-furrow irrigation system could decrease N availability because of drier soil conditions in the nonirrigated furrow. Row placement of N fertilizer seems to be beneficial in both alternate-furrow and every-furrow irrigation applications.

FURROW IRRIGATION is commonly used in arid, semiarid, and subhumid regions to apply supplemental water to row crops. Deep percolation losses of water generally occur with furrow irrigation because, to apply sufficient water to replenish the root zone of the soil farthest from the source, overirrigation occurs near the source. Water is usually applied to each furrow in the field, but some researchers (Fischbach and Mulliner, 1974; Musick and Dusek, 1974; Crabtree et al., 1985) have proposed irrigating alternate furrows instead of every furrow in a field to increase water use efficiency. Small yield losses were recorded for sugarbeet (*Beta vulgaris* L.), sorghum [*Sorghum bicolor* (L.) Moench], and potato (*Solanum tuberosum* L.) by Musick and Dusek (1974) and for soybean [*Glycine max* (L.) Merr.] by Crabtree et al. (1985) for the alternate-furrow irrigation system when compared with every-furrow irrigation, but irrigation water use decreased by 30 to 50%. The greatest yield losses for alternate-furrow irrigation were at locations farthest from the water source, which indicated that inadequate water was being applied. Fischbach and Mulliner (1974) did not observe lower corn yields with alternate-furrow than with every-furrow irrigation, even though irrigation water application was 30% less with alternate-furrow irrigation.

Overirrigation can lead to greater leaching of fertilizers and pesticides into groundwater. A study of wells in the alluvial aquifer of the South Platte River Valley in Weld County, Colorado (Schuff, 1992), showed 70% of the wells with higher nitrate levels than the EPA-recommended level of 10 mg L^{-1}. Furrow-irrigated corn, extensively grown in the valley, was considered a major contributor to this pollution (Wylie et al., 1994). Artiola (1991) measured as much as 40% of the available NO_3–N lost from the root zone with one 300-mm irrigation on a clay loam. Most of the nitrate losses occurred on the two-thirds of the field closest to the irrigation source and no significant nitrate losses were measured on the third of the field furthest from the water source.

If deep percolation of water is inevitable in part of a field under furrow irrigation, one method to limit chemical movement to groundwater is to isolate the chemical from the percolating water. Kemper et al. (1975) showed that leaching of salt out of the root zone could be reduced in a furrow irrigation system by placing the band of salt in the ridge at a level equal to or higher than the water level in the furrow. They measured no salt leaving the root zone with a band of salt placed at or above the level of water in the furrow, even with a loamy sand soil and 1000 mm of overirrigation. When the salt was broadcast with flood irrigation on a level surface or placed in a band below the level of water in the furrow of a ridge–furrow surface, nearly all the salt was leached from the soil after 1000 mm of overirrigation. Hamlett et al. (1986) showed reduced nitrate and bromide leaching from a band of fertilizer placed under the row in a ridge

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tillage system compared with a flat tillage system for equal precipitation. Their analysis of water movement suggested that the ridge helped isolate nitrate and bromide from leaching, even though more downward movement of water occurred in the ridge system. Benjamin et al. (1994) showed the potential for less leaching of a salt when it was placed in the ridge than if placed in the furrow. They also showed less leaching when the chemical was placed in the nonirrigated furrow than if placed in the irrigated furrow. The study concluded that, for a fertilizer salt, there was sufficient wetting of the nonirrigated furrow that the fertilizer would be available for plant uptake.

Our objectives were (i) to determine if alternate-furrow irrigation can be as effective as every-furrow irrigation for supplying water to plants and obtaining an economic crop yield in fine textured soils, (ii) to determine if N fertilizer placed in a nonirrigated furrow is as available for plant uptake as N fertilizer placed in an irrigated furrow, and (iii) to determine if N fertilizer placed in the ridge is more available for plant uptake than N fertilizer placed in the furrow, particularly early in the growing season.

