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Agronomic and economic evaluation of various furrow irrigation strategies for corn production under limited water supply

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Abstract: It is commonly known that furrow irrigation is a less efficient method of irrigation than a sprinkler center pivot system, but many fields' irregular shapes prevent the use of center pivot irrigation. Restricted water allocations of surface and subsurface water are forcing farmers to implement irrigation strategies that will reduce water application on furrow-irrigated fields. The study site was located in south central Nebraska. The objective of this study was to evaluate two irrigation scheduling scenarios: (1) the every-furrow irrigation method with 50% (0.5), 70% (0.7), and 90% (0.9) field capacity (FC) treatments and (2) the every-furrow (EF) irrigation method compared to the every-other-furrow (EOF) method with both using the 75% field capacity (0.75 FC) treatment effects on corn (*Zea mays* L.) yield, net economic return, and residual soil nitrate-nitrogen. The experimental design was a randomized complete block with three replications. Grain yield showed no significant difference in both years for all irrigation treatments. Irrigation water application with the 0.5 FC strategy reduced the amount of applied water by approximately 70% and 200% compared to 0.7 FC and 0.9 FC, respectively, in both years. The water savings with the EOF method over the EF method was 23%. The economic return with 0.5 FC was 6% to 13% and 36% to 69% over 0.7 and 0.9 FC irrigation treatments, respectively. The 0.5 FC strategy showed no significant reduction in nitrate-nitrogen loss over 0.7 FC and 0.9 FC, while the EOF method reduced soil nitrate-nitrogen loss by 11% to 26% over the EF irrigation method in both years. The average economic return over two years with the 0.5 FC strategy was 9.5% and 52.5% over 0.7 FC and 0.9 FC irrigation treatments, respectively, while the average economic return with the EOF method over the EF method was 9.5%. Findings demonstrated that economic and environmental benefits of using 0.5 FC or the EOF method is much superior to other furrow irrigation strategies, especially in areas with limited water resources where less efficient irrigation methods may lead to significant water loss.

Key words: every-furrow irrigation—every-other-furrow irrigation—furrow irrigation—nitrate leaching—surface irrigation

The frequent severe droughts in western and central Nebraska are causing many producers in South Central Nebraska to face shortages of irrigation water supplies. Restrictions resulting from litigation with neighboring states over water issues and poor inflows into reservoirs have encouraged farmers to find methods of maintaining profitability while using less water (Payero et al. 2006). Reduction in surface water availability, along with an increase in agricultural production input costs has producers in south central Nebraska searching for more efficient irrigation methods that do not decrease yields. While some producers are contemplating conversion to dryland production, research by Norwood (2000) on silt loam soils suggests that one or two irrigations for corn will significantly increase the yield compared to dryland management in situations where water is limited. Based on research in North Dakota on sandy loam and loam soils, Stegman (1982) recommended irrigation management strategies where root zone available water depletion was limited to near field capacity (FC) at planting, no more than 60% to 70% during early vegetative growth stage, 30% to 40% during 12 leaf to blister kernel growth stages, and 50% to 60% later at the grain fill growth stage.

Many studies have been conducted on limited irrigation and the effects of moisture stress during the growing season. Barrett and Skogerboe (1978) suggest that the total amount of water available to the crop during the growing season is more important than the timing of the water, as long as the stress is not so great that it actually desiccates the crop. Studies by Schneekloth et al. (2006) found that reduction of water during the vegetative growth stage has little or no effect on yield. Water deficit during the vegetative growth stage of corn can result in shorter plants and smaller leaf area (Denmead and Shaw 1960; NeSmith and Ritchie 1992; Abrecht and Carberry 1993; Traore et al. 2000).

Significant reductions in yields can be attributed to shortages of water during the reproduction stages (Robins and Domingo 1953; Denmead and Shaw 1960; Harder et al. 1982; Bennett et al. 1989; Schneekloth et al. 1991). Musick and Dusek (1980) found that stress at any growth stage reduced overall yields, but greater reduction was caused by stress during the reproduction growth stage. In Minnesota on clay loam soils, Johnson et al. (1987) showed that irrigated corn responded as well to midseason irrigation as it did to more frequent irrigations at 50% soil water depletion.

Fishbach and Mulliner (1974) and Sepaskhah and Kamgar-Haghighi (1997) have used an every-other-furrow (EOF) irrigation method on clay loam soils as a strategy to improve irrigation efficiency by reducing the amount of applied water. They found that this irrigation method decreased water evaporation from the soil surface and allowed the soil to hold more water after a rain event. Other studies by Sepaskhah and Parand (2006) showed that deep percolation was reduced when the EOF irrigation method was compared to the every-furrow (EF) method, but yields were significantly different, with the EF method having a greater yield than the EOF on clay loam soils. However, other studies showed that both EOF and EF irrigation methods produced similar yields (Benjamin et al. 1998;

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Fischbach et al. 1974). It was also found that at lower water application rates, the EOF method would produce greater grain yield than the same application rate of the EF method, but at higher water application rates, the EOF method yields were not significantly different than EF yields.

Due to the increase in the price of nitrogen and the concern over groundwater quality, it has become important to reduce the amount of nitrate leaching caused by over-irrigation. Lehrsch et al. (2000) showed on silt loam soils that the EOF method can reduce the amount of nitrate-nitrogen (NO_3-N) leached from the root zone.

Two experiments were conducted in this study: (1) three management strategies that delayed irrigation application until FC declined to 50%, 70%, and 90% were compared; and (2) the EF irrigation method was compared to the EOF irrigation method. The objective of the two experiments was to evaluate the effects of these different irrigation methods on yield, amount of applied water, economic return, and residual soil nitrate.

