Section B

Recent trends in nitrogen fertilizer and water use in irrigated corn

Water, nitrogen, and corn yields

Water plays a crucial role in the life of plants. Of all the resources that plants need to grow and function, water is typically the most limiting for agricultural productivity. The fact that water is limiting is the reason for applying irrigation. In turn, nitrogen (N) is the mineral element that plants require in the greatest amounts. Water and N deficiency reduce leaf area expansion, hasten leaf senescence, and reduce photosynthetic rates, which ultimately reduces corn yield.

This section summarizes historical trends in corn yield and N fertilizer use in Nebraska and presents the current status of on-farm N and irrigation water use based on data collected by the Natural Resources Districts (NRDs).

Figure B-1 shows some general relationships between grain yield, N uptake, and water use for corn in Nebraska. The response of corn yield to N uptake follows a curvilinear shape (yield increase slows with increasing N uptake and gradually approaches a plateau) (*Figure B-1A*). The level of the plateau is determined by the site-specific yield potential. On the contrary, the relationship between corn grain yield and crop water use is fairly linear (*Figure B-1B*), thus each additional inch of crop water use produces essentially the same amount of grain yield.

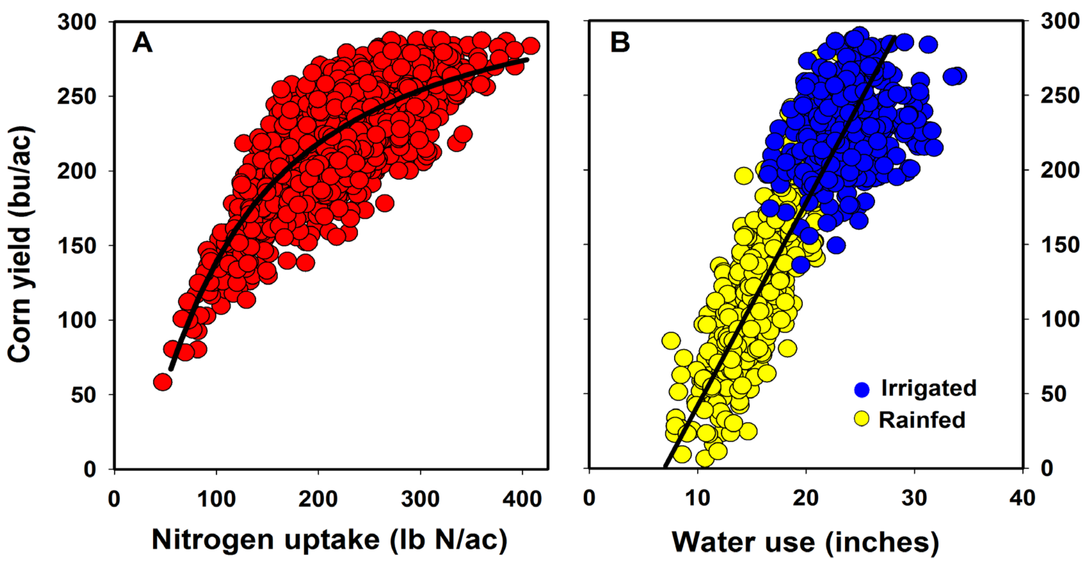

Figure B-1. Relationship between corn yield and corn N uptake (A) and corn yield and water use or crop ET (B). (Adapted from Grassini et al. 2009 and Setiyono et al. 2010).

Producers in Nebraska apply N fertilizer and irrigation water because N supplied by mineralization of soil organic matter and water supplied by precipitation are not enough to satisfy crop N and water requirements for high yields. At low N fertilizer or irrigation rates, increases in these inputs produce parallel increases in crop N uptake and water use, resulting in large yield increases. However, as input rates increase and yields approach their yield potential, it becomes more difficult to achieve the same yield increase per unit of applied N or irrigation water. This is because factors other than N and water become more limiting and less of the applied N fertilizer and irrigation water is recovered by the crops and more is prone to be lost into the environment. Hence, the challenge in crop production is to optimize, for a given field, the applied N fertilizer and irrigation water in relation to crop requirements to ensure high yields while minimizing the environmental impact. Later in this manual, methods for obtaining more grain yield for each pound of N and for each inch of water will be discussed with the goal of protecting groundwater quality.

