WRC RESEARCH REPORT 186

WATER MANAGEMENT ON CLAYPAN SOILS IN THE MIDWEST

by

S. K. Sipp
Department of Agronomy

W. D. Lembke
Department of Agricultural Engineering

C. D. Boast
Department of Agronomy

M. D. Thorne
Department of Agronomy

University of Illinois at Urbana-Champaign

P. N. Walker
Department of Agricultural Engineering
Pennsylvania State University
University Park

FINAL TECHNICAL COMPLETION REPORT
To Bureau of Reclamation, USDI, Washington, DC 20240

Project B-141-ILL
Matching Grant Agreement No. 14-34-001-1222

This project was partially supported by funds provided by the U.S. Department of Interior as authorized under the Water Resources Research and Development Act of 1978

WATER RESOURCES CENTER
208 North Romine Street
Urbana, Illinois 61801

June 1984

An aerial view looking south showing the treatments in September 1983.

ABSTRACT

Irrigation scheduling with soil moisture monitoring devices provided the most efficient use of water on claypan soils. Corn was found to be particularly responsive to both drainage and irrigation with average yield increases of 80 bushels per acre over the seven year period of the experiment. Consequently, water management was found to be an important aspect of corn production. Hybrid selection was found to be important to maximize the benefits of water management.

Soybeans were found to be less responsive to irrigation than corn. Also, soybeans were found to be more responsive to drainage during the growing season than corn. Soybean variety selection was found to be important to prevent lodging when irrigation was used.

Surface drainage is an important practice in water management but irrigation was found to be necessary to prevent yield reduction particularly with corn, when top soil was removed during the construction needed for surface drainage.

Sipp, S. K.; W. D. Lembke; C. D. Boast; M. D. Thorne; and P. N. Walker

WATER MANAGEMENT ON CLAYPAN SOILS IN THE MIDWEST
Final Technical Completion Report to Bureau of Reclamation, U.S.
Department of the Interior, April, 1984, Washington, DC 20240

KEYWORDS--water use, agriculture, irrigation, drainage, claypan, corn, soybeans, Illinois, Midwest, soil moisture

ACKNOWLEDGEMENTS

Special acknowledgement goes to the Certainteed-Daymond Corporation of Ann Arbor, Michigan, for providing the support needed to begin field research on combined irrigation and drainage on claypan soils. Substantial support in addition to that from U.S. Department of Interior has come from the Illinos Soybean Program Operating Board; Rain Bird Sprinkler Manufacturing Corporation of Glendora, California; Advanced Drainage Systems, Inc. of Columbus, Ohio; Springfield Plastics of Springfield, Illinois; Illinois Foundation Seeds, Tolono, Illinois; Pioneer Seeds, Bloomington, Illinois; the Illinois Water Resources Center, and the Illinois Agricultural Experiment Station.

Acknowledge is given to many individuals at the University of Illinois for their support. Acknowledgement also goes to F. Zajicek, J. Biggs, J. L. Carter and W. H. Brink of the Brownstown Agronomy Research Center; G. E. Stout of the Illinois Water Research Center; J. K. Mitchell, C. J. W. Drablos, W. D. Goetsch, and S. M. Maddock of the Agricultural Engineering Department; and L. V. Boone and L. F. Welch of the Agronomy Department.

Several undergraduate students at the University of Illinois were involved in both field work and analysis of data. We want to particularly acknowledge Janet Cherry and Jane Unkraut.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Efficient agricultural production on the nearly 10 million acres of claypan soils in the midwest has long been considered dependent on effective water management, but very little data has been available to model production systems. Also, information is needed to implement either irrigation or drainage practices. Nearly 5 percent of Illinois is included in the claypan region with most of these soils in Southern Illinois. An initial study by Walker and Lembke (1977) provided a compilation of literature whereby the experiences of other researchers could be used as a guide toward planning a field study of water use on claypan soils. Such a study should incorporate both drainage and irrigation practices for commonly grown field crops. A field study of water management was begun in 1977, and reported by Walker et al. (1981) and Walker et al. (1982). Corn was grown continuously on the twenty plots during the project period and several conclusions were drawn: (1) Drainage and irrigation individually increased yields significantly during the project period (2) There was a positive synergistic effect on yield when drainage was combined with irrigation (3) The method of irrigation, whether surface or sprinkler, had little effect on yield and (4) Similarly, the method of drainage, whether surface or subsurface, had little effect on yields. All of the conclusions of this first field study were based on yields. A soil moisture model and a treatment-yield model were developed for irrigation and drainage on tight claypan soils but sufficient data was not collected to make any verification.

SOILS

Claypan soils in Illinois consist primarily of the Hoyleton-Cisne-Huey soil association and occur on the uplands of south-central and southern Illinois.

These soils have developed under grass vegetation and consist of 2.5 to 4 feet of wind blown loess on weathered Illinoian glacial till. Since they are strongly weathered, they are acid and light colored even though they were formed under grass vegetation. They have a heavy silty-clay-loam subsoil at a depth of 18 to 24 inches that is very slowly permeable and which severely limits root development and water penetration. Consequently droughtiness is a problem. A high percentage of these soils occur on nearly level to gently sloping land making them well adapted to the use of large machinery but making adequate surface drainage a major problem.

The soils that make up the Brownstown Research Center are primarily Cisne Association types. The Cisne series is a fine, montmorillonitic, mesic Mollic Albaqualf. These soils typically have very dark grayish brown silt loam Ap horizons. The A2 horizons are grayish brown and light gray silty types. Mottled grayish brown heavy silty clay loam makes up the B2t horizons. Mottled light brownish gray silty clay loam B3 horizons and dark grayish brown silt loam C horizons at depths of about 60 inches complete the soil profile of the Cisne series. Typically, there is a very tight claypan layer located between the 12- and 18-inch depths. Figure 1 indicates the location of the Cisne silt loam and associated soils in Illinois. The soil types in the experimental plots are shown in Figure 2. Note that the plots are made up of two Cisne Association soil types, the Cisne and the Hoyleton. The major difference between the two is slope: Hoyleton is gently to moderately sloping while the Cisne is nearly level.

WATER AND CLAYPAN SOIL AGRICULTURE

The area of Illinois with the largest concentration of claypan soils is in the south-central part of the state where the average annual rainfall is approximately 40 inches. While this is an adequate amount of water for crop production, the distribution is uncertain and with the low plant-available water storage capacity of these soils, drought stress is frequent during critical crop growth periods during the summer months (Austin, T. A. et al., 1981). When excess rainfall does occur during these months, the low permeability of the soil and the flat topography sometimes results in excessive water in the plant root zone. When this excessive water comes in the earlier months, planting operations are delayed, thus reducing the yield potential of the crop. When the surplus comes in the mid-growing season period, the shallow root system becomes saturated with a lack of oxygen necessary for proper root function. When the excess rainfall occurs during late season, harvesting operations are delayed with accompanying losses in both yield and quality. Since crop production is very sensitive to either an excess or a deficiency of water, water management is an important cultural practice on claypan soils.

WATER SUPPLY

In order for irrigation to be a practical crop production option, water must be available in sufficient quantities with an economic means of application (Walker et al., 1981; Miller et al., 1981). Since the claypan areas of Illinois are generally over very poor groundwater aquifers, the only waters available for irrigation are surface water suplies either from natural streams or from artificial empoundments.

Miller et al. (1981) found that with a discount interest rate of less than 12% and with irrigated yields exceeding dryland yields by 45 bushels per acre, it is economical to construct irrigation empoundments on claypan soil. They assumed slightly less than $1.00 per cubic yard of earth moved in construction and a 3 to 1 ratio between water stored and earth moved. They assumed claypan soils with steep slopes. Since many areas of Illinois have claypan soils that are nearly flat, the earth moving costs and land costs for the empoundment areas may be greater. We must conclude from the literature available on empoundment construction that the economics of irrigation on the claypan soils of Illinois is site specific and dependent on the costs of a water supply.

PREVIOUS WORK

Fehrenbacher et al. (1969) studied the effect of fertility management on crop rooting patterns and yield for claypan and other soils. They found that, as a result of increased fertilization, corn yields were increased three-fold on the claypan soils. They concluded that part of the yield increase was due to greater rooting depth and more available moisture.

Walker et al. (1981) described the previous research that began in 1977 with four years of data ending with 1980. The conclusions they drew were based on corn yield. Corn yields were increased by 13 bu/acre by drainage alone and 50 bu/acre by irrigation alone. Irrigation and drainage combined were found to increase yields synergistically with an average increase of 92 bu/acre when drainage and irrigation were combined. They found that the method of irrigation, whether sprinkler or furrow, had little effect on yield and that the method of drainage, whether surface or subsurface, had little effect on yield. The water supply for this study consisted of two small artificial empoundments constructed to contain only sufficient water to provide the annual irrigation needs.

METHODS

The study area is located at the Brownstown Agronomy Research Center in south central Illinois approximately 8 miles east of Vandalia, Illinois. The plots are on a Cisne-Hoyleton soil association in the southwestern part of the research center. The layout includes two replications of each irrigation-drainage treatment combination for both corn and soybeans. The plots were instrumented for intensive soil moisture monitoring and meteorological measurements in addition to determination of grain yield.

TREATMENT COMBINATIONS AND LAYOUT

The demonstration-research study area consists of four sets of ten one-sixth-acre plots, each plot having one of ten different irrigation and drainage treatments. Corn was grown on two sets, soybeans on the other two. The crops are rotated annually. Two sets of plots were established in 1976, on series 1100 and 1200 of the research center prior to the beginning of this study. The remaining two sets were constructed in 1980 on series 900 and 1000.

The initial irrigation treatments were sprinkler, surface (furrow), and no irrigation. In 1982, the furrow irrigated plots were equipped with sprinkler irrigation to treat different irrigation intensities for corn and to investigate the effect of irrigation on double crop soybeans. The drainage treatments are surface, subsurface, both surface and subsurface (combination), and no drainage. Because of the physical incompatibility of some treatment combinations, only ten of possible twelve combinations were used. Furrow irrigation requires the field to slope in one direction, thus ruling out the pairing of furrow irrigation and treatments without surface drainage.

The treatment combinations, plot configuration and treatment layout used in the study are shown in Figure 3. Each plot measures 64 ft by 108 ft. An earthen dike isolates each plot from surface water sources. A vertical plastic film placed to a depth of 5 ft restricts the movement of subsurface water into and out of individual plots.

Surface-drained plots have a slope of 0.5 percent parallel with the long dimension of the plot. Runoff is discharged to a collection sump at the end of the plot. Corrugated plastic tubing 3 inches in diameter provides the subsurface drainage. Three lines spaced 20 ft apart were installed parallel with the long dimension of the plot, with an average depth of soil cover of 1 ft. The drain lines, which are parallel with the long dimension of the field, were installed with a slope of 0.2 percent on plots with only subsurface drainage. The plots that have only subsurface drainage are graded level. The tile lines in the surface plus subsurface drainage plots have 0.5% slope.

Plots without drainage are graded level and, like the other plots, have earthen dikes and plastic film barriers to restrict movement of water into or out of the plots. In 1981, surface inlets were installed to limit ponding depth and duration on these plots in order to better simulate level field conditions rather than depressional situations.

Water for irrigation is pumped from two nearby ponds. Furrow irrigation water was applied between each row by means of gated pipe: row slope is 0.5 percent. Sprinkler spacing is 32 ft x 32 ft. Irrigation water was applied at the rate of 0.2 inch per hour with the furrow irrigation and 0.1 inch per hour with the sprinkler system. Irrigation efficiency during the field study was assumed to be 0.80 for both the sprinkler system and the gated pipe. These factors were used to determine water volume amounts required to achieve the desired net irrigation application.

CROP MANAGEMENT

Pertinent crop management data are located in Tables 1 and 2 for corn and soybeans respectively. Initial plans called for a zero till cropping system; however, difficulties encountered with weed control and stand establishment caused a shift to shallow conventional tillage. Deep tillage methods cannot be generally practiced on the plots in order to avoid damage to the tile drainage system.

Fertility, weed control and pest control are managed at levels to promote high production.

As soon as soil conditions on both replications would allow, each treatment was planted. In most years, the entire crop was planted on the same date and in the years that simultaneous planting was not possible, only the planting of the non-drained plots was delayed. The delayed planting date in 1978 was caused by construction activities rather than weather related soil conditions.

Unless otherwise noted, all crop yield data are from samples harvested with the commercial model combine at the research center. Each sample is weighed in an integrally mounted tank; a moisture sample is taken before the grain is dumped into the holding bin. All yields are calculated at a standard moisture content: 15.5% for corn and 13% for soybeans.