Materials and Methods

The two-year study was conducted on a production farm (40.57 latitude and 99.47 longitude) near Holdrege, Nebraska. The site's slope was approximately 1% from west to east. The soil on the site was Holdrege silt loam (fine-silty, mixed, superactive, mesic Typic Argiustolls). The soil had a moderate organic matter content of 2.8% and high natural fertility (USDA 1973). The moisture holding capacity at the site was 6.4, 5.8, and 5.1 cm per 30 cm for the soil depths of 0 to 30, 30 to 60, and 60 to 120 cm (2.5, 2.3, and 2.0 in per 1 ft for soil depths of 0 to 12, 12 to 24, and 24 to 48 in), respectively (USDA 1973). The average annual precipitation at the study site was 58 cm (23 in), where only 34 cm (13.5 in) fell from May 1 to September 1 (USDA 1973).

In 2004 and 2005, corn was planted on the site. In the fall of 2005, the corn residue was shredded with a 5.5 m (18 ft) Matthews Company stalk shredder. In the fall of 2005 and 2006, the site was disked twice with a 637 John Deere 9 m (29 ft) disk. On April 13, 2006, 5.86 L ha^{-1} (0.63 gal ac^{-1}) of Lumax, 2-chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl]acetamide, [S-metolachlor-atrazine-mesotrione]2-chloro-4-ethylamino-6-isopropylamino-s-triazine, 2-[4-(methylsulfonyl)-2-nitrobenzoyl]-1,3-cyclohexanedione and 2.1 L ha^{-1} (0.22 gal ac^{-1}) of atrazine [2-chloro-4-ethylamino-6-isopropylamino-s-triazine], along with 190.5 kg ha^{-1} (170 lb ac^{-1}) of urea ammonium nitrate (32-0-0) was applied using an 8103 Ag-Chem liquid floater. On November 15, 2006, 190.5 kg ha^{-1} (170 lb ac^{-1}) of urea ammonium nitrate (32-0-0) was knifed into the soil using a liquid applicator. On November 20, 2006, 56 kg ha^{-1} (50 lb ac^{-1}) of monoammonium phosphate (11-52-0), 29.1 kg ha^{-1} (26 lb ac^{-1}) of granular potash (0-0-60), and 2.2 kg ha^{-1} (2 lb ac^{-1}) of zinc sulfate were applied using an 8103 Ag-Chem floater spreader. On April 14, 2007, 4 L ha^{-1} (0.43 gal ac^{-1}) of Bicep II Magnum ([2-chloro-4-ethylamino-6-isopropylamino-s-triazine], Acetamide [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)-,(S)]) along with 33.6 kg ha^{-1} (30 lb ac^{-1}) of urea ammonium nitrate (32-0-0) were applied using an 8103 Ag-Chem liquid floater. A 1010 John Deere 10.4 m (34 ft) field cultivator was used before planting both years. Hybrid Pioneer 34A18 was planted at 76,600 plants ha^{-1} (31,000 ac^{-1}) on April 17, 2006, and hybrid Pioneer 33T59 was planted at 76,600 plants ha^{-1} (31,000 ac^{-1}) on April 18, 2007, using a 1720 John Deere 16-row MaxEmerge XP planter. Previous corn crops could potentially have differences in yield due to corn rootworm. Therefore, hybrids with the corn rootworm–resistant gene were planted. On June 2, 2006, and June 5, 2007, a post-emergence application of 73.1 mL ha^{-1} (1 oz ac^{-1}) Spirit herbicide [1-(4-methoxy-6-methyltriazin-2-yl)-3-[2-(3,3,3,-trifluoropropyl)-phenylsulfonyl]-urea,3-[4,6-bis (difluoromethoxy)-pyrimidin-2-yl]-1-(2-methoxycarbonylphenylsulfonyl)urea] was applied to control sunflowers using a 4920 John Deere sprayer. On July 1, 2007, 438.3 mL ha^{-1} (6 oz ac^{-1}) of Headline fungicide [pyraclostrobin: (carbarmic acid, [2-[[[1-(r-chlorophenlyl)-1H-pyrazol-3-yl]oxy]methyl]phenyl]methoxy-, methyl ester)] was applied by airplane for the control of grey leaf spot and southern rust.

Experiment I: Every-Furrow Irrigation Method. The EF experiment method was a randomized complete block with three replications. All plots consisted of 8 rows by 805 m (2,640 ft) long and a row spacing of 76 cm (30 in). The surface irrigation water application treatments were (1) 90% (0.9), 70% (0.7), and 50% (0.5) FC. Irrigation was not applied to the treatments until soil moisture in a 75 cm (30 in) soil profile reached the designated FC levels.

Experiment II: Every-Furrow Irrigation Compared to Every-Other-Furrow Irrigation. The EF versus the EOF method experiment was conducted on an adjacent site of the same soil characteristics. The experimental design was a randomized complete block with three replications. All plots consisted of 8 rows that were 805 m (2,640 ft) long with a row spacing of 76 cm (30 in). Irrigation was not applied until soil moisture reached 75% of field water holding capacity, with both irrigation methods.

Soil Moisture Measurements. Gypsum blocks were used to monitor soil moisture at different soil depths in both experiments for irrigation scheduling. The gypsum blocks were installed soon after emergence by using a 2.24 cm (0.88 in) diameter soil probe. One set of gypsum blocks was placed in the corn row between plants at a location in the middle of each plot. One gypsum block was placed at each depth in a separate hole in each plot at depths of 15, 45, 75, and 105 cm (6, 18, 30, and 42 in). A small amount of slurry was placed around the gypsum block to ensure good soil to block contact. Soil was then carefully tamped while filling the hole. A knot was tied in the lead wire that was connected to each gypsum block to indicate the depth of each block. The wire was then attached to an electric fencepost for easier access when taking measurements.