MATERIALS AND METHODS

The study was conducted at the Agricultural Research, Development, and Education Center (ARDEC) near Fort Collins, CO, on an Ulm clay loam (fine, smectitic, mesic Ustic Haplargids) in 1994 and 1995. The experiment had a split plot design with four replications. Ridges approximately 0.1 m higher than the corresponding furrow were built with a cultivator in the spring before planting and fertilizer application. The main plots, 21 m long and 4.5 m (six rows) wide, consisted of irrigation water placed either in every furrow or in alternate furrows. Because of the relatively short plot lengths, and also to have precise control of the volume of water applied to each plot, we simulated furrow irrigation by modifying a low-energy, precision-application (LEPA) linear-move irrigation system. The drop nozzles on the LEPA system were fitted with socks to apply the water in the center of the furrows. Small furrow dikes were constructed in the furrows so that the water ponded in the furrow while the linear-move irrigator traveled the length of the plot. Water was applied approximately weekly at a rate equal to 100% of estimated evapotranspiration. The equivalent volume of water was placed either in every furrow or in alternate furrows, as appropriate, so that the total amount of water was the same for each treatment.

Each irrigation main plot was split crosswise into two subplots, each 9.1 m long and 3 m wide, centered along the middle four rows of the main plot for furrow placement and row placement band applications of N fertilizer. A small slot, approximately 0.1-m deep, was dug by hand near the plant row for row placement and in alternating furrows for furrow placement in both every-furrow and alternate-furrow irrigation treatments. The furrow treatments were placed such that the fertilized furrow was the nonirrigated furrow of the alternate-furrow irrigation treatment. Nitrogen-15-depleted fertilizer as $(NH_4)_2SO_4$ (99.99 % atomic percent ^{14}N) was dissolved in water and applied with a hand sprayer to the bottom of the trench at a rate of 4.0 L for each 3-m length of row at a N rate of 145 kg ha^{-1}. Fertilizer was applied shortly after planting as shown in Fig. 1. The delay of fertilizer application in 1995 compared with 1994 was caused by unusually rainy conditions after planting.

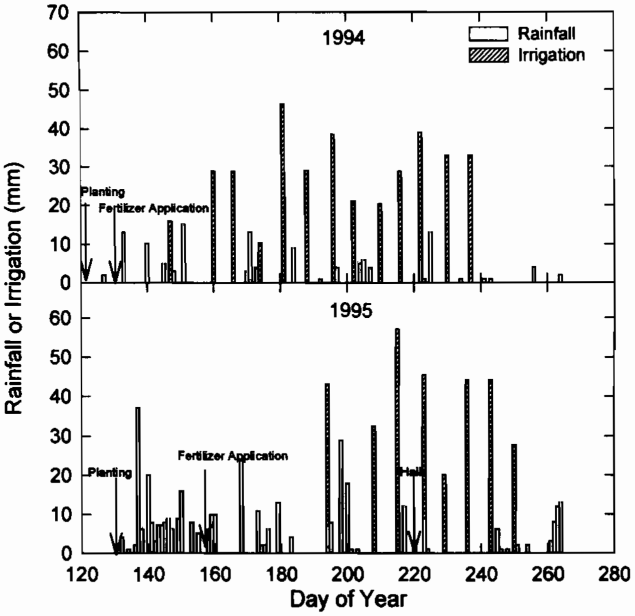

Fig. 1. Rainfall and irrigation distribution for the 1994 and 1995 growing seasons at the Agricultural Research, Development, and Education Center (ARDEC) near Fort Collins, CO. Also shown are dates of planting, fertilizer application, and major weather events (a hailstorm in 1995).

Neutron probe access tubes (1.8 m long) were installed in two furrows and in the row between the furrows inside of each fertilizer plot in the middle of the irrigation plot. Water contents were measured at 30-cm intervals from 0.15 to 1.65 m before each irrigation and 48 h after each irrigation. Undisturbed soil cores (100 mm diam.) were collected at 75-mm intervals to a depth of 1 m from each replication to determine the water retention characteristics of the soil.

First-year planting occurred on 3 May 1994, with a seeding population of approximately 81 500 plants ha^{-1}. The plots were thinned to 71 600 plants ha^{-1}. Plant emergence was measured daily until full emergence. All plants had emerged by 25 May. Plant development stage (Ritchie and Hanway, 1982) was measured weekly between full emergence and tasseling. For determining plant development stage, 10 plants were identified for repeated leaf counts. Leaves were marked on these plants to account for senescence of the lower leaves as the plant developed. Plant samples for biomass and ^{15}N analysis were collected at the V6 (15 June), V12 (11 July), R1 (20 July), and R6 (10 Sept.) development stages. Four plants were collected from each fertilizer plot at each time and the plants were separated into plant parts (leaves, stems, cob, and grain as appropriate for the growth stage). The plant parts were weighed for biomass determination and analyzed for total N and for atom percent of ^{15}N on a continuous flow combustion analyzer coupled with an isotope-ratio mass-spectrometer. The V12 samples in 1994 were inadvertently discarded before total N and ^{15}N analysis could be conducted. Two 9-m rows separate from the rows sampled for plant weights were harvested for grain yield at maturity.