IRRIGATION SCHEDULING

For the course of this study, irrigation was scheduled using tensiometers to estimate plant-available soil moisture depletion. Each plot is irrigated on demand as indicated by the tensiometer readings at the one foot level. One inch (net) of water is the desired amount for an irrigation application; however, small variations in individual applications exist.

With the exception of the low tension corn plots in 1982 and 1983, a plot was irrigated when the average tensiometer reading at the one foot depth exceeded 625 millibars - approximately 50% plant-available soil moisture depletion. The low tension corn plots were watered at a mean tensiometer reading of 425 millibars - approximately 33% plant-available soil moisture depletion.

From 1977 through 1979, irrigation scheduling was determined using a seven-day moisture total. Precipitation plus irrigation for the previous seven days was totaled daily. Sufficient irrigation was applied to all plots to raise the total to one inch whenever the total for the seven-day sum was below that amount. Up to three days were required to complete an irrigation cycle; consequently, the possibility of a seven day moisture total of less than one inch for a plot existed for up to a two-day period.

Average net irrigation by treatment is indicated in Table 3 for corn and in Table 4 for soybeans. The approximate number of irrigation applications received by a tretment may be determined by dividing the irrigation amount by 1.0 inch, the desired irrigation amount. Since each plot could be irrigated individually in 1981 and succeeding years, the average amounts may not reflect the differences in water required by individual plots.

A later section in this report beginning on page 19 describes a method proposed to practically schedule irrigation of claypan soils.

WEATHER

Annual variation in weather is the most important factor controlling crop yield. This experiment was conducted to determine the effectiveness of managing the only factor of weather that can be practically modified on a local basis, water. The drainage factor of the treatments is used to control excess water; the irrigation factor adds supplemental water when precipitation is less than the amount required for crop production. The remaining weather factors, temperature, relative humidity, wind and solar radiation were not controlled.

Summaries of the daily precipitation at the Brownstown Agronomy Research Center are included in Appendix A of this report as an aid in evaluating the yield differences and irrigation needs in this experiment. Rains of .25 inches or less are largely ineffective as a source of moisture for plant growth, particularly after the crop canopy has closed, because most of the water is retained on the plant leaves. Most of the moisture from such light rains that reaches the soil surface is lost to evaporation before it can move into the root zone.

A summary of critically high temperatures is included in Appendix B since excessively high temperatures are a major component of high evaporation and transpiration which induces moisture stress.

INSTRUMENTATION AND MEASUREMENTS

Soil moisture was intensively monitored during the study. Each plot was equipped with two soil moisture stations located as indicated in Figure 4. Each moisture station consisted of three tensiometers at 12, 18 and 24 inch depths, three gypsum blocks at 6, 12 and 18 inch depths, and a five foot long neutron probe access tube. In 1982 and 1983, a 30-inch observation well was added at each station to monitor the free water table above the claypan. Neutron probe tubes were not installed in 1983.

The tensiometers, gypsum blocks and observation wells were read daily during the growing season. Readings were not taken on weekends or holidays unless irrigation needs were imminent. Neutron probe readings were taken on a periodical basis during the growing season.

Daily weather parameters including maximum-minimum air temperature, relative humidity, precipitation, class A pan evaporation, solar radiation and wind run were monitored at a weather station adjacent to the plots.

STATISTICAL ANALYSIS

Because of the desired comparisons in the experiments, several statistical analyses were necessary. Addition of varieties and modification of some treatments during later years further complicated matters.

After considerable deliberation, several different analyses were run in order to adequately make all of the desired comparisons.

Since the corn hybrids were not constant across years nor were two hybrids grown in all years, a randomized complete block with split plot analysis was run for each year when two hybrids were used to test for hybrid differences.

Then, in order to pool the data for tests across years, mean yields of varieties within plots were calculated and used for the analysis of the total experiment of the corn data. A seven year analysis as a randomized complete block was performed to test for treatment differences. The low tension irrigated plot data were pooled with the furrow irrigation data from the previous five years for the respective drainage treatments in this analysis since individual annual comparisons indicated no major differences were created by the change of treatments.

Analogus analyses were performed on the soybean results except that three analyses were required on the means of varieties - one for 1980-81 on all ten treatments to compare furrow irrigation, one for 1982-83 containing double crop soybeans with and without irrigation, and a four year analysis of the eight treatments remaining constant across the four years.

The appropriate error mean squares determined in the randomized complete block analyses were then used to make further comparisons in several factorial analyses to determine interactions between irrigation and drainage.

A 3 x 2 factorial analysis was run on the 1977-1981 mean corn yields and the 1980-1981 mean soybean yields to test for main effects of irrigation method (Furrow, Sprinkler, Dryland) and the applicable drainage methods (Surface, Combination), and for interaction effects of these factors. A similar factorial was run on the 1982-83 mean corn yields to test for differences due to irrigation intensity with the same drainage methods. A 2 x 4 factorial analysis was then run on the original sprinkler irrigated and dryland seven year mean corn yields and four year mean soybean yields to test for main effects of irrigation (Sprinkler, Dryland) and drainage (Surface, Combination, Tile, None), and for interaction effects of these factors.

VARIETY EFFECTS

In the years when two corn hybrids were corn, there were no significant differences between hybrids or significant treatment-hybrid interactions with the exception of 1983. In 1983, the late planting date required the planting of a short season hybrid on the non-drained plots which produced anticipated variety and variety-treatment interations. The varieties grown on drained plots did not produce significantly different yields in 1983.

Soybean varieties on the other hand, as shown in Table 6, produced significantly different yields in all years except 1983. No significant treatment-variety interactions were observed.

In spite of the lack of significant differences between corn hybrids, an important point is illustrated in Table 7, particularly in 1981 and 1982. The difference in yield potential under ideal moisture conditions (i.e. irrigated) of the hybrids may well be the margin between success and failure of irrigation. The results in Table 7 indicate that B73 x Pa91 when planted on a timely schedule is more susceptible to drought stress than Pioneer 3183. Also B73 x Pa91 produces a greater yield response to irrigation than Pioneer 3183. The virtual crop failure under dryland conditions and the extremely late planting date in 1983 mask this effect.

RANDOMIZED COMPLETE BLOCK TREATMENT EFFECTS

Tables 8 and 9 contain rankings of each treatment averaged across variety by year and for the entire experiment across years for corn and soybeans. Table contains only eight of the ten original treatments since the conversion to double crop soybeans following small grain on the furrow irrigation plots creates a situation that is not analogos to the corresponding treatments in the corn.

TREATMENT EFFECTS - CORN

Over the course of the study corn yields show a wide variation from year to year; however, inspection of Table 8 indicates several trends.

First, all treatments with drainage under irrigation (#1,2,4,6,7) nearly always produced significantly higher yields than their non-irrigated counterparts (#3,5,8); yet, significant differences in yield within these groups of treatments are rare.

Secondly, in those years when the non-irrigated treatments have considerably lower yields than their irrigated counterparts (dry years with high moisture stress), the irrigated, non-drained treatment (#9) usually produces yields which are not significantly lower than the irrigated treatments with drainage. The exception is 1983, when excessively wet soil conditions delayed planting of the non-drained treatments for nearly a month.

Third, in the years of relatively low moisture stress (high yields on non-irrigated treatments relative to irrigated plots), the irrigated non-drained treatment yields tend to fall into an intermediate group which is not significantly different than either the irrigated, drained treatments or the non-irrigated treatments. 1979 is the exception to this trend when a short period of extremely heavy precipitation late in the growing season completely flooded the non-drained treatments, killing practically all of the crop before maturity.

Fourth, the surface drained non-irrigated treatment (#3) produced the lowest yields by a considerable margin over most of the experiment. A similar trend is noticeable from 1977 through 1979 on the surface drained furrow irrigated treatment (#1). These two treatments are located adjacent to each other on the east end of the replicate in series 1200. Excessive topsoil removal during construction and grading of these plots has been previously recognized (Walker et al., 1981) as a major factor in the low yields of treatment 3 over the course of the experiment. This effect would be masked to a great extent by irrigation. However, during the initial three years of the experiment, the irrigation scheduling method added equal amounts of water to all plots rather than irrigating each plot on demand. Consequently, the south replicate of treatment #1 was quite probably under more severe water stress than its counterpart during the early years of the experiment.

Finally, when the yields of all years are combined, all of the irrigated, drained treatments fall into a group whose extremes are significantly different from each other, but neither is significantly different from the intermediate members. The irrigated treatment without drainage produces significantly lower yields than any of the other irrigated treatments, but significantly greater yields than any non-irrigated treatment. The non-irrigated treatments fall into two groups which differ significantly from each other.

TREATMENT EFFECTS - SOYBEAN

Analysis of the soybean yields in Table 9 indicates a different reaction than occurred with the corn; however, the results are generally consistent with those that would be expected since soybeans are known to be somewhat more drought tolerant and somewhat less tolerant to excess water than corn.

In looking at individual annual results, two trends are apparent. In years with drought stress (1980; 1983) irrigation has a positive effect on yield while drainage treatment tends to be neutral. In years with reasonably adequate moisture supply (1981, 1982) irrigation has little effect with adequate drainage, while drainage has a positive impact on yield. Drainage method does not appear to have a significant effect.

Analysis of the four years data suggests that irrigation with adequate drainage will provide a significant yield increase; however, under poorly drained conditions, irrigation produces no significant yield increase above dryland. Drainage treatment produced no significant differences under dryland.

THREE BY TWO FACTORIAL COMPARISONS

IRRIGATION METHOD

The results of the comparison of furrow, sprinkler irrigation methods and no irrigation on the applicable drainage combinations are shown in Tables 10, 11 and 12 for corn and Tables 13, 14 and 15 for soybeans.

Over the five year period when corn was grown under the two irrigation methods, both furrow and sprinkler irrigation produced significant yield increases over dryland conditions; however, neither irrigation treatment was significantly different from each other. Drainage treatments produced significant yield differences; however, these differences are probably caused by the previously discussed problems caused by plot construction. There were no significant interaction effects between irrigation and drainage in the irrigation method comparison.

The analogous comparison for soybeans produced no significant differences from either irrigation or drainage over the two year test. As with corn, no significant interaction effects were present.

Irrigation Intensity - Corn

Over the two years when irrigation intensity was evaluated as shown in Tables 16, 17 and 18, both irrigation intensities produced significantly higher corn yields than dryland; however, yields under the two irrigation intensities were not significantly different. No significant differences in yield were attributable to drainage method, nor were significant interactions between irrigation intensity and drainage method present.

DOUBLE CROP SOYBEANS

Table 19 indicates the results of two years irrigation trials with double crop soybeans under adequate drainage. The two years combined data indicate no significant increase in yield for double crop soybeans under irrigation. However, in comparing individual years, 1983 produced a highly significant yield increase from irrigation because of the extreme drought, while 1982 produced no yield differences in a season with very favorable precipitation resulting in no effective irrigation at all.

TWO BY FOUR FACTORIAL COMPARISONS

DRAINAGE METHODS UNDER SPRINKLER IRRIGATION AND DRYLAND - CORN

Tables 20, 21 and 22 show the annual and combined corn yield results for a 2 x 4 irrigation-drainage factorial. Over a seven year period, significant yield differences can be attributed to irrigation and to drainage treatment. A significant positive interaction between irrigation and drainage treatment is present.

IRRIGATION FACTOR - CORN

The results shown in Table 20 indicate that irrigation as a main factor consistently increases corn yield. The magnitude of the increase within years varies with the weather. The smallest increase of 22 bushels per acre was produced in 1982 when relatively cool temperatures and quite favorable precipitation distribution prevailed. The largest yield increase of 127 bushels per acre was produced in 1983 during the worst summer drought on record; the increase would have been even greater if spring and early summer rainfall allowed a reasonably normal planting date. The seven year means indicate an increase in corn yield of 62 bushels per acre.

DRAINAGE FACTOR - CORN

The seven year mean corn yields contained in Table 21 indicate that drainage likewise significantly increases production by up to 28.3 bushels per acre. However on an annual basis, the effect of drainage is not consistent. Corn yields in only two of the seven years, 1979 and 1983, were significantly reduced by a lack of drainage, but those reductions of 162 and 31.6 bushels per acre below the top ranking yield were sufficient to create a significant difference overall. Notably, in three of the seven years, the no-drainage factor produced the top yields; and in five of the seven years, produced yields ranking in the upper class of significance.