Soil moisture levels were read with a Delmhorst Instrument Company moisture meter. Measurements were taken at all four depths of the gypsum blocks once a week early in the growing season and then twice a week after the corn reached the 11-leaf growth stage for both experiments. Decisions were made to determine which gypsum block readings to use for irrigation scheduling, depending on the growth stage of the corn and the depth of the roots. Prior to the 11-leaf growth stage, the gypsum block moisture readings in the 0 to 15 cm and 15 to 45 cm (0 to 6 in and 6 to 18 in) depths showed that the majority of roots were in the top 15 to 45 cm depth. Therefore, soil moisture from those depths was used for water application decisions. As the season progressed and the roots deepened, the 0 to 15 cm, 15 to 45 cm, and 45 to 75 cm (0 to 6 in, 6 to 18 in, and 18 to 30 in) readings were used to decide when to irrigate. The fourth soil depth (75 to 105 cm [30 to 42 in]) of moisture measurements was used to determine if irrigation was causing deep percolation. An increase in soil moisture at the 75 to 105 cm soil depth would mean deep percolation was taking place.

Rainfall was measured throughout the growing season with a rain gauge at the study site and was used to schedule irrigations. Dates, length of irrigation applications, and irrigation amounts were recorded for each treatment. Electricity used for pumping water was also recorded for each irrigation event for both experiments.

Crop Measurements. Before corn reached maturity, corn stalk diameter was measured at the fourth node for randomly selected plants. The plant height of the corn was measured from ground level to the top end of the tassel.

The plots were harvested on September 14, 2006, and September 7, 2007. A John Deere 9550 combine with an eight-row corn head was used for harvesting corn grain at both experiment sites. Yields were determined by harvesting the eight rows of each plot. Grain yields were adjusted to a moisture content of 15.5%.

At harvest, a composite soil sample of seven soil cores was taken from each plot at a depth of 0 to 91 cm (0 to 36 in) with a 2.24 cm (0.88 in) soil probe and was placed in a bag in a cooler. A 20 cm (8 in) segment of the corn stalk was cut 30 cm (12 in) above the ground on 12 to 15 random plants in each plot to test for corn stalk nitrate, and these segments were placed in a paper bag for storage. A 0.72 L (3 C) grain sample from the combine bin during the harvest of each plot was taken for crude protein testing, and the grain samples were placed in plastic bags for storage. The soil, corn stalks, and grain samples were sent to the lab the next day for analysis. This analysis was conducted using the following procedures: for soil NO_3-N using the QuickChem 8000, Method 10-107-04-1-A with Lachat Instruments (Lachat Instruments, 6645 West Mill Road, Milwaukee, Wisconsin) (Gelderman and Beegle 1998); the stalk NO_3-N by flow injection with the QuikChem 8000, Method 10-107-05-1-A using a Lachat Instrument (Lachat Instruments, INC, 6645 West Mill Road, Milwaukee, Wisconsin); and for crude protein with the Dumas method No. 968.06 (Nitrogen in Feeds. No. 203-821-026) (Padmore 1990) using the CN analyzer (LECO Corporation, St. Joseph, Michigan) at Ward Laboratories, Kearney, Nebraska.

Statistical Analysis. Data from both experiments were analyzed as a randomized complete block design with three replications using the Generalized Linear Models procedure (SAS 2005) using a significance level of 0.05. Mean comparisons of treatments for yield, gross income, net income, water application, water cost, residual soil NO_3-N, grain crude protein, stalk NO_3-N, stalk height, and stalk diameter were performed using the Student's t-test (SAS 2005).

Table 1
Yield response and economic return of three furrow irrigation strategies in 2006 and 2007.

Year	Treatment	Water applied (cm ha^{-1})	Water costs (\$ ha^{-1})*	Grain yield (Mg ha^{-1})	Gross income (\$ ha^{-1})	Other costs (\$ ha^{-1})†	Net return (\$ ha^{-1})
2006	0.5 FC	69.7a	114.0a	14.6a	1,724.4a	1,787.7a	431.7a
	0.7 FC	106.3b	164.5b	14.6a	1,726.4a	1,787.7a	406.6b
	0.9 FC	215.8c	315.8c	14.8a	1,749.2a	1,787.7a	254.7c
2007	0.5 FC	40.1a	73.0a	14.5a	1,709.9a	1,787.7a	458.2a
	0.7 FC	76.8b	123.8b	14.5a	1,716.3a	1,787.7a	423.8a
	0.9 FC	123.2c	188.0c	14.5a	1,702.3a	1,787.7a	335.6b

Notes: Means with the same letter within each column within each year are not significantly different at $p \leq 0.05$. FC = field capacity.

* Water costs is the total of the electrical connection charge, electricity used, and \$ cm^{-1} of water used.

† Other costs were calculated at \$499 ha^{-1} seed and chemicals, \$247 ha^{-1} machinery, \$74 ha^{-1} labor, and \$358 ha^{-1} land (Duffy and Smith 2007). Gross income for each irrigation treatment was calculated by multiplying treatment yield by \$118 Mg^{-1}.

Table 2
Nitrogen status and plant response indicators to three furrow irrigation strategies in 2006 and 2007.

