1985

Irregation in Brookings County: An Economic Study of Irrigated Corn

Douglas Taylor

JANUARY 1985

TB 81

Irrigation in Brookings County:

An economic study of irrigated corn

Agricultural Experiment Station • South Dakota State University • Brookings, South Dakota 57007

Irrigation in Brookings County :

AN ECONOMIC STUDY OF IRRIGATED CORN

by

Donald C. Taylor

Professor of Economics
South Dakota State University

CONTENTS

ACKNOWLEDGEMENTS

I wish to express special appreciation to several people who made critical inputs into the research reported in this bulletin:

- Robert Kohl, SDSU soil scientist, and Darrell DeBoer, SDSU agricultural engineer, for especially helpful insights at the time when the design for the research was developed;

- Leroy Cluever, SDSU Extension agricultural engineer, for collecting and providing data on the field performance of the center pivot systems studied;

- William Lytle, SDSU climatologist, for providing historical data on Brookings County precipitation, and Gary Lemme and Douglas Malo, SDSU soil scientists, for providing data and counsel on the handling of data on the soil variables in the regression analysis;

- David Gullickson, Farmers' Irrigation and Implement, Brookings, for providing very helpful background information on reduced pressure irrigation in Brookings County;

- Paul Kiendl, SDSU graduate assistant, for collecting information from the respondents in the field survey;

- the 37 irrigator respondents in Brookings County who provided information on their experiences with center pivot irrigation in 1982;

- Clarence Mends, SDSU research assistant, for estimating the study's many production functions on the SDSU mainframe computer;

- Wayne Ellingson, Han Kim, and Robert Lacher for technical insights regarding procedures in the production function analysis; and

- Herbert Allen, Robert Kohl, and Ardelle Lundeen for their helpful review comments on an earlier draft manuscript.

While the conduct of the research depended on contributions from these colleagues and friends, I accept responsibility for any errors of fact, judgment, and interpretation that may be in the bulletin.

Donald C. Taylor
September 7, 1984

SUMMARY AND CONCLUSIONS

An above-average rate of growth in irrigated corn production took place in Brookings County during the past decade. Corn is by far the largest component in the county's mix of irrigated crops. The vast majority of Brookings County's irrigation units are electrically powered center pivot systems.

Most of the center pivots purchased in Brookings County during the 1970s involved traditional high pressure water distribution. With the sharp energy price hikes during the 1970s and the development of new energy-saving reduced pressure irrigation technology, Brookings County irrigators began in 1980 to purchase reduced pressure center pivot machines. With reduced pressure water distribution, however, yields may be adversely affected because of possible non-uniform water infiltration and/or more water runoff.

The research reported in this paper is based on the experience of 37 irrigators in Brookings County who raised corn grain in 1982 under 57 center pivots energized by electricity. The impacts of reduced pressure water distribution on corn yields receive special emphasis.

The 1982 corn grain yields reported by the irrigator respondents ranged from 80 to 165 bu/A and averaged 123 bu/A. Average fertilizer applications per acre were 143 lb elemental nitrogen (N), 48 lb phosphorus (P_2O_5), and 36 lb potassium (K_2O). The average seeding rate was

26.4 MVK/A. On 1/2 of the quarter-sections studied, reduced tillage practices (involving only discs and/or chisel plows rather than moldboard plows) were followed.

The water distribution pressures for the 57 center pivots studied averaged 53 pounds per square inch (psi). About 1/3 of the center pivots involved "low" pressure water distribution ranging from 22 to 44 psi, 1/3 involved "medium" pressures of 45 to 65 psi, and 1/3 "high" pressures of 66 to 86 psi.

Seasonal rainfall -- defined to cover June 10th to September 15th -- on the quarter-sections studied averaged 11.6 inches. Precipitation during 1982 was much above-average, particularly during the critical corn pollination period when the 1982 level was nearly double the average for 1951 to 1980.

Irrigation applications on the various quarter-sections studied ranged from 0.6 to 9.0 inches and averaged 3.85 inches. This rate of water application is only about 40% of the average level during 1970 to 1983.

Soil moisture measurements on the quarter-sections studied at the time of corn pollination ranged from 10.0 to 31.3% and averaged 20.0%.

The main analytic focus in this study was on determining -- via regression estimations -- input factors associated with higher corn grain yields. Selected findings from the analysis follow.

Irrigation water distributed under higher pressures was not associated with higher yields on the irrigator respondent farms in 1982.

The unusually low irrigation water applications in the year of the study could have precluded possible negative impacts of reduced pressures on yields from manifesting themselves. On the other hand, the "low" pressure center pivots studied are positioned on flat quarter-sections with relatively light soils. Only if reduced pressure irrigation is used on sloping fields and/or with heavy soils would a yield reduction from uneven water infiltration or added water runoff be expected.

It appears that soil moisture levels at the time of corn pollination on the irrigator respondent farms in 1982 may have been somewhat excessive.

The statistical results from the study show some evidence that higher moisture levels during the pollination period deterred from the achievement of higher yields. One extenuating circumstance was near twice normal precipitation at the time of pollination.

Larger rainfall and irrigation applications throughout the entire season and during the vegetative and maturation periods for corn tended to be directly related to higher corn yields.

The coefficients on these variables were always positive. About 1/3 of the coefficients differed significantly from zero. These results indicate some tendency for rainfall and irrigation to positively influence yield, but less than would normally be expected. If precipitation levels had been more nearly normal, it is quite likely that the relationships between the moisture variables and yield would have been more stable.

The irrigation respondents used relatively high, but economically advantageous, levels of nitrogen on their corn grain in 1982.

The average elemental nitrogen (N) application during 1982 was 143 lb/A. The production function results show that, for each additional pound of N applied at the margin, approximately 0.15 to 0.25 bu/A additional corn grain was produced. With 1982 prices, this involved an added return in corn grain of $0.30 - 0.50 for an added expenditure from nitrogen of about $0.25.

The irrigator respondents as a group in 1982 may have applied uneconomically large amounts of phosphorus and potassium to their corn grain.

For the 11 quarter-sections for which soil tests had been taken, eight had "very high" or "high" levels of soil phosphorus (P) and eight had "very high" or "high" levels of potassium (K). On 90% of the quarter-sections studied, phosphorus (P_2O_5) applications were 20 lb/A or more. The average P_2O_5 applications was 48 lb/A. On nearly 56% of the quarter-sections studied, the potassium (K_2O) applications were 20 lb/A or more. The average K_2O application was 36 lb/A.

The results of the production function analysis showed no evidence of statistically significant higher yields with higher levels of either P_2O_5 or K_2O. For K_2O, the relationship was neutral. In some instances for P_2O_5, the relationship was inverse. Why high levels of P_2O_5 might adversely affect yields is not understood.

Earlier planted corn on the irrigators' fields in 1982 was higher yielding.

The planting dates in 1982 ranged from May 3 to May 30. The statistical results show that, for each day earlier in planting, the yield was approximately 0.8 to 1.0 bu/A higher.

The yields for irrigators using reduced tillage practices were no less than for those using conventional tillage practices.

The statistical results from the analysis show no evidence of reduced yields on quarter-sections in which land was prepared with reduced tillage methods.

A major limitation of the study arose from the much above-average precipitation experienced during the crop season under investigation. If the study could be repeated in another season which would have normal precipitation, the chances of obtaining more realistic and statistically stable relationships between the moisture-related variables and yields should improve. In turn, this would enable a clearer determination of the economics of irrigated corn production than was possible in this study.

A second research-related suggestion is to examine the impact of reduced pressure water distribution on potentially problematic soils. As reduced pressure units are introduced on fields with slopes and/or heavier soils, yield reductions can be expected. Multidisciplinary research to determine the extent of yield reductions associated with increasingly uneven topography and increasingly heavy soils could provide insights regarding an appropriate technical and economic frontier for the introduction of low pressure irrigation units.

Third, further research focused on why high levels of P_2O_5 might adversely influence yield, why plant populations were unrelated to yield in this study, and the development of soil productivity ratings for irrigated soils would also be beneficial.

AN ECONOMIC STUDY OF IRRIGATED CORN GRAIN PRODUCTION IN BROOKINGS COUNTY

by Donald C. Taylor

TOTAL CORN GRAIN PRODUCTION: AN OVERVIEW

South Dakota is at the extreme western edge of the U.S. Corn Belt. During recent years, the state has ranked either ninth or tenth nationally in total corn grain production.[1] South Dakota accounts for only 2 to 3% of the nation's total corn grain production, however (USDA-SRS, annual).