Second-year planting occurred on 11 May 1995. As in the first year, the seeding population was approximately 81 500 plants ha^{-1} and the plots were thinned to a population of 71 600 plants ha^{-1}. Plant emergence was delayed in 1995 compared with 1994 due to cooler temperatures. All plants had emerged by 9 June. Plant development measurements were the same as in 1994. Because of the rainy spring and uncertainty of field operations in 1995, samples were collected at

Table 1. Analysis of variance for total plant weight, total-nitrogen uptake, and fertilizer-nitrogen uptake of corn for 1994 and 1995.

Growth stage	Source	df	Plant weight 1994	Plant weight 1995	Total-N uptake 1994	Total-N uptake 1995	Fertilizer-N uptake 1994	Fertilizer-N uptake 1995
V6 or V5‡	Irrigation treatment	1	NS	NS	NS	NS	NS	NS
	Fertilizer placement	1	*	**	NS	**	**	**
	Irrigation × fertilizer placement	1	NS	NS	NS	NS	†	NS
V12	Irrigation treatment	1	NS	NS	n/a	NS	n/a	†
	Fertilizer placement	1	NS	*	n/a	†	n/a	**
	Irrigation × fertilizer placement	1	NS	NS	n/a	NS	n/a	NS
R1	Irrigation treatment	1	NS	NS	NS	NS	**	NS
	Fertilizer placement	1	NS	NS	†	NS	*	NS
	Irrigation × fertilizer placement	1	NS	NS	†	NS	**	NS
R6 or R5§	Irrigation treatment	1	†	NS	NS	NS	*	NS
	Fertilizer placement	1	NS	*	†	*	†	*
	Irrigation × fertilizer placement	1	NS	NS	NS	NS	NS	NS

†,*,** Significant at the 0.1, 0.05, and 0.01 levels, respectively, according to an *F*-test; n/a, no analysis (missing data).
‡ V6 in 1994; V5 in 1995.
§ R6 in 1994; R5 in 1995.

V5 (5 July), V12 (30 July), and R1 (7 Aug.) development stages. A hailstorm occurred at the R1 growth stage. A killing frost occurred before physiological maturity at about R5, so the last sample was taken at that time.

Fertilizer N (fertN) was determined from the total N in the plant (totN) and by the change of atom % ^{15}N in the sample (sap^{15}N) due to application of the ^{15}N-depleted fertilizer by

$$\text{fertN} = \text{totN}\ (\text{sap}^{15}\text{N} - \text{nap}^{15}\text{N})/(\text{aap}^{15}\text{N} - \text{nap}^{15}\text{N}) \quad [1]$$

where aap^{15}N is the atom % ^{15}N in the fertilizer (0.01%). Plant samples collected outside the fertilizer plots had an atom % ^{15}N (nap^{15}N) of 0.372%.

An analysis of variance (ANOVA) was used to determine treatment differences. The results of the ANOVA are shown in Table 1. A protected least significant difference (LSD) test was used to separate irrigation and fertilizer placement differences of plant biomass, total-N uptake, and fertilizer-N uptake. The LSD used to compare treatment effects was calculated only if the probability > F was less than 0.05.

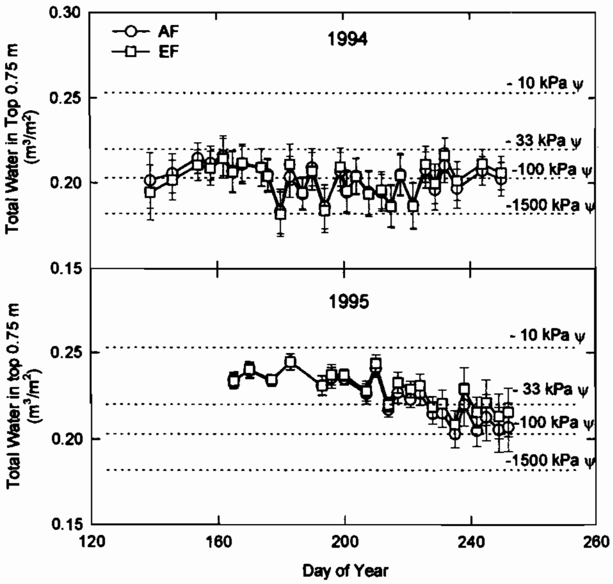

Fig. 2. Total water for one row (0.75 m) in the top 0.75 m of soil during 1994 and 1995 for the alternate-furrow (AF) and every-furrow (EF) irrigation treatments. Dashed lines indicate the total water at −10, −33, −100, and −1500 kPa water potential. Error bars indicate ±1 SD from the mean.