Year	Treatment	Stalk height (cm)	Stalk diameter (cm)	Soil nitrate (kg ha^{-1})	Stalk nitrate (ppm)	Grain protein (%)
2006	0.5 FC	289.6a	2.9a	27.7a	3,169a	9.3a
	0.7 FC	332.7b	3.5b	24.7a	1,240ab	9.2a
	0.9 FC	330.2b	3.2ab	32.9a	837b	9.2a
2007	0.5 FC	273.9a	2.6a	34.2a	1,805a	9.3a
	0.7 FC	282.2a	2.7a	39.6a	1,115a	9.2ab
	0.9 FC	279.8a	2.5a	34.4a	2,012a	9.1b

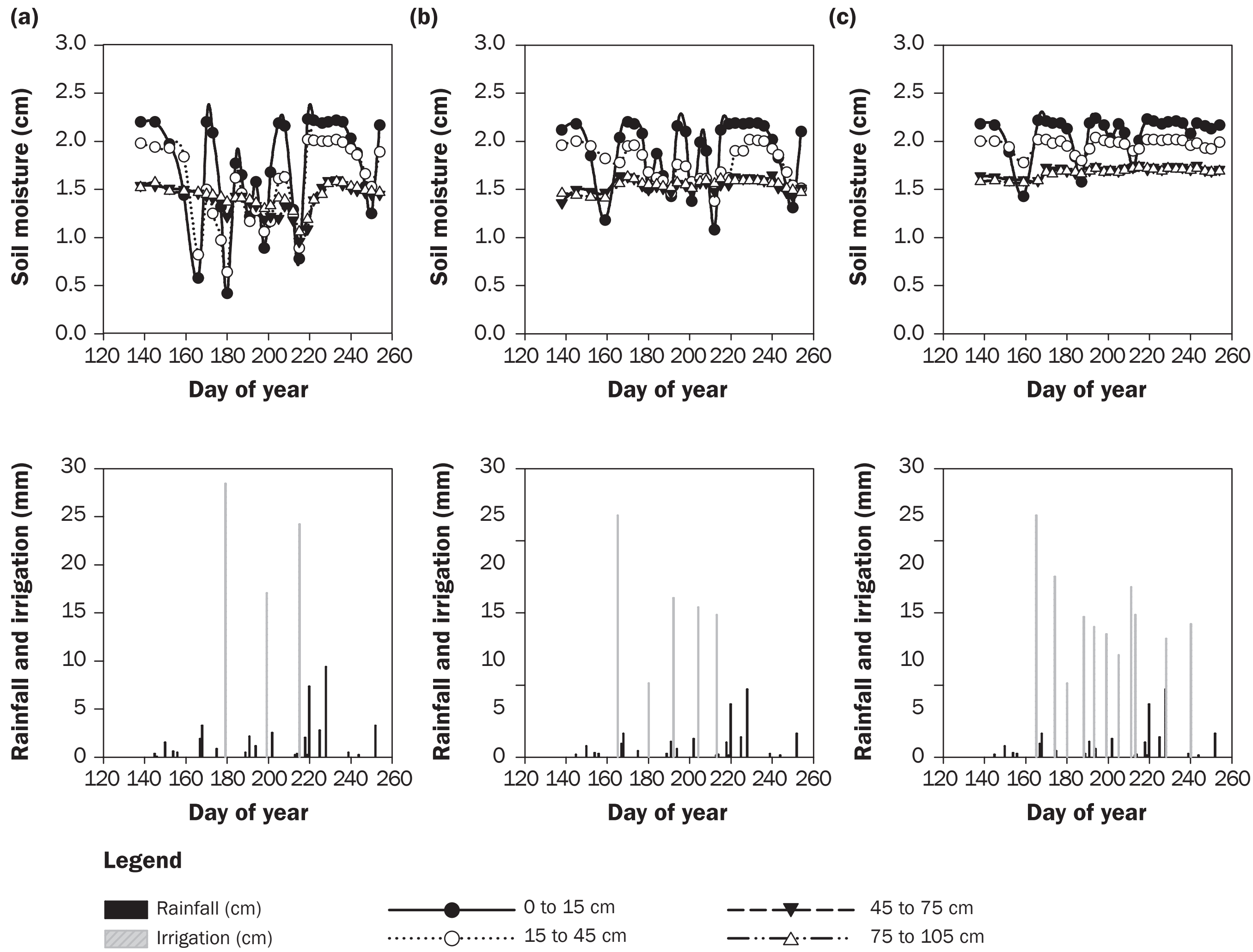
Notes: Means with the same letter within each column within each year are not significantly different at $p \leq 0.05$. FC = field capacity.

Results and Discussion

Experiment I: Every-Furrow Irrigation Method Grain Yield, Water Use, and Economic Return. Grain yields of the three irrigation treatments were not significantly different (table 1). These results suggest that soil moisture at FC can be depleted to 50% before irrigation is applied without significantly decreasing yields. It also indicates that a 0.9 FC irrigation may lead to overapplication of water (table 1).

In 2006, average seasonal water applications were 70, 106, and 216 cm ha^{-1} (11.1, 16.9, and 34.4 in ac^{-1}) for 0.5 FC, 0.7 FC, and 0.9 FC, respectively, were significantly different (table 1). Similarly, in 2007, average seasonal water applications of 40, 77, and 123 cm ha^{-1} (6.4, 12.2, and 19.7 in ac^{-1}) for 0.5 FC, 0.7 FC, and 0.9 FC, respectively, were significantly different (table 1). There were significant differences in corn plant heights and stalk diameters between the 0.5 FC , 0.7 FC, and 0.9 FC treatments in 2006, but there were no significant differences in these measurements in 2007 (table 2). The lower water application during the vegetative growth stage for the 0.5 FC treatment contributed to shorter plant height and stalk diameter but resulted in no significant difference in grain yield compared to the 0.7 FC and

Figure 1
Soil moisture profile and applied water (rainfall and irrigation water) of three irrigation management strategies—(a) 50% (0.5), (b) 70% (0.7), and (c) 90% (0.9) field capacity (FC)—as a function of time during the corn growing season in 2006.