---

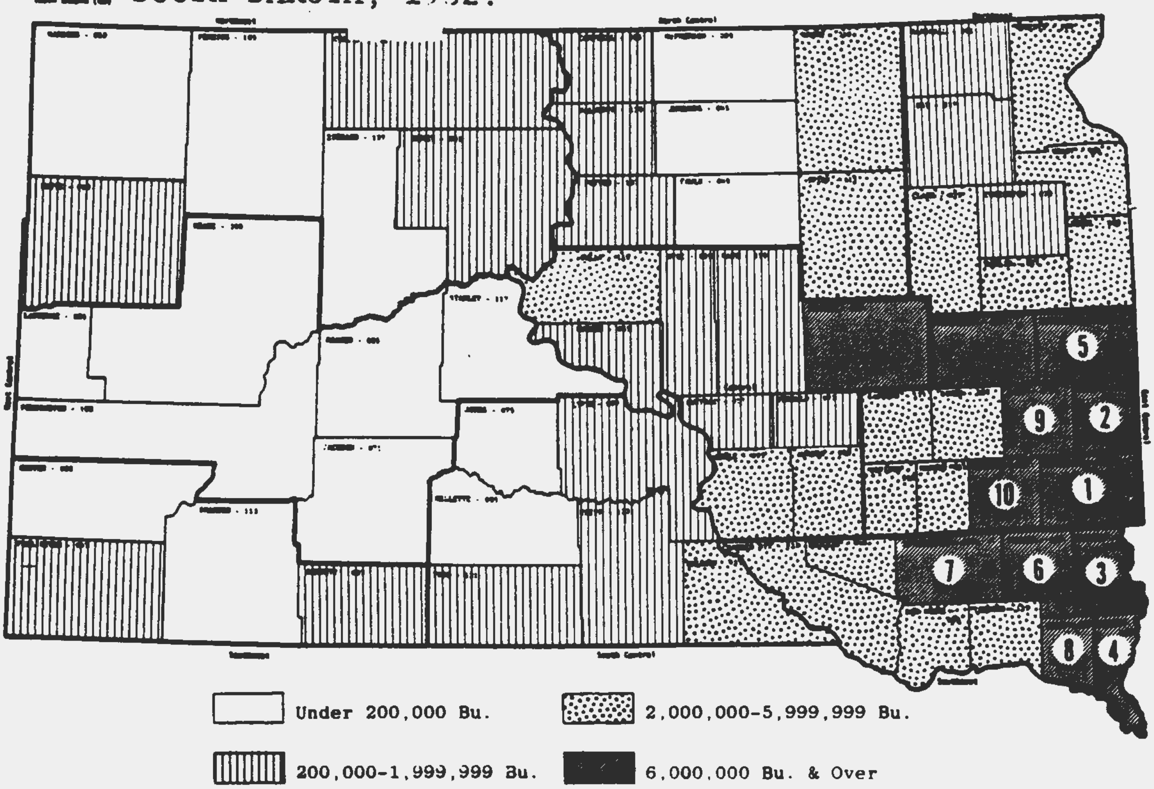
[1]Corn is, by a very large margin, the top U.S. crop. In the mid-1970s, corn was sown on 20% of U.S. cropland. The annual harvest of about 150 million tonnes was about twice the tonnage of all other grain crops (wheat, rice, oats, barley, sorghum, rye) together (Smil, _et al_., 1983, 3).

Combined Dryland and Irrigated Production

About 95% of South Dakota's total corn grain -- both dryland and irrigated -- is produced east of the Missouri River. The area of greatest concentration in the east is a two to three tier band of counties extending along the southern half of the eastern border of the state (Figure 1). The 10 top producing counties in the state account for just under half of the state's total corn grain production (SDCLRS, annual).

During recent years, Brookings County has ranked either fifth or sixth among the state's counties in corn grain production. In the 1960s and 1970s, Brookings County accounted for 3 to 4% of the state's total production. In the early 1980s, Brookings County's share of the state total appears to have increased to about 5% (SDCLRS, annual).

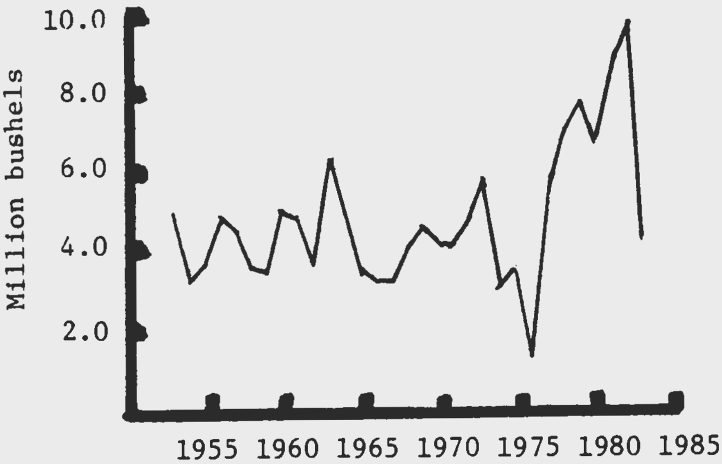
FIGURE 1 CORN HARVESTED FOR GRAIN, TOTAL PRODUCTION, BY COUNTY IN SOUTH DAKOTA, 1982.



SOURCE: SDCLRS (1983,9)
NOTE: THE RANKING OF THE TOP TEN COUNTIES IS SHOWN.

Data showing total corn grain production in Brookings County during the past 30 years are presented in Figure 2. Between 1953 and 1975, the levels fluctuated most commonly between 3.2 and 5.0 million bushels per year -- with no clear upward or downward trend. Since then, production has been highly unstable. In 1976 -- a year of severe drought -- production dropped to 1.2 million bushels. In 1982 -- the record-breaking year nationally -- Brookings County's production rose to over 9.6 million bushels. In 1983, the production dropped to 4.1 million bushels.

FIGURE 2. CORN HARVESTED FOR GRAIN, TOTAL PRODUCTION, BROOKINGS COUNTY, 1953 - 1983

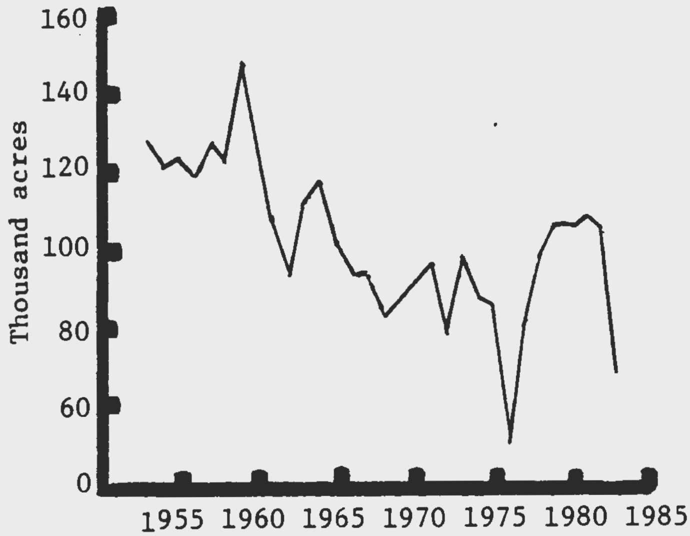


Source: SDCLRS (annual)

The extent of year-to-year variability between 1953 and 1982 in corn grain production in Brookings County was measured by the coefficient of variation. The results of these computations indicate that in 32 of 100 years the year-to-year variation in total corn grain production in the county can be expected to vary by more than 36%. Year-to-year variations in the state are slightly less (31%).

Underlying changes in total production are changes in the acres harvested and in yields. Over the past 30 years, there has been a clear downward trend in the acres of corn grain harvested in Brookings County (Figure 3). Acreages in excess of 120 thousand were common early in the period, whereas in recent years 80 to 105 thousand have been common. This general downward trend in corn acreage in Brookings County is consistent with that for the state as a whole (SDCLRS, annual), and nationally as well (Sundquist, et al., 1982, II-1).

FIGURE 3. CORN ACREAGE HARVESTED FOR GRAIN, BROOKINGS COUNTY, 1953 - 1983



Source: SDCLRS (annual)

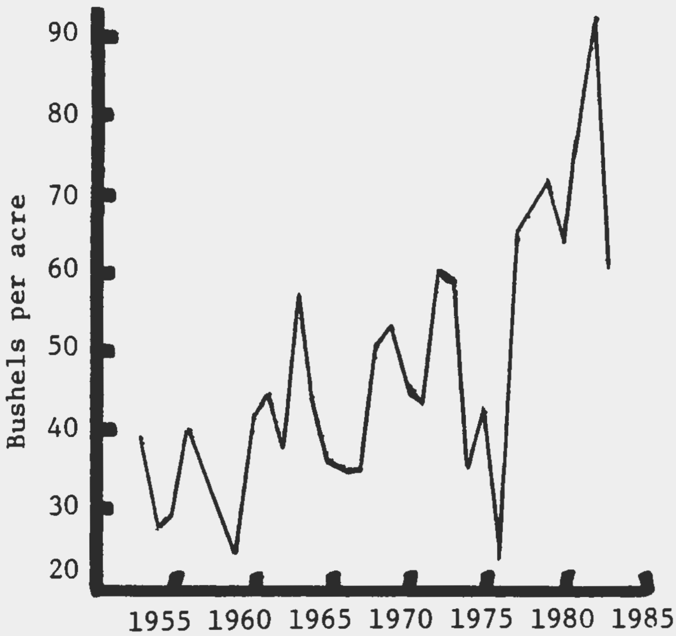
The trend in corn grain yields in Brookings County over the past 30 years has definitely been increasing (Figure 4). Yields of 25 to 40 bu/A were common early in the period. Yields ranging from 60 to 80 bu/A are common in recent years. On the average over the past 30 years, corn grain yields have increased in Brookings County by 1.3 bu/yr.[1]

In 20 of the past 30 years, corn grain yields in Brookings County have

---

[1]Yield was regressed against time, with the coefficient on the time variable being 1.35.

FIGURE 4. CORN GRAIN YIELD PER HARVESTED ACRE, BROOKINGS COUNTY, 1953 - 1983



Source: SDCLRS (annual)

exceeded the average for the state. Over the 30 year period, the county's yields have commonly been 6 to 8% higher than the average for the state. Year-to-year variations in yields are substantial -- 32% of the time exceeding 35% -- but they have not tended to be greater in Brookings County than for the state as a whole.

Irrigated Corn Grain

Between 1969 and 1982, the total irrigated area in South Dakota increased from 148,000 to 376,457 acres. In Brookings County, the increase was from 984 to 16,074 acres. This implies an over 16-fold increase in irrigated area between 1969 and 1982 in Brookings County. Only in Union and Sully counties was the relative rate of increase faster (USDC, Census Years).

In the late 1950s, only three farmers in Brookings County produced irrigated corn for grain (Table 1). The pace of growth in irrigated corn production in the 1960s was very modest. Between 1969 and 1978, however, the number of irrigated corn producers in Brookings County increased from seven to 70. Their acreage of corn grain under irrigation increased from 678 to 7,612. This over 11-fold increase far exceeded the 4.4-fold increase during the same period in irrigated corn production in the state as a whole (Taylor, 1984a).