In comparing the drainage methods, overall means indicate that tile drainage may produce slightly increased yields above combination drainage; although the difference of 4.1 bushels is not significant. Surface drainage significantly reduced yield below tile or combination drainage, 12.1 and 8.0 bushels per acre, respectively. This difference is probably a reflection of the previously discussed problem of excessive topsoil removal on the dryland surface drained plot in series 1200. Inspection of the treatment combinations in Table 22 finds the dryland surface drainage mean well below its tile and combination drained counterparts in 1977 through 1980 and in 1982 when the corn experiment was on series 1100 and 1200. This difference does raise a serious question about the advisability of land leveling on claypan soils to achieve drainage unless irrigation is planned because of the possibility of creating fairly large areas of drought susceptible land.

INTERACTION - CORN

Interaction effects of drainage and irrigation are illustrated by Table 22. When irrigation is used, the type of drainage system is not a significant factor in corn production, so long as drainage is achieved. In "ordinary" years, drainage does not appear to be a significant limiting factor under irrigation. In 1979 and 1983, when drainage under irrigation caused significant increases in corn yield, two different problems associated with poor drainage in a field situation are illustrated. The 1983 results may illustrate the more common problem associated with poor drainage in a field. In a field situation, tillage and planting must be delayed until the poorly drained areas reach the proper moisture conditions; consequently, yield reductions associated with timely planting are important across the entire field. The 1979 season illustrates the other potential problem of flooding of the crop during the growing season. Although, the yield reductions over the field might not be as severe as those experienced in this experiment, production losses in field situations where ponding occurred would be experienced.

Without drainage irrigation could be expected to produce an average of 40 bushels per acre increase above dryland. Addition of drainage could double that increase to 80 bushels per acre as shown in Table 22 when comparing "Dryland and None" with "Sprinkler and Tile". In fields with adequate drainage practices yield increases in the range of 60 to 80 bushels per acre might be expected quite frequently from irrigation.

DRAINAGE METHODS UNDER SPRINKLER IRRIGATION AND DRYLAND - SOYBEANS

Soybean yields for the annual and combined results of the 2 x 4 irrigation-drainage factorial are presented in Tables 23, 24 and 25. Over the four year period, significant yield increases were produced by irrigation and drainage factors. The interaction effects of irrigation and drainage are not statistically significant.

IRRIGATION FACTOR - SOYBEANS

From inspection of Table 23, the combined 4 year analysis indicates that soybean yields are positively affected by irrigation with a mean increase of 6.7 bushels per acre. However, by looking at the annual means for the irrigation factors, this difference may be questionable in spite of the statistical significance.

In two of the four seasons, irrigation produced significantly increased yields; both of these years, 1980 and 1983 were characterized by well above normal temperatures and well below normal precipitation during the growing season - drought stress. In 1981 and 1982, temperatures and rainfall were generally quite favorable for crop growth; although, periods of deficient rainfall occurred during both years. Soybean yields were negatively affected by irrigation during those years; more so in 1981 than 1982. The near crop failure on the dryland plots in 1983 appears to have created the positive irrigation effect. Several years additional data will be necessary to establish valid estimate of potential yield under irrigation.

DRAINAGE FACTOR - SOYBEANS

Table 24 indicates that any of the drainage methods will significantly increase soybean yield over a non-drained situation by 5 to 6.4 bushels per acre. There is no significant difference between the three methods of drainage.

Annual results are consistent with the reaction to irrigation. In dry years, drainage does not significantly increase soybean yield while in years of plentiful moisture, drainage positively affects soybean production by 12 to 13 bushels per acre.

INTERACTION

The irrigation-drainage treatment comparisons in Table 25 show one interesting trend in the overall means, which does not occur during an individual year. The overall means appear to indicate that irrigation without drainage and dry land with adequate drainage produce equivalent yields; however, the annual comparisons lend little support to this conclusion. The nearly complete crop failure on the dryland treatments in 1983 has probably reduced the means of the dryland treatments to a greater degree than long term averages will indicate.

The individual annual results do illustrate the importance of drainage in years of adequate or excessive precipitation, particularly when irrigation is used.

IRRIGATION SCHEDULING TO OPTIMIZE WATER USE ON CLAYPAN SOILS

Irrigation scheduling is an important part of both management and planning of irrigation systems. If the irrigation cycle begins too early, there is a waste of water and an overtaxing of the drainage system. If there is a delay in irrigation crop yields will be reduced and benefits that could have resulted from timely irrigation will be lost.

During the 1981 growing season a study was made of the applicability of a commonly used irrigation scheduling procedure to the corn treatment 7. The procedure selected was the checkbook method of irrigation scheduling (Lundstrom, D. R. and Stegman, E.C., 1983). This method involves use of maximum daily temperature and rainfall records, the soil water holding capacity and crop growth stages. It has the advantage of simplicity for ready farm use and has been adopted as an acceptable method by the Illinois Irrigation Association. The soil moisture content predicted by the checkbook method was compared to the soil moisture determined using tensiometers. In order to convert tensiometer data to water content on a volume basis, soil water characteristics were necessary. The soil water characteristics curve used was that specified in the checkbook method. All measurements were made on plots 909 and 1004 as shown in Figure 3.

Since the soil association on the plots selected was Cisne silt loam with a very heavy substratum (claypan), the water holding capacity of a clay loam soil, 2.6 inches per foot, was selected for the base water content. Corn is ordinarly a deep rooted crop but because of the restrictive claypan layer, roots are generally limited to less than two feet, consequently 1.5 feet was selected for the rooting depth throughout the growing season.

Three critical time periods were selected during the summer of 1981. These periods were selected because they represented the crop water use during times of low precipitation for the early, middle and late growing season.

Figures 5 and 6 show the calculated and measured values of soil water together with rainfall and irrigation for the 1981 season. Tensiometer values were determined by averaging readings at the 12 and 18 inch depth and converting these readings to volumetric moisture in inches per foot.

The negative slopes of the plotted lines in Figures 5 and 6 show the water use rate between irrigations, a most important factor in an irrigation scheduling model. When these slopes are compared they show that the checkbook method provided a conservative estimate of water use based on 1981 data.

The positive increments of soil water shown in Figures 5 and 6 result from irrigation on July 11 and rainfall on July 14. The predicted increases are based on a no loss assumption and are greater than the measured values. Water losses are highly variable on claypan soil, depending on all factors affecting runoff as well as those which determine evapotranspiration during irrigation and rainfall.

Analysis of 1981 data showed that the checkbook method of irrigation scheduling could be adapted to claypan soils. In practice the checkbook values should be corrected after every rainfall or irrigation using devices, such as tensiometers, to provide input of actual field moisture measurements.

DRAINAGE OF CLAYPAN SOILS

The purpose of agricultural drainage in humid regions such as in Central Illinois is to lower the water content of the root zone so that air can penetrate to the plant roots, thus providing oxygen to the roots and transporting away the carbon dioxide produced. The necessary chemical reactions and activity by microorganisms are facilitated by the presence of air and removal of carbon dioxide. The water content at which drainage becomes critical is very near saturation, consequently the water table or phreatic surface in the soil is often used as the indication of adequate drainage. The devices used to determine the lower water contents in the soil that are critical in evaluating drought stress are usually not very effective in determining the position of the water table. The usual device used to determine water table elevation is an open observation well. Almost all drainage design criteria is based on control of the position of the water table in the soil as measured with such wells.

The effect of water table depth on crop yield (Sieben, 1964) has led to the acceptance of SEW_{30}. SEW_{30} is the sum of excess water-table rises above the 30-cm depth ordinarily measured in cm days. For example, if the water table is at an average depth of 20 cm for 10 days, SEW_{30} = 100 cm days. The total measure of SEW_{30} during the growing season gives a value that relates inversely to the effectiveness of a drainage system.

Certain soil parameters are very useful in designing drainage systems. These same soil parameters can be used in comparing the drainability of soils. Hydraulic conductivity, K, is one such parameter while drainable porosity, f, is another.

Patronsky and Schwab (1979) describe a method whereby field measured values of water table, measured during drawdown, can be used to determine the effectiveness of a drainage system.

During 1982 two observation wells were installed at the center line between the subsurface drains for each of the plots after planting operations and at the same point in plots without drains. Readings of water elevation were taken in each well on a daily basis during periods of high water table. This permitted a measure of SEW_{30} for each drainage treatment. Figure 7 shows the results of this 1982 study of SEW_{30}. Each value in Figure 7 represents an average of 4 values, 2 from each of 2 plots. There was a wide variation in measurements thus limiting the level of significance of the 1982 data but some inferences can be made from the averages: (1) The nondrained treatments had total SEW_{30} values more than two times greater than the highest value for a drainage treatment. All drainage treatments effectively reduced the SEW_{30} value, (2) The irrigated treatments resulted in greater SEW_{30} values than nonirrigated treatments and (3) There was very little difference in SEW_{30} values between drainage treatments.

During the fall of 1983 two subsurface drainage plots were selected to conduct a test of K/f using the method of Patronsky and Schwab (1979). The plots selected were 1202 and 1206. The plots were saturated by irrigation on November 14 and drawdown measurements were made for a 12 hour period after saturation. The calculated average K/f value using observation wells at the .1 spacing point was found to be 0.037 m/hr. This is a very low value of K/f when compared to other heavy soils and indicates that the 20 foot drain spacing used in this research is appropriate for such slowly permeable soil. A twenty foot spacing between drains is probably not an economical practice for grain crops. Since there is very little difference in SEW_{30} between the subsurface drainage treatment and the surface drainage treatment, probably surface drainage is the more economical drainage practice on these soils if we consider the year when SEW_{30} values were collected, 1982, to be a typical year.

PLASTIC TUBING PERFORMANCE

One set of twenty plots, the 1100 and 1200 series, was constructed in 1976 including a subsurface drainage system, consequently 1983 was the seventh season of operation. An investigation of the 3-inch plastic tubing was made in August of 1983 to evaluate its condition. The tubing depth to grade averaged 15.5 inches with an average of 12 inches of cover. No sediment control measures had been used during installation. Twenty-three excavations were made on 8 plots, a sample of drain tubing was removed and replaced, and observations were made of sediment and roots in the drains as well as deflection. The maximum deflection found in any drain at the excavation point was 6%. This is much less than the allowable 20% used as the current standard for platic tubing for most drainage installations. Four to six inch disking had been the deepest tillage used at any time during the study with the exception of 1980 (see Tables 1 and 2). The sediment in drains was a more disturbing factor than deflection. Of the 23 samples collected 14 contained measurable quantities of sediment and in 6 samples the sediment had displaced over 20 percent of the tubing diameter. In many cases roots had entered the tubing through drain openings. In some cases the roots had formed a fibrous mat that exceeded 10 percent of the drain diameter. Figure 8 shows an example of a section of tubing where root intrusion was excessive.

The study of plastic tubing condition resulted in two conclusions: 1. The three inch plastic tubing used in this study was structurally adequate with one foot of soil cover. No deep tillage was used during the study. 2. Roots and sediment were problems in shortening drain life. Some sediment control measures should have been used during installation.

ECONOMIC CONSIDERATIONS

An economic analysis of irrigation using a center pivot system with a groundwater source indicates that corn yield increases of 50 to 64 bushels per acre are necessary to cover fixed and variable costs; soybean yield increases of 20 to 27 bushels per acre are necessary to cover the same costs (Bruckner et al., 1982). The average corn yield increases over seven years are probably sufficient to pay for the system and perhaps produce some profits under these assumptions; soybean yield increases from irrigation are too low to pay for the system, under the assumed conditions. On a yearly basis, increases in corn yield would have been profitable in three of the years, and unprofitable in four years. Soybean production increases would have been marginal during one year, 1983, and insufficient to pay costs during the other three years.

Some additional factors which are important on claypan soil should receive careful consideration prior to installation of an irrigation system. Unless the area to be irrigated is adequately drained naturally, drainage installation costs may be significant. Probably the most important consideration will be availability of a suitable site for a reservoir to provide water for the irrigation system since groundwater supplies are generally inadequate for this purpose in the claypan region. The land and development costs for a reservoir of sufficient size to provide a dependable water source are almost certain to exceed the development cost of the well assumed by Bruckner et al. Another complication associated with reservoir construction is the potential loss of cropland to the reservoir; probably most of the cropland lost to a reservoir would be of the higher productivity classes.

CONCLUSIONS

1. Corn was found to be particularly responsive to both drainage and irrigation with an average yield increase of 80 bushels per acre when comparing "No irrigation" and "No drainage" with "Sprinkler irrigation" and "Tile drainage".

2. Irrigation of claypan soils significantly increases corn yields even during years with quite favorable precipitation distribution. Yield increases of 12 to 40 bushels per acre may be expected during those favorable years with proper irrigation scheduling. Soybeans are less responsive to irrigation; although, significant yield increases from irrigation are possible under persistent drought conditions.