Historical trends in yield and N fertilizer use and efficiency

Nitrogen Use Efficiency, NUE_F: refers to the amount of yield produced per unit of N fertilizer applied and is calculated by dividing the total grain or forage yield by pounds of N applied.

Water Use Efficiency (WUE) is the amount of yield produced per water applied and is calculated by dividing the unit of total grain or forage yield by inches of water applied.

Corn yields and N fertilizer and water use efficiencies have increased steadily in Nebraska during the past four decades (*Figure B-2*). Irrigated yield has increased at an annual rate of 2.0 bu/ac and rainfed yields have increased 1.6 bu/ac from 1965 to 2010 (*Figure B-2A*). However, N fertilizer rates have been relatively stable since the early 1970s with an average rate of 138 lb N/ac (*Figure B-2B*). The increase in corn grain yields without any significant increase in N rate over the same time translates into an increase in the yield produced per unit of N fertilizer (NUE_F) from 0.6 bu/lb N in the early ’70s to 1.1 bu/lb N in the 2000s. *Figure B-2C* presents the increase in **N use efficiency** based on the average corn yield for both rainfed and irrigated fields. Likewise**, the amount of yield produced per unit of in-season water (precipitation plus irrigation**) in both dryland and irrigated corn has increased during the same time period (*Figure B-2D*).

The increase in yield and use efficiencies of N fertilizer and water to produce grain are explained by genetic and agronomic management improvements, as well as the interactions between them. The important improvements are: hybrids more tolerant to high plant densities, earlier planting dates, adoption of reduced tillage and corn-soybean rotations, shift from a single large N fertilizer application in the fall to one or more applications during the growing season, replacement of surface irrigation systems with more efficient center pivots, and better control of weeds, insect pests, and diseases.