About 3/4 of the irrigated area in Brookings County is devoted to corn production (Taylor and Shane, 1983, 16). This contrasts with about 1/2 of the

TABLE 1. IRRIGATED CORN FOR GRAIN, BROOKINGS COUNTY, 1959-1978 (Census Years)

Years	Number of Farms	Acres
1959	3	62
1964	5	398
1969	7	678
1974	15	918
1978	70	7,612[a]

Source: USDC (Census Years)

[a]This is 7.7% of the total corn grain acreage harvested in Brookings County in 1978. In 1978, 12.8% of the U.S.'s total corn acreage was under irrigation. For the Ogalla region, which extends from the southernmost part of South Dakota to Texas, the corresponding figure is 72.6% (Sloggett, 1983, 6).

state's overall irrigated area being under corn production (Taylor, 1983, 66).[1]

About 70% of the irrigation systems in Brookings County involve center pivot water distribution. About 90% of the irrigation units in the county are energized by electricity.[2] Most of the center pivots purchased in Brookings County during the 1970s involved traditional high pressure (60 to 65 psi or more) water distribution. With the sharp energy price hikes in 1973-74 and 1979-80 and the development of energy--saving reduced pressure irrigation technology, Brookings County irrigators began in 1980 to purchase reduced pressure center pivot machines.

SURVEY OF IRRIGATED CORN GRAIN PRODUCERS

In recognition of the rapid growth of irrigation in Brookings County, an above-average importance of corn in the county's mix of irrigated crops, the domination of electrically powered center pivot systems in Brookings County irrigation, and the very recent introduction of reduced pressure irrigation technology in the county, the research reported in this report was undertaken. The primary purposes of the research were to determine (1) the farm-level performance of irrigated corn grain production under reduced pressure water distribution and (2) the economics of investing in reduced pressure center pivot systems. The study was limited to Brookings County center pivots energized by electricity and under which corn grain was produced.

In this report, emphasis is given to the research findings involving corn production economics. In a companion report (Taylor, 1984b), primary emphasis is given to the effects of reduced pressure irrigation on energy economics.

Nature of the Field Survey

Irrigation equipment dealers indicated in early 1982 the following numbers of irrigators in Brookings County producing corn grain under electrically-powered center pivot systems: 20 "low" pressure, 17 "medium" pressure, and 61 "high" pressure. Because of the relatively small number of "low" pressure irrigators and a primary interest in the research in reduced pressure irrigation, it was decided to obtain field information from all 20 "low" pressure irrigators. Two thirds of the irrigators having "medium" pressure systems and 1/5 of those having only "high" pressure systems were randomly selected for study as well.

Several of the sampled farmers operated more than one center pivot. Information was obtained on more than one center pivot per irrigator if (1) irrigation water was distributed under substantially different operating pressures through an irrigator's different center pivots or (2) the production environment (involving soil types, field slopes, tillage and

---

[1]An underlying factor for corn being a common irrigated crop is its efficient use of moisture in the photosynthetic process. As a "C-4" plant, corn transpires less than 600 moles of water per mole of CO_2 fixed. Other major food and feed crops -- such as wheat, barley, oats, rye, rice, and potatoes -- transpire between 900 and 1,150 moles of water per mole of CO_2 fixed (Good and Bell, 1980).

[2]These are the percentages reported by the SD Dept of Water and Natural Resources (DWNR, 1979) for irrigators in 1979 in the Sioux River Basin. Brookings County rests within the Sioux River drainage area. While the types of irrigation systems and energy sources undoubtedly vary from county to county within the basin, data on such variations are not available. The more aggregate basin-level data are, therefore, used as a rough reflection of the situation in Brookings County.

fertilization practices) differed for corn produced under an irrigator's different center pivots having similar operating pressures.

Resulting from these procedures was the selection for study of 37 irrigators[1] and 57 center pivots. About 1/3 of the center pivots involved "low" pressure units with water distribution pressures ranging from 22 to 44 psi, 1/3 involved "medium" pressures ranging from 45 to 65 psi, and 1/3 "high" pressures ranging from 66 to 86 psi.

The field survey involved the study of the 1982 crop season. Four approaches were used for obtaining information.

First, two rounds of personal interviews were conducted with the respondents by Paul Kiendl, a graduate assistant in the SDSU Economics Department. The first round of interviews -- conducted soon after planting -- involved seeking clarifications on the nature of the center pivots being operated by the respondents and obtaining early-season corn tillage, planting, and fertilization information. The second round of interviews -- conducted after season's end -- involved seeking additional production data, information on corn grain yields (enabling a standardization to 15.5% moisture), and selected data on the center pivot systems and several farming operations being studied.

Second, respondents were provided rain gauges and asked to record the dates and amounts of rainfall received during the growing season. They also recorded the date and "percentage timer" reading on their center pivot machines each time that irrigation water was applied. The "percentage timer" information was converted into inches of irrigation water application through the use of appropriate formulas.

Third, tests of irrigation pumping plant efficiencies were performed by the SDSU Agricultural Engineering Department on the center pivot systems of those respondents indicating a desire to have their pumping plants tested. One component of the tests was measurement of center pivot water distribution pressures.[2]

Fourth, soil moisture samples at 12, 24, and 36 inch depths were taken when corn was at the pollination (silking or tasseling) stage at three or four locations in each quarter-section studied. In those quarter-sections in which soil types and/or slopes were definitely not uniform, the soil moisture samples were taken only for the most common soil type and slope situation in the quarter-section. The production and yield information mentioned above was targeted to that part of individual quarter-sections from which the soil moisture samples were taken.

Description of Respondents' Farms

On the average, respondents operated 860 acres of cropland per farm during 1982. Of this total, 610 acres were dryland and 250 were irrigated. The areas irrigated ranged from 43 to 890 acres per farm, with 43% of the farms having less than 150 irrigated acres, 27% between 150 and 300 irrigated acres, and 30% more than 300 irrigated acres.

The farms in the field survey are much above-average in size. The 1978

---

[1]These 37 irrigators represented 44% of Brookings County's total irrigators in 1982 (Satterlee, 1984).

[2]Tests were made on 24 center pivots. For 16 others, the Extension agricultural engineer who made the tests "estimated" the water distribution pressure. On 10 other center pivots, the respondents provided information on water distribution pressures. On seven center pivots, no specific information was available on the actual operating pressures of the systems.

Agricultural Census shows the average irrigated farm in Brookings County to have 460 acres of harvested cropland, 135 of which are irrigated (USDC, 1978, 202).

About 15% of the respondents were full owners of the land they operated in 1982 and another 15% were full tenants. The remaining 70% of the respondents cultivated both owned and rented land. Compared to typical farmers in 1982 in Brookings County, a much larger proportion of the respondents were part owners (70 versus 38% for the county) and a much smaller proportion were full owners (14 versus 46% for the county) [USDC, 1982 (prel.)]. An above-average renting-in of land is undoubtedly one explanation for the above-average size of farm operated by the respondents.

The 37 respondents operated 57 center pivots in 1982. Of the 57 center pivot systems, 37% were leased, 33% were owned by the operators, and 30% were included with land rented-in by the farm operators.

The farms in the field survey were highly diversified. The number of enterprises per farm -- reflecting beef, dairy, hogs, and/or sheep plus the number of different crops raised on each farm -- ranges from two to 12 and averages 5.8. One of three farms had seven or more different enterprises, and five of six had five or more enterprises. Four or more different crops are raised on over 3/4ths of the farms, and two or more different livestock enterprises are found on 3/5ths of the farms (Appendix Table 1).

All of the respondents -- by virtue of the sample selection process -- cultivated irrigated corn for grain production. The irrigated corn grain acreages ranged from 20 to 890 per farm, and averaged 192 for the 37 farms. About 77% of the respondents' total irrigated area in 1982 was in corn grain production. Thirteen percent was in soybeans and 5% was in alfalfa (Appendix Table 2).

The most common dryland crop raised by the respondents was corn (on 94% of the respondents' farms). Corn covered 35% of the total dryland area cropped, and the average acreage per farm was 226. Soybeans and oats ranked second and third -- accounting for 19 and 15% of the cropped area, respectively. Alfalfa, spring wheat, and sunflowers were next in line with each accounting for 8 to 10% of the dryland cropped area (Appendix Table 2).

Beef cattle were the most common type of livestock enterprise on the respondents' farms. Three of five farms had cow-calf operations, one in two marketed fat cattle, and one in four sold feeder cattle. Hogs were the second most common livestock enterprise, with finishing operations being more common than farrowing operations. About one in three respondents had dairy cows and one in five sheep and lambs (Appendix Table 3).

ECONOMICS OF IRRIGATED CORN GRAIN PRODUCTION

Production Environment

Yields. The 1982 corn grain yields (15.5% moisture) reported by the respondents ranged from 80 to 165 bu/A and averaged 123 bu/A. On one in four of the quarter-sections studied, yields were 110 bu/A or less and on one in eight they exceeded 140 bu/A (Table 2).[1] These yields are slightly less than the average yield of 129 bu/A reported by Everson (1979) for irrigated corn in Brookings County.

Seeding rates. Plant populations at the time of seeding in the quarter-

[1]Respondents were asked to indicate typical dryland yields for corn grain raised on soils similar to those in their irrigated quarter-sections. The dryland-irrigated corn grain yield differentials reported by them averaged about 35 bu/A.

sections studied ranged from 22 to 32 thousand kernels (MVK) per acre and averaged 26.4 MVK/A. The most common seeding rate was 25.0 to 27.5 MVK/A, followed by 27.6 to 30.0 MVK/A (Table 3).

Sundquist, et al. (1982, V-4) report an average yield response to irrigation on fine and medium textured soils in the Corn Belt of 30 to 60 bu/A. Shaw and Arjnand (1981) report yield increases to irrigation on experimental plots in Lamberton, Minnesota, as follows: for high moisture capacity Webster soils 34 bu/A and for low moisture capacity Dickman sandy soils 72 bu/A.

Tillage practices. For 28 of the 57 quarter-sections studied, farmers used conventional land preparation tillage practices. For 23 of the quarter-sections, only discs and/or chisel plows were used. For the other six quarter-sections, both moldboard and chisel plows were used.

Fertilizer application. Nitrogen applications (elemental N) on the quarter-sections studied ranged from 32 to 266 lb/A and averaged 143 lb/A.