0.9 FC treatments. This would suggest that the 0.5 FC was stressed enough to decrease plant size, but the water stress had no effect during ear-size determination and grain fill on grain yields. These results were similar to those of Denmead and Shaw (1960), NeSmith and Ritchie (1992), Abrecht and Carberry (1993), and Traore et al. (2000). In 2007, above normal precipitation during the vegetative growth period resulted in no water stress.

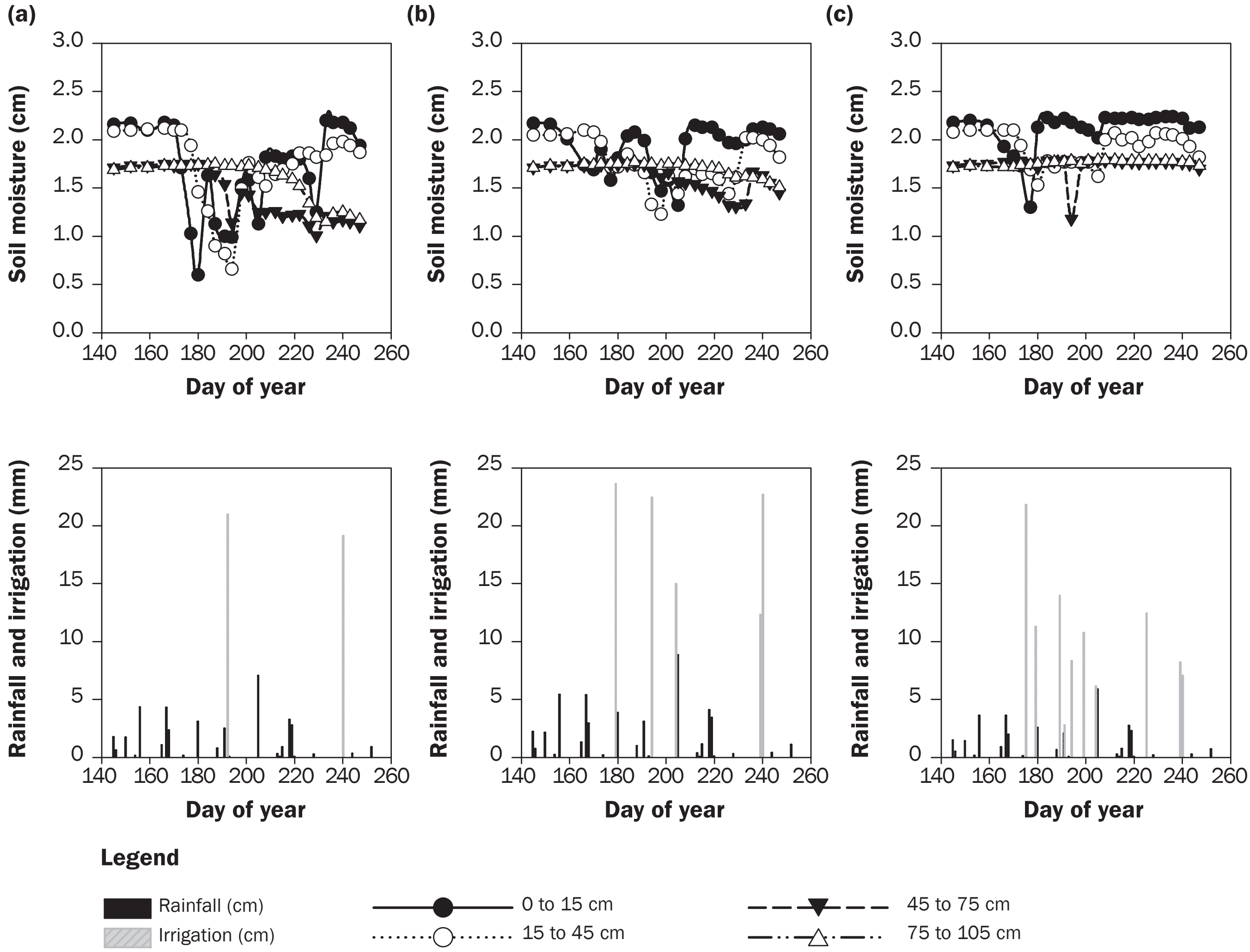
Net economic return per ha was significantly different between the three irrigation treatments. Water costs were calculated by summing the dollar value of the electrical connection charge, electricity used, and water used. Total water costs for the three irrigation treatments were significantly different (table 1). These results suggest that allowing soil moisture to be depleted to 0.5 FC before initiating irrigation significantly increases net return (table 1) and that managing soil moisture to capture precipitation can help limit irrigation applications. Studies in southwestern Nebraska showed no significant difference in yield when more than 30.5 cm (12 in) of irrigation water was applied (Schneekloth et al. 2001). Irrigation water application over 30.5 cm (12 in) increased pumping costs, which resulted in a lower net return.

Irrigation Strategies and Soil Moisture Use. Moisture readings taken during the growing season are summarized in figures 1 and 2. The moisture contents at the 0 to 15 cm and 15 to 45 cm (0 to 6 in and 6 to 18 in) soil depths for the 0.5 FC treatment were below 2.5 cm (1 in) of water four times during the 2006 growing season (figure 1). Soil moisture content decreased throughout the 2006 growing season for the 0.5 FC treatments in the 45 to 75 cm and 75 to 105 cm (18 to 30 in and 30 to 42 in) soil depths until a rainy period during August. After August 3, 2006, (day 215), the moisture content increased throughout the remainder of the growing season for the 0.5 FC treatments at the 45 to 75 cm and 75 to 105 cm soil depths. However, in 2006, the 0.5 FC treatment showed moisture content below 2.5 cm four times at the at the 0 to 15 and 15 to 45 cm soil depths, below 3 cm (1.2 in) four times at the 45 to 75 cm soil depth and two times at the 75 to 105 cm soil depth. However, declines in soil moisture did not significantly affect yield.

