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OPTIMIZATION OF WATER USE FOR FIELD CROP PRODUCTION IN THE UPPER MIDWEST

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ABSTRACT

This project investigated combinations of both irrigation and drainage treatments in order to determine the best water management practices for field crop production in claypan soils in the upper Midwest. Four years of corn and one year of soybean yield data from forty field plots are presented. The irrigation treatments were sprinkler, furrow, and no irrigation; the drainage treatments were surface, subsurface, surface plus subsurface, and no drainage.

The plots were located on a claypan soil in south-central Illinois. Sprinkler irrigation was provided by a solid set system. Furrow irrigation was done with gated pipes. The plots with surface drainage had a slope of 0.5%; the others were graded level. Subsurface drainage was provided by plastic tubing on 20-ft centers. Drainage water from the plots and surrounding areas was stored in ponds and recycled as irrigation water.

The data indicate average corn yield increases of 13 and 50 bu/acre due to drainage and irrigation, respectively. Together, they act synergistically to produce an average yield increase of 92 bu/acre.

This synergistic yield increase provides economic impetus to combining irrigation and drainage systems and storing drainage water in ponds or lakes for later use in irrigation. This combination will have the added effect of conserving water resources, of improving water use efficiency and downstream water quality, and of lessening downstream flooding.

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INTRODUCTION

Water management on agricultural lands is a problem of utmost concern if we are to meet the demands for food and fiber in the twenty-first century. Proper water management can result in conservation of water supplies, decreased flooding, improved discharge-water quality, and increased crop production. The midwestern soils with the greatest need for water management research are those with a claypan.

There are about 10 million acres of claypan soils in the Midwest. These soils have a 6- to 18-inch layer of silt loam topsoil with a heavy clay subsoil. The topography associated with these soils is quite flat with usually less than 0.5 percent slope. And, often, groundwater supplies are limited. The crop yields on these soils are usually low because of limited water management. With proper water management these soils can be very productive every year.

The area with the largest concentration of claypan soils is south-central Illinois. The mean annual precipitation in this area is 40 inches, which would be plentiful for crop production if it were properly distributed. Unfortunately, excess rainfall often occurs in the spring, contributing to a problem of excessively wet soils; and often there are several weeks without rainfall in the summer, causing drought. Periods of excessively wet soil and periods of drought often occur within the same growing season.

IRRIGATION AND DRAINAGE

The water management practices needed for these soils are irrigation and drainage. The thin topsoil in claypan areas means that crop roots have only a small volume of soil from which to extract water between rainfall events. Therefore, irrigation is necessary to avoid plant stress during these periods and to maximize yields. The virtual absence of groundwater supplies in this area means that irrigation must rely on development of surface water resources. Many farmers are constructing ponds on their property to catch and store intermittent runoff and to divert peak storm flows for later use in irrigation as well as to reduce soil erosion. Irrigation must be done very efficiently in order to conserve water supplies. Nearly all of the irrigation done in the Midwest is by sprinklers. However, because claypan soils have an impermeable subsurface layer and a flat topography, they are particularly adaptable to furrow irrigation, which can be more energy efficient and more water efficient if tailwater is collected and reused. This research provides information necessary to irrigate this soil efficiently both by sprinklers and by furrow irrigation. Additionally, the demonstration function of these plots provides part of the impetus required for farmers to start choosing the more efficient furrow irrigation system.

A drainage system is needed on these soils to remove the excess water which exists nearly every spring and occasionally later in the growing season. The subsurface soil layers are impermeable, thereby limiting natural subsurface drainage; and the surface topography is generally flat with occasional depressions, thereby limiting natural surface drainage.

The presently recommended drainage practice on this soil is surface drainage (land grading). Conventional subsurface drainage systems will not work because of the clay subsoil. Surface drainage systems are not entirely satisfactory because the required grading removes the topsoil from some areas of a field and reduces its productivity. Additionally, surface drainage water is laden with sediments and nutrients. A subsurface drainage system could be more satisfactory. It would not require the movement of topsoil, and the drainage water would be virtually free of sediment and have a lower nutrient concentration.

The advent of corrugated plastic drain tubing makes possible the manufacture of lower-cost small-diameter subsurface drain lines. In claypan soil, these lines can be placed at close spacings above the claypan layer. This type of system was not feasible with conventional drain materials. This research project also addresses this type of drainage system and helps provide the information necessary to design an optimum subsurface drainage system.

When irrigation and drainage practices are integrated, the drainage water is stored in a surface reservoir and used for irrigation during drought periods. By recycling the water, the conservation of water supplies will be maximized because the amount of water leaving the farm will be minimized. This in turn will substantially lessen the potential for downstream flooding. Furthermore, the storage of this water will improve the quality of that water which does leave the land because the amounts of chemical and sediment pollutants leaving the farm will be greatly reduced.

The combination of irrigation and drainage should also have a synergistic effect on crop yields; that is, the increase in crop yield due to irrigation plus drainage should more than equal the increase in yield due to irrigation alone added to the increase in yield due to drainage alone. The reason is that poor drainage can negate yield increases due to irrigation and that drought can similarly negate yield increases due to better drainage.

PREVIOUS WORK

This research project builds on the previous efforts of the principal investigators. In 1976 an extensive literature search was done to find available information on water management for claypan soils and to determine a suitable research plan for future work (Walker and Lembke, 1977). This previous effort was supported by the Illinois Water Resources Center. The Departments of Agricultural Engineering and Agronomy at the University of Illinois at Urbana-Champaign collaborated on an irrigation study on sandy soils from 1974 through 1979 and are now conducting irrigation research on reclaimed strip-mined soils. The information and experience gained assisted in the design of this study and enhanced its success.

LIMITATIONS

Funding problems limited the scope of this project. The Office of Water Research and Technology (OWRT) of the U.S. Department of the Interior approved the three-year project and provided first-year funds for the project as part of a four-state regional effort including Indiana, Iowa, Minnesota, and Illinois. Funding was not, however, provided during the second and third years of the project, presumably because of a new OWRT policy against funding regional projects.

Funds from other sources were found which enabled the continuation of the project the second year on a very limited basis. Without the additional two years of data, only limited inferences can be made from this study.

OWRT has recently provided the funds to continue the total monitoring program for another two years.

METHODS

Forty field plots were established on a Cisne Association soil at the Brownstown Agronomy Research Center in southern Illinois. The center is located on Illinois Route 185 about eight miles east of Vandalia, Illinois. The setup included replications of each of several irrigation and drainage treatment combinations for both corn and soybeans. These plots were instrumented for meteorological and water balance measurements--that is, the amount of water entering, leaving, and being stored on each of the plots. Additionally, semiweekly plant leaf water potential and annual grain yields were determined for each plot.

These measurements were used to give annual averages of the effects of each of the treatment combinations. However, tens of years of data would need to be collected before the data could be expected to represent long-term average effects. This longevity would be required because yearly variations in the weather pattern are substantial.

Because such long-term studies are impractical, it was decided to use the meteorological water balance, leaf water potential, and yield measurements taken over a three-year period to develop relationships between (1) weather and soil moisture, i.e., a water balance, (2) soil moisture, weather, and leaf water potential, and (3) leaf water potential and crop yield. These relationships would then be combined with historical weather data to predict the long-term effects of each water management combination treatment.

Because of the cut-off of funds mentioned earlier, this entire program was not carried out for the three years originally planned. Field plots were constructed and complete data were collected during the first fully funded year. Meteorological and yield data were the only useful measurements taken during the second and final year of this study.

SOIL INFORMATION

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.

TREATMENT COMBINATIONS AND LAYOUT

The demonstration-research study area consisted of two sets of twenty one-sixth-acre plots, each having one of ten different irrigation and drainage treatments. Corn was grown on one set, soybeans on the other. The corn plots were established in 1976, prior to the beginning of this study. The soybean plots were started in 1980. The irrigation treatments were sprinkler, surface (furrow), and no irrigation, while the drainage treatments were surface, subsurface, both surface and subsurface, and no drainage. Because of the physical incompatibility of some treatment combinations, only ten of the 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 used in the study are shown in Figure 3. The plot configuration and treatment layout are shown in Figure 4. Each plot measured 64 ft by 108 ft. An earthen dike isolated each plot from surface water sources. A vertical plastic film placed to a depth of 5 ft restricted the movement of subsurface water into and out of each individual plot.