TABLE 2. IRRIGATED CORN GRAIN YIELD, REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

Yield category	Frequency of response
(bu/A)	%
Less than 100	7.3
100-110	18.2
111-120	25.4
121-130	25.4
131-140	10.9
More than 140	12.8

TABLE 3. SEEDING RATE, CORN GRAIN UNDER CENTER PIVOTS IN REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

Plant population category	Frequency of response
(MVK/A)	%
Less than 25.0	19.3
25.0 - 27.5	47.4
27.6 - 30.0	31.6
More than 30.0	1.7

On about 18% of the quarter-sections, less than 100 lb/A was applied. At the other extreme, on 23% of the quarter-sections, more than 175 lb/A was applied (Table 4).

These levels of nitrogen are slightly less than the average of 150 lb/A reported by Everson (1979) for irrigated corn in Brookings County. Given the information provided by those respondents who had had soil tests, however, it appears that the levels of nitrogen applied on many of the quarter-sections were probably at or possible slightly greater than the recommended levels (Gerwing, et al., 1984).[1]

---

[1]Soil nitrate-nitrogen levels from the 11 soil tests reported ranged from about 25 to 100 lb/A and averaged about 50 lb/A. Soil organic matter levels ranged from 1.6 to 4.5%.

TABLE 4. NITROGEN APPLICATIONS, CORN GRAIN UNDER CENTER PIVOTS IN REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

Nitrogen (N) application category	Frequency of response
(lb/A)	(%)
Less than 100	17.5
100-125	19.3
126-150	26.3
151-175	14.1
More than 175	22.8

TABLE 5. PHOSPHORUS AND POTASSIUM APPLICATIONS, CORN GRAIN UNDER CENTER PIVOTS IN REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

Level of application category	Frequency of response	
	Phosphorus (P_2O_5)	Potassium (K_2O)
(lb/A)	(%)	(%)
Less than 20	10.5	42.1
20-40	36.9	36.8
41-60	35.1	8.8
61-80	3.5	7.0
81-100	10.5	1.8
More than 100	3.5	3.5

Phosphorus applications (P_2O_5) on the quarter-sections studied ranged from 0 to 105 lb/A and averaged 48 lb/A. On nearly 3/4ths of the quarter-sections, from 20 to 60 lb/A of P_2O_5 was applied (Table 5).

These levels are definitely less than those reported by Everson (1979) for irrigated corn in Brookings County. Even so, it appears that the applications on a majority of the quarter-sections studied may exceed recommended levels (Gerwing, et al., 1984).[1]

Potassium applications (K_2O) on the quarter-sections studied ranged from 0 to 200 lb/A and averaged 36 lb/A. On over 40% of the quarter-sections studied, however, less than 20 lb/A of K_2O was applied (Table 5).

Everson (1979) reported an average K_2O application on irrigated corn grain in Brookings County of 20 lb/A. The respondents on the average in the 1982 survey applied more potassium than that reported in the earlier Everson survey.

---

[1]Soil phosphorus (P) levels ranged from 5 to 100 lb/A and averaged 45 lb/A. Six of the 11 soil tests showed "very high" phosphorus levels, two were "high", two "medium", and one "low".

The actual K_2O levels applied on at least some of the quarter-sections studied appear to exceed the recommended levels (Gerwing, et al., 1984).[1]

Rainfall and irrigation. Seasonal rainfall -- defined to cover June 10th to September 15th -- on the various quarter-sections studied in 1982 ranged from 6.3 to 15.6 inches and averaged 11.6 inches. On about one in four of the quarter-sections, 10 inches or less of precipitation was experienced. On one in seven, precipitation exceeded 14 inches (Table 6).

Corn yields are influenced as much or more by the timing of rainfall as by the overall amount of rainfall. A wide body of literature shows moisture stress during the pollination stage to have greater influence on corn yield than during either the vegetative or maturation stages.[2]

---

[1]Soil potassium (K) levels ranged from 95 to 590 lb/A and averaged 275 lb/A. One of the 11 soil tests showed a "very high" potassium level, seven "high", two "medium", and one "low".

[2]See, for example Robins and Domingo (1953), Howe and Rhoads (1955), Denmead and Shaw (1960), Flinn and Musgrave (1967), Burt and Stauber (1971), Downey (1972), Stewart, et al. (1975), Anderson and Maass (1978), Hexem and Heady (1978), Stone, et al. (1978), and Buller and Roth (1982).

TABLE 6. SEASONAL RAINFALL, QUARTER-SECTIONS IN REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

Precipitation category	Frequency of response
(inches)	(%)
Less than 8.0	5.9
8.0 - 10.0	20.6
10.1 - 12.0	17.6
12.1 - 14.0	41.2
More than 14.0	14.7

The 1982 season was divided into three stages, with the "pollination" stage defined to cover July 10 to August 10, the "vegetative" stage preceding July 10, and the "maturation" stage subsequent to August 10. The average precipitation levels on the quarter-sections studied during these three successive stages were 2.85, 5.54, and 3.17 inches, respectively.

Rainfall in Brookings County was generally above-average during 1982. This was especially true during the critical pollination period when the 1982 precipitation was nearly double the average for the 30-year period 1951 to 1980 (NCC, 1982; Lytle, 1984).

Irrigation water applications on the quarter-sections studied ranged from 0.6 to 9.0 inches and averaged 3.85 inches for the growing season. For one in four of the center pivots, 2.0 inches or less was applied. At the other extreme, for one in four of the center pivots, more than 5 inches was applied (Table 7).

These irrigation applications are definitely less than normal. During 1970 to 1983, for example, the average seasonal irrigation water application reported by irrigators in the Sioux River Basin -- of which Brookings County is a part -- ranged from 5.1 to 14.5 inches. The average for the period was 9.2 inches (DNWR, annual).[1]

The average irrigation applications on the quarter-sections studied during the vegetative, pollination, and maturation periods were 0.72, 1.85, and 1.25 inches, respectively. Taking into account both precipitation and irrigation, the averages for the respective periods were 3.57, 7.39, and 4.42 inches, for a seasonal total of 15.4 inches.

Soils. Brookings County is in the Rolling Till Prairie Major Land Resource Area in the Central Feed Grains and Livestock Region. Most of this area is in farms, and about 70% is cropland. Most of the soils are Borolls which are deep and loamy and silty (USDA, 1982, 75).

---

[1]Seven of eight respondents in the 1982 survey reported less than normal irrigation water applications during 1982.

TABLE 7. SEASONAL IRRIGATION WATER APPLICATIONS TO CORN GRAIN, REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

Irrigation water application category	Frequency of response
(inches)	(%)
Less than 1.0	5.4
1.0 - 2.0	18.9
2.1 - 3.0	8.1
3.1 - 4.0	27.1
4.1 - 5.0	16.2
5.1 - 6.0	8.1
6.1 - 7.0	8.1
More than 7.0	8.1

The three most common soil series on the quarter-sections studied are Fordville loam, Estelline silt loam, and Vienna loam (each "nearly level"). Together, these three soil series represent the dominant soil on 1/2 of the quarter-sections studied. The soils on the other quarter-sections are widely variable, with 20 different soil series involved (Westin, et al., 1959).

"Soil capability classes" show the relative degree of limitation or hazard for permanent use. Of the quarter-

TABLE 8. LAND CAPABILITY CLASSES AND SUBCLASSES, QUARTER-SECTIONS IN REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

Land capability classes and subclasses[a]	Frequency of response	
		(%)
Class 1		21.8
Class 2		
s	40.0	
e	9.1	
w	5.5	54.6
Class 3		
s	10.9	
e	3.6	14.5
Class 4		
s	5.5	
w	3.6	9.1
Total		100.0

[a]The "classes" are defined as follows:

- Class 1 soils have few limitations that restrict their use;
- Class 2 soils have moderate limitations that reduce the choice of plants, or that require moderate conservation practices;
- Class 3 soils have severe limitations that reduce the choice of plants, or that require special conservation practices, or both; and
- Class 4 soils have severe limitations that reduce the choice of plants, or that require very careful management, or both.

The subclasses involve the following types of limitations:

- s - shallow, droughty, or stony;
- e = erosion-prone, unless close-growing plant cover is maintained; and
- w = water in or on the soil interfering with plant growth or cultivation (Malo and Westin, 1978, 113-114).

sections studied, 22% have Class 1 soils, 55% Class 2 soils, 14% Class 3 soils, and 9% Class 4 soils. The "subclass" shows the kind of limitation or hazard. The majority of soils in the 1982 study have a "shallow, droughty, or stony" limitation (Table 8).

Malo and Westin (1978) have determined comparative crop ratings for each "soil phase" (a further breakdown of subclass by slope) in South Dakota. These ratings reflect the relative yield producing capability of particular soil phases under dryland conditions for various crops individually, as well as for the group of crops for which particular soil phases are adapted.

The corn grain yield productivity rating for the predominant soils in each quarter-section studied ranged from 35 to 87 bu/A and averaged 61 bu/A. The most common yield rating is 40 to 50 bu/A, followed by 71 to 80 bu/A and 61 to 70 bu/A (Table 9). How well these relative dryland productivity ratings reflect relative irrigated productivity ratings has not yet been determined by the soil scientists.

Virtually all the predominant soils in the quarter-sections studied have definite loam content. Over 48% are pure loam, 30% silty loam, 11% sandy loam, and 9% silty clay loam. Only 2% involve other types of soil.

The within-field slopes of 84% of the quarter-sections studied are 1% or less. About 9% have 2 to 4% slopes, 5% have 5 to 8% slopes, and only 2% have slopes greater than 8%.

Determinants of Yield

Production function methodology. Production functions to determine the relationship between various inputs used by respondents in production and their resulting corn grain yields were estimated in this study. Since this is the first production function analysis of irrigated crop production undertaken in the SDSU Economics Department,[1] a brief background on production function studies by agricultural economists of input-output relations for irrigation water is first presented.

[1]In Papendick's (1978) thesis research in Agriculture Engineering at SDSU on irrigated corn production in central South Dakota, a simple linear regression of water use against grain yield was estimated.