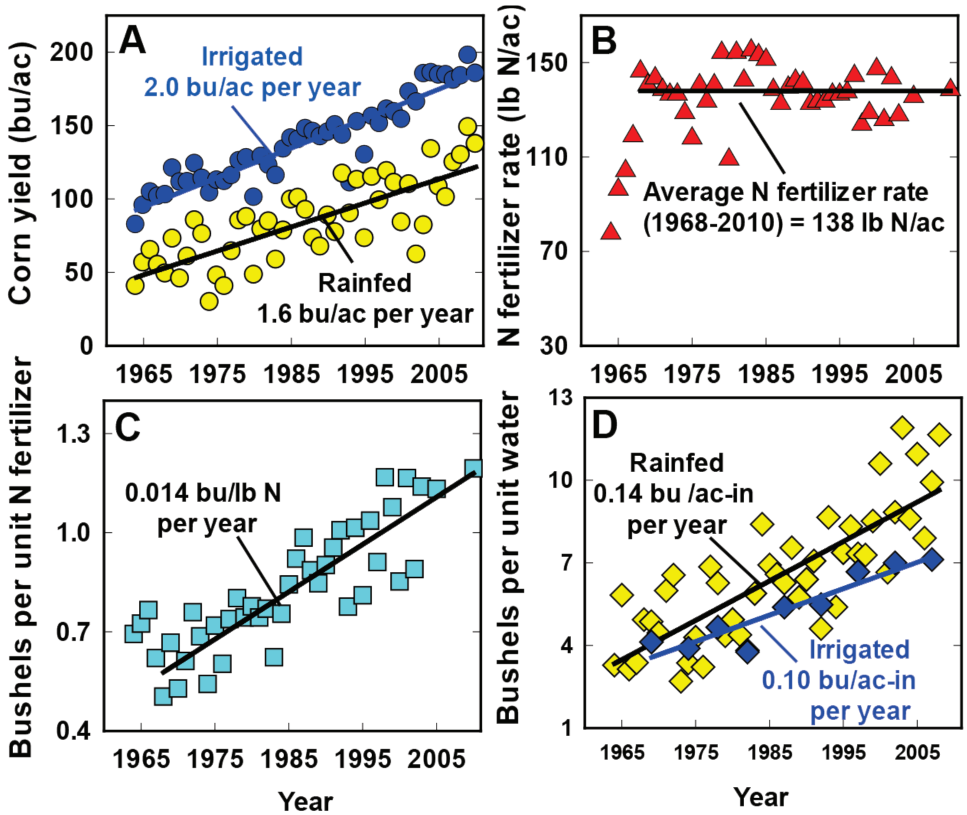

Figure B-2. Trends in corn grain yield (A), N fertilizer rate (B), grain yield produced per unit of N fertilizer (NUE_F) (C), and per unit of in-season water (WUE) (D) for the period from *1965-2010*. Separate trends are shown for rainfed (yellow) and irrigated crops (blue) in (A) and (D). In-season (May-Aug.) water includes rainfall and irrigation. Rainfall data (D) were retrieved from five representative locations in Nebraska. Yield, N fertilizer, and irrigation water data were retrieved from USDA-NASS.

Nitrogen fertilizer use and use efficiency for irrigated corn

Data from Natural Resources Districts nitrogen management areas

Many Nebraska NRDs have implemented Nitrogen Management Areas during the past few decades. Producers with fields located in Nitrogen Management Areas report field-specific information on corn yield, N fertilizer rate, and irrigation water applied every year. The number of fields reporting data and type of data varies among NRDs. In this section, we use data from six regions of Nebraska with NRD-collected data from 2006 to 2011 on yield, N fertilizer, and irrigation (*Figure B-3*). These six regions cover a range in climate, soils, and management practices for the major corn producing regions in Nebraska. In addition to yield, N fertilizer rate, and irrigation, the NRD data also include residual soil N (in the upper 3 ft.), irrigation water N amount, and recommended N fertilizer application rates based on the UNL N algorithm (explained in later sections of this manual). This information is presented as averages in *Tables B-1*, *B-2,* and *B-3*.

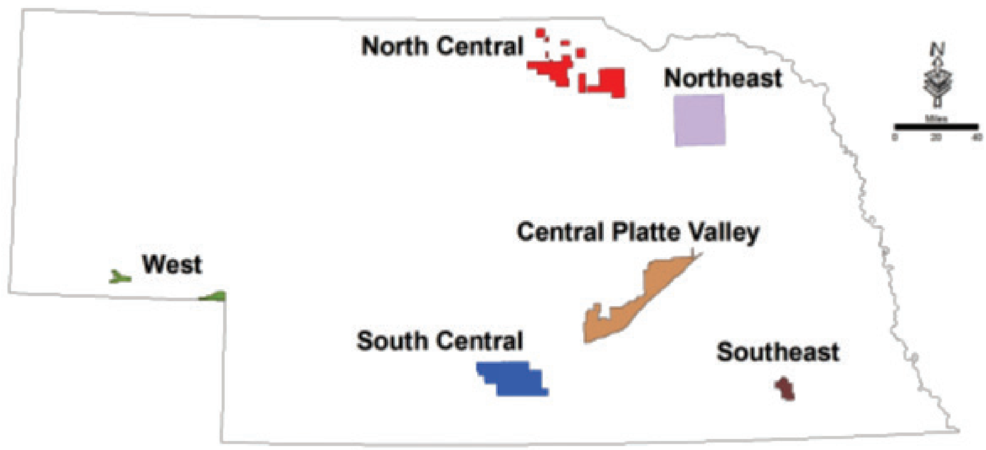

Figure B-3. Map of Nebraska indicating the six regions in Nebraska with available yield, N fertilizer rates, and irrigation data collected from NRD Nitrogen Management Areas and used in this section.

The average number of reporting fields in each year, as well as some key characteristics such as average irrigation, annual precipitation, and soil texture, are shown for each region in *Table B-1*. We used this information to calculate fertilizer N use and its efficiency for each region. Fertilizer NUE calculations were performed for corn fields either under continuous-corn or under corn-soybean rotation but did not receive manure application. Though it can be locally important, the average N applied from manure in Nebraska is very small (7 lb N/ac).

Table B-1. Average number of annual reporting fields, annual precipitation, proportion of pivot- and surface-irrigated fields, topography, and soil texture of dominant soils in the six data-reporting regions in Nebraska shown in *Figure B-3*.