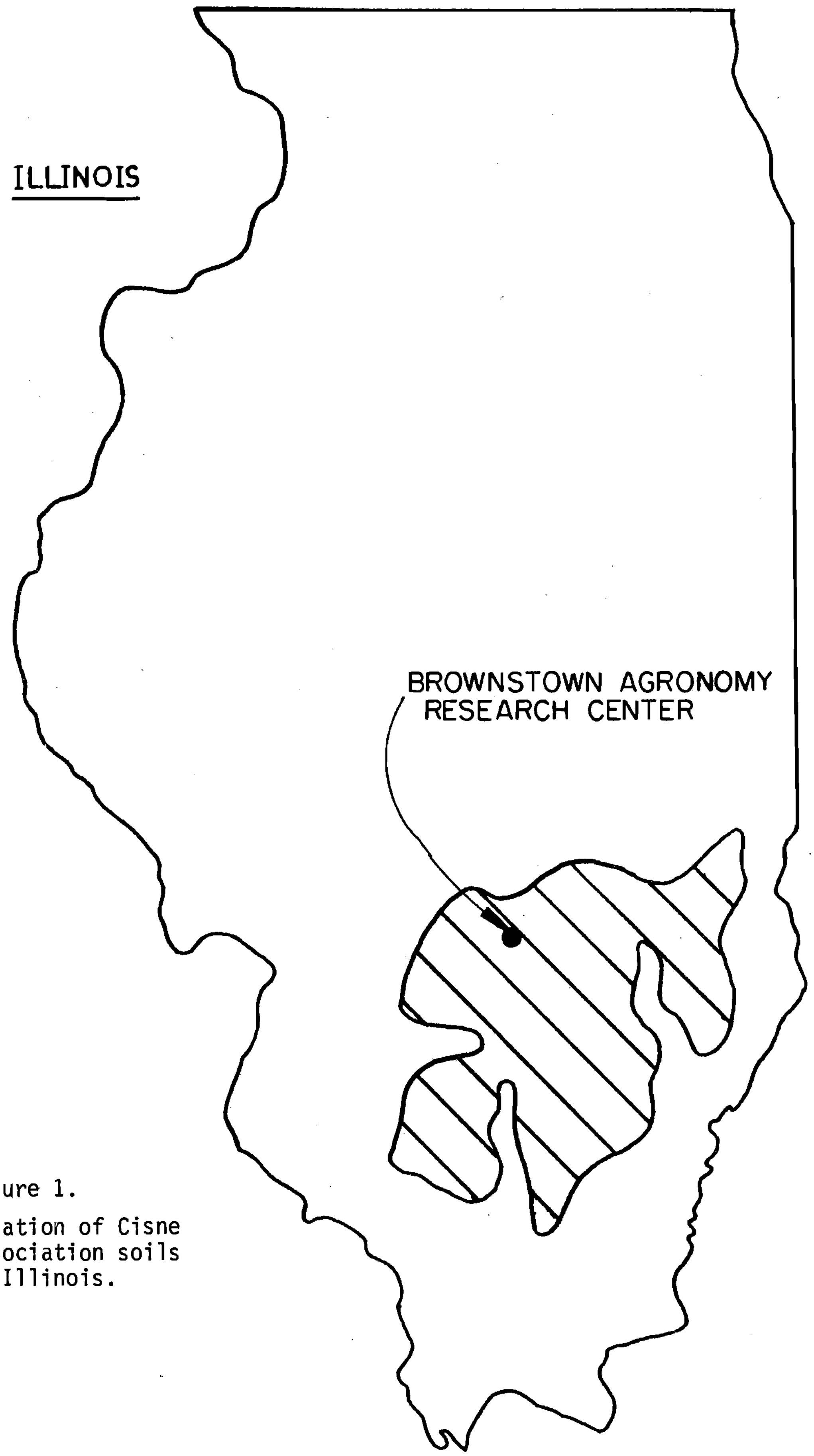


Figure 1.

Location of Cisne Association soils in Illinois.

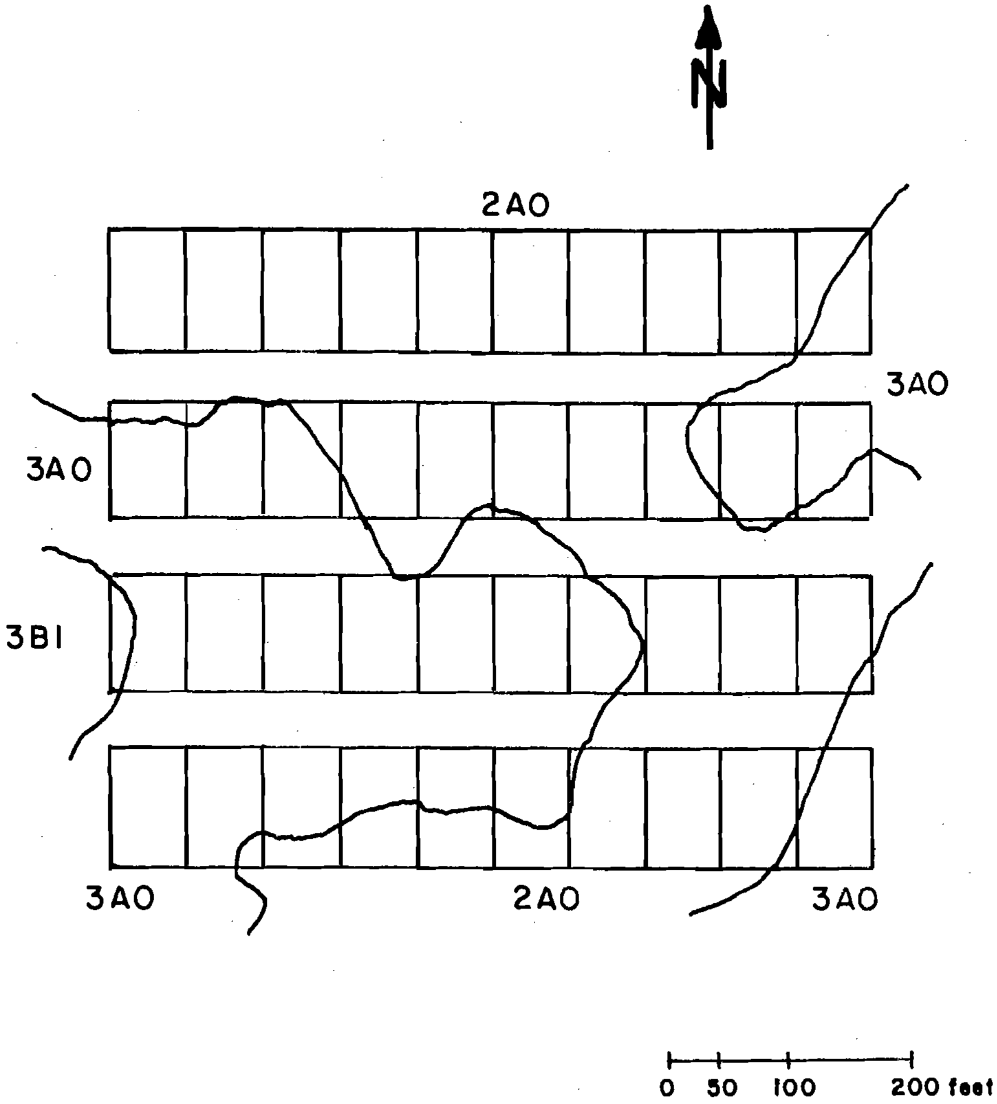
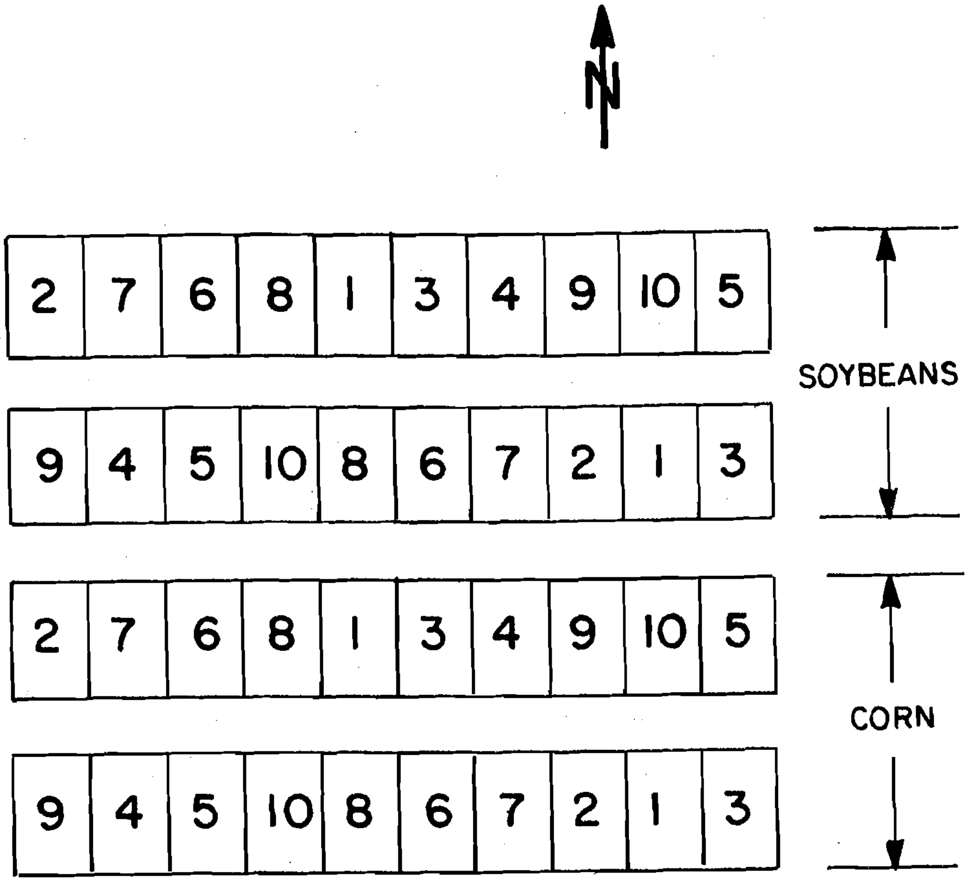