RESULTS AND DISCUSSION

Rainfall and irrigation application were fairly typical for eastern Colorado in 1994 (Fig. 1). Total rainfall for the growing season was 127 mm, and total irrigation was 366 mm. Spring rainfall was much higher in 1995 and resulted in total growing season precipitation of 384 mm. Irrigation started about 45 d later in 1995 than 1994, and the total irrigation application was 298 mm. Figure 2 shows the amount of water stored in the top 0.75 m of soil across one row and the corresponding water stored at −10, −33, −100, and −1500 kPa water potentials determined from desorption measurements on soil cores. High rainfall resulted in a wetter soil profile at the start of the growing season in 1995 than in 1994. In 1995, the soil water content seldom decreased to less than field capacity (−33 kPa), but in 1994 the water content was seldom above field capacity. There were no differences in water storage or water usage by the plant due to irrigation placement.

Approximately twice as much fertilizer-N uptake occurred with row placement than furrow placement at the V6 stage in 1994 (Table 2). The greater fertilizer-

Table 2. Average plant weight, total-N uptake, and fertilizer-N uptake of corn, 1994.

Growth stage	Irrigation placement	Fertilizer placement	Avg. plant wt.	Total N	Fertilizer N
			kg ha^{-1}		
V6	Alternate furrow	Furrow	646a†	20.0a	1.7b
	Alternate furrow	Row	531a	17.9a	5.2a
	Every furrow	Furrow	571a	18.6a	3.2b
	Every furrow	Row	441a	15.0a	4.4a
V12	Alternate furrow	Furrow	5 076a	nd‡	nd
	Alternate furrow	Row	7 095a	nd	nd
	Every furrow	Furrow	5 513a	nd	nd
	Every furrow	Row	5 112a	nd	nd
R1	Alternate furrow	Furrow	9 300a	113.1a	20.0b
	Alternate furrow	Row	10 718a	158.2a	59.4a
	Every furrow	Furrow	9 973a	143.9a	66.6a
	Every furrow	Row	10 059a	144.0a	60.1a
R6	Alternate furrow	Furrow	20 005a	189.0a	37.2b
	Alternate furrow	Row	19 274a	210.5a	61.6ab
	Every furrow	Furrow	20 477a	210.5a	74.5a
	Every furrow	Row	21 866a	230.6a	84.5a

† Within columns and growth stage, treatment means followed by a different letter are significantly different at the 0.95 confidence level.
‡ nd, no data available for analysis.

Table 3. Average plant weight, total-N uptake, and fertilizer-N uptake of corn, 1995.

Growth stage	Irrigation placement	Fertilizer placement	Avg. plant wt.	Total N	Fertilizer N
				kg ha^{-1}	
V5	Alternate furrow	Furrow	78.0c†	3.8b	0.4b
	Alternate furrow	Row	234.1a	6.9a	4.3a
	Every furrow	Furrow	148.9b	4.2b	0.5b
	Every furrow	Row	207.6a	6.2a	3.9a
V12	Alternate furrow	Furrow	4 038b	76.6a	30.1b
	Alternate furrow	Row	4 231a	82.6a	40.8a
	Every furrow	Furrow	3 909b	75.2a	36.5ab
	Every furrow	Row	4 303a	82.3a	44.4a
R1	Alternate furrow	Furrow	8 270a	108.8a	55.1a
	Alternate furrow	Row	9 036a	128.2a	70.2a
	Every furrow	Furrow	8 406a	119.6a	68.0a
	Every furrow	Row	9 165a	126.0a	71.6a
R5	Alternate furrow	Furrow	13 876b	164.0a	78.8b
	Alternate furrow	Row	16 897a	186.9a	90.2a
	Every furrow	Furrow	14 105b	159.0a	68.0b
	Every furrow	Row	16 253a	181.9a	90.2a

† Within columns and growth stage, treatment means followed by a different letter are significantly different at the 0.95 confidence level.