Region of Nebraska	Reporting Fields	Precipitation (inches)	Irrigation System	Topography	Dominant Soil Textures
South Central	360	23	Pivot (67%), Surface (33%)	Flat to gently rolling plains	Silt loam
Central Platte Valley	3718	22	Pivot (50%), Surface (50%)	Flat, wide alluvial valley	Highly variable (Silt loam, loam, sandy loam)
Southeast	36	25	Pivot (50%), Surface (50%)	Flat to gently rolling plains	Loam, silty clay loam
Northeast	332	27	Pivot (≈100%)	Level to rolling plains or low hills	Highly variable (from silty clay loam to loamy sand)
North Central	578	21	Pivot (≈100%)	Tablelands with dissect slopes	Loam to loamy sand
West	84	9	Pivot (≈100%)	Alluvial valley	Sandy loam

On-farm corn yields, N inputs, and use efficiencies

Average (2006-2011) irrigated corn yields in Nebraska were well above the average U.S. corn yield of 150 bu/ac during the same time period, ranging from 165 bu/ac in the West Region to 207 bu/ac in the South Central Nebraska Region (*Table B-2*). Lower irrigated yields in the West Region were expected due to a shorter growing season. Across regions, average corn yield was 35% (Southeast) to 185% (west) greater in irrigated versus rainfed conditions and much less variable among years. Irrigation averaged 11 inches per year, ranging from 8 inches in the Southeast Region to 18 inches in the West Region. These differences were due to the east-west gradient in precipitation and evapotranspiration, though soil texture also explained part of the variation in irrigation totals among regions (for example, sandy soils in North Central Nebraska). In addition to geographic location, the high proportion of surface-irrigated fields in the Central Platte Valley increased the average irrigation inches within this region.

Irrigation Water Use Efficiency (IWUE) is the amount of yield produced per inch of irrigation water applied. It is calculated by subtracting the dryland grain yield from the irrigated grain yield and dividing by the inches of irrigation water applied.

Irrigation water use efficiency (IWUE) indicates how many extra bushels of grain were produced per unit of irrigation compared to the yield under rainfed conditions. On average, irrigated producers obtained an extra 7 bu/ac for every inch of water applied. However, the overall IWUE varied from nearly 10 bu/ac-in in the South Central Region to less than 6 bu/ac-in in the Central Platte Valley (*Table B-2*).

Table B-2. Average (2006-2011) irrigated and dryland corn yield, coefficients of variation (CVs[1]), total irrigation, and irrigation water use efficiency[2] in each of the six data-reporting regions in Nebraska.

Region of Nebraska	Irrigated Corn		Rainfed Corn		Total Irrigation	Irrigation-Water Use Efficiency
	Yield (bu/ac)	CV (%)	Yield (bu/ac)	CV (%)	(inches)	(bu/ac-in)
South Central	207	6	123	18	9.0	9.6
Central Platte Valley	180	7	116	15	11.4	5.5
Southeast	185	4	136	16	7.6	7.7
Northeast	197	3	132	16	8.7	6.7
North Central	197	4	96	27	13.1	6.3
West	165	6	58	30	18.0	6.1
Average	189	5	110	20	11.6	7. 1

[1]The CV is a measure of the year-to-year variation in yields; the greater the CV, the greater the yield variation among years.
[2]Irrigation water use efficiency was estimated as the difference between irrigated and dryland yields, divided by the total irrigation, in each region and in each year.

Coefficient of Variation is a measure of the relative year-to-year variation in yields; the greater the CV, the greater the yield variation among years.

Average (2006-2011) total N supply and its components (fertilizer, residual soil N, and irrigation water N), and nitrogen-use efficiency are shown in *Table B-3*. Total N supply through fertilizer, residual soil N, and groundwater N added via irrigation ranged from 243 to 317 lb N/ac across regions. On average, N fertilizer, residual soil N, and groundwater N accounted for 65, 20, and 15% of the total N supply (*Table B-3*). The greatest N supplied to corn was observed in the North Central Region where dominant soils are sandy and spring weather is typically cooler than in the rest of Nebraska.