Figure 2. Soils map for plot area.

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

IRRIGATION DRAINAGE	FURROW	SPRINKLER	NONE
SURFACE	1	2	3
SUBSURFACE	☒	4	5
SURFACE PLUS SUBSURFACE	6	7	8
NONE	☒	9	10

Figure 3. Treatment combinations with arbitrarily assigned numbers.



2	7	6	8	1	3	4	9	10	5
9	4	5	10	8	6	7	2	1	3
2	7	6	8	1	3	4	9	10	5
9	4	5	10	8	6	7	2	1	3

Figure 4. Treatment layout.

Numbers shown are treatment numbers from Figure 3.

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

Plots without drainage were graded level and, like the other plots, had earthen dikes and plastic film barriers to restrict movement of water into or out of the plots.

Water for irrigation was pumped from two nearby ponds. Furrow irrigation water was applied between each row by means of gated pipe: row slope was 0.5 percent. Sprinkler spacing was 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 the sprinkler system and 0.95 for the gated pipe. These figures were used to determine water volume amounts required to achieve the desired net irrigation application.

IRRIGATION SCHEDULING

To schedule irrigation, a seven-day moisture total was determined each day by adding the amount of precipitation plus irrigation received on a given day to that received in the previous six days. Enough irrigation water was then applied to raise the total to a value of 1 inch. Three days were required to complete an irrigation cycle, thus allowing the possibility of the seven-day moisture total dropping below the 1-inch level during a 2-day period.

AGRONOMIC PRACTICES

A no-till cropping system was used with fertilizer applications made at a rate required for high-level management cropping.

1979 Corn

During the 1979 season, a Missouri 17 x H100 corn hybrid was used. All drained plots were planted on May 9; the undrained plots were planted on June 6. Actual plant population was 21,000 plants per acre on the unirrigated plots and 26,000 plants per acre on the irrigated plots. Harvesting occurred on September 26 for the drained plots and on October 30 for the undrained plots.

Preplant fertilizer applications consisted of 17-45-0 at 300 lb per acre, 0-0-60 at 150 lb per acre, and 34-0-0 at 600 lb per acre. An additional 300 lb per acre of 34-0-0 was added after planting, giving a total application of 357-135-90 per acre. Weed control consisted of Lasso at 2 qt per acre and AATrex 4L at 1.5 qt per acre.

1980 Corn

During the 1980 season, two corn hybrids were used. The east 12 rows of each plot were Pioneer 3183, and the west 8 rows were Pioneer 7227 (experimental). All plots were planted on May 13, and plants emerged on May 21. The population at harvest was 24,000 plants per acre on unirrigated plots and 33,000 plants per acre on irrigated plots. The plots were harvested between October 1 and October 10.

The preplant fertilizer application consisted of 34-0-0 at 200 lb per acre, 0-46-0 at 200 lb per acre, and 0-0-60 at 150 lb per acre. An additional 200 lb of 34-0-0 was added in two postplant applications, giving a total application of 204-92-90 per acre. The pesticides applied were Bladex 4L at 1.5 qt per acre, Dual 8E at 1.25 qt per acre, and Furadan 10-G at 14 lb per acre.

1980 Soybeans

In 1980, two soybean varieties were used. The east 12 rows of each plot were Williams, and the west 8 rows were Mitchell. All plots were planted on May 27. The plant population was 130,000 plants per acre. The Williams variety was harvested on October 1, and the Mitchell variety was harvested on October 8.

The fertilizer application consisted of 0-46-0 at 220 lb per acre and 0-0-60 at 330 lb per acre, giving a total application of 0-101-198 per acre. The pesticides applied were Paraquat at 1 qt per acre with X-77 surfactant, Sencor 4 at 0.75 pt per acre, and Lasso at 2 qt per acre. On August 27, Cygon 400 at 1 pt per acre was applied to control grasshoppers.

INSTRUMENTATION AND DATA COLLECTION

During the 1979 growing season, three types of soil moisture monitoring equipment were installed: tensiometers, gypsum blocks, and neutron probe access tubes. The tensiometers were purchased from Soilmoisture Equipment Corporation, Santa Barbara, California. The gypsum blocks and gypsum block meter were purchased from Delmhorst Instrument Company, Boonton, New Jersey. The intermediate-scaled gypsum block meter and the Series 2300 tensiometer tubes were used.

Each plot contained two complete sets of instruments for measuring soil moisture, one at the half drain-line spacing and one at the quarter drain-line spacing. Each set contained three tensiometers, three gypsum blocks, and one neutron probe access tube. Tensiometers and gypsum blocks were installed at 1-ft, 2-ft, and 3-ft depths. Neutron probe readings were taken at depths of 6 in, 1 ft, 2 ft, 3 ft, 4 ft, and 5 ft. Tensiometer and gypsum block readings were taken on a daily basis, while neutron probe measurements were taken on a weekly basis--mainly because of the large amount of time required for neutron probe readings.

Gravimetric soil moisture sampling and bulk density sampling were also carried out on various plots three times during the growing season at the 1-, 2-, and 3-ft depths. Gravimetric sampling was done with the use of a hollow-tube soil probe. Samples were taken at each depth and dried 12 hours at 100 degrees Celsius. Bulk density sampling was done at the same three depths with 2-inch brass rings. The overall average bulk density was then calculated and used to convert the gravimetric data to volumetric soil moisture. This was done to enable comparisons between gravimetrically sampled percent soil moisture and measurements by the other three methods.

Also during 1979, drainage amounts from both surface and subsurface drainage were monitored, using plastic drain sumps 18 inches in diameter to collect the water. Sump-pump/clock configurations were used to measure the water volumes. Whenever the inflow into the sumps raised the water level enough to switch on the sump pump, the water would be pumped into the discharge sump. Included in the pump line was a mercury switch that caused the clocks to run whenever water was being pumped from the drainage sumps into the discharge sump. This setup enabled us to measure the pump running time and thus estimate the drainage water volume from each plot.

Extensive meteorological data were also collected during 1979, including daily maximum and minimum air temperatures, 24-hour relative humidity, rainfall, class A pan evaporation, and wind travel.

Plant leaf water potentials were taken, using the pressure bomb method, to indicate plant water-stress conditions throughout the growing season for various soil moisture conditions. The leaf water potential readings were taken between 6:00 and 7:00 A.M. to insure consistency of environment among all twenty plots. One to two hours are required to take these readings on twenty plots, and the leaf water potential is nearly constant at this time of day.