3. The irrigation methods tested produce equivalent yield responses from both corn and soybeans.

4. Irrigation of corn at less than fifty percent soil moisture depletion neither increases or decreases yield; consequently, irrigation for maximum yield on dry sites within a field will not reduce production on the more moist areas.

5. Irrigation scheduling with soil moisture monitoring devices produces the most efficient use of water supplies. The checkbook scheduling system can produce similarly good water use efficiency. The antecedent total moisture method of irrigation scheduling is less efficient.

6. Irrigation of double crop soybeans is promising; however, two years data is insufficient to draw firm conclusions concerning the productivity increase.

7. Drainage method is of little importance to crop yield under irrigation, so long as drainage is provided.

Without irrigation, surface drainage, particularly wide scale leveling, may reduce topsoil depth causing severe yield reductions in localized areas.

Tile drainage of soils with adequate surface drainage produces no yield increases. Tile drainage of inadequately drained sites is a viable alternative to surface drainage. Since grading is not necessary, topsoil disturbance is held to a minimum. A further advantage of tile drainage is the improved water quality since the tile effluent is practically sediment free. Disadvantages of tile drainage in claypan soils are some limitation of tillage options because of the necessarily shallow depth of installation and sedimentation into the tile. The sedimentation problem may be corrected by use of a sediment barrier over the tile.

8. Corn hybrids and soybean varieties used in the experiment have illustrated some potentials and problems associated with irrigation. The superior response of the B73 x Pa91 corn hybrid to irrigation in 1981 and 1982 suggests that hybrid selection is of considerable importance. Likewise, careful selection of soybean varieties under irrigation is necessary. The indeterminate types used were all subject to considerable lodging under irrigation, but lodging was not observed in the determinate type soybean that was grown.

9. The results of this study are site specific and careful economic analysis of the development costs associated with irrigation system installation on claypan soils including drainage and water supply will be required to determine feasibility for a particular situation.

Table 1. CROP MANAGEMENT, CORN

Series	1977 1100,1200	1978 1100,1200	1979 1100,1200	1980 1100,1200	1981 900,1000	1982 1100,1200	1983 900,1000
Variety	Pioneer 3184	Pioneer 3543	Mo17 x H100	Pioneer 3183 Pioneer Ex7227	Pioneer 3183 B73 x Pa91	Pioneer 3183 B73 x Pa91	Pioneer 3183 B73 x Pa91 DeKalb T1100*
Planting Date	April 26	July 3	May 9 June 6*	May 13	April 21	May 1	June 13 July 12*
Population	22,000 (Dropped)	24,000 (Dropped)	26,000 21,000	33,000 24,000	27,000 25,000	33,000 27,400	24,800 19,800
Tillage	Zero-Till	Disc (Twice) Disc (once)*	Zero-Till	Chisel between tile lines Disc (Twice)	Disc	Disc (Twice) Field Cultivate	Disc Field Cultivate
Fertility Management	0-46-0 100 lbs/A 0-0-60 100 lbs/A 34-0-0 365 lbs/A	34-0-0 600 lbs/A 0-46-0 260 lbs/A 0-0-60 265 lbs/A	17-45-0 300 lbs/A 0-0-60 150 lbs/A 34-0-0 600 lbs/A 34-0-0 300 lbs/A	34-0-0 200 lbs/A 0-46-0 200 lbs/A 0-0-60 150 lbs/A 34-0-0 100 lbs/A	Urea 435 lbs/A 0-46-0 200 lbs/A 0-0-60 200 lbs/A 34-0-0 440 lbs/A	Urea 217 lbs/A 0-46-0 200 lbs/A 0-0-60 400 lbs/A 34-0-0 294 lbs/A 34-0-0 294 lbs/A	Urea 217 lbs/A Anhydrous Ammonia 240 lbs/A* 0-46-0 200 lbs/A 0-0-60 400 lbs/A 34-0-0 530 lbs/A
Weed Control	Atrazine 80W 1.25 lb/A Princep 80W 1.25 lb/A 2,4D 1 pt/A Paraquat 1 qt/A Surfactant	AAtrex 4L 1 qt/A Lasso 2 qt/A Princep 1 qt/A Paraquat 1 qt/A Surfactant	Lasso 2 qt/A AAtrex 4L 1.5 qt/A Bladex 80W 1.5Lb/A Roundup 2 qt/A	Bladex 4L 1.5 qt/A Dual 8E 1.25 qt/A	AAtrex 4L 1 qt/A Lasso 2.5 qt/A	Bladex 4L 1 qt/A AAtrex 4L 1 pt/A Lasso 2.5 qt/A	Bladex 4L 1.25 qt/A AAtrex 4L 1 pt/A Lasso 3 qt/A AAtrex 4L 1.25 qt/A* Lasso 2 qt/A*
Pest Control	----------	Diazinon 1 lb/A (Earworm and armyworm)	----------	Furadan 10g 14 lb/A (In furrow)	Diazinon (seed box) Furadan 10 g 10 lb/A (Aerial-cornborers)	Diazinon (seed box) Sevin bait (Cutworms)	----------
Harvest Date	October 4	November 9	September 26 October 30*	October 9-10	September 25-26	September 23 September 27*	November 1 November 10*

*Non-Drained plots
All corn is planted in 30-inch rows.

Table 2. CROP MANAGEMENT - SOYBEANS

	Conventional				Double Crop	
Series	1980 900,1000	1981 1100,1200	1982 900,1000	1983 1100,1200	1982 900,1000	1983 1100,1200
Variety	Williams, Mitchell	Williams, Pixie	Williams, Pixie	Williams, Pixie Williams, Lawrence	Williams, Lawrence	Williams, Lawrence
Planting Date	May 27	May 1	May 11	June 22, June 24* July 7 (Replant)	July 13	July 7
Seeding Rate	45 lb/A - 30"	45 lb/A - 30" (Will) 60 lb/A - 30" (Pix)	90 lb/A - 15"	60 lb/A - 30"	90 lb/A - 15"	60 lb/A - 30"
Tillage	Disc	Disc	Disc	Disc Field Cultivator	Zero-Till	Zero-Till
Fertility Management	0-46-0 220 lb/A 0-0-60 330 lb/A	0-46-0 200 lb/A 0-0-60 300 lb/A	0-46-0 200 lb/A 0-0-60 400 lb/A (Fall-disc incorp.)	0-46-0 200 lb/A 0-0-60 200 lb/A	0-46-0 200 lb/A 0-0-60 400 lb/A (Prior to planting small grain)	0-46-0 130 lb/A 0-0-60 200 lb/A (Fall, prior to wheat seeding)
Weed Control Pre-emergent	Sencor 4 .75 pt/A Lasso 2 qt/A Paraquat 1 qt/A Surfactant	Lorox 50W 1 lb/A Lasso 2 qt/A Surflan 4AS .75 qt/A	Sencor 4 .75 pt/A Treflan .75 qt/A Dual .75 qt/A (Disc incorporated)	Lasso 3 qt/A Lorox 1.75 pt/A Paraquat 1 qt/A	Roundup 2 qt/A Lorox 1 qt/A Surflan 1 qt/A Furloe 2 qt/A Surfactant	Lasso 3 qt/A Lorox 1.75 pt/A Paraquat 1 qt/A
Post-emergent	---------	Handweeded (3 times)	Poast 1 qt/A* Handweeded (Twice)	---------	Hoelon 1.5 qt/A	---------
Pest Control	Cygon 400 1 pt/A	Sevin 80W 1-1/4 lb/A April 28-Bean beetle August 11-Blister beetle Benlate 50 .5 lb/A (July 21 & August 11)	Grandstand (seed treatment) Benlate 50 .5 lb/A (August 5)	---------	---------	---------
Harvest Date	October 1 (Wil) October 8(Mit)	September 26 (Wil) September 29 (Pix)	September 29 (Wil) October 5 (Pix)	November 1	November 8	November 1

*Non-Drained plots

Table 3. Irrigation Amounts, Corn

	Furrow		Sprinkler			
Year	Surface	Combination	Surface	Combination	Tile	None
1977	6.8	6.8	4.6	4.6	4.6	4.6
1978	7.1	7.1	7.1	7.1	7.1	7.1
1979	4.4	4.4	4.2	4.2	4.2	4.2
1980	9.2	9.2	7.0	7.0	7.0	7.0
1981	5.4	5.7	3.9	5.3	4.4	3.3
1982	3.2*	3.3*	2.2	2.5	2.0	2.4
1983	9.8*	9.3*	8.8	8.9	7.8	6.0

*Sprinkler irrigation applied at 1/3 plant available moisture depletion.

Table 4. Irrigation Amounts, Soybeans

	Furrow		Sprinkler			
Year	Surface	Combination	Surface	Combination	Tile	None
1980	4.5	4.5	5.1	5.1	5.1	5.1
1981	4.8	4.8	2.7	2.9	2.9	3.0[1]
1982	0*	0*	2.0	2.0	2.0	1.2
1983	5.8*	5.8*	7.2	7.7	7.4	8.0

*Sprinkler irrigation on zero-till double crop beans following small grain.

[1]One plot, the other plot had a greatly reduced population from early flooding and did not require irrigation.

Table 5. Corn Hybrids - Mean Yield

Hybrid	1980	1981	1982	1983
Pioneer 3183	118.3	187.9	178.6	99.2
B73 x Pa91	--	193.6	181.9	83.9
Pioneer Ex7227	114.3	--	--	--
DeKalb T1000*	--	--	--	44.5

*Non-drained plots only

Table 6. Soybean Varieties - Mean Yields

Variety	1980	1981	1982	1983
Williams	42.1	49.7	43.9	21.7
Pixie	--	57.3	41.0	--
Lawrence	--	--	31.8*	19.5
Mitchell	44.4	--	--	--

*Double crop only

Table 7. Corn Hybrid Performance and Irrigation

Variety	1980		1981		1982		1983	
	Sprinkler	Dryland	Sprinkler	Dryland	Sprinkler	Dryland	Sprinkler	Dryland
Pioneer 3183 (A)	153.4	59.1	193.2	179.9	182.7	172.1	158.8*	1.6*
Pioneer Ex7227 (B)	148.3	54.9	--	--	--	--	--	--
B73 x Pa91 (B)	--	--	206.7	174.7	195.4	162.1	132.4*	3.5*
Difference (A - B)	+5.1	+4.1	-13.5	+5.2	-12.7	+10.0	+26.4	-1.9

*Drained plots only

Table 8. Corn Yield

Treatment Year	4	7	6	2	1	9	5	8	10	3	LSD
1977	150.0 A	150.6 A	150.8 A	148.9 A	140.0 A	142.7 A	64.1 BC	62.2 BC	75.0 B	43.3 C	21.60
1978	91.6 A	80.8 AB	75.9 AB	75.6 AB	61.4 BC	96.4 A	41.5 CD	40.5 CD	38.2 D	25.1 D	
1979	195.0 A	186.5 AB	184.0 AB	185.5 AB	167.0 BC	9.5 E	161.0 C	150.0 C	22.5 E	117.0 D	
1980	144.6 B	157.6 AB	173.0 A	157.8 AB	158.8 AB	143.4 B	54.7 D	57.0 D	81.4 C	34.8 E	
1981	201.0 A	201.3 A	199.5 AB	203.3 A	198.9 AB	194.2 AB	188.9 ABC	170.7 C	177.9 B	171.7 C	
1982	197.9 A	190.5 AB	184.9 ABC	185.2 ABC	192.7 A	182.7 ABC	176.8 ABCD	164.1 CD	169.4 BCD	158.0 D	
1983	147.3 A	148.1 A	145.1 A	141.5 A	142.7 A	83.9 B	4.8 C	1.6 C	5.1 C	1.2 C	
All years	161.0 A	159.3 AB	159.0 AB	156.8 AB	151.6 B	121.8 C	98.8 D	92.3 D	81.4 E	78.8 E	8.16

Treatments with the same letter are not significantly different.

Table 9. Soybean Yield

Treatment Year	7	4	2	5	8	3	9	10	LSD
1980	45.4 A	48.1 A	47.7 A	41.8 AB	30.6 B	38.6 AB	45.7 A	42.6 A	11.52
1981	53.2 A	54.2 A	51.2 A	59.4 A	59.4 A	54.1 A	36.6 B	49.8 A	
1982	48.2 A	46.0 A	46.5 A	47.2 A	48.8 A	47.8 A	30.2 B	38.1 AB	
1983	38.2 A	35.5 A	33.6 A	4.4 B	10.2 B	6.1 B	34.0 A	8.4 B	
All years	46.3 A	45.9 A	44.8 A	38.2 B	37.3 B	36.7 B	36.6 B	34.7 B	5.76

Treatments with the same letter are not significantly different.