Average fertilizer N rates for irrigated corn in Nebraska (172 lb N/ac) was 27% greater than the national average N fertilizer rate (135 lb N/ac), which is mostly based on rainfed corn production. However, because yields in Nebraska were 25% greater than the national average, fertilizer NUE_F in irrigated corn in Nebraska was equal to the national average NUE for corn (1.10 bu/lb N). ***In summary, irrigated producers in Nebraska are achieving corn yields much greater than the national average without sacrificing N fertilizer use efficiency.***

Total Nitrogen Use Efficiency
NUE_T is the grain or forage yield per unit of total nitrogen available to the crop including soil residual N, groundwater N added via irrigation, and fertilizer N.

Average N application rates of 172 lb N/ac (*Table B-3*) are greater than the 138 lb N/ac average N rate in Nebraska shown in *Figure B-2* for the 1968-2010 time period. This is because the long-term average includes rainfed corn that received much lower N rates but also achieved much lower yields. When other non-fertilizer N sources are accounted for in the calculation of NUE (irrigation water N and soil residual N), the **total nitrogen-use efficiency** (NUE_T) for irrigated corn averaged 0.72 bu/lb N. Greatest N use efficiencies were calculated for the South Central and Southeast Regions (0.85 and 0.76 bu/lb N) while the least NUE_T was observed in the North Central and West Regions (0.62 and 0.67 bu/lb N). Interestingly, the two least NUE_T corresponded to regions where: 1) soil residual N plus groundwater irrigation N was greatest; and 2) the difference between actual N application rates compared to the recommended N application rates were greatest. In the other four regions, actual average N fertilizer application rates were similar, or even below the recommended N rate. However, use of average values masks the overall variability among fields, with many of them receiving N rates much less or greater than needed, resulting in large field-to-field variability in NUE_F and NUE_T.

Table B-3. Average N fertilizer, residual soil N in the upper 3 feet, groundwater irrigation water N, and total N supply (sum of fertilizer, residual soil and groundwater irrigation N) in irrigated corn fields in each of the six data-reporting regions in Nebraska for the 2006-2011 time period.

Region of Nebraska	Fertilizer N Applied (lb N/ac)	Soil Residual N (lb N/ac)	Groundwater N Added via Irrigation (lb N/ac)	Total N Supply (lb N/ac)	Fertilizer Nitrogen Use Efficiency NUE_F (bu/lb N)	Total Nitrogen Use Efficiency NUE_T (bu/lb N)	Recommended Fertilizer N Application (lb N/ac)
South Central	177	43	24	244	1.17	0.85	201
Central Platte Valley	160	49	45	254	1.13	0.71	150
Southeast	184	38	21	243	1.01	0.76	177
Northeast	181	67	24	272	1.09	0.72	190
North Central	182	58[1]	77	317	1.08	0.62	137
West	149	62	37	248	1.11	0.67	129
Average	172	52	38	263	1.10	0.72	164

[1]Residual soil N in the North Central Region was reported for the upper 2 ft. Nitrogen use efficiency (bu/lb N) is based on yields reported in *Table B-2* and N fertilizer applied (N fertilizer use efficiency, NUE_F) and total N supply (total N use efficiency, NUE_T). Recommended N fertilizer application is based on the UNL algorithm and accounts for all field-specific sources of N (residual soil N, irrigation water N, N credit from previous crop) and yield goal. **Manured fields were not included in this analysis**. The data were averaged for both corn following corn and corn following soybean (see next section for an assessment of rotation impact on yield, N fertilizer use, and N use efficiency).

Field-to-field variation in applied inputs and use efficiencies

Averages may be deceiving since most field managers are interested in specific fields and not NRD wide averages. Box plots are one way to display the range of values, for a given variable, in a single graph. To illustrate the variability in input use efficiency among fields, *Figure B-4* shows box plots of field NUE_F and irrigation amounts in 2009 for the six regions in Nebraska. Horizontal lines inside each box represent the median value. The box represents the range of NUE_F and irrigation amounts in 50% of the fields whereas the top and bottom box bars indicate the range in 80% of the fields, and the upper and lower dots indicate the range in 90% of the fields. The box plots in *Figure B-4* show that variability in NUE_F and irrigation among individual fields is several times larger than observed for the same two variables among regions. Even though the regions were relatively small and soils were similar within most of the regions (except for the Central Platte Valley and Northeast Regions), NUE_F and irrigation amounts varied widely within each region, ranging from 0.7 to 2.0 bu/lb N for NUE_F and 5 to 30 inches of applied irrigation water. Based on the results in *Figure B-4*, field managers have a great opportunity to improve the N and irrigation water use efficiency in Nebraska.