Yield data were taken using a scale-tip bucket device installed on the commercial grain harvester normally used for yield measurement at the Brownstown farm.

FIELD DATA ANALYSIS

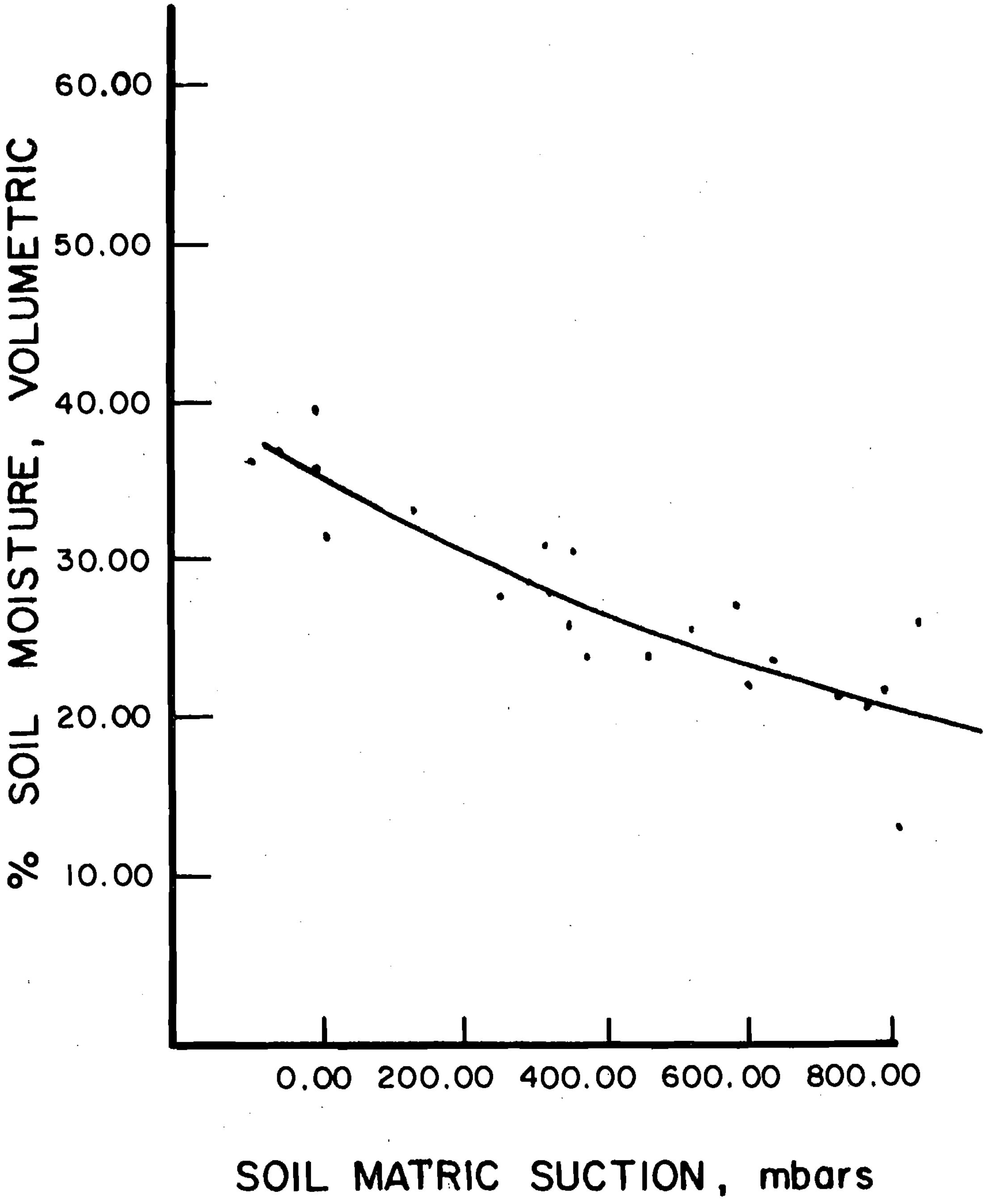
SOIL MOISTURE

Figures 5, 6, and 7 show the relationships between gravimetrically sampled soil moisture and the other three methods in 1979. As one can see from the R^2 values, the correlation between the data set and the best fit curve is not good even at the one-foot depth. The neutron probe data (Figure 7) seem to indicate moisture levels about 10 percent higher than the gravimetric readings. This could be attributed to inaccurate calibration of the probe at the factory, or the measured soil bulk density of 1.45 gm/cc may have been higher than the true value. The tensiometer data (Figure 5) seem to have less deviation than the neutron probe data, as indicated by the R^2 values.

PLANT STRESS

Plant stress, as indicated by leaf water potential, was monitored using the pressure bomb method. The pressure bomb measures the amount of pressure needed to overcome the plant's own hold on the leaf moisture. The higher the plant's stress condition, the lower the plant leaf water potential. Figures 8, 9, and 10 show relationships between the three moisture monitoring devices and plant leaf water potential. These figures represent the inversely proportional relationship between soil moisture and plant stress. However, one would expect that, at the highest moisture levels, plant stress would again increase because of decreased root aeration. This relationship was not found. Even in the undrained plots, where standing water remained for long periods after heavy rainfall, plant leaf water potential did not decrease on the live plants even though many of the plants died and the yields in these plots were greatly reduced.

Irrigation scheduling information can be taken from Figures 8, 9, and 10. Plant leaf water potential decreased to -0.55 bars at approximately 34-40% soil moisture as measured by the neutron probe, 400-600 mbars soil matric suction as measured by the tensiometer, and 6.0 to 8.0 scale units of the gypsum block, all of which equal approximately 25% soil moisture as measured gravimetrically. Any one of these methods of