Table 10. Corn Yield, Irrigation Method

Irrigation Method	1977	1978	1979	1980	1981	Average
Furrow	145.4 A	68.7 A	175.5 A	165.9 A	199.2 A	150.9 A
Sprinkler	149.7 A	78.2 A	186.0 A	157.7 A	202.3 A	154.8 A
Dryland	52.8 B	32.8 B	133.5 B	45.9 B	171.2 B	87.2 B
LSD	15.27 →					6.90

Treatments with the same letter are not significantly different.

Table 11. Corn Yield, Drainage Method

Drainage Method	1977	1978	1979	1980	1981	Average
Surface	110.7 A	54.1 A	156.5 B	117.1 A	191.3 A	125.9 B
Combination	121.2 A	65.7 A	173.5 A	129.2 A	190.5 A	136.0 A
LSD	12.47 →					5.58

Treatments with the same letter are not significantly different.

Table 12. Corn Yield, Drainage and Irrigation Combined

Irrigation x Drainage	1977	1978	1979	1980	1981	Average
Furrow x Surface	140.0	61.4	167.0	158.8	198.9	145.2 B
Furrow x Combination	150.8	75.9	184.0	173.0	199.5	156.6 A
Sprinkler x Surface	148.9	75.6	185.5	157.8	203.3	154.2 AB
Sprinkler x Combination	150.6	80.8	186.5	157.6	201.3	155.4 A
Dryland x Surface	43.3	25.2	117.0	34.8	171.7	78.4 D
Dryland x Combination	62.2	40.5	150.0	57.0	170.7	96.1 C
LSD	21.60 →					9.66

Treatments with the same letter are not significantly different.

Table 13. Single-cropped Soybean Yield, Irrigation Method

	1980	1981	Average
Furrow	45.9 A	58.4 A	52.2 A
Sprinkler	46.5 A	52.4 A	49.5 A
Dryland	34.6 B	56.8 A	45.7 A
LSD	9.58 →		6.77

Treatments with the same letter are not significantly different.

Table 14. Single-cropped Soybean Yield, Drainage Method

	1980	1981	Average
Surface	44.6 A	54.3 A	49.5 A
Combination	40.1 A	57.4 A	48.8 A
LSD	7.82 →		5.53

Treatments with the same letter are not significantly different.

Table 15. Single-cropped Soybean Yield, Irrigation and Drainage Combined

	1980	1981	Average
Furrow x Surface	47.5	57.6	52.6 A
Furrow x Combination	44.3	59.3	51.8 A
Sprinkler x Surface	47.7	51.2	49.4 A
Sprinkler x Combination	45.4	53.5	49.5 A
Dryland x Surface	38.6	54.1	46.4 A
Dryland x Combination	30.6	59.4	45.0 A
LSD	13.55 →		9.58

Treatments with the same letter are not significantly different.

Table 16. Corn Yield, Irrigation Intensity Comparison

	1982	1983	Average
Low Tension	188.8 A	143.9 A	166.3 A
Normal	187.8 A	144.8 A	166.3 A
Dryland	161.1 B	1.4 B	81.2 B
LSD 15.27 →			10.80

Treatments with the same letter are not significantly different.

Table 17. Corn Yield, Drainage Method Comparison on Irrigation Intensity Plots

	1982	1983	Average
Surface	178.6 A	95.1 A	136.9 A
Combination	179.9 A	98.3 A	139.1 A
LSD 12.47 →			8.82

Treatments with the same letter are not significantly different.

Table 18. Corn Yield, Irrigation Intensity Drainage Method Combined

	1982	1983	Average
Low Tension x Surface	192.7	142.7	167.7 A
Low Tension x Combination	184.9	145.1	165.0 A
Regular x Surface	185.2	141.5	163.4 A
Regular x Combination	190.5	148.1	169.3 A
Dryland x Surface	158.0	1.2	79.6 B
Dryland x Combination	164.2	1.6	82.9 B
LSD 21.60 →			15.27

Treatments with the same letter are not significantly different.

Table 19. Double-Crop Soybeans

	1982	1983	Average
Sprinkler	30.8 A	26.7 A	28.7 A
Dryland	31.8 A	9.4 B	20.6 B
LSD 6.50 →			4.60

Treatments with the same letter are not significantly different.

Table 20. Corn Yield, Irrigation Averaged Across Drainage

	1977	1978	1979	1980	1981	1982	1983	Average
Sprinkler	148.0 A	86.1 A	144.1 A	150.8 A	200.0 A	189.1 A	130.2 A	149.8 A
Dryland	61.2 B	36.3 B	112.6 A	57.0 B	177.3 B	167.1 B	3.2 B	87.8 B
LSD	10.80 →							4.08

Treatments with the same letter are not significantly different.

Table 21. Corn Yield, Drainage Averaged Across Irrigation

	1977	1978	1979	1980	1981	1982	1983	Average
Surface	96.1 A	50.4 B	151.2 B	96.3 B	187.5 A	171.6 B	71.4 A	117.8 B
Combination	106.4 A	60.6 AB	168.2 A	107.3 AB	186.0 A	177.3 AB	74.8 A	125.8 A
Tile	107.0 A	66.5 A	178.0 A	99.6 AB	194.9 A	187.4 A	76.1 A	129.9 A
None	108.9 A	67.3 A	16.0 C	112.4 A	186.0 A	176.0 AB	44.5 B	101.6 C
LSD	15.27 →							5.77

Treatements with the same letter are not significantly different.

Table 22. Corn Yield, Treatment Combinations

	1977	1978	1979	1980	1981	1982	1983	Average
Sprinkler x Surface	148.9 A	75.6 A	185.5 A	157.8 A	203.3 A	185.2 ABC	141.5 A	156.8 A
Sprinkler x Combination	150.6 A	80.8 A	186.5 A	157.6 A	201.3 A	190.5 AB	148.1 A	159.3 A
Sprinkler x Tile	150.0 A	91.6 A	195.0 A	144.6 A	201.0 A	197.9 A	147.3 A	161.0 A
Sprinkler x None	142.7 A	96.4 A	9.5 D	143.4 A	194.2 AB	182.7 ABC	83.9 B	121.8 B
Dryland x Surface	43.3 C	25.1 B	117.0 C	34.8 D	171.7 C	158.0 D	1.2 C	78.8 E
Dryland x Combination	62.2 BC	40.5 B	150.0 B	57.0 C	170.7 C	164.1 CD	1.6 C	92.3 C
Dryland x Tile	64.1 BC	41.5 B	161.0 B	54.7 CD	188.9 ABC	176.8 ABCD	4.8 C	98.8 C
Dryland x None	75.0 B	38.2 B	22.5 D	81.4 B	177.9 BC	169.4 BCD	5.1 C	81.4 D
LSD 21.60 ⟶								8.16

Treatments with the same letter are not significantly different.

Table 23. Single-crop Soybean Yield, Irrigation Averaged Across Drainage

	1980	1981	1982	1983	Average
Sprinkler	46.7 A	48.9 B	42.7 A	35.3 A	43.4 A
Dryland	38.4 B	55.7 A	45.5 A	7.2 B	36.7 B
LSD 5.76					2.88

Treatments with the same letter are not significantly different.

Table 24. Single-crop Soybean Yield, Drainage Averaged Across Irrigation

	1980	1981	1982	1983	Average
Surface	43.2 A	52.7 A	47.2 A	19.8 A	40.7 A
Combination	38.0 A	56.5 A	48.5 A	24.2 A	41.7 A
Tile	44.9 A	56.8 A	46.6 A	19.9 A	42.1 A
None	44.2 A	43.2 B	34.1 B	21.2 A	35.7 B
LSD 8.15					4.07

Treatments with the same letter are not significantly different.

Table 25. Single-crop Soybean Yield, Treatment Combinations

	1980	1981	1982	1983	Average
Sprinkler x Surface	47.7 A	51.2 A	46.5 A	33.6 A	44.8 A
Sprinkler x Combination	45.4 A	53.5 A	48.2 A	38.2 A	46.3 A
Sprinkler x Tile	48.1 A	54.2 A	46.0 A	35.5 A	45.9 A
Sprinkler x None	45.7 A	36.6 B	30.2 B	34.0 A	36.6 B
Dryland x Surface	38.6 AB	54.1 A	47.8 A	6.1 B	36.6 B
Dryland x Combination	30.6 B	59.4 A	48.8 A	10.2 B	37.2 B
Dryland x Tile	41.8 AB	59.4 A	47.2 A	4.4 B	38.2 B
Dryland x None	42.6 A	49.8 A	38.1 AB	8.4 B	34.7 B
LSD 11.52					5.76

Treatments with the same letter are not significantly different.

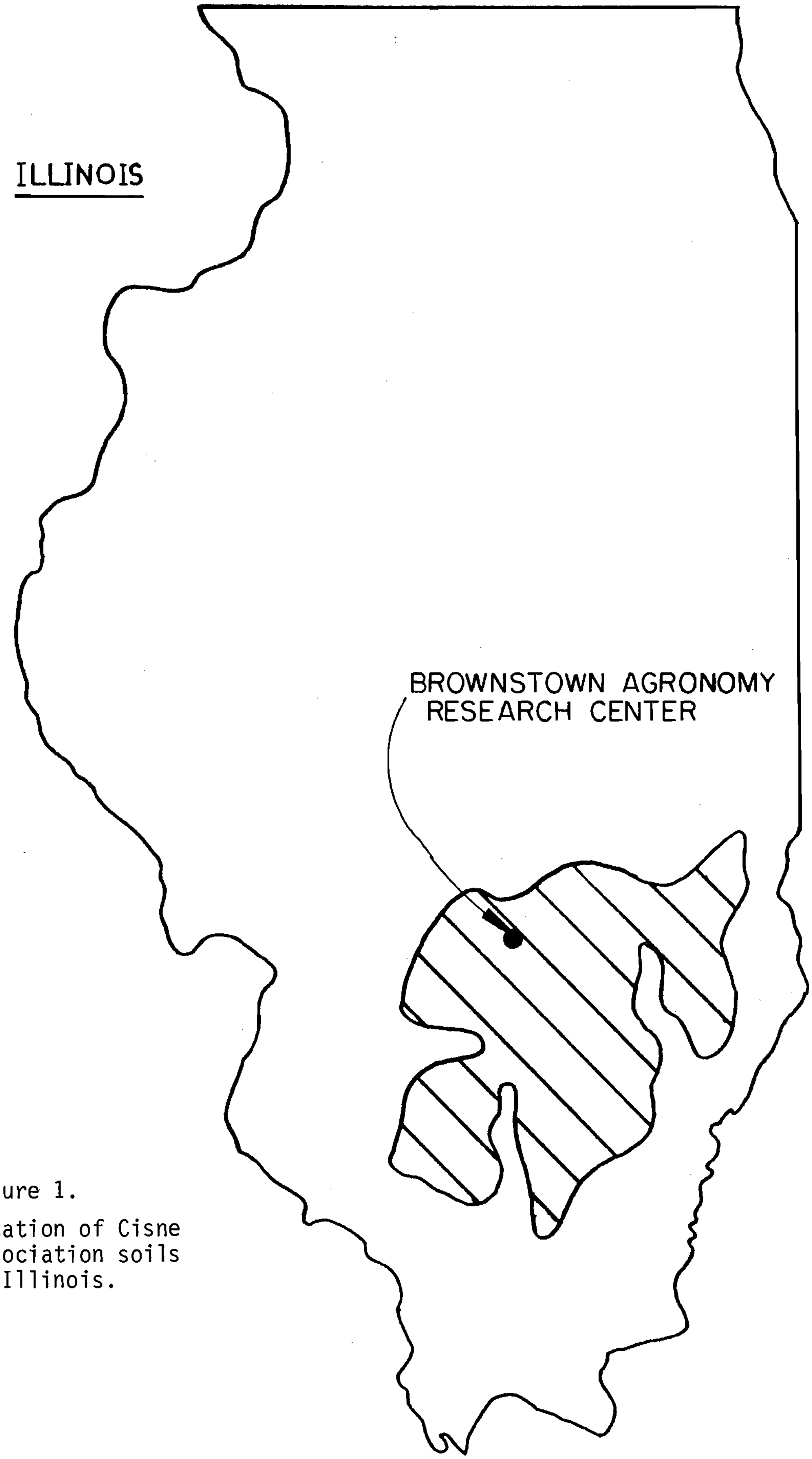

Figure 1.

Location of Cisne Association soils in Illinois.