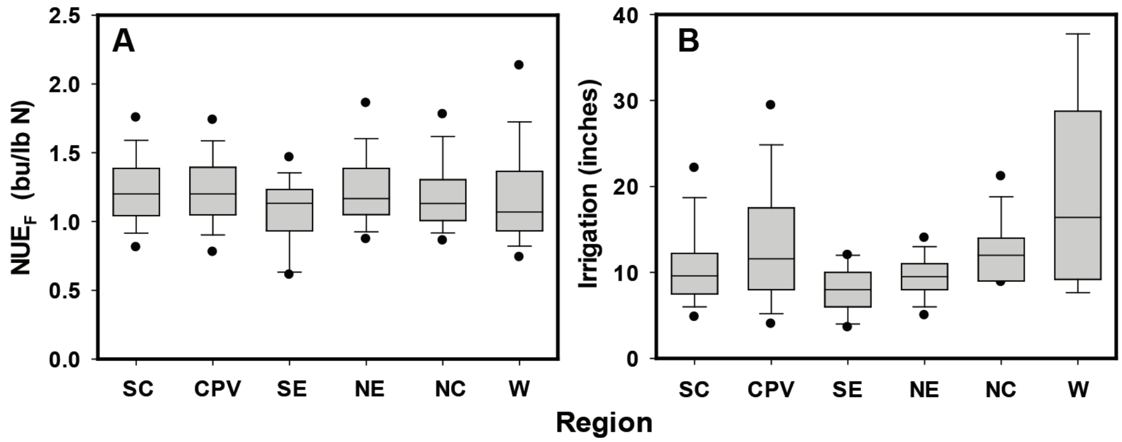

Figure B-4. Box plots for field N use efficiency (NUE$_F$) and total irrigation showing the variation across irrigated corn fields in the six regions in Nebraska for the 2009 crop season (SC: South Central; CPV: Central Platte Valley; SE: Southeast; NE: Northeast; NC: North Central; W: West).

One factor that influences NUE$_F$ is crop rotation. *Figure B-5* shows average irrigated yield, N fertilizer rate, and NUE$_F$ in irrigated corn in fields in the South Central region under corn-soybean rotation and continuous corn. Average irrigated corn yield in corn-soybean rotation was 6 bu/ac greater than continuous-corn yield, while the N fertilizer rate was 23 lb N/ac less. This resulted in an increase in NUE$_F$ when using a corn-soybean rotation. The rotation effect on corn yield may be associated with a range of factors including crop establishment issues, greater plant-to-plant variation, and greater N immobilization by corn residue produced in continuous corn fields. These findings should not be extrapolated to other regions of Nebraska where the rotation effect has not been rigorously evaluated.