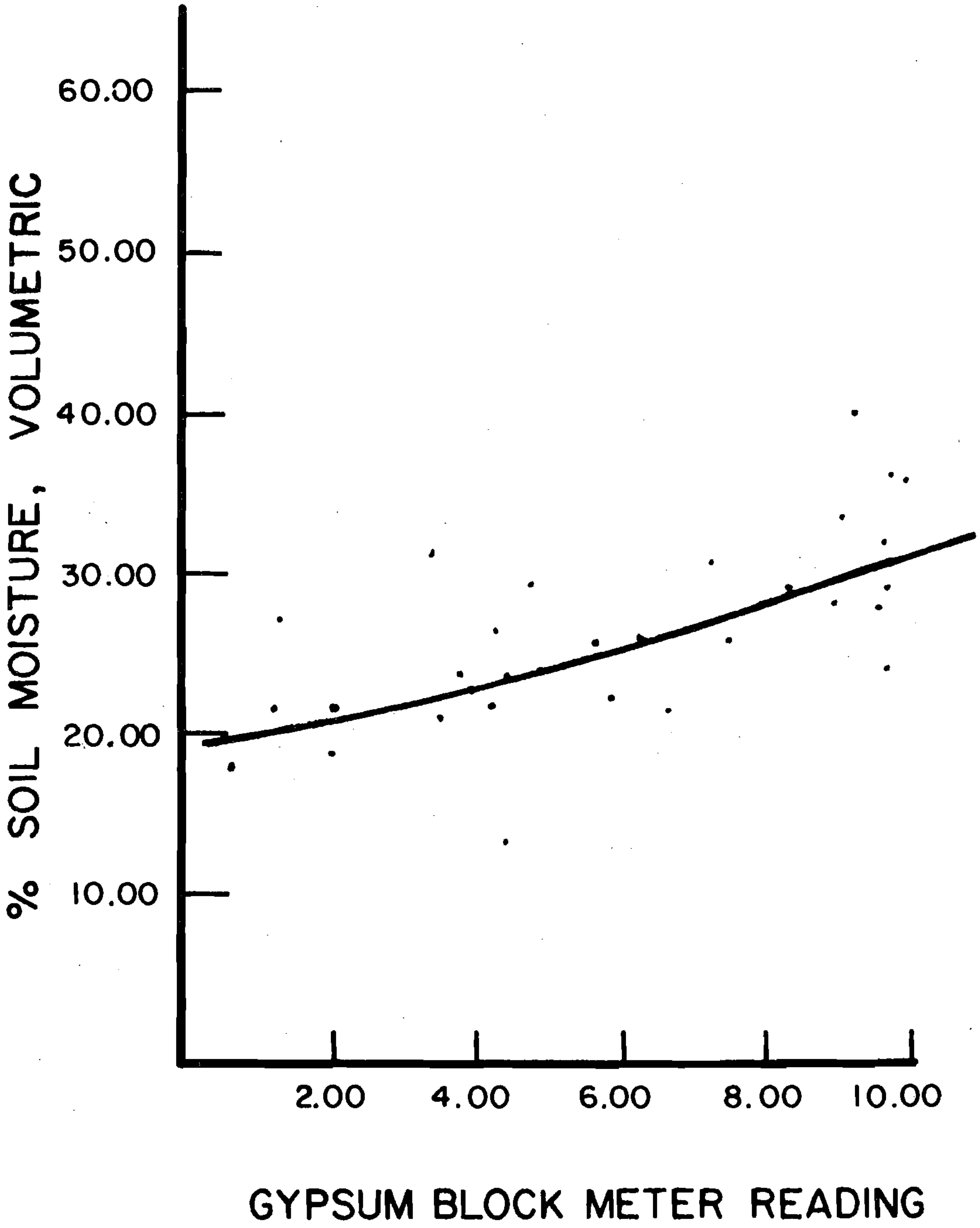


% Volumetric Soil Moisture

$$= 36.3 \exp[-0.00068(\text{Soil Matric Suction})]$$

$R^2 = 0.70$

Figure 5. Soil matric suction (mbars) versus volumetric percent soil moisture, both from the 1-ft depth.

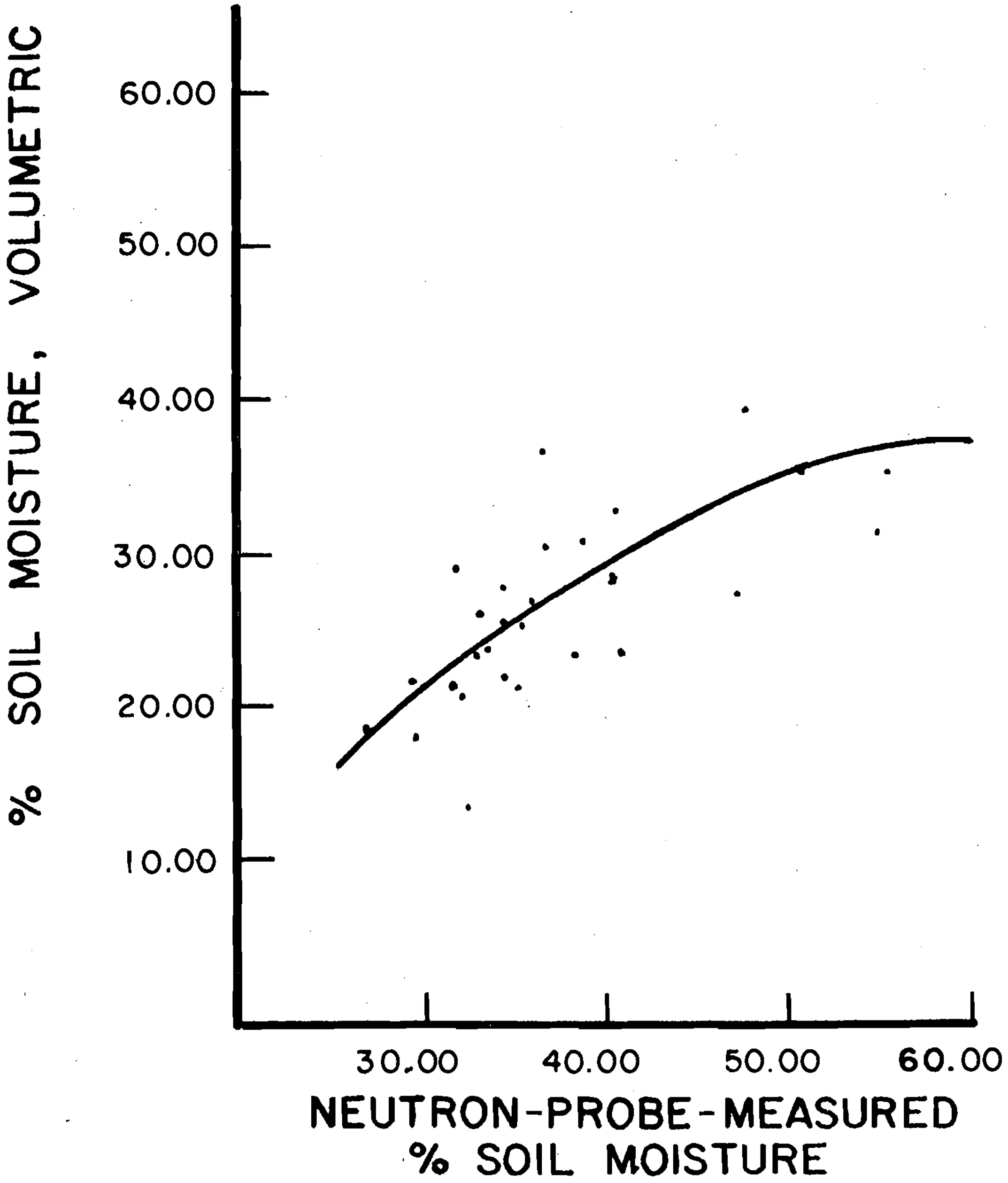


% Volumetric Soil Moisture

= +19.7 exp [0.0477(Gypsum Block Meter Reading)]

$R^2 = 0.42$

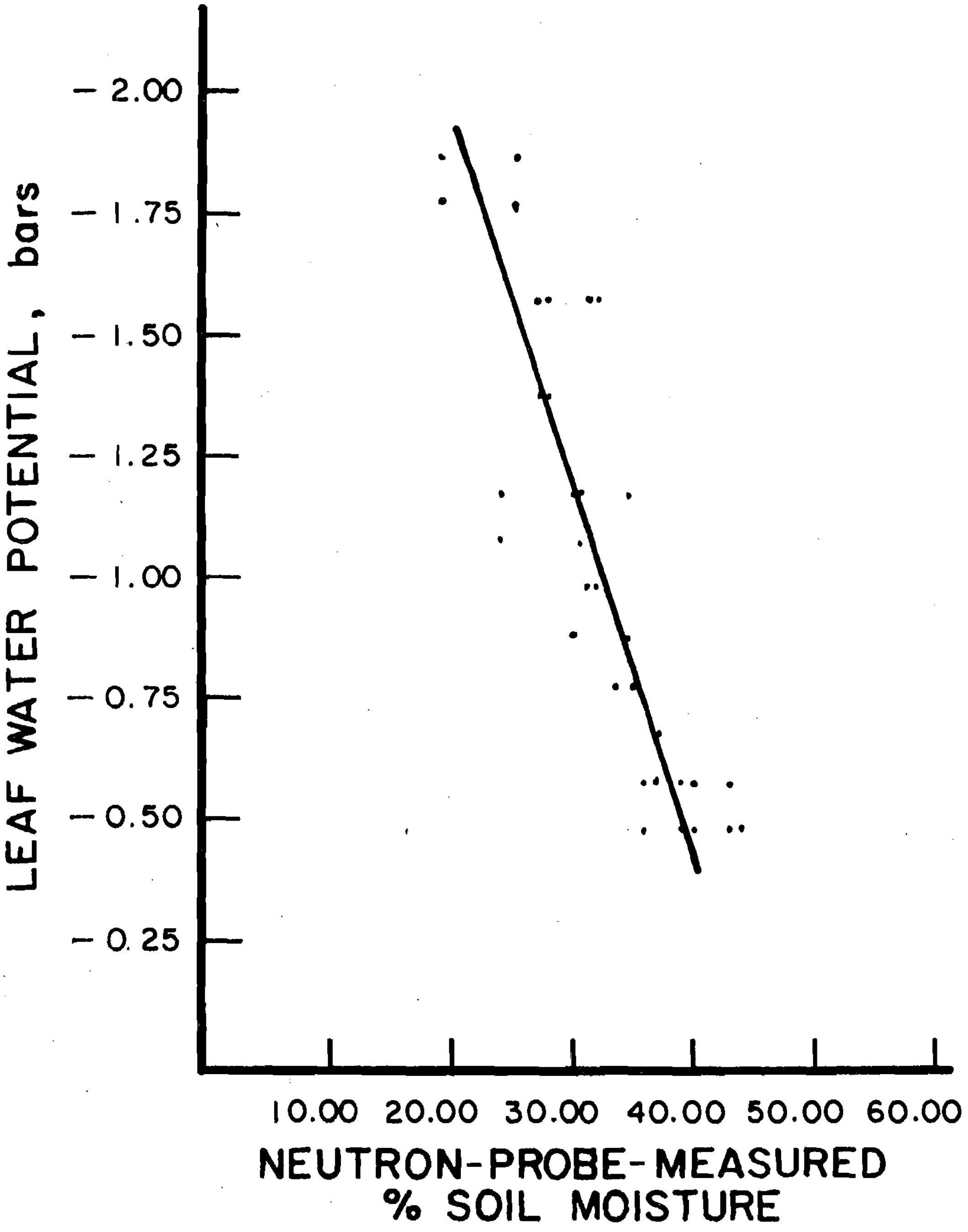
Figure 6. Gypsum block meter reading versus volumetric percent soil moisture, both from the 1-ft depth.