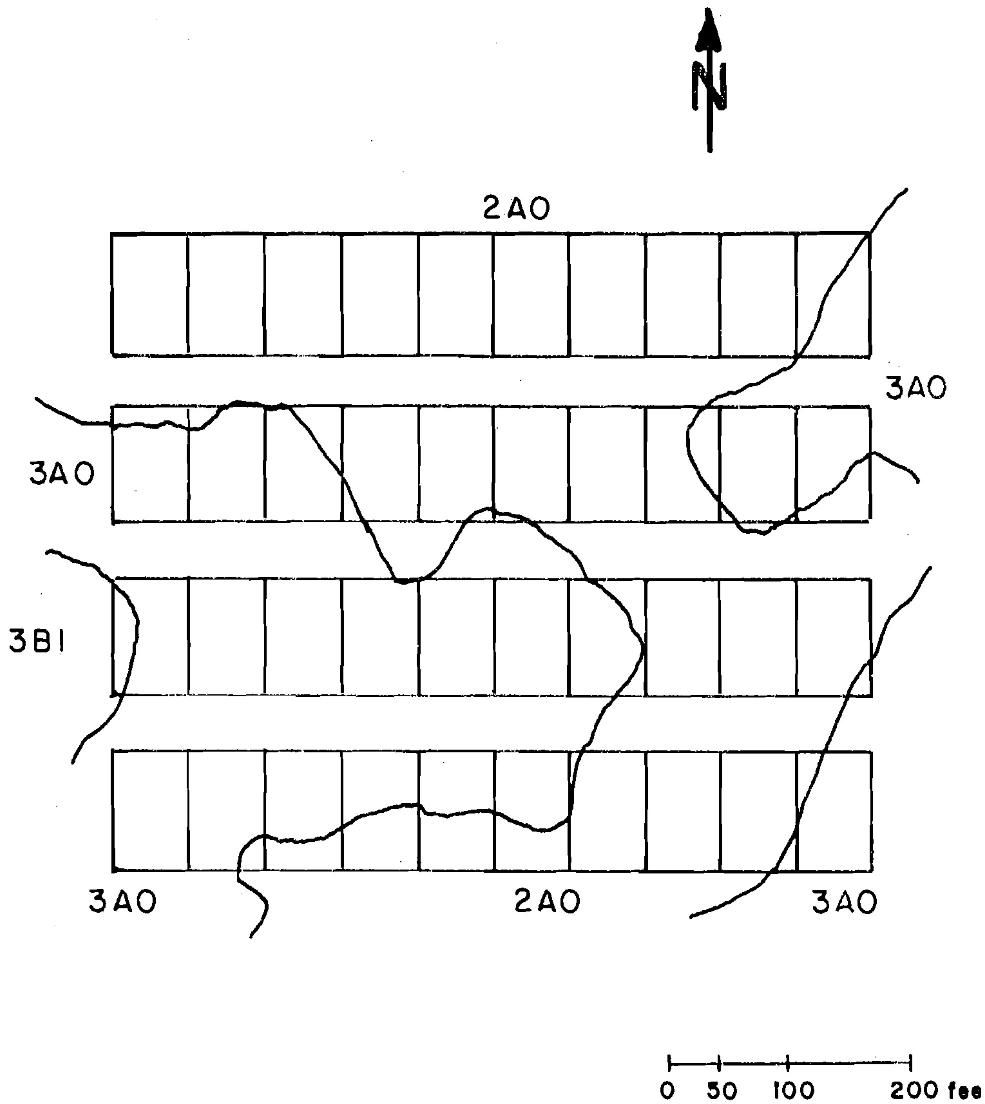

Figure 2. Soils map for plot area.

Soil types shown are:
2A0 -- Cisne, 0-1.5% slope, no erosion
3A0 -- Hoyleton, 0-1.5% slope, no erosion
3B1 -- Hoyleton, 1.5-5.0% slope, slight erosion

Treatment Combinations

Irrigation / Drainage	Surface	Sprinkler	None
Surface	1	2	3
Subsurface	X	4	5
Surface Plus Subsurface	6	7	8
None	X	9	10

Plot Layout

N ↑

10	9	8	7	6	5	4	3	2	1	Series
2	7	6	8	1	3	4	9	10	5	900
9	4	5	10	8	6	7	2	1	3	1000
2	7	6	8	1	3	4	9	10	5	1100
9	4	5	10	8	6	7	2	1	3	1200

Treatment numbers have been arbitrarily assigned. Treatments were as illustrated, 1977-1981. Treatments were randomly assigned to blocks (Series 1100 and 1200) in 1977. When series 900 and 1000 were added in 1980, the original randomized layout was duplicated and soybeans were planted on the new plots. After 1980 corn and soybeans were rotated. In 1982, Treatments #1 and #6 were modified as follows:

Corn

Series 1100-1200
Treatment #1 - Low Tension, Sprinkler Irrigation
Treatment #6 - Low Tension, Sprinkler Irrigation

Soybeans

Series 900
Treatment #1 - Double Crop, No Irrigation
Treatment #6 - Double Crop, Sprinkler Irrigation

Series 1000
Treatment #1 - Double Crop, Sprinkler Irrigation
Treatment #6 - Double Crop, No Irrigation

Figure 3. Brownstown Irrigation and Drainage Study.

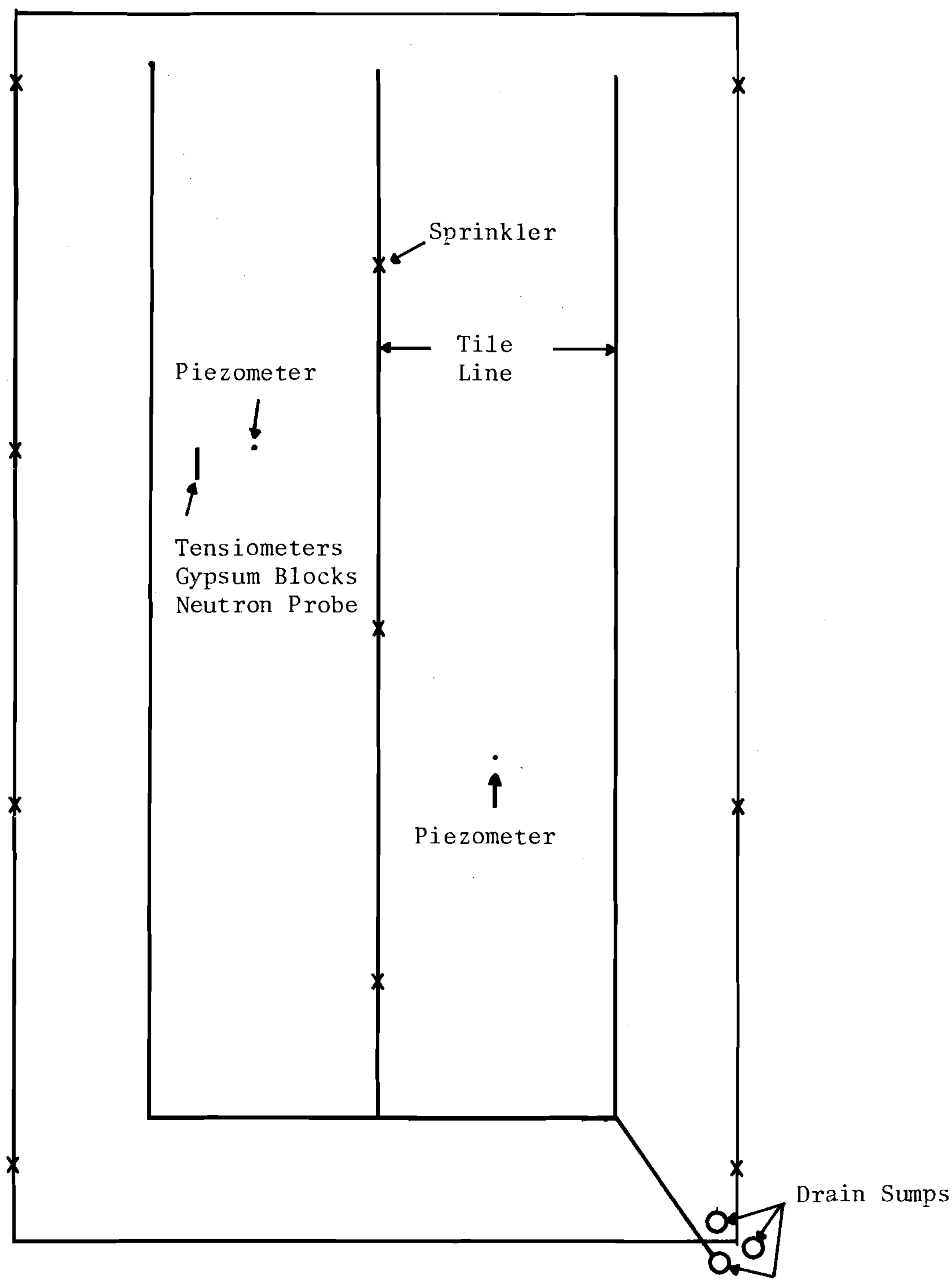

Figure 4. Plot Layout of Treatment 7 Showing Instrument Locations.

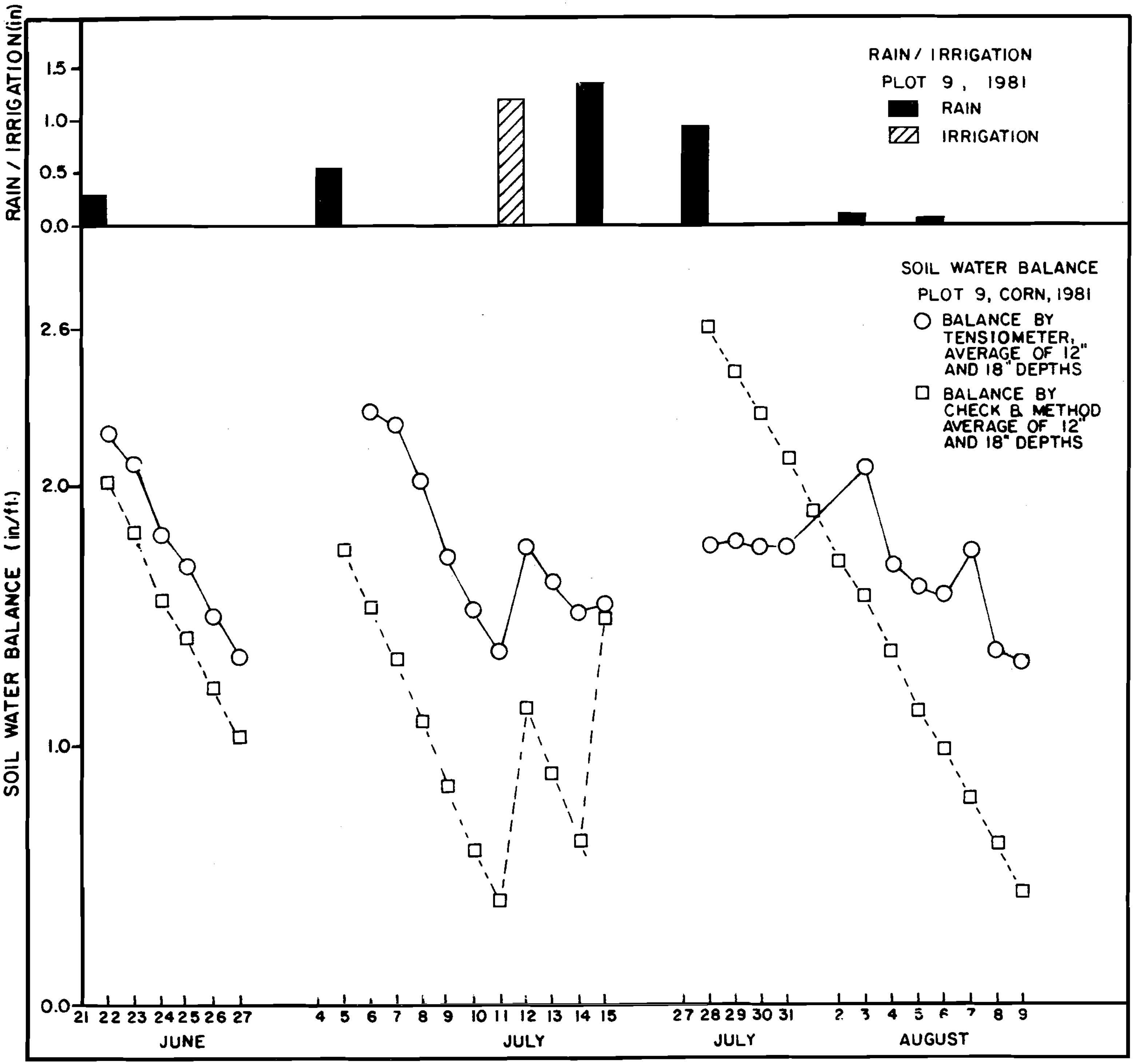

Figure 5. Soil Water Balance on Plot 9, 1981.