During the 2007 growing season, available soil moisture content was below 2.5 cm (1 in) twice at the 0 to 15 cm (0 to 6 in) soil

Figure 2

Soil moisture profile and applied water (rainfall and irrigation water) of three irrigation management strategies—(a) 50% (0.5), (b) 70% (0.7), and (c) 90% (0.9) field capacity (FC)—as a function of time during the corn growing season in 2007.



depth and three times at the 15 to 45 cm (6 to 18 in) soil depths of the 0.5 FC treatments (figure 2). Soil moisture content showed a steady decline from July 25 (day 206) until September 3, 2007, (day 246) for the 0.5 FC treatments at the 45 to 75 cm and 75 to 105 cm (18 to 30 in and 30 to 42 in) soil depths. This suggests that irrigation was overapplied for the 0.7 FC and 0.9 FC treatments. The results from 2006 and 2007 suggest that soil moisture levels can be depleted to levels of 2.5 cm or slightly greater without decreasing yields.

Residual Soil Nitrogen and Corn Stalk Nitrate. Residual soil nitrate in the top 91 cm (36 in) for the three irrigation treatments was not significantly different for either year (table 2). Corn stalk nitrate concentration for 0.5 FC treatment compared to the 0.9 FC treatment was significantly different in 2006 but not in 2007. Grain crude protein was not significantly different in 2006 but was significantly different between the 0.5 FC treatment and the 0.9 FC treatment in 2007. These results suggest that leaching of nitrogen below the root zone of the top 91 cm was similar for all treatments and did not have an effect on yield. Studies by Spalding et al. (2001) found that nitrate leaching was at high levels with furrow irrigation in south central Nebraska, where the average pore-water concentrations rose to approximately 30 mg NO_3-N L^{-1} during the study using furrow irrigation. This high level of nitrate leaching is a reflection of the irrigation efficiency of surface irrigation regardless of the amount of applied water. However, the depletion of soil moisture to 50% of FC also provides more soil storage capacity than the other two treatments (0.7 FC and 0.9 FC).

Experiment II: Every-Furrow and Every-Other-Furrow Irrigation Methods Grain yield, Water Use, and Economic Return. Grain yields of the two irrigation treatments were not significantly different (table 3). These results were similar to those by Benham et al. (1997), where the EF method treatment grain yield was only 0.13 Mg ha^{-1} (2 bu ac^{-1}) greater than that of the EOF method treatment. Water application in 2006 averaged 91 and 112 cm ha^{-1} (14.5 and 17.8 in ac^{-1}) for EOF and EF methods, respectively, and were significantly different. In the 2007 growing season, water application averaged 75 and 58 cm ha^{-1} (11.93 and 9.26 in ac^{-1}) for the EOF and EF methods, respectively, and were significantly different (table 3).

Table 3

Yield response and economic return of two furrow irrigation strategies in 2006 and 2007.

Year	Treatment	Water applied (cm ha^{-1})	Water costs (\$ ha^{-1})	Grain yield (Mg ha^{-1})	Gross income (\$ ha^{-1})	Other costs (\$ ha^{-1})*	Net return (\$ ha^{-1})
2006	EOF	90.9b	143.2b	14.6a	1,727.2a	1,178.7a	405.3a
	EF	111.5a	171.6a	14.5a	1,717.8a	1,178.7a	367.5b
2007	EOF	74.9b	121.1b	14.2a	1,680.6a	1,178.7a	380.8a
	EF	58.1a	97.9a	14.2a	1,675.2a	1,178.7a	398.6a

Notes: Means with the same letter within each column within each year are not significantly different at $p \leq 0.05$. EOF = every other furrow irrigation. EF = every-furrow irrigation. Water costs is the total of the electrical connection charge, electricity used, and \$ cm^{-1} of water used.

* Other costs were calculated at \$499 ha^{-1} seed and chemicals, \$247 ha^{-1} machinery, \$74 ha^{-1} labor, and \$358 ha^{-1} land (Duffy and Smith 2007). Gross income for each irrigation treatment was calculated by multiplying treatment yield by \$118 Mg^{-1}.

Corn plant heights were significantly different between the treatments in 2006 but were not significantly different in 2007 (table 4). However, no significant difference between the treatments was found for corn stalk diameter in either year. These results suggest that there is no direct correlation between plant dimensions and grain yield.

Net return per ha showed significant differences between both irrigation treatments in 2006 but showed no significant difference in 2007 (table 3). Total water costs and net economic return were significantly different between both treatments in both years (table 3). These results indicate that it may be more cost effective to irrigate every other furrow since yields were not significantly different using either irrigation method.

Irrigation Strategies and Soil Moisture Use. Soil moisture measurements that were taken during the growing season are summarized in figures 3 and 4. The moisture content at the 45 to 75 cm and 75 to 105 cm (18 to 30 in and 30 to 42 in) soil depths for the EF method never decreased below 2.5 cm (1 in) in 2006 or in 2007. In contrast, the moisture content for the EOF method was below 2.5 cm six times during the 2006 growing season at the 45 to 75 cm soil depth and three times during the 2006 growing season at the 75 to 105 cm soil depth. In 2006, soil moisture in the EOF method at 45 to 75 cm and 75 to 105 cm soil depths were decreasing throughout the growing season until a rainy period during August. After August 10, 2006, (day 222), soil moisture increased in the EOF method at the 45 to 75 cm and 75 to 105 cm soil depths through the remainder of the growing season (figure 3). Although the EOF method treatments showed low moisture content six times at the 45 to 75 cm soil depth and three times at the 75 to 105 cm soil depth in 2006, the soil moisture never declined to a level below 50% of FC or affected crop growth. This may be due to the fact that the soil under the EOF method was drier and could hold more water when it rained so as not to reduce yields.