$$\% \text{ Volumetric Soil Moisture} = 53.3 - \frac{944}{\% \text{ NP Soil Moisture}}$$

$R^2 = 0.53$

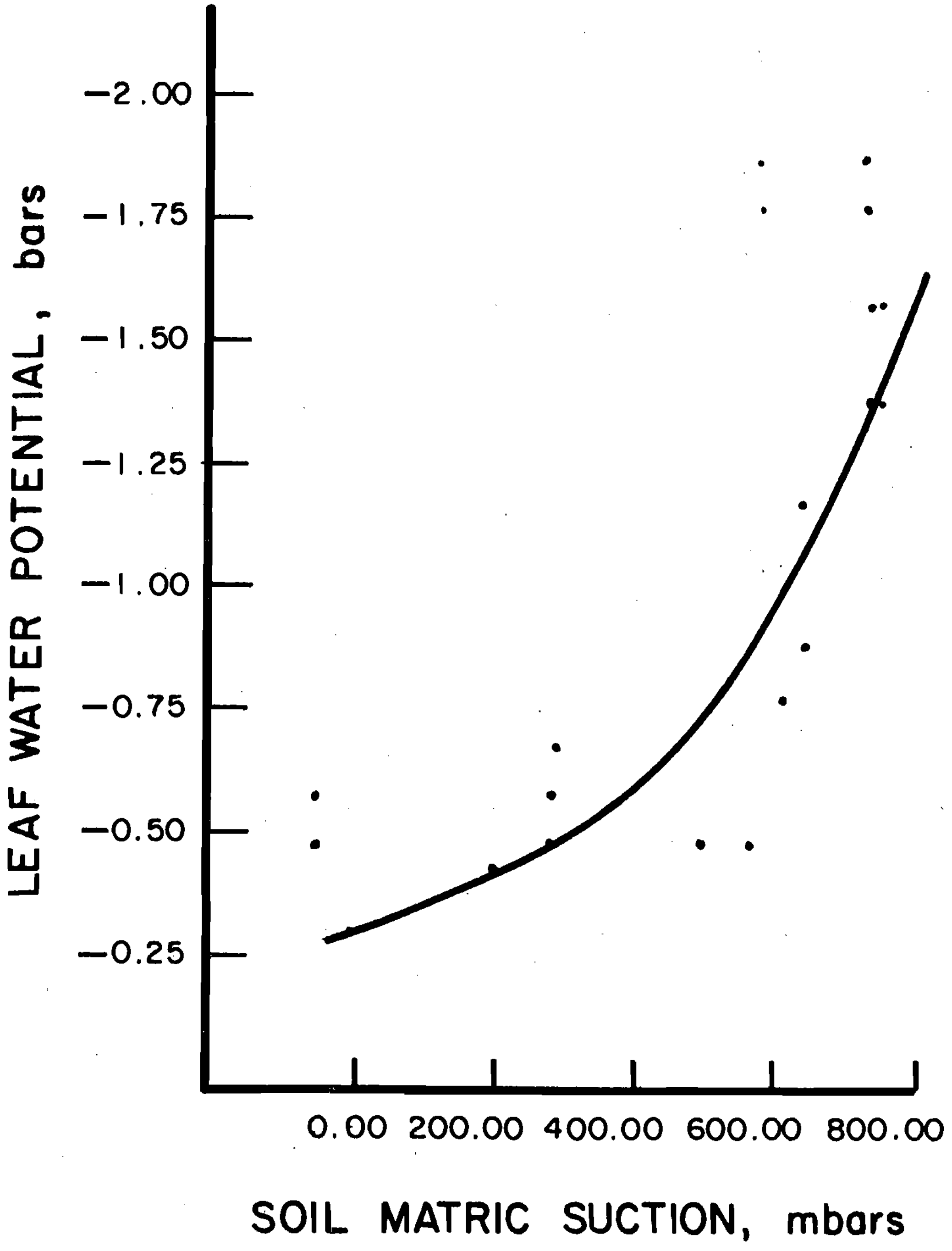
Figure 7. Neutron-probe-measured percent soil moisture versus volumetric percent soil moisture, both from the 1-ft depth.



Leaf Water Potential = -3.05 + 0.0620(% NP Soil Moisture)

$R^2 = 0.77$

Figure 8. Neutron-probe-measured percent soil moisture at the 1-ft depth versus plant leaf water potential (bars) from plots 5-N and 6-S during the month of July, 1979.

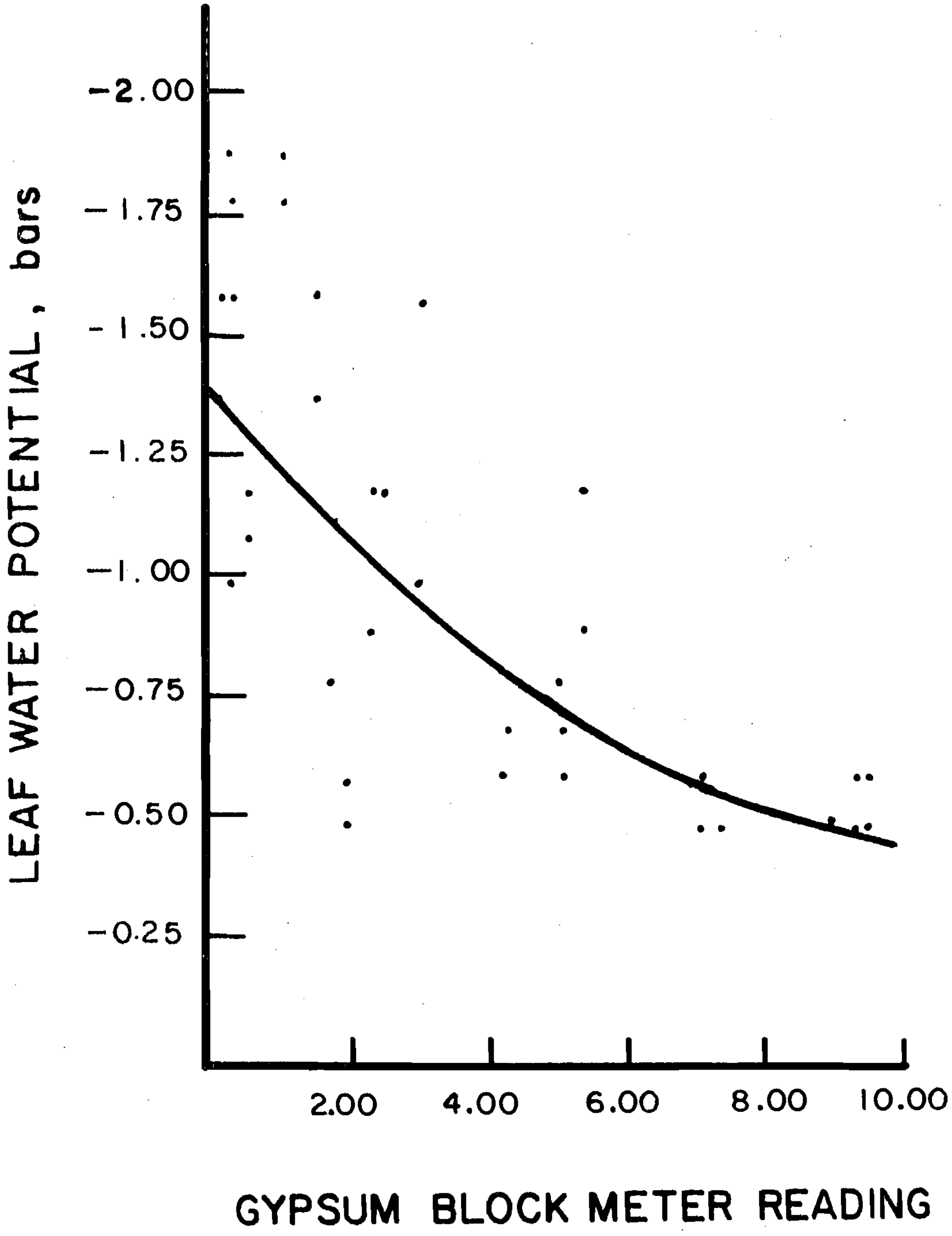


Leaf Water Potential

= -0.270 exp [0.00223(Soil Matric Suction)]