TABLE 9. CORN PRODUCTIVITY RATING, QUARTER-SECTIONS IN REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

Productivity rating category[a]	Frequency of response
(%)	(%)
Less than 40	1.8
40 - 50	34.6
51 - 60	10.9
61 - 70	21.8
71 - 80	29.1
More than 80	1.8

[a]These ratings are based on Malo and Westin (1978) and personal communication with Malo.

A common "traditional" assumption by natural scientists is that crops have unique water requirements. A crop's "water requirement" is viewed to be that quantity of water -- based on evapotranspiration needs[1] -- which is necessary for "desirable" plant growth (Blaney and Criddle, 1962). Usually this is interpreted to involve amounts of water which do not stress plant growth[2] or which, in other words, enable maximum yields.

This perspective, of course, is antithetic to the fundamental economic concept that the appropriate quantity of an input to use in producing a crop depends not only on biological and physical possibilities but also on the prices of various inputs and the commodity produced.[3] With production function analysis, joint consideration is given to biological, physical, and economic aspects of production.

---

[1]"Evapotranspiration" is the combined loss of water from a given area and during a specified period of time by (a) evaporation from the soil surface and (b) transpiration from plants. It is influenced by exposure to direct sunlight, air temperature, humidity, wind movements, and atmospheric pressure.

[2]Kramer (1963) reports four general functions of water in plants: (1) as a constituent of physiologically active tissue; (2) as a reagent in photosynthesis and hydrolytic processes such as starch digestion; (3) as a solvent in which salts, sugars, and other solutes move from cell to cell and from organ to organ; and (4) to maintain turgidity necessary for cell enlargement and growth. Water deficits impede plant growth as they block the full expression of one or more of these functions.

[3]In this study, price information is used in interpreting the results of the production function analysis. In a research project currently being undertaken in the Economics Department (Taylor and Lundeen, 1983), crop-water production functions are being estimated in which a proxy for the price of water is included directly in the production function.

In their classic treatment of agricultural production functions, Heady and Dillon (1961) indicate that polynomial production functions -- with possible square root, first power, three-halves, quadratic, and interaction terms -- are used most often with input-output data generated via experimental design procedures, and that power functions such as the Cobb Douglas are usually more appropriate for analyzing input-output data generated through farm-level field surveys. Limited degrees of freedom and rather aggregate types of input variables common in field survey studies usually detract from the appropriateness of polynomial functions in analyzing farm level data (Heady and Dillon, 1961; Hexem and Heady, 1978).[1]

Empirical studies by agricultural economists of irrigated corn grain production are consistent with this data source-type of production function distinction.[2] Further, studies involving controlled experimental data are much more common than those with field survey data. Examples of the former are:

---

[1]Inherent mathematical properties of the functions also help to determine their appropriateness for describing agricultural production data relationships. Each functional form has certain features that conform with, but also other features that conflict with, expected types of real-world input-output production relationships. Illustrations follow. The Cobb-Douglas function allows either increasing, constant, or diminishing marginal physical productivity (MPP). On the other hand, in Cobb-Douglas estimations, negative MPP and varying marginal rates of substitution among inputs are precluded. With simple quadratic equations, both declining and negative MPP are allowed, but the marginal product curve is linear (Heady and Dillion, 1961).

[2]The most significant early work undertaken by agricultural economists on input-output relations for irrigation water was conceptual. Beringer (1959 and 1961) drew attention to the importance of irrigation water,

- Miller, et al. (1965), Oregon;
- Hexem and Heady (1978), Arizona, California, Colorado, Kansas, and Texas;
- Buller and Roth (1982), Kansas;
- Hoyt (1982), Texas High Plains;
- Kelly and Ayer (1982), California;
- Miller (1982), Arizona, California, Colorado, Kansas, and Nebraska; and
- Hoyt (1984), Colorado.

In all of these studies, polynomial functions were estimated.

Embedded in the water variables created for use in these studies are the following dimensions: (1) irrigation applications, rainfall, and/or pre-season moisture availability; (2) water availability according to phases within the crop production season or, less frequently, total seasonal water availability; (3) "pan evaporation" reflecting the evaporative demands on crops after the crops have attained canopy closure; (4) interaction of water with nitrogen; and (5) varying polynomial degrees on the water variables. Nitrogen applications were also commonly included in the design of the experiments and hence became part of the estimated production functions. In most of this research, no more than one or two additional variables were included. Examples include plant population, location, year, variety, and soil salinity.

In addition to estimating polynomial additive functions with controlled experimental data, Miller et al. (1965) also analyzed via Cobb-Douglas functions field survey data from 43 irrigated corn grain producers in Oregon. The form and content of the function they estimated were as follows:

$$y = ax_1^{b_1} x_2^{b_2} x_3^{b_3} x_4^{b_4} \mu, \text{ where:}$$

y = gross income from the sale of dry shelled corn per acre;

x_1 = dollar value of purchased inputs per acre;

x_2 = hours of machinery use per acre;

x_3 = water-use in inches per acre;

x_4 = drainage in feet per acre; and

μ = the stochastic error term.

The analysis undertaken in the 1982 field survey study of irrigated corn production in Brookings County represents most directly an extension of that in the Miller, et al. (1965) study. The principal feature of the more extended analysis in the Brookings County study is attention to a wider range and more detailed specification of yield determining variables.[1] In

——— continued

[2]not as a production input in and of itself, but as an input that impacts soil moisture and in turn yields. He presented the idea of using an integrated moisture stress index rather than the quantity of water, in estimating production functions for water in agriculture.

Moore (1961) postulated a relationship between crop yield and available soil moisture via a "moisture release curve" (the rate at which water is released from the soil between field capacity and the permanent wilting point). He envisioned the existence of such curves on specific soils as indicators of the expected growth rate of plants grown on those soils.

Flinn and Musgrave (1967) built on the work of Beringer and Moore via a simulation study of input-output relations for irrigation water. A major feature of their analysis was determining the optimal frequency of irrigation during each of eight separate phases in the crop production cycle. Their analysis showed that the time of applying irrigation water had a greater impact on productivity than the total quantity of water used.

[1]Anderson and Wilson (1967) regressed three sets of rather detailed specified yield determining variables -- physical, water management, and non-water management -- against yield in a similar field survey based study of irrigated alfalfa in Utah's Sevier River Basin.

addition, the disturbing impact of possible input and commodity price differences among the irrigator respondents was eliminated by collecting and analyzing all data in physical (i.e., not monetary) terms.

Because several of the variables in this field survey based study were specified in considerable detail, attention was given to estimating both Cobb-Douglas power production functions of the form

$$y = e^{a} x_1^{b_1} \ldots x_n^{b_n} e^{b_{n+1} d_{n+1}} \ldots e^{b_{n+m} d_{n+m}}$$

and polynomial production functions of the form

$$y = c + \sum_{i=1}^{n} (b_i x_i) + \sum_{j=n+1}^{n+m} (b_j x_j) + \mu$$

with selected interaction, quadratic, and square root terms also included in two of the polynomial regression estimations, where:

y = corn grain yield (bu/A);

a = constant term;

c = intercept term;

x_i = various yield determinants, for $i = 1, 2, \ldots, n$;

x_j = various yield determinants involving the dummy variables d, for $j = n+1, n+2, \ldots, n+m$;

b_i = production elasticities in the Cobb-Douglas power functions and production coefficients in the polynomial functions;

b_j = production coefficients in the Cobb-Douglas power and polynomial production functions; and

μ = the stochastic error term.

The production functions in this study involve ordinary least-squares estimates using the SAS-MAXR and PROC REG programs on the SDSU mainframe computer (SAS Institute, 1982). An early check on simple correlations between pairs of variables showed potential problems of multi-collinearity for six pairs of independent variables. To overcome the potential multi-collinearity, only one member of each pair was included in any single estimation.[1]

Explanatory variables. Data on five groups of yield-determining variables were collected and analyzed. The variables comprising each group are briefly defined and the hypothesized relationship between each and yield is indicated.

The first group of variables involves conditions at the time of planting. This includes the time of planting which ranged from May 3rd to May 30th, the seeding rate which ranged from 22 to 32 MVK/A (Table 3), and whether reduced tillage practices (disc and/or chisel plow in place of moldboard plows) were used. The latter was measured via a dummy variable with a value of "0" assigned for conventional tillage and "1" for reduced tillage. The sign on the time of planting variable was hypothesized to be negative, the sign on the seeding rate variable was hypothesized to be positive, and the coefficient on the reduced tillage dummy variable was hypothesized not to differ significantly from zero.

---

[1]The existence of possible correlations between individual variables and linear combinations of the variables in the estimated regression was investigated through the SAS-Collinearity Diagnostics program. The values of the "condition indices" for the variables in a selected estimation were 65 or less. The variables with condition indices less that 65 were regressed against the variable whose condition index was 65 (call it V) to determine the extent of correlation between the linear combination of the other variables and V. The adjusted R^2 for this estimation was 27.9%. This was viewed to reflect the absense of multi-collinearity as a confounding element in the estimation.

The second group of variables concerned the predominant soil in each quarter-section studied.[1] The soils were described in terms of their dryland corn grain yield productivity rating which ranged from 35 to 87 bu/A (Table 9) and overall soil productivity rating which ranged from 17.4 to 89.5%, as described in the preceding section. The soil organic matter content of the predominant soils studied averaged 5.5% and ranged from 2.0 to 20.5%.

Data on each of three soil-water properties were also determined and used. Available water capacity reflects the quantity of water that a soil is capable of storing for use by plants. Values for this variable averaged 0.19 and ranged from 0.10 to 0.21 inches of water per inch of soil depth.[2] Soil water intake reflects the rate at which water infiltrates the surface layer of soil. Values for this variable averaged 0.64 and ranged from 0.3 to 3.0 inches per hour. Soil permeability reflects a soil's internal drainage capacity. Its average value was 1.7, and it ranged from 0.4 to 13.0 inches per hour of downward water movement through the saturated soil profile.

The coefficients on the corn yield productivity, overall soil productivity, and soil organic matter variables were each hypothesized to be positive. Depending on particular soil-water conditions, the coefficients on the available water capacity, soil water intake, and soil permeability variables could be expected to be either positive, negative, or not significantly different from zero.