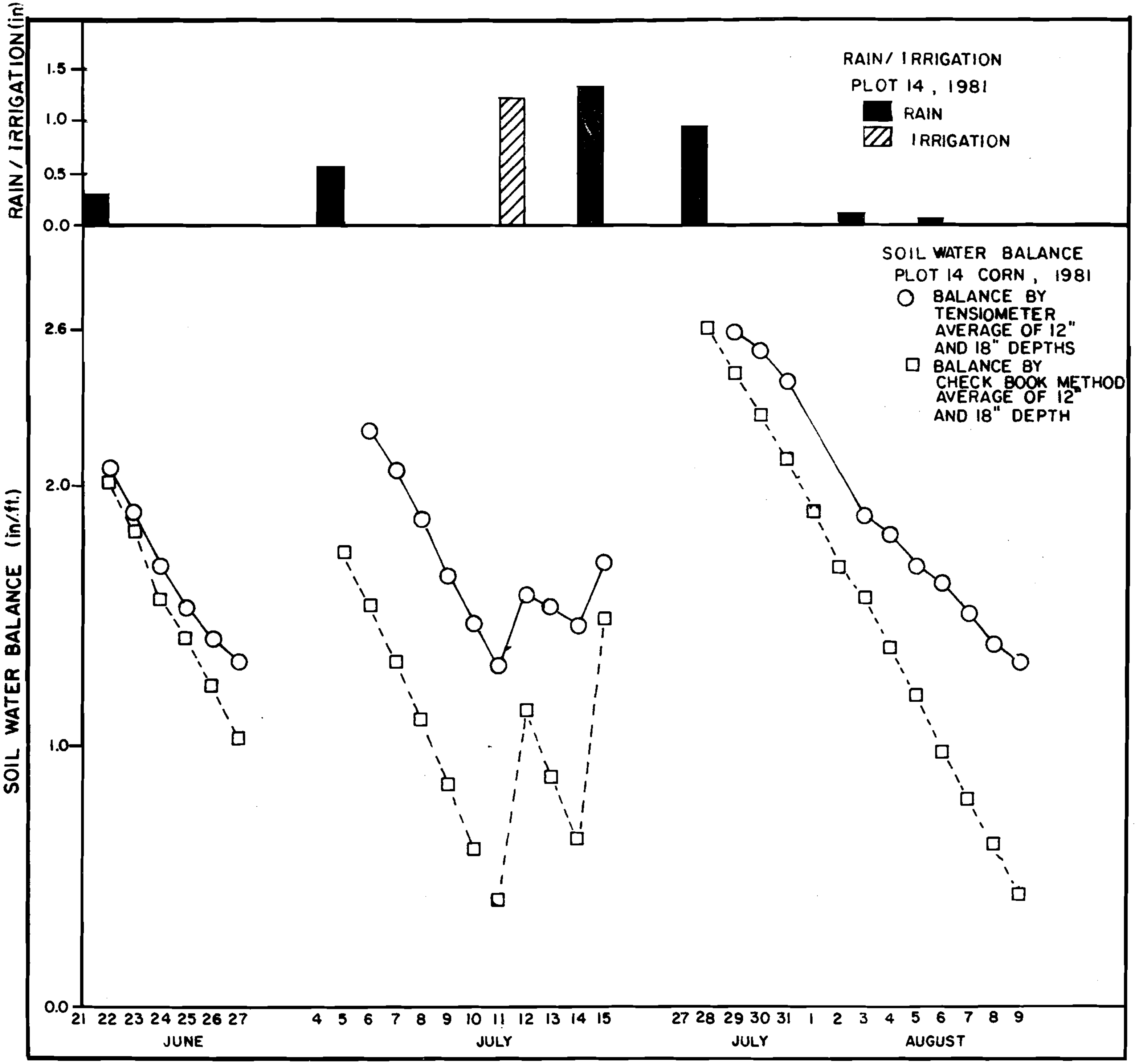

Figure 6. Soil Water Balance on Plot 14, 1981.

Irrig. / Dr.	Sprink. Irrig. — Irrig. at 425 mb	Sprink. Irrig. — Irrig. at 625 mb	None
Surface	139*	106	36
Subs.	X	87	42
Surface plus Subs.	71	70	23
None	X	354	230

*SEW_{30} for the growing season

Figure 7. Total SEW_{30} for 1982 growing season, corn and single crop soybeans.

Figure 8. Sample Section of Drain Tubing Showing Roots and Sediment.

APPENDIX A

Summaries of Daily Precipitation at the Brownstown Agronomy Research Center

1977 RAINFALL (inches)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec*
1											.16	
2			.15	.50					.05			
3			.75									
4				.12	.13				.64			
5				.05						.26		
6					1.00					.11		
7						.02		.38		1.45		
8						.70						
9								.30			.04	
10						.81		.14				
11			2.41				.39	.02		.04		
12		.52							1.06			
13						.80			.04			
14									.20			
15											1.63	
16	S											
17	N		.29									
18	O								.09			
19	W		.10	.17							.79	
20					.20							
21			.30	.28								
22						.87				.03		
23		1.11		.12		.30		2.12			.18	
24				.04		1.37			.68	.60		
25					.30		.50			.24		
26		1.19										
27			2.80			.42						
28			.11		.11	.33		.98				
29							.47					
30						.15	.26		.76	.19	1.21	
31												
Monthly		2.82	6.91	1.28	1.74	4.97	1.62	3.94	3.52	2.92	4.01	
To Date			9.73	11.01	12.75	17.72	19.34	23.28	26.80	29.72	33.73	

*No December Data

1978 BROWNSTOWN RAINFALL (inches)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1						.89	.14	.09				
2				.11				.27				
3										.26		1.00
4				.09	.80							
5												
6				.16		.34		.04				
7					1.06						.11	.44
8												.33
9							.02					
10				.60			.89					
11					.77					.42		
12						.01		.41	.33	.10		
13			1.29		1.15		.09		.16	.87	.01	
14										.16	1.08	
15							.01				.47	
16			.87	.62			.14	.18	.49		.02	
17				.18					.02		1.61	
18				.25		1.77						
19				.14								
20						.90						
21			.75						.01			.10
22				.29	.28							
23				.04	.34	.10				.03	.60	
24				.25	.02		.93					.01
25											.30	
26			2.09							.20	.32	
27							.62	.07			.08	
28					.10			1.28				
29			.09	.10	.04			.87				
30							.13		.17			1.45
31								.13				.44
Monthly	1.98	.94	5.09	2.83	4.56	4.01	2.97	3.34	1.18	2.04	4.60	3.77
To Date		2.92	8.01	10.84	15.40	19.41	22.38	25.72	26.90	28.94	33.54	37.31

1979 BROWNSTOWN RAINFALL (inches)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	.05		.30	.20		.48		2.35			.29	
2				.07				.39	.17	.18		
3		.01	.60		.36		1.97			.01		
4			1.35	.30	.08		.47			.05		
5	.03			.07								
6												
7	.12					.23						
8			.01			.01	.02				.07	
9		.07		.85		1.83					.60	
10			.05							.03	.01	
11				.89	.12			.45				
12	.04			1.97	.36					.07		
13	.19			.20	.05		.02					
14	.12		.02		.12	.05	.34					
15		.04						.12		.06		
16										.88		
17										.18		
18												
19	.22	.04	.34									
20												
21	.02	.29	.57					.12			.49	
22			.01	.02							.38	
23		1.10	.69							.89	.17	.50
24	.76		1.17	.83		.59	.15	.08				1.60
25			.03	.26			.17					.20
26		.01		.73			1.07				1.20	
27	.30				1.07		1.85	.01				
28	.09		.16	.15			3.13	.05		.01	.16	
29			.49			.26	.01	.08				
30			.35				.13					
31	.09		.02				.86					
Monthly	2.03	1.56	6.16	6.54	2.16	3.45	10.19	3.65	.17	2.36	3.37	2.30
To Date		3.59	9.75	16.29	18.45	21.90	32.09	35.74	35.91	38.27	41.64	43.94

1980 BROWNSTOWN RAINFALL (inches)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1			.08			.05		.33				
2	Trace					1.20			1.74	.03		
3	Trace			.06			.39	.09				
4	Trace			.14			.39			.08		
5	Trace	.12	.06			.15	.13	.27	.06			.01
6		.07			.03	Trace			.10			
7	.05			.26		Trace	.54	.01	.06			Trace
8			.01	.35		Trace						.01
9		.04		.06								.42
10				.21			.04					Trace
11	.26				.29		.16	.22				
12					.36							
13			.18		.12				Trace			
14	Trace		.11	.55				Trace				
15		.65		.12				.34			.06	
16	.03	.28	Trace			.88		.93	.33		Trace	
17	.05		.69		.62			.08	2.18	.67	.05	
18			.09		.13					.02	.13	
19					.01			.05				
20	Trace	.01				.78						
21		.08	.24		Trace		.04					
22	Trace	.16					.18					
23					.57	1.24			.28		.35	
24			.53			.32				.20	.01	.06
25	.02	.11	.54						.03	.49		Trace
26		.02								Trace		
27							1.28			.06	.50	
28			.04	.13			.01			.73	.10	
29			.20	.04		.69						.04
30	.15		1.33	.09								Trace
31	.16		.05		.39							
Monthly	.72	1.54	4.15	2.01	2.52	5.31	3.16	3.02	4.78	2.28	1.20	.54
To Date		2.26	6.41	8.42	10.94	16.25	19.41	22.43	27.21	29.49	30.69	31.23

1981 BROWNSTOWN RAINFALL (inches)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	Trace	.73			.04		.76		.17			.50
2		.02				.11			.11		.31	
3		Trace				.06	Trace	.09				
4			.19	.48			.07			Trace	.12	
5			.43	Trace	.03		.56			.36	.05	
6	.05	Trace			.63	.07		.05		.56		
7	.04					.18						
8	Trace					.02			.22			
9	Trace			.22	Trace						.25	
10	Trace	.70		.02	.78	1.02				Trace		
11	Trace	.63		.07	1.04	.10		.13		.04		
12				.59	Trace	.09						
13				Trace	Trace	.29						
14				.08	.45	Trace				.01		
15					.03		1.28	.81		.07		
16	Trace	.07	Trace	.06		.33	.02		.10		.34	
17		Trace				.30				.81		.26
18		Trace	.08	.04	1.57				.04	.61		
19			Trace	.46	.95	.08	Trace					
20				.25	.11	.12	2.37				.13	
21	.25		Trace			.21	.37					.16
22	Trace	.46	Trace	.09		.31				.45		
23		.04		.55	.07		.01			.39		.85
24		Trace					.27				.11	
25					.32							
26					.09		1.08	.07		.22		
27					.10		.09	1.56	.22		.03	
28		.06					1.00					.05
29				.40				.35				
30			.08	.22	.48							
31					.04			2.20				
Monthly	.34	2.71	.78	3.53	6.73	3.29	7.88	5.26	.86	3.52	1.34	1.87
To Date		3.05	3.83	7.36	14.09	17.38	25.26	30.52	31.38	34.90	36.24	38.11

1982 BROWNSTOWN RAINFALL (inches)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1						.52			.60		.21	
2									.65		.01	.07
3	.26	.02		.72			1.33				.36	1.41
4	1.00	.17	.30			.02				.05		1.21
5						.42	.52					.45
6		.02	.02	.44			.01	.07				.04
7					.72			.02		1.68		
8				.07		.46	.03	.02	.28			
9		.48	.07	.07		.17				.77		
10			.04			.01	1.21	.05		.22		
11			.45				.29	1.06			.04	.10
12			.05			.03					.68	
13			.63			.01			.70			
14	.14								.29			
15			.40						1.50			.02
16		.08	.15	.21	.04	.67		.02				
17		.75		.79		.06						
18		.13							.97		.03	
19		.03	1.97			.36				.08	.03	.01
20			.07	.14			.60		.03	.42	.16	
21	.11				.16	.01		.37			.13	
22	.27				.02	.12	.68					
23	.44					.22	.06				.57	
24								.11	.01		.23	1.87
25	.05		.55	.07				.03	.02			1.66
26			.05	.01	.90						.55	
27				.07	.69			.92				.07
28					.01	1.08	.13				.38	.05
29					.59	.01				.08	.14	
30	3.11				.16	.28		.58				
31	1.80				.73					.03		
Monthly	7.18	1.68	4.75	2.59	4.02	4.45	4.86	3.25	5.05	3.33	3.52	6.96
To Date		8.86	13.61	16.20	20.22	24.67	29.53	31.78	36.83	40.16	43.68	50.64