In 2007, soil moisture levels at the 45 to 75 cm and 75 to 105 cm (18 to 30 in and 30 to 42 in) soil depths never decreased below 2.5 cm for the EOF method (figure 4). Soil moisture gradually decreased for the EOF method after August 12, 2007, (day 224) at the 45 to 75 cm and 75 to 105 cm soil depths until the crop reached maturity. This suggests that irrigation was overapplied on the EF method treatments. In 2007, low rainfall in July caused significant moisture depletion in the soil profile of all depths in the EOF method treatments between day of year 160 and day 212. Lower moisture content in the EOF method required more irrigation to bring soil moisture to the desired level of 0.75 FC (table 3). Benham et al. (1997) concluded that if water had recently been applied to every row, there may be less storage space available for potential rainfall. Therefore, deep percolation is less likely to take place when irrigating every other furrow compared to every furrow. It also suggests that there is less evaporation from the dry furrow with EOF method irrigation (Sepaskhah and Khajehabdollahi 2005).

Residual Soil Nitrogen and Corn Stalk-Nitrate. In 2006, residual soil NO_3-N content in the soil profile in the top 91 cm (36 in) was significantly different between the EOF method and the EF method treatments at levels of 54.9 and 25.1 kg ha^{-1} (49 and 22.3 lb ac^{-1}), respectively (table 4). In contrast, in 2007, residual NO_3-N content in the soil profile in the top 91 cm (36 in) of the two treatments was not significantly different at levels of 48.2 and 42.2 kg ha^{-1} (43 and 37.7 lb ac^{-1}) for EOF and EF method treatments, respectively. Corn stalk nitrate concentrations under both irrigation treatments were significantly different in 2006, where greater nitrate concentration was observed in stalks of EOF method treatments compared to EF method treatments. Differences in corn stalk nitrate concentrations were not significant in 2007 (table 4). However, percentage of grain crude protein content was not significantly different between the two treatments for either year (table 4). Results suggest that irrigating every furrow increased leaching of nitrate through the soil profile. The leaching did not have an effect on yields but would increase the amount of nitrogen that would be needed the following crop year. The difference in residual soil nitrate between treatments was lower in 2007 than 2006, which could be attributed to heavy rains early in the 2007 growing season that led to greater nitrate leaching under both treatments (table 4).

Table 4

Nitrogen status and plant response to two furrow irrigation strategies in 2006 and 2007.

Year	Treatment	Stalk height (cm)	Stalk diameter (cm)	Soil nitrate (kg ha^{-1})	Stalk nitrate (ppm)	Grain protein (%)
2006	EOF	315.8b	3.3a	54.9b	3,503.7b	9.3a
	EF	326.0a	3.2a	25.1a	1,602.3a	9.3a
2007	EOF	278.8a	2.6a	48.2a	2,297.0a	9.3a
	EF	276.7a	2.8a	42.2a	2,201.3a	9.3a

Notes: Means with the same letter within each column within each year are not significantly different at $p \leq 0.05$. EOF = every other furrow irrigation. EF = every-furrow irrigation.

Summary and Conclusions

Allowing soil moisture to be depleted to 50% of FC significantly reduced the need for irrigation without affecting yield. Reduced irrigation applications also increased net economic return. The net economic return for the 0.5 FC treatment in 2006 over the 0.7 FC and 0.9 FC was 13% and 69%, respectively. This return was 6% and 36% greater than returns for the 0.7 FC and 0.9 FC treatments in 2007, respectively. Economic return was also 11% greater for the EOF method compared to the EF method treatments in 2006. However, in 2007, EF method economic return was 8% greater than that for EOF method due to greater water application with EOF method system in 2007. The reason for the greater water application in 2007 was due to a dry period of several weeks, which led to greater application to bring field moisture to 0.75 FC.

Soil moisture content at the 75 to 105 cm (30 to 42 in) soil depth suggests that deep percolation was occurring on a regular basis in the soil of the 0.9 FC treatments. This suggests that seasonal rain variability had a great influence on the irrigation management strategy. The soil moisture content in the top 45 to 75 cm (18 to 30 in) in the EOF method treatments showed drier soil profiles, which contributed to greater soil water storage than that of the EF method treatments after rainfall. Allowing soil water to deplete to 50% available water is a viable irrigation strategy. There was a significant difference in the amount of residual soil nitrate after harvest, where soil nitrate in the EOF method treatments was greater than that in the EF method treatments in both years. The depletion of soil moisture to 50% of FC before irrigating resulted in 68% less water application, compared to irrigating at 90% FC in both years. The use of the EOF method strategy led to 19% less water applied than using the EF method of irrigation in 2006.

Our results suggest that irrigating every furrow and allowing soil moisture to deplete to 50% of FC means less water will be applied without negatively affecting yields. Irrigating every other furrow can also result in less water applied and a greater economic return compared to the EF method. These results also suggest that the EOF method of irrigation may reduce deep percolation below the root zone and reduce nitrate leaching compared to the EF method of irrigation. However, both of these strategies conserve water without decreasing economic returns based on the results of this study.

Figure 3

Soil moisture profile and applied water (rainfall and irrigation water) of two irrigation management strategies—(a) the every-other-furrow method and (b) the every-furrow method—as a function of time during the corn growing season in 2006.