The third group of variables concerned soil fertility. Since soil tests had been taken on only 11 of the 57 quarter-sections studied, pre-season fertility status could not be incorporated into the analysis. The levels of nitrogen, phosphorus, and potassium applied by farmers are described in the preceding section (Tables 4 and 5).

The fourth group of variables concerned the soil moisture environment for the irrigated corn grain studied. Pre-season moisture levels and climatic conditions affecting evapotranspiration were assumed to be uniform on the 57 quarter-sections studied.[1] Data on rainfall and irrigation for each of the vegetative, pollination, and maturation phases of the growing season are described in the preceding section. Variables were created to reflect rainfall and irrigation separately and rainfall and irrigation in combination with each other for each of the growth phases and for the total season as well.

Variables reflecting the percent moisture in the predominant soils studied at the time of pollination and center pivot operating pressures were also included in the estimations. The means of the soil moisture measurements at the 12, 24, and 36 inch depths for the various center pivots were calculated. Values for the resulting soil moisture variable averaged 20.0% and ranged from 10.0 to 31.3%. The center pivot operating pressures averaged 53 psi and ranged from 22 to 86 psi.

The coefficients on all the moisture variables, except center pivot operating pressures, were hypothesized to be positive. The coefficient on the center pivot operating pressure variable was hypothesized not to differ significantly from zero.

The fifth category of variables was socio-economic. One such variable -- the acres of irrigated land operated by each respondent during 1982 -- was

---

[1]The various soil characteristics were determined via the interpretation of relevant soil maps and related information, not by actual tests of the soils in farmers' fields.

[2]In the regression estimations, the unit for this variable was termed "percent."

[1]The 57 quarter-sections studied spanned an area in Brookings County of less than 30 miles.

included in the estimations. A positive coefficient for this variable was hypothesized.

Results of analysis. Several stepwise regressions (SAS-MAXR) were initially estimated to obtain a preliminary idea about those variables having some apparent association with corn yield and those variables which consistently showed no association with corn yield. Taking into account these preliminary statistical results, and knowledge of the agronomic and economic relationships involved, six variables were dropped when the final production function estimations (SAS-PROC REG) were made.

The final results of the regression analysis are reported in Appendix Tables 4 and 5. Nine Cobb-Douglas power functions were estimated, two of which involved the soil moisture variable and the seven others of which involved various combinations of the rainfall and irrigation variables. Polynomial functions were estimated for the same nine sets of variables and in addition for regressions involving two different combinations of interaction, quadratic, and square root terms.

In 19 of the 20 estimations, the overall regressions are statistically significant. The adjusted R^2s -- reflecting the percentage of the total variation in corn yield explained by the variables included in the regression -- range from 26.7 to 64.8% and most commonly are from 40 to 50%. These statistical properties are comparable with those in the previously cited field survey-based study by Miller, et al. (1965).

The statistical properties of the various Cobb-Douglas power functions are neither consistently superior or inferior to those for the polynomial functions. The results, therefore, are described with no greater attention to one set of estimations than the other.

From three to seven of the yield-determining independent variables are statistically significant in each of the functions estimated. The discussion of results is in terms of the non-moisture-related variables showing (1) the most stable relationship with corn grain yield, (2) a statistically significant relationship with yield in some estimations but not in others, and (3) no apparent relationship with yield. The results concerning the moisture-related variables are then discussed.

Variables consistently related to yield. The coefficients on three variables -- nitrogen, planting date, and available water capacity -- are statistically significant in all but one or two of the estimations. For each variable, the signs on the coefficients are always the same.

The results indicate that, for each additional pound of elemental nitrogen applied at the margin, approximately 0.15 to 0.25 bu/A additional corn grain is produced. In 1982, the cost of one pound of elemental nitrogen was $0.24 (Aanderud and Allen, 1981). With corn priced at $2.05/bu (SDCLRS, 1982-83), the value of the added production resulting from the extra $0.24 expenditure on nitrogen is $0.30 - 0.50. These results suggest that, while nitrogen applications by the respondents in 1982 were relatively high (an average application of 143 lb/A), the levels were not uneconomically high.

The sign on the planting date variable is consistently negative as hypothesized. For each day earlier in planting, the yield is approximately 0.8 to 1.0 bu/A higher. This outcome is consistent with that reported by Pendleton (1965) in which he indicates that earlier planted corn in the Corn Belt involves (1) shorter plants with lower ears and better standability, (2) pollination and grain filling during long light days, and (3) reduction in soil water evaporation because of earlier shading. Earlier planting can also be a proxy for soils with superior drainage properties.

The sign on the available water capacity variable is also consistently negative.[1] This outcome is reasonable in that soils with low available water capacity can be expected to be responsive to irrigation. The added returns from irrigation on soils with a high available water capacity may be inadequate to justify the expenditures required in irrigation.

Variables sometimes associated with yield. The sign on the phosphorus (P_2O_5) variable, contrary to expectation, is consistently negative. In 14 of the 20 regressions, the coefficient differs significantly from zero.

While the relationship between phosphorus and yield is not as stable as that for any of the three earlier variables and yield, the consistently inverse relationship which is statistically significant in more than 2/3 of the regressions is disturbing. Phosphorus applications on many of the quarter-sections -- as reported earlier -- do appear to be more than required. But why phosphorus might have a negative impact on yield is not understood.

The sign on the irrigated acres operated variable is consistently positive. In only nine of the 20 regressions, however, does the coefficient differ significantly from zero. This outcome reflects some evidence that irrigators operating larger acreages have higher yields. The added progressiveness possibly associated with expanded farm operations could be associated with the achievement of higher crop yields.

---

[1] Of the three soil-water variables, only soil permeability failed to show association with corn yield in the preliminary regressions. The comparative results involving available water capacity and soil water intake, reflected in Equation 1 versus 2 and in Equation 10 versus 11, show slightly higher overall F-ratios and adjusted R^2s when available water capacity is included in the estimation. Soil water intake was, therefore, dropped from the other final estimations.

Variables not associated with yield. Under the conditions on the quarter-sections studied in 1982, seven variables were shown to be unrelated with yield.

One of the variables -- the soil dryland corn yield productivity rating -- was included in all the estimations. This was done to determine whether this rather recently developed measure of dryland productivity (Malo and Westin, 1978) would have a stable relationship with yield under irrigated conditions. In 16 of the 20 regressions, the sign on the yield rating variable is positive, but only for two does the coefficient differ significantly from zero. Thus, the results from this study suggest that the dryland soil productivity rating for corn grain may not be a very satisfactory proxy for irrigated soil productivity.

Six other variables were not statistically significant in preliminary regression estimations, and therefore were not included in the final production function analysis. These variables are:

- Potassium (K_2O) applications;
- Seeding rate;
- The tillage dummy variable;
- An overall soil productivity rating;
- Soil organic matter; and
- Soil permeability.

These findings should not be interpreted to imply that these variables have no potential association with yield. The interpretation is more limited. Variations in the values of these variables did not contribute significantly to explaining variations in yields in 1982 among the quarter-sections studied. For different levels and types of input use (e.g., potassium applications, plant populations, methods of land preparation) in different years on the quarter-sections studied, statistically stable input-output relations involving these variables might emerge. Further, in different production environments, different outcomes might be obtained.

Nevertheless, with the evidence at hand, it is concluded that the respondents in 1982 as a group may have applied uneconomically large amounts of potassium and used uneconomically large plant populations. Further, their use of reduced tillage practices did not adversely affect their yields.

Moisture-related variables. In the regression analysis, either the variable reflecting the percentage of soil moisture at the time of pollination was included, or different combinations of variables involving rainfall and irrigation were.

In all four estimations involving the percentage of soil moisture, the sign on this variable was unexpectedly negative. In three of the four estimations, the coefficient differed significantly from zero. This outcome, of course, shows added soil moisture at the time of pollination to deter from the achievement of higher yields.

A negative sign for the pollination period rainfall and irrigation variables in nine out of 10 (only one of which is statistically significant, however) of the regressions involving these variables further reinforces the idea that moisture levels may have been excessive at the time of corn pollination in 1982. It will be recalled that pollination period precipitation in 1982 was nearly double the average for 1951 to 1980.

In general, the overall F-ratios and adjusted R^2s were higher for the production functions involving the rainfall variables than for those involving the irrigation variables. This undoubtedly reflects, in part, the facts that irrigation levels during 1982 were (1) only 33% as much as seasonal rainfall and (2) only about 40% of the average level during 1970 to 1983.

The coefficients on all 26 rainfall and irrigation total seasonal variables and vegetative and maturation period variables were positive. In eight instances, the coefficients differed significantly from zero. These results indicate some tendency for rainfall and irrigation to positively influence yield, but less than would normally have been expected. If precipitation had been more nearly normal in 1982, it is quite likely that the relationships between the moisture variables and yield would have been more statistically stable.[1]

In 14 of the 20 estimations, the sign on the center pivot operating pressure variable was positive. In only three instances was the coefficient statistically significant. The mixture of signs on and lack of statistical significance of this water distribution pressure variable indicate that reduced pressure irrigation on the study center pivots in 1982 had no adverse effects on yields.

The fact that irrigation applications during 1982 were so limited, however, reduced the chances of the possible impact of water distribution pressure on yields to show itself. Apart from this weather-related phenomenon, the fields where "low" pressure center pivots have been established are flat (none have within-field slopes of more than 1%) and involve relatively light soils (only 20% of the "low" pressure quarter-sections studied have any nominal clay content). Where field slopes are greater and soils are heavier, the chances for less uni-

---

[1]Two factors underly this expectation. With more normal precipitation, fewer days in which precipitation would exceed evapotranspiration needs would be expected. The probability of being able to identify stable relationships between the precipitation variables and yield would thereby increase. Second, with less precipitation, the frequency and amount of irrigation on at least some fields would very likely increase. This would result in a broadened range of observations on the irrigation variables -- thereby increasing the probability of being able to identify a statistically stable relationship between irrigation levels and yield.

form water infiltration and more water runoff from reduced pressure irrigation increases. In such cases, yields may be adversely affected by reduced pressure water distribution.