$R^2 = 0.49$

Figure 9. Soil matric suction (mbars) from tensiometer measurement at the 1-ft depth versus plant leaf water potential (bars) from plots 5-N and 6-S during the month of July, 1979.



Leaf Water Potential

$$= -1.38 \exp[-0.113(\text{Gypsum Block Meter Reading})]$$

$R^2 = 0.56$

Figure 10. Gypsum block meter reading from the 1-ft depth versus plant leaf water potential (bars) from plots 5-N and 6-S during the month of July, 1979.

monitoring soil moisture can indicate when irrigation water application is warranted. The data from the 2-ft tensiometer depth indicates that minimal moisture was removed from that depth and that the claypan layer near the 1-ft depth functioned as a barrier to soil moisture removal by the crop from depths below the 1-ft level.

DRAINAGE

Drainage volumes for all plots were monitored using submersible sump pumps to remove runoff water from collection sumps on each drained plot. The pump run time was monitored using standard-production alarm clocks with second hands. Pump response curves for various inflow rates were used to convert clock time to plot runoff. The accuracy of this technique was judged to be unsatisfactory.

The surface and subsurface drain volumes are shown in Table 1. A ten-day storm lasting from July 23 to August 1 produced 74% of the season's rainfall and an even larger percentage of the season's runoff. This storm has a recurrence interval of approximately one hundred years.

One of the most important things learned from these data is that the subsurface drainage system can remove large volumes of water on the plots without surface drainage, as is particularly evident for the July 23 to August 1 storm.

The data in Table 1 also show that for every storm the surface drainage from the furrow-irrigated plots is much greater than from the sprinkler-irrigated plots. This presumably results from the fact that the furrow-irrigation water creates well-developed pathways through the field--the furrows between the rows. They carry water very efficiently because the irrigation water has made the furrow surface smooth so that it doesn't trap water. The furrow is also likely to be wetter, so there is less infiltration. The increased surface drainage may be either a benefit or a detriment. During periods when the soil moisture is high, the increased runoff will help to prevent yield reductions caused by too much water. On the other hand, if soil moisture is lower, this runoff must be replaced by irrigation, making the runoff a detriment.

TABLE 1

Surface and Subsurface Drainage Volumes for 1979

Date	Rainfall (inches)	[1]Repl.	Drainage Volume (inches)										
			No Irrigation				Sprinkler Irrigation				Furrow Irrigation		
			Surface Drainage	Subsurface Drainage	Surface & Subsurface		Surface Drainage	Subsurface Drainage	Surface & Subsurface		Surface Drainage	Surface & Subsurface	
					Surface	Subsurface			Surface	Subsurface		Surface	Subsurface
7/3 - 7/4	2.25	N	0.01	0	0	0	trace	0.02	0.01	trace	0.90	0.42	0.02
		S	0.02	0	0.03	0.03	0	0	trace	0	1.01	0.62	0.05
7/13 - 7/14	0.24	N	trace	0	0	0	0	0.02	0	0	.51	0.18	trace
		S	0	0	0	0	trace	0	0	0	.61	0.44	0.03
7/23 - 8/1	9.85	N	7.30[2]	3.38	4.95	0.63	5.64	*	4.95	0.62	7.51[1]	7.12	0.56
		S	*	5.72	*	0.63	*	2.63	*	0.89	*	*	0.73
8/11	0.52	N	0.01	trace	0	0	0	0.01	0	trace	0.01	0	0
		S	trace	0	0.01	trace	trace	trace	0.01	0	0.01	0	0.01
8/16 - 8/17	0.15	N	0	0	0	0	0	0	0	0	0.07	0.01	0
		S	0	0	0	0	0	0	0	0	0.13	0.11	0.01
8/27 - 8/29	0.12	N	0.01	0	0	0	0	0.01	0	0	0.40	0.27	trace
		S	0	0	0.33	0.03	0	0	0	0	0.34	0	trace
9/3 - 9/5	0.16	N	0	0	0	0	0	0.02	0	0	0.39	0.21	trace
		S	0	0	0	0	0	0	0	0	0.28	0.33	0.04
Total[3]	13.29		7.32	4.55	5.14	0.66	5.65	2.67	4.96	0.76	9.78	8.42	0.73
					5.80				5.72			9.15	

*Missing data due to system malfunction.

[1] Replication abbreviations are for North and South plots.

[2] Data point was estimated based on incomplete data.

[3] Plot data from each storm were averaged and averages were summed.

It is again emphasized that all of the field data analysis presented to this point was done for data collected in 1979, because of the termination of funding after that year.

YIELDS

Corn and soybean yields from the test plots are given in Tables 2-6. Corn yields for 1977 and 1978 are presented, even though financing of the study by the Office of Water Research and Technology did not commence until 1979.

The yields in 1977 and especially 1978 are considerably lower than would be expected. The low yields are the result of planting and irrigation delays associated with troubleshooting new plots. In spite of the low yields, comparisons between treatments are believed to be valid.

Effect of Irrigation on Drained Plots

Table 2 clearly shows that irrigation increases the yield on drained plots. The four-year average corn yield on the drained plots with sprinkler irrigation was 150 bushels per acre compared with 72 bushels per acre without irrigation. That amounts to an increase of 78 bu/acre or 108%. The lowest single-year increase due to irrigation was in 1979 where the increase was only 46 bu/acre. The highest increase was in 1980 with a 122 bu/acre increase due to irrigation.

Note that the yields on the south replication of the no-irrigation surface-drainage treatment are consistently considerably lower than on the north replication. This is the only treatment with such an obvious discrepancy of yields between replications. The lower yields on the south plot are believed to result from excess topsoil removal during grading for surface drainage. On one hand is the argument that topsoil removal is an inherent problem with surface drainage and that the results from that plot should be considered in the analysis. On the other hand, the problem of topsoil removal on this plot appears to be greater than on other plots, and therefore there is justification for omission of yield data from this plot. If those data are not considered, the yield increases due to irrigation will be slightly lower than the figures given above.