N uptake did not, however, result in greater total-N uptake or greater plant weights. There was a significant irrigation × fertilizer placement interaction for fertilizer-N uptake at the R1 growth stage, with less fertilizer-N uptake from the alternate-furrow furrow placement treatment (fertilizer placed in the nonirrigated furrow) than from the other treatments. Plant uptake of fertilizer placed in the nonirrigated furrow was only about 33% of the fertilizer placed in the row or the irrigated furrow at R1. By R6, plant uptake of fertilizer from the alternate-furrow furrow placement treatment was about half of the uptake for row placement. Total-N uptake was less, though not significantly so, by the amount of reduction in fertilizer-N uptake.

In 1995, plant uptake of fertilizer N (Table 3) was 10 times greater on average for the row placement than for furrow placement at the V5 growth stage. Total-N uptake by the plant was greater with row placement than with furrow placement by about the same amount as the increased fertilizer uptake. In 1995, greater total-N uptake did result in greater average plant weight at V5. At the V12 growth stage, row placement showed consistently greater fertilizer-N uptake than for furrow placement in both irrigation systems. Although the total-N uptake difference was not significantly different among treatments, the trend for greater total-N uptake with row placement of fertilizer than for furrow placement was apparent. The row placement treatment also resulted in greater plant weight. By R1, fertilizer-N uptake, total-N uptake, and average plant weight were similar among treatments, but there was the trend for less fertilizer-N uptake from the fertilizer band placed in the dry furrow. At the R5 growth stage, row placement of fertilizer resulted in greater plant weight and greater fertilizer-N uptake compared with furrow placement, but there was no difference between dry or wet furrow placement, contrary to the observations in 1994. Greater rainfall during the growing season in 1995 and, subsequently, less irrigation resulted in more similar water conditions in the fertilized furrow with either every-furrow and alternate-furrow irrigation. Therefore, fertilizer availability was less restricted by root environmental conditions in 1995 than 1994.

CONCLUSIONS

Placement of irrigation water either in every furrow or only in alternate furrows had no effect on plant development, growth, or grain yield. N fertilizer placed in the row increased N uptake, particularly early in the growing season. Total-N uptake was enhanced by the increased fertilizer-N uptake but, in this experiment, did not necessarily result in greater plant weights or greater grain yields. The advantage of row placement to increase N fertilizer uptake may be greater in soils that have less N mineralization. Placing N fertilizer in the nonirrigated furrow of an alternate-furrow irrigation system, as a way to decrease leaching, could result in less N uptake by the plant due to dry conditions in the nonirrigated furrow.

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REFERENCES

Artiola, J.F. 1991. Nonuniform leaching of nitrate and other solutes in a furrow-irrigated, sludge amended field. Commun. Soil Sci. Plant Anal. 22:1013–1030.

Benjamin, J.G., H.R. Havis, L.R. Ahuja, and C.V. Alonso. 1994. Leaching and water flow patterns in every-furrow and alternate-furrow irrigation. Soil Sci. Soc. Am. J. 58:1511–1517.

Crabtree, R.J., A.A. Yassin, I. Kargougou, and R.W. McNew. 1985. Effects of alternate-furrow irrigation: water conservation on the yields of two soybean cultivars. Agric. Water Manage. 10:253–264.

Fischbach, P.E., and H.R. Mulliner. 1974. Every-other furrow irrigation of corn. Trans. ASAE 17:426–428.

Hamlett, J.M., J.L. Baker, and R. Horton. 1986. Anion movement under ridge tillage: A field study. ASAE Pap. 86-2509 (1986 winter meet.). Am. Soc. Agric. Eng., St. Joseph, MI.

Kemper, W.D., J. Olsen, and A. Hodgdon. 1975. Fertilizer or salt leaching as affected by surface shaping and placement of fertilizer and irrigation water. Soil Sci. Soc. Am. Proc. 39:115–119.

Musick, J.T., and D.A. Dusek. 1974. Alternate-furrow irrigating of fine textured soils. Trans. ASAE 17:289–294.

Ritchie, S.W., and J.J. Hanway. 1982. How a corn plant develops. Spec. Rep. 48. Rev. ed. Iowa State Univ. Coop. Ext. Serv., Ames, IA.

Schuff, S.. 1992. Nitrates can leach, but they can't hide. Colorado Rancher and Farmer (Nov. 1992), p. 6–10, 12.

Wylie, B.K., M.J. Shaffer., M.K. Brodahl, D. Dubois, and D.G. Wagner. 1994. Predicting spatial distributions of nitrate leaching in northeastern Colorado. J. Soil Water Conserv. 49:288–293.