Most researchers who have used experimental data in plant water-nutrient-yield studies have created (1) interaction terms involving nitrogen and water and/or plant population and water and (2) quadratic and/or square root terms involving nitrogen and water. The last two production functions in Appendix Table 5 involve such variables in this study. They also involve a tillage dummy-center pivot operating pressure interaction variable, with the hypothesis that greater plant residues on the soil surface from reduced tillage may help mitigate possible adverse water infiltration problems from reduced pressure irrigation (Gilley, 1982).

In general, the statistical properties of the production functions with the interaction, quadratic, and square root terms are superior to those for the log linear and linear additive production functions. The signs on the quadratic and square root terms are as expected, but only one of the four coefficients differs significantly from zero.

The signs on the tillage dummy-center pivot operating pressure interaction terms are as hypothesized, but the coefficients are not statistically significant.

The signs on the nitrogen-rainfall and plant population-nitrogen interaction terms are all negative, indicating substitutional rather than complementary relationships between the respective pairs of variables. The literature, however, more commonly shows complementary relationships for such interaction terms (e.g., Miller, et al., 1965 ; Hexem and Heady, 1978; Miller, 1982).

APPENDIX

APPENDIX TABLE 1. DIVERSIFICATION OF CORN GRAIN FARMS, REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

	Percentage of respondents having the indicated number of different enterprises									
			Crop enterprises on farms with:							
	Livestock enterprises[a]		Both irrigated and dryland crops		Only irrigated crops		Only dryland crops		Total crop and livestock enterprises	
Number of enterprises	Percent per category	Cumulative percent	Percent per category	Cumulative percent	Percent per category	Cumulative percent	Percent per category	Cumulative percent	Percent per category	Cumulative percent
>7	0	0	2.8	2.8	0	0	2.8	2.8	11.1	11.1
7	0	0	2.8	5.6	0	0	2.8	5.6	22.2	33.3
6	0	0	8.3	13.9	0	0	8.3	13.9	30.6	63.9
5	0	0	25.0	38.9	0	0	22.2	36.1	19.4	83.3
4	5.5	5.5	38.9	77.8	8.3	8.3	36.1	72.2	8.3	91.6
3	13.9	19.4	16.7	94.5	11.1	19.4	19.4	91.6	5.6	97.2
2	38.9	58.3	5.5	100.0	50.0	69.4	5.6	97.2	2.8	100.0
1	25.0	83.3	0	0	30.6	100.0	2.8	100.0	0	0
0	16.7	100.0	0	0	0	0	0	0	0	0

[a]The different livestock enterprises are beef, dairy, hogs, and sheep.

APPENDIX TABLE 2. CROP ENTERPRISES ON CORN GRAIN FARMS, REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

Crop	Percentage of total area operated by respondents	Percentage of respondents having the enterprise	Size of enterprise (acres per respondent) Mean[a]	Range
Irrigated				
Corn	77.4	100.0	192	20-890
Soybeans	12.8	41.7	76	20-155
Alfalfa	5.1	33.3	38	15-120
Sunflowers	2.2	5.6	98	80-115
Spring wheat	1.4	8.3	44	30-61
Oats	1.1	8.3	33	13-70
Dryland				
Corn	34.9	94.4	226	5-1,180
Soybeans	19.2	75.0	157	12-800
Oats	14.9	72.2	126	15-600
Alfalfa	9.6	77.8	76	10-250
Spring wheat	8.3	41.7	121	12-360
Sunflowers	8.1	27.8	177	44-450
Barley	2.3	16.7	86	50-200
Flax	2.3	11.1	126	54-180
Other	0.4	5.6	41	12-70

[a]These means are based on only those farms which have the indicated enterprises.

APPENDIX TABLE 3. LIVESTOCK ENTERPRISES ON CORN GRAIN FARMS, REDUCED PRESSURE IRRIGATION STUDY, BROOKINGS COUNTY, 1982

Type of livestock enterprises	Percentage of respondents having the enterprise	Size of enterprise (no. of animals per respondent) Mean[a]	Range
Beef cattle			
Cows calved	61.1	83	15-200
Fat cattle sold	47.2	158	20-800
Feeder cattle sold	25.0	136	10-400
Hogs			
Sows farrowed	16.7	43	16-63
Market pigs sold	36.1	516	25-1,200
Dairy cows freshened	30.6	55	14-100
Sheep			
Ewes lambed	19.4	94	20-200
Market lambs sold	19.4	108	16-260

[a]These means are based on only those farms which have the indicated enterprises.

APPENDIX TABLE 4. Regression parameters and production elasticities for Cobb-Douglas power functions relating various independent variables to yield of irrigated corn grain (bu per acre), reduced pressure irrigation study, Brookings County, 1982[a]

	Equation Number								
	1	2	3	4	5	6	7	8	9
Regression parameters									
F-ratio of the regression	4.9***	5.4***	6.8***	2.7***	3.1**	5.1***	2.8**	1.9	3.3**
No. of center pivot observations[b]	44	44	32	35	26	32	34	25	25
Adjusted R^2	44.7	47.4	59.3	28.5	39.7	56.4	34.3	31.2	47.8
No. of statistically significant prod. elasticities	4	5	4	5	5	4	7	5	5
Production elasticities									
Nitrogen (lb N/A)	30.0***	28.8***	30.4***	19.6**	23.6***	30.3***	19.7**	23.7**	23.8***
Phosphorous (lb P_2O_5/A)	-14.4***	-12.8***	-10.2**	-10.0**	- 9.6**	-10.6**	- 9.4**	- 9.1*	- 8.3*
Planting date	- 3.1	- 6.3*	-12.3***	- 5.4	- 7.4*	-11.3**	- 6.9*	- 9.8*	-10.6**
Soil water intake (in/hr)	9.6*								
Available water capacity (%)		-40.9**	-62.9**	-47.4**	-68.8**	-62.6**	-57.2**	-69.4*	-72.8**
Soil corn yield productivity (bu/A)	16.4	10.8	18.1	8.7	15.0	11.4	7.9	- 2.0	- 3.9
Problem soil dummy[c]	2.6	- 0.6							
Irrigated acres operated	2.4	2.6	3.7	8.7**	8.5*	4.5	11.5***	11.0**	8.1*
Center pivot operating pressure (psi)	7.5	7.6	- 0.4	7.4	- 5.4	- 0.6	8.7	- 4.5	- 9.8
Soil moisture, pollination (%)	-27.5**	-23.5*							
Seasonal total (acres-inches)									
Rainfall			18.9						
Irrigation				7.9**					
Rainfall plus irrigation					7.2				
Rainfall (inches)									
Vegetative period						3.8		6.7	
Pollination period						- 6.4		-21.2	
Maturation period						4.1		0.2	
Irrigation (acre-inches)									
Vegetative period							12.2*	11.8	
Pollination period							- 3.5	- 9.1	
Maturation period							14.1**	12.4	
Rainfall plus irrigation (acre-inches)									
Vegetative period									7.9
Pollination period									-27.5
Maturation period									6.1

[a]The levels of significance for the overall regression and the various independent variables in each estimation are denoted as follows: *** = 0.01, ** = 0.05, and * = 0.10.

[b]For 13 of the 57 center pivots under study, data on one or more variables included in the regressions was missing. Information on irrigation was not obtained for nine of the 44 other center pivots, and on rainfall for 12 of the other 44 center pivots.

[c]In preliminary estimations, the sign of the soil moisture variable was unexpectedly negative. Certain soils, which under normal moisture conditions are quite productive, can be quite adversely affected by excessive moisture. To deal with this analytically, a problem soil dummy variable was created with a value = 1 for such potentially problematic soils and a value = 0 for the other soils. Since the coefficient on this variable was not significant in any of the first four estimations in which the variable was included, the variable was dropped from subsequent estimations.

APPENDIX TABLE 5. Regression parameters and production coefficients for polynomial functions relating various independent variables to yield of irrigated corn grain (bu per acre), reduced pressure irrigation study, Brookings County, 1982[a]

	Equation Number										
	10	11	12	13	14	15	16	17	18	19	20
Regression parameters											
F-ratio of the regression	5.0 ***	5.4 ***	7.8 ***	2.6 **	3.4 **	6.1 ***	2.4 **	2.5 *	2.8 **	5.4 ***	5.5 ***
No. of center pivot observations[b]	44	44	32	35	26	32	34	25	25	32	32
Adjusted R^2	45.1	47.5	63.0	26.7	42.5	61.5	28.7	43.3	41.8	64.1	64.8
No. of statistically significant prod. coefficients	6	5	5	5	3	4	7	3	4	6	6
Production coefficients											
Nitrogen (lb N/A)	0.25***	0.25***	0.28***	0.18***	0.18**	0.27***	0.19***	0.14*	0.18**	1.35**	0.05
Phosphorous (lb P_2O_5/A)	- 0.32***	- 0.28**	- 0.22*	- 0.25*	- 0.21	- 0.22	- 0.22*	- 0.03	- 0.15	- 0.22	- 0.21
Planting date	- 0.73**	- 0.84**	- 1.23***	- 0.77**	- 0.95**	- 1.21***	- 0.91**	- 1.19**	- 1.04***	- 1.11***	- 1.09***
Soil water intake (in/hr)	8.63*										
Available water capacity (%)		- 2.35**	- 3.24**	- 2.10	- 2.82**	- 3.24**	- 2.61*	- 2.49	- 3.45**	- 3.11**	- 3.00**
Soil corn yield productivity (bu/A)	0.22	0.17	0.30	0.14	0.19	0.32	0.07	- 0.02	- 0.03	0.42*	0.41*
Problem soil dummy[c]	0.56	- 2.02									
Irrigated acres operated	0.001	0.002	0.01	0.02	0.04	0.02	0.02*	0.04	0.04*	0.05*	0.05*
Center pivot operating pressure (psi)	0.22*	0.20*	0.05	0.25*	0.03	0.06	0.24	0.09	0.06	0.07	0.05
Soil moisture, pollination (%)	- 1.2*	- 1.06									
Seasonal total (acres-inches)											
Rainfall			2.29**								
Irrigation				2.57*							
Rainfall plus irrigation					0.82						
Rainfall (inches)											
Vegetative period						1.00		1.29			
Pollination period						2.38		- 2.31			
Maturation period						3.19**		2.81			
Irrigation (acre-inches)											
Vegetative period							7.51**	16.13			
Pollination period							- 1.21	- 7.79*			
Maturation period							5.56*	7.40			
Rainfall plus irrigation (acre-inches)											
Vegetative period									1.47		
Pollination period									- 2.42		
Maturation period									2.17		
Interaction terms											
Nit. and tot. rainfall										- 0.05*	- 0.06*
Pl. pop. & tot. rainfall										- 0.14	- 0.17
Till. dum. & C.P. oper. press.[d]										- 0.004	- 0.003
Quadratic terms											
Nitrogen (lb/A)										- 0.002	
Tot. rainfall (inches)										- 0.06	
Square root terms											
Nitrogen (lb/A)											18.58*
Tot. rainfall (inches)											40.18

[a,b,c]See Appendix Table 4 for these three footnotes.