1983 BROWNSTOWN RAINFALL (inches)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec*
1					1.36			.03				
2		1.00		1.00	.54						.55	
3		.03		.17		1.35	.05				.01	
4					.06	.17				.13	.04	
5				.02						.43		
6		.05	.85	.39		1.53						
7		.13	.04	.31	.01				.19		.04	
8			.12									
9				.49						.07		
10	.01		.10	.02							.70	
11	.10										.22	
12					.03				1.59	1.29		
13				.15	.12					.11		
14				.79	.80					.15		
15					.37	.70						
16									.11		.02	
17				.04								
18			.76	.25						.16		
19			.13		.17	.21						
20			.27						.08	2.46	1.30	
21	.83		.41						.98	1.06		
22	.41				.90			.04		1.00		
23	.20							.20		.70	1.35	
24	.05						.02	.01			2.81	
25							.17					
26												
27			.25			.06					.76	
28			.16	.49	.20	.04		.18			1.52	
29				.23		.09						
30	.15		.12	.70		2.87						
31			.01				.01					
Monthly	1.75	1.21	3.22	5.05	4.56	7.02	.25	.46	2.59	7.56	9.32	
To Date		2.96	6.18	11.23	15.79	22.81	23.06	23.52	26.47	34.03	43.35	

*No December Data

APPENDIX B

Critically High Temperatures

Critical Temperature Data - 1977

Date	Max. - Min. °F
May	
20	90 - 60
23	90 - 60
26	90 - 62
27	90 - 57
28	90 - 60
31	90 - 60
June	
6	97 - 72
July	
1	90 - 60
5	95 - 72
6	95 - 69
7	96 - 74
8	94 - 71
9	92 - 70
13	91 - 74
14	97 - 75
15	96 - 75
16	96 - 74
17	95 - 71
18	94 - 71
19	96 - 75
20	95 - 72
21	90 - 73
22	91 - 70
23	91 - 60
24	91 - 60
25	91 - 68
31	90 - 63
August	
1	92 - 58
6	90 - 74
7	92 - 70
15	90 - 67
27	90 - 61
September	
1	90 - 61
2	92 - 71
3	92 - 66

Total Days	
100° or above	0
95° or above	10
90° or above	35

Critical Temperature Data - 1978

June	Max. - Min. °F
17	92 - 73
18	92 - 64
25	90 - 63
26	93 - 74
27	96 - 74
28	99 - 71
29	97 - 74
30	97 - 70
July	
1	100 - 70
2	97 - 69
6	92 - 65
7	95 - 72
8	96 - 72
9	94 - 73
14	91 - 64
15	92 - 64
16	91 - 77
17	92 - 64
18	93 - 68
19	92 - 72
20	92 - 74
21	96 - 74
22	96 - 72
23	92 - 73
27	94 - 63
30	94 - 69
August	
3	90 - 68
10	91 - 62
11	90 - 64
13	90 - 68
15	92 - 72
16	94 - 69
19	97 - 77
23	92 - 61
24	94 - 69
25	99 - 72
26	97 - 68
27	92 - 72
28	95 - 70
September	
4	91 - 61
5	91 - 56
8	91 - 63
9	93 - 64
10	93 - 64
11	91 - 68

September	Max. - Min. °F
12	91 - 71
18	91 - 75
19	92 - 71
20	94 - 67
21	92 - 63

Total Days	
100° or above	1
95° or above	14
90° or above	50

Critical Temperature Data - 1979

June	Max. - Min. °F
19	90 - 65
20	90 - 67
July	
14	91 - 78
15	90 - 70
31	90 - 72
August	
5	91 - 70
6	92 - 74
7	91 - 72
8	93 - 73
9	91 - 73

Total Days	
100° or above	0
95° or above	0
90° or above	10

Critical Temperature Data - 1980

June	Max. - Min. °F
6	90 - 72
7	93 - 76
8	94 - 62
15	97 - 71
16	91 - 57
20	90 - 47
23	91 - 66
26	91 - 67
27	93 - 73
28	95 - 78
29	97 - 70
30	90 - 58
July	
2	99 - 75
3	95 - 71
5	96 - 70
6	95 - 71
8	97 - 78
9	98 - 77
10	99 - 76
11	96 - 73
12	97 - 81
13	99 - 73
14	94 - 74
15	99 - 78
16	104 - 77
17	101 - 66
18	98 - 67
19	96 - 72
20	102 - 77
21	101 - 75
26	93 - 67
27	95 - 69
30	93 - 66
31	94 - 78
August	
1	97 - 70
2	94 - 78
3	94 - 66
5	96 - 70
8	98 - 75
9	101 - 74
10	103 - 76
11	101 - 69
12	91 - 63
13	90 - 66
14	95 - 72
15	90 - 73
18	95 - 73

August	Max. - Min. °F
19	92 - 71
20	97 - 75
21	98 - 72
26	93 - 63
27	99 - 65
28	100 - 67
29	95 - 71
30	90 - 68
31	93 - 74
September	
1	95 - 77
2	93 - 68
4	92 - 69
7	96 - 64
8	93 - 67
9	99 - 71
10	94 - 54
13	91 - 74
21	90 - 73
22	92 - 76
23	92 - 53
October	
9	91 - 54

Total Days	
100° or above	8
95° or above	37
90° or above	68

Critical Temperature Data - 1981

June	Max. - Min. °F
9	90 - 71
15	90 - 75
16	90 - 64
25	92 - 70
30	91 - 63
July	
9	93 - 76
10	94 - 74
11	94 - 60
12	92 - 72
13	97 - 77
14	97 - 74
15	96 - 73
16	91 - 74
21	90 - 68
August	
5	91 - 74
6	90 - 71

Total Days	
100° or above	0
95° or above	3
90° or above	16

Critical Temperature Data - 1982

July	Max. - Min. °F
3	90 - 66
4	93 - 68
6	90 - 77
17	90 - 76
22	90 - 70
25	90 - 67
26	90 - 72
August	
2	91 - 68
3	92 - 75
4	95 - 75
5	95 - 72
6	94 - 73

Total Days	
100° or above	0
95° or above	2
90° or above	12

Critical Temperature Data - 1983

June	Max. - Min. °F
15	95 - 59
22	90 - 62
24	90 - 65
25	96 - 74
26	96 - 74
27	97 - 75
July	
2	96 - 78
3	96 - 67
4	92 - 82
10	95 - 66
11	95 - 73
12	94 - 68
13	95 - 71
14	94 - 70
15	93 - 71
16	93 - 72
17	94 - 71
18	94 - 71
19	94 - 71
20	97 - 73
21	98 - 75
22	99 - 73
23	103 - 79
24	103 - 74
25	98 - 73
28	90 - 72
29	96 - 75
30	94 - 74
31	92 - 71
August	
1	94 - 62
3	90 - 64
4	96 - 71
5	95 - 72
6	94 - 67
7	95 - 65
8	92 - 66
9	94 - 65
10	96 - 64
11	96 - 65
12	95 - 59
16	94 - 66
17	98 - 75
18	98 - 77
19	95 - 74
20	99 - 70
21	103 - 77
22	99 - 71

August	Max. - Min. °F
23	96 - 67
24	90 - 68
25	95 - 69
26	98 - 71
27	98 - 75
28	97 - 69
29	91 - 64
30	96 - 65
September	
3	91 - 65
4	91 - 67
5	92 - 70
6	93 - 74
7	94 - 62
9	93 - 67
10	97 - 70
11	97 - 69
18	92 - 78
19	92 - 75
20	91 - 68

Total Days	
100° or above	3
95° or above	36
90° or above	66

APPENDIX C

Treatment Descriptions and Irrigation Scheduling Methods

Treatments

Corn

1 = Furrow irrigation, surface drainage (1977-1981); sprinkler irrigation at low tension (1982-1983)

2 = Sprinkler irrigation, surface drainage

3 = Dryland, surface drainage

4 = Sprinkler irrigation, tile drainage

5 = Dryland, tile drainage

6 = Furrow irrigation, combination drainage (1977-1981); sprinkler irrigation at low tension (1982-1983)

7 = Sprinkler irrigation, combination drainage

8 = Dryland, combination drainage

9 = Sprinkler irrigation, no drainage

10 = Dryland, no drainage

Treatments

Soybeans

1 = Furrow irrigation, surface drainage (1980-1981); double crop - one block sprinkler irrigation, one block dryland (1982-1983)

2 = Sprinkler irrigation, surface drainage

3 = Dryland, surface drainage

4 = Sprinkler irrigation, tile drainage

5 = Dryland, tile drainage

6 = Furrow irrigation, combination drainage (1980-1981); double crop - one block sprinkler irrigated, one block dryland (1982-1983)

7 = Sprinkler irrigation, combination drainage

8 = Dryland, combination drainage

9 = Sprinkler irrigation, no drainage

10 = Dryland, no drainage

Cropping Rotation

Corn

1977-1980	Block 1 = Series 1100,	Block 2 = Series 1200
1981	Block 1 = Series 900,	Block 2 = Series 1000
1982	Block 1 = Series 1100,	Block 2 = Series 1200
1983	Block 1 = Series 900,	Block 2 = Series 1000

Soybeans

1980	Block 1 = Series 900,	Block 2 = Series 1000
1981	Block 1 = Series 1100,	Block 2 = Series 1200
1982	Block 1 = Series 900,	Block 2 = Series 1000
1983	Block 1 = Series 1100,	Block 2 = Series 1200

Corn Irrigation Scheduling

1979-1979 Minimum one inch of water (Irrigation & Precipitation) per seven days - all irrigated treatments

1980-1981 One inch of irrigation at tensiometer reading of 625 millibars (50% moisture depletion) at the one foot level

1982-1983 One inch of irrigation at tensiometer reading of 625 millibars (50% moisture depletion) at the one foot level - Treatments 2,4,7,9;

One inch of irrigation at tensiometer reading of 425 millibars (33% moisture depletion) at the one foot level - Treatments 1,6.

REFERENCES

Austin, T. A., C. E. Anderson, H. P. Johnson, R. H. Shaw, J. Golchin, Z. Shahvar and O. Arhmand. 1982. Efficient Use of Water for Irrigation in the Upper Midwest, ISWRRI-117. Ames: Water Resources Research Institute, Iowa State University.

Bruckner, D., P. Ellinger and D. E. Erickson. 1982. Irrigation: Some Economic Considerations - Update 1981-82. Illinois Irrigation Newsletter, v. 4, No. 1. 4 p.

Fehrenbacher, J. B., B. W. Ray and J. D. Alexander. 1969. How Soils Affect Root Growth. Crops and Soils Magazine. January: 14-18.

Lundstrum, D. R. and E. C. Stegman. 1983. Irrigation Scheduling by the Checkbook Method. Cooperative Extension Service, North Dakota State University, Fargo. 13AENG-6-1. 15 p.

Miller, W. L., R. L. Clouser, P. Erhabor and J. Sobek. 1981. The Economic Opportunity to Irrigate Corn and Soybeans on Midwestern Claypan Soils, Technical Report 93. West Lafayette: Indiana Water Resources Research Center, Purdue University.

Patronsky, R. J. and G. O. Schwab. 1979. A Plan for Field Evaluation of Subsurface Drains in Heavy Soils and Soils with a Restrictive Layer. Eighth Technical Conference. U.S. Committee on Irrigation, Drainage and Flood Control. Spet. 26-29. Phoenix, Arizona.

Sieben, W. H. 1964. Literature translated in Drainage for Agriculture Edited by J. Van Schilfgaarde and published by American Soc. of Agronomy, 1974. p. 70.

Walker, P. N. and W. D. Lembke. 1977. Recycling agricultural runoff. Research Report 119. Urbana, Illinois: Water Resources Center, University of Illinois. 88 p.

Walker, P. N., M. D. Thorne, E. C. Benham and W. D. Goetsch. 1981. Optimization of Water Use for Field Crop Production in the Upper Midwest. UIUC-WRC-81- 0159. Urbana: Water Resources Center, University of Illinois at Urbana- Champaign.

Walker, P. N., M. D. Thorne, E. C. Benham and S. K. Sipp. 1982. Yield Response of Corn and Soybeans to Irrigation and Drainage on a Claypan Soil. Transactions of ASAE 25:(6)1617-1621.