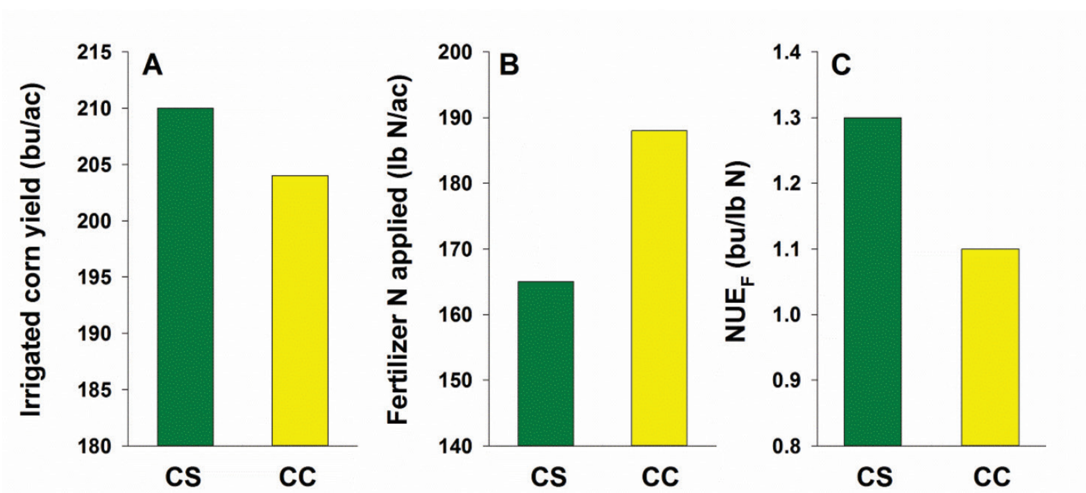

Figure B-5. Average (2006-2011) yield (A), fertilizer N (B), and fertilizer nitrogen use efficiency NUE$_F$ (C) in irrigated corn grown in corn-soybean rotations (CS) versus continuous corn (CC) in the South Central region.

The type of irrigation system (pivot or furrow) greatly influences the ability to control the water applied with each irrigation event and IWUE. *Figure B-6* shows average irrigated corn yields (A), irrigation water applied (B), and IWUE (C) in the South Central Region for furrow- and pivot-irrigated fields. Average yields were identical in fields irrigated with either type of irrigation system; however, irrigation application depth was just over half for pivot- vs surface-irrigated fields. Given that grain yields were the same, IWUE was about 4 bu/ac-in greater in pivot irrigated fields than for furrow-irrigated fields.

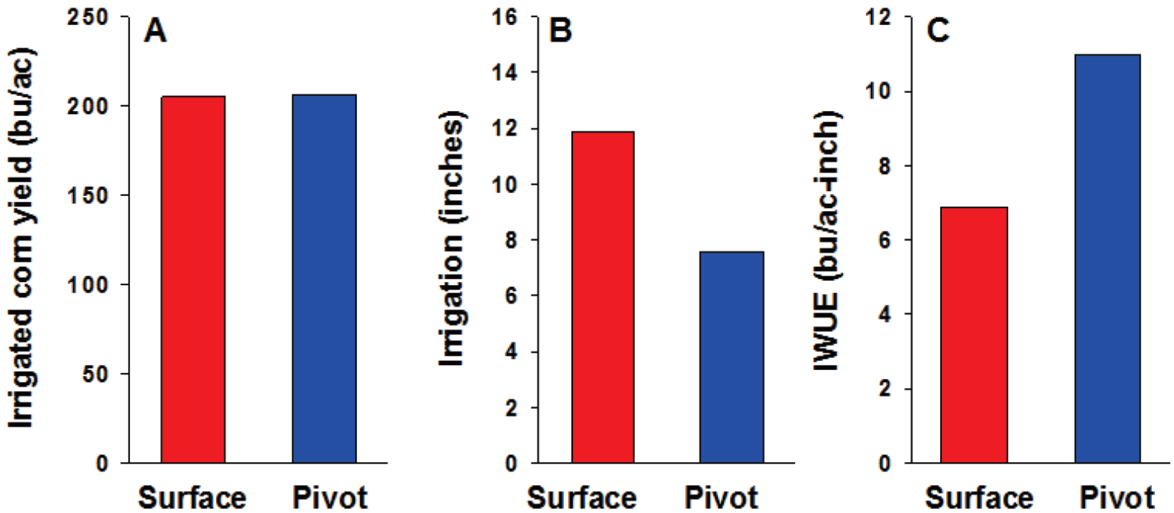

Figure B-6. Average (2006-2011) irrigated yield (A), irrigation inches applied (B), and irrigation water use efficiency (IWUE) (C) in surface- and pivot-irrigated corn fields in the South Central region.

Conclusions

Irrigated producers in Nebraska are achieving corn yields much greater and with much lower year-to-year variability than the national U.S. corn yield average, without sacrificing efficiency in the use of water and N. There is a wide range of fertilizer-N and irrigation water use efficiency across fields within the same year and region of Nebraska, highlighting the potential for further improvement in efficiencies through increased adoption of BMPs related to N and irrigation water management. Improvement is possible especially in fields that exhibit lower use efficiencies or greater N or irrigation applications in relation to the average for the respective region.

For More Information

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