TABLE 2

Yields from Irrigated and Nonirrigated plots with Drainage

	Corn (Bu/A)					Soybeans (Bu/A)
	1977	1978	1979	1980	Avg.	1980
Sprinkler Irrigation						
Surface Drainage						
N Repl.	152	67	184	167	143	46
S Repl.	146	85	187	185	151	50
Avg.	149	76	186	176	147	48
Subsurface Drainage						
N Repl.	160	87	201	186	159	51
S Repl.	140	96	189	160	146	45
Avg.	150	92	195	173	153	48
Sur. & Sub. Drainage						
N Repl.	155	84	194	170	151	45
S Repl.	147	77	179	182	146	46
Avg.	151	81	187	176	149	46
Average	150	83	189	175	150	47
No Irrigation						
Surface Drainage						
N Repl.	72	41	141	52	77	38
S Repl.	15	9	93	12	32	39
Avg.	44	25	117	32	55	39
Subsurface Drainage						
N Repl.	60	39	165	46	78	38
S Repl.	68	44	157	89	90	45
Avg.	64	42	161	68	84	42
Sur. & Sub. Drainage						
N Repl.	60	38	148	44	73	32
S Repl.	64	43	152	72	83	29
Avg.	62	41	150	58	78	31
Average	57	36	143	53	72	37
Average*	66	41	151	59	80	

---

* without south replication of no-irrigation, surface-drainage treatment

TABLE 3

Yields from Sprinkler- and Furrow-Irrigated Plots with Drainage

	Corn (Bu/A)					Soybeans (Bu/A)
	1977	1978	1979	1980	Avg.	1980
Sprinkler Irrigation						
Surface Drainage						
N Repl.	152	67	184	167	143	46
S Repl.	146	85	187	185	151	50
Avg.	149	76	186	176	147	48
Sur. & Sub. Drainage						
N Repl.	155	84	194	170	151	45
S Repl.	147	77	179	182	146	46
Avg.	151	81	187	176	149	46
Average	150	79	187	176	148	47
Furrow Irrigation						
Surface Drainage						
N Repl.	150	74	161	171	139	46
S Repl.	130	49	173	170	131	49
Avg.	140	62	167	171	135	48
Sur. & Sub. Drainage						
N Repl.	165	81	195	176	154	46
S Repl.	137	70	173	184	141	43
Avg.	151	76	184	180	148	45
Average	146	69	176	176	142	47

TABLE 4

Yields from Sprinkler-Irrigated and Nonirrigated Plots with No Drainage

	Corn (Bu/A)					Soybeans (Bu/A)
	1977	1978	1979	1980	Avg.	1980
Sprinkler Irrigation						
N Repl.	150	95	3	188	109	48
S Repl.	136	98	16	178	107	43
Avg.	143	97	10	183	108	46
No Irrigation						
N Repl.	74	38	29	98	60	43
S Repl.	76	38	16	93	56	42
Avg.	75	38	23	96	58	43

TABLE 5

Yields from Drainage and No-Drainage Plots without Irrigation

	Corn (Bu/A)					Soybeans (Bu/A)
	1977	1978	1979	1980	Avg.	1980
No Drainage						
N Repl.	74	38	29	98	60	43
S Repl.	76	38	16	93	56	42
Avg.	75	38	23	96	58	43
Surface Drainage						
N Repl.	72	41	141	52	77	38
S Repl.	15	9	93	12	32	39
Avg.	44	25	117	32	55	39
Subsurface Drainage						
N Repl.	60	39	165	46	78	38
S Repl.	68	44	157	89	90	45
Avg.	64	42	161	68	84	42
Sur. & Sub. Drainage						
N Repl.	60	38	148	44	73	32
S Repl.	64	43	152	72	83	29
Avg.	62	41	150	58	78	31
Average of All Drainage Treatments						
Avg.	57	36	143	53	72	37
Avg.*	66	41	151	59	80	

---

* without south replication of surface drainage without irrigation

TABLE 6

Yields from Drainage and No-Drainage Plots with Sprinkler Irrigation

	Corn (Bu/A)					Soybeans (Bu/A)
	1977	1978	1979	1980	Avg.	1980
No Drainage						
N Repl.	150	95	3	188	109	48
S Repl.	136	98	16	178	107	43
Avg.	143	97	10	183	108	46
Surface Drainage						
N Repl.	152	67	184	167	143	46
S Repl.	146	85	187	185	151	50
Avg.	149	76	186	176	147	48
Subsurface Drainage						
N Repl.	160	87	201	186	159	51
S Repl.	140	96	189	160	146	45
Avg.	150	92	195	173	153	48
Sur. plus Sub. Drainage						
N Repl.	155	84	194	170	151	45
S Repl.	147	77	179	182	146	46
Avg.	151	81	187	176	149	46
Average of All Drainage Treatments						
Avg.	150	83	189	175	150	47

The 1980 average soybean yield on the irrigated plots with drainage was 47 bu/acre, while the average on the nonirrigated plots with drainage was only 37 bu/acre.

Comparison of Furrow and Sprinkler Irrigation on Drained Plots

Table 3 shows that there is little difference between the yields obtained with sprinkler and furrow irrigation. The four-year average corn yields were 148 and 142 bu/acre with sprinkler and furrow irrigation respectively. The slightly lower average for the furrow-irrigated plots is believed to result from less moisture in these plots due to overestimating the irrigation efficiency during 1977-79.

The 1980 average soybean yield for furrow irrigation was 47 bu/acre, which was only slightly above the 46 bu/acre average for sprinkler irrigation.

Effect of Irrigation on Plots with No Drainage

A considerable increase in yield resulted from irrigation even on the no-drainage plots. Table 4 shows that, over the four years of the study, corn yields averaged 108 bu/acre on the irrigated no-drainage plots and only 58 bu/acre on the no-drainage plots without irrigation. Irrigation substantially increased yield each year except 1979. The rainfall was excessive during August of that year, and irrigation apparently compounded the drainage problem and decreased the yield.

The 1980 soybean yields also indicate that irrigation improves yield on plots without drainage. The average yields were 46 and 43 bu/acre with and without irrigation, respectively.

Effect of Drainage on Plots without Irrigation

The four-year average corn yield on plots with no drainage and without irrigation was 58 bu/acre compared to 72 bu/acre for plots with drainage but not irrigation (see Table 5). This difference indicates the beneficial effect of drainage. However, it should be noted that during two of the four years the reverse is true; that is, higher yields were obtained without drainage. The cause for the lower yields with drainage during these years cannot be determined with certainty. However, the probable cause is that the benefit of extra moisture stored in the non-drained plots during the droughty part of the year outweighed the disadvantage of excess soil water during the wetter parts of the year. Another contributing cause might be that the soil structure was damaged in the drainage installation process. This damage, if it exists, would be an inherent part of a field-installed drainage system in this soil also. Therefore, reductions in yield caused by soil damage are realistic. Also note that drainage type appears to have little effect on yield, especially if the south replication of the surface drainage treatment is ignored.

The one year of soybean data is insufficient for drawing valid conclusions.

Effect of Drainage on Plots with Sprinkler Irrigation

Table 6 shows that the average increase in corn yield due to drainage on the irrigated plots was 42 bu/acre, which is the difference between 150 and 108 bu/acre. However, like the plots without irrigation, drainage was a slight disadvantage during parts of the years. Note that drainage type had little effect on yield.

Synergistic Effect of Combining Irrigation and Drainage

The average increase in corn yield attributable to irrigation alone is 50 bu/acre (108 minus 58), as is shown in Table 4. Likewise, the average increase in yield due to drainage alone is 13 bu/acre (72 minus 58), as is shown in Table 5. However, the yield due to the interactive effects of irrigation plus drainage of 92 bu/acre (150 from Table 2 minus 58 from Table 4) is considerably greater than the sum of the increase due to irrigation and drainage independently (50 + 13 = 63 bu/acre.

SOIL MOISTURE MODELING

A soil moisture model for an entire growing season consists of a water balance model where the soil moisture in the profile at any one time is a function of moisture added, moisture subtracted, and storage capacity. Moisture added consists of rainfall and irrigation water, while moisture subtracted consists of drainage water and evapotranspiration. The storage capacity is a function of the specific soil profile under consideration.

Many models have been developed in recent years which consider various aspects of the soil-water-air regime. However, none apply directly to combined irrigation and drainage on heavy soils. Because the research plots have a very tight claypan soil, a new model was developed by the principal investigators, using parts of existing models and adding new parts.

EVAPOTRANSPIRATION

The evapotranspiration model used by Stuff and Dale (1978) and by Dale, Nelson, and Scheeringa (1979) was adapted for this study. The model makes use of soil moisture relationships, corn-crop silking data, and pan evaporation to predict daily evapotranspiration (ET). The model consists of three factors: a non-moisture-stress factor, a crop development factor, and pan evaporation. The equations making up the model are shown below, with corrections for units.

$$ET = NS * F * Ep$$

where ET = predicted evapotranspiration

Ep = class A pan evaporation

F = crop developmental factor
$= -1.58 + 0.0463\ W - 0.00022\ W$

where W = date, with $W = 100$ defined as the date of silking (anthesis)

NS = non-moisture-stress factor
= 1.19 - [4.2926 * Ep * (1 - PAV / 100)]

where PAV = percentage available moisture
= [(S - WP) / (H - WP)]

where S = actual soil moisture (% volumetric)
WP = permanent wilting point (volumetric soil moisture at 15 bars tension)
H = upper holding capacity (volumetric soil moisture at 0.10 bars tension)