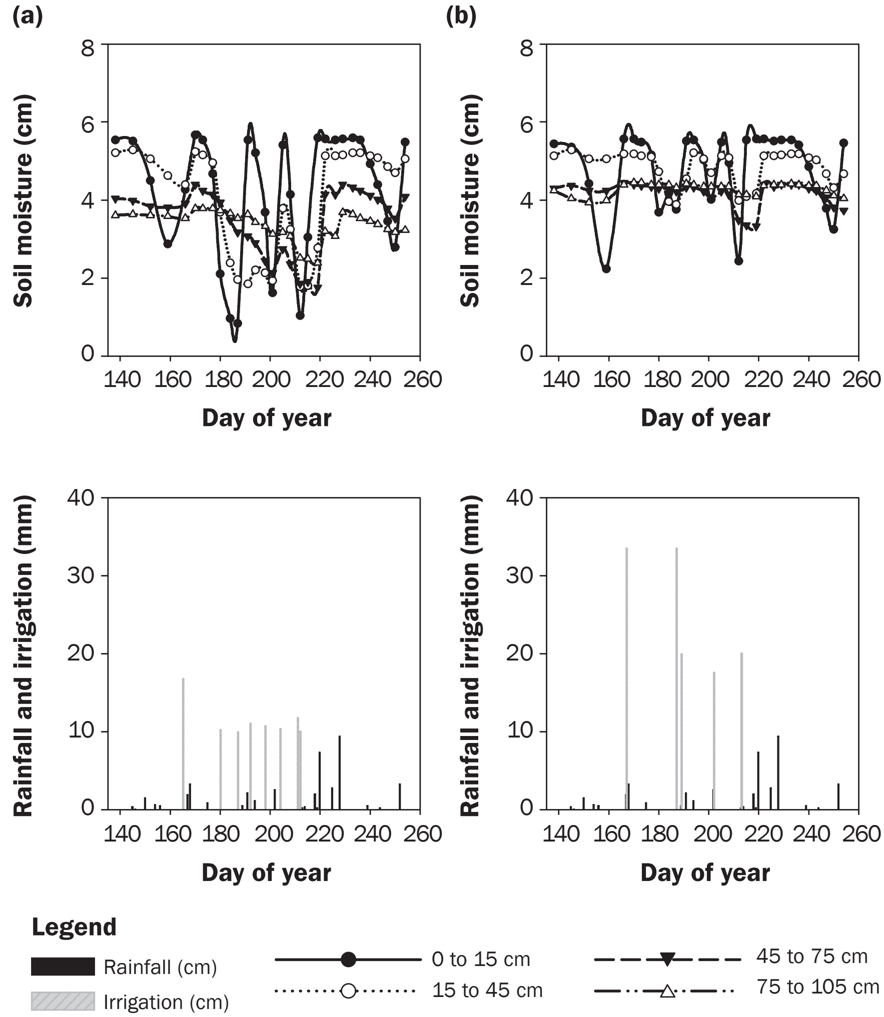


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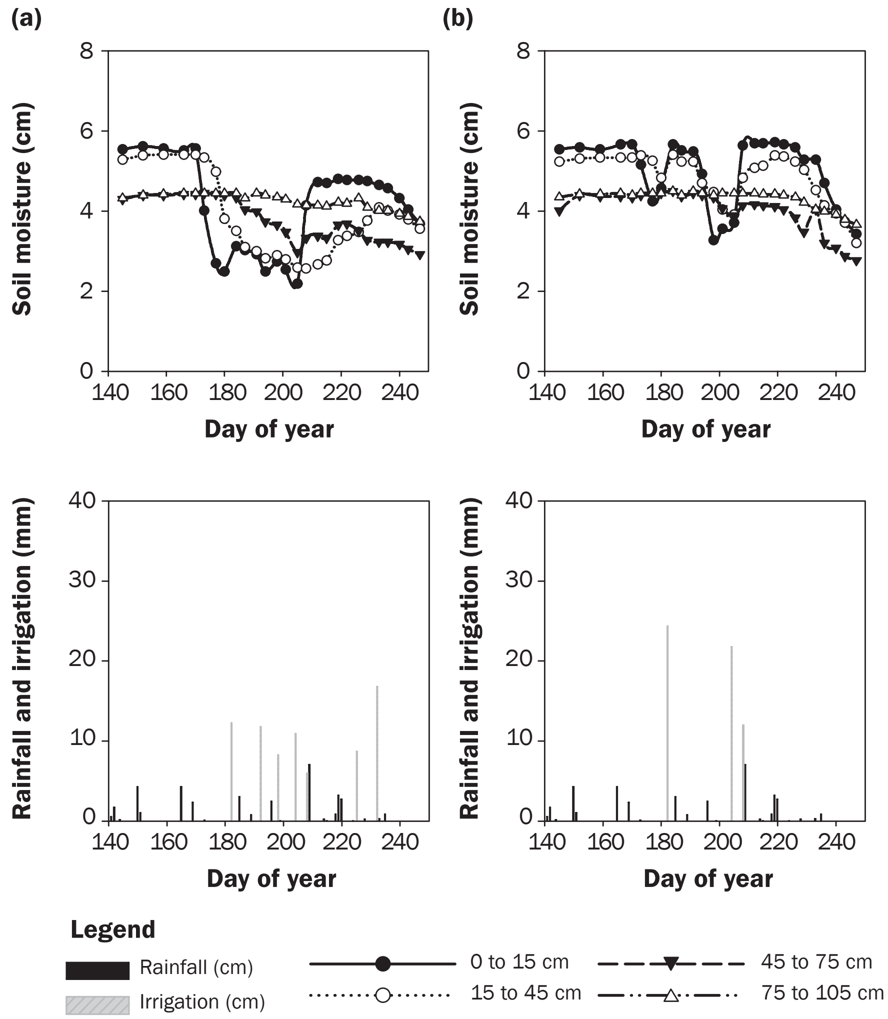
Figure 4

Soil moisture profile and applied water (rainfall and irrigation water) of two irrigation management strategies—(a) the every-other-furrow method and (b) the every-furrow method—as a function of time during the corn growing season in 2007.



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