[d]For the tillage dummy variable, a value of 0 was assigned for conventional tillage and 1 for reduced tillage.

REFERENCES CITED

Aanderud, Wallace G. and Herbert R. Allen. 1981. Expected production costs for major crops for six production areas in South Dakota. Brookings: SD CES EMC 864.

Anderson, Jay C. and David L. Wilson. 1967. Evaluating increments of irrigation water, Sevier River Basin, Utah. In Water Resources and Economic Development of the West. Conf Proc, Com on the Econ of Wat Res Dev of the West, Agri Econ Res Coun, San Francisco, Rep No. 16.

Anderson, R.L. and A. Maass. 1978. A simulation of irrigation systems. Washington, D.C.: USDA, Econ Stat and Coop Ser, Tech Bul No. 1431.

Beringer, Christopher. 1959. Some conceptual problems in determining the production function for water. In the West in a Growing Economy, Proc West Farm Econ Assoc, 32nd Ann Mtg, Logan, Utah.

_______. 1961. An economic model for determining the production function for water in agriculture. Davis: Calif Agric Exper Sta, Giannini Found Res Rep 240.

Blaney, Harry F. and Wayne D. Criddle. 1962. Determining consumptive use and irrigation water requirements. Washington, D.C.: USDA Tech Bul 1275.

Buller, Orlan and Mike Roth. 1982. Water response in corn and grain sorghum. Manhatten: Dept of Econ, Kan AES, Res Pap 82-79-5.

Burt, Oscar R. and M.S. Stauber. 1971. Economic analysis of irrigation in a subhumid climate. Amer J of Agric Econ, LIII (1):33-46.

DWNR. 1979. Irrigation questionnaire information. Pierre: Div of Water Rights, SD Dept of Water and Nat Res, mimeo.

Denmead, O.T. and R.H. Shaw. 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn, Agronomy J, LII:272-274.

Downey, L.A. 1972. Water-yield relations for non-forage crop. J of Irrig and Drain Div, ASCE, IIC(IR 1):107-115.

Everson, Curtis A. 1979. An estimation of the economic value of water used for irrigation in eastern South Dakota. Brookings: SDSU, unpublished Masters' thesis.

Flinn, J.C. and W.F. Musgrave. 1967. Development and analysis of input-output relations for irrigation water. Australian J of Agric Econ, XI(1):1-19.

Gerwing, James, Paul Fixen, Ron Gelderman and Paul Carson. 1984. Fertilizing corn. Brookings: SD CES, FS 432.

Gilley, James R. 1982. Water and energy conservation using center pivot irrigation and reduced tillage practices. Submitted to Off of Wat Research and Tech, US Dept of Int. Lincoln: Nebraska Water Resources Center, Proj Comp Rep B-048-NEB.

Good, N.E. and D.H. Bell. 1980. In photosynthesis, plant productivity, and corn yield. P.S. Carson editor. New York: Academic Press.

Heady, Earl O. and John L. Dillon. 1961. Agricultural production functions. Ames: Iowa State Univ Press.

Hexem, Roger W. and Earl O. Heady. 1978. Water production functions for irrigated agriculture. Ames: Iowa State Univ Press.

Howe, O.W. and H.F. Rhoads. 1955. Irrigation practices for corn in relation to stage of plant development. Soil Sci Soc Am Proc, XIX:94-98.

Hoyt, Paul G. 1982. Crop-water production functions and economic implications for the Texas high plains region. Washington, D.C.: USDA, Nat Res Econ Div, Econ Res Ser, ERS Staff Rep AGES820405.

_______. 1984. Crop-water production functions: economic implications for Colorado. Washington, D.C.: USDA, Nat Res Econ Div, Econ Res Ser, ERS Staff Rep AGES 840427.

Kelly, Sharon and Harry Ayer. 1982. Water conservation alternatives for California agriculture: a microeconomic analysis. Washington, D.C.: USDA, Nat Res Econ Div, Econ Res Ser, ERS Staff Rep AGES 820417.

Kramer, Paul J. 1963. Water stress and plant growth. Agron J, LV(1):31-35.

Lytle, William F. 1984. Personal communication based on SD climate data bank, April 3.

Malo, D.D. and F.C. Westin. 1978. Rating South Dakota soils according to productivity. Brookings: SD AES Bul 657.

Miller, Stanley F., Larry L. Boersma and Emery N. Castle. 1965. Irrigation water values in the Willamette Valley: a study of alternative valuation methods. Corvallis: Oregon State Univ AES, Tech Bul 85.

Miller, William L. 1982. An economic comparison of the irrigation of corn in humid and arid regions of the United States. West Lafayette: Wat Res Res Cen, Purdue Univ, Tech Rep 142.

Moore, Charles V. 1961. A general analytical framework for estimating the production function for crops using irrigation water. J of Farm Econ, XLIII(4):876-888.

NCC. 1982. Monthly climatological data. Asheville, NC: National Climatic Center, National Oceanic and Atmosphere Administration, Environmental Data and Information Service, US Dept of Comm, monthly, June-Sep.

Papendick, Stanley E. 1978. Water and nitrogen husbandry for irrigated corn in central South Dakota. Brookings: SDSU, unpublished Masters' thesis.

Pendleton, J.W. 1965. Cultural practices and spacing. Proc 20th Ann, Hybrid Corn Ind Res Conf, Vol. 20:51-58.

Robins, J.S. and C.E. Domingo. 1953. Some effects of severe soil moisture deficits at specific growth stages of corn. Agron J, XLV:618-621.

SAS Institute. 1982. SAS user's guide: statistics. Cary, NC: SAS Inst, Inc.

SDCLRS, annual. South Dakota agricultural statistics. Sioux Falls: SD Crop and Live Rep Serv, published annually in May, 1953 through 1984.

Satterlee, James. 1984. South Dakota agricultural census handbook. Brookings: Census Data Center, Dept of Rur Soc, SD AES, Update Ser. C229, No. 16.

Shaw, Robert H. and Olya Arjmand. 1981. Chapter 4 of efficient use of water for irrigation in the upper midwest. Ames: Iowa State Wat Res Res Inst, ISWRRI-117.

Sloggett, Gordon. 1983. Ground water irrigation development in the plains. Stillwater: Oklahoma State Univ, Agric Econ Dept, AE No. 8359.

Smil, Vacav, Paul Nachman and Thomas V. Long, III. 1983. Energy analysis and agriculture: an application to U.S. corn production. Boulder: Westview Press.

Stewart, J.I., R.D. Misra, W.O. Pruitt and R.M. Hagen. 1975. Irrigating corn and grain sorghum with a deficient water supply. Trans ASAE, XVIII(2):270-280.

Stone, L.R., R.E. Gurn, Jr. and M.A. Dillon. 1978. Corn and grain sorghum yield response to limited irrigation. J of Soil and Wat Conser, XXX(5):235-238.

Sundquist, W. Burt, Kenneth M. Menz and Catherine F. Newmeyer. 1982. A technology assessment of commercial corn production in the United States. St. Paul: Univ of Minnesota AES, Sta Bul 546.

Taylor, Donald C. 1983. The 1970s: a decade of growth in South Dakota irrigation. Brookings: SDSU Econ Dept, Res Rep 83-4.

_______. 1984a. Regional shifts during the 1970s: South Dakota irrigation. Brookings: SD AES, C243.

_______. 1984b. The economics of reduced pressure irrigation. Brookings: SD AES Bul in press.

_______ and Ardelle A. Lundeen. 1983. The economic impact of alternative electric rate structures on energy and water use in South Dakota: a research proposal. SD AES Res Proj 7107-163.

_______ and Richard C. Shane. 1983. The impact of rising energy prices on crop production: Brookings and Turner Counties. Brookings: SD AES, Bul 684.

USDA. 1982. Land resource regions and major land resource areas of the United States. Washington, D.C.: USDA, Soil Cons Ser, Ag Hdbk. 296.

USDA-SRS, annual. South Dakota's rank in agriculture. Sioux Falls: USDA Stat Rep Serv, published annually in Feb, 1981 through 1984.

USDC, Census Years. U.S. Census of Agriculture, South Dakota. Washington, D.C.: Bur of the Census, US Dept of Commer, Govt Printing Off, for Census years 1959, 1964, 1969, 1974, 1978, and 1982 (prel).

Westin, F.C., G.J. Buntley, F.E. Shubeck, L.F. Puhr and N.E. Bergstreser. 1959. Soil survey of Brookings County, South Dakota. Brookings: USDA, Soil Cons Serv, in cooperation with SD AES, Bul 468.

Published in accordance with an Act passed in 1881 by the 14th Legislative Assembly, Dakota Territory, establishing the Dakota Agricultural College and with the Act of re-organization passed in 1887 by the 17th Legislative Assembly, which established the Agricultural Experiment Station at South Dakota State University

File: 3.5--AX083 5 4 3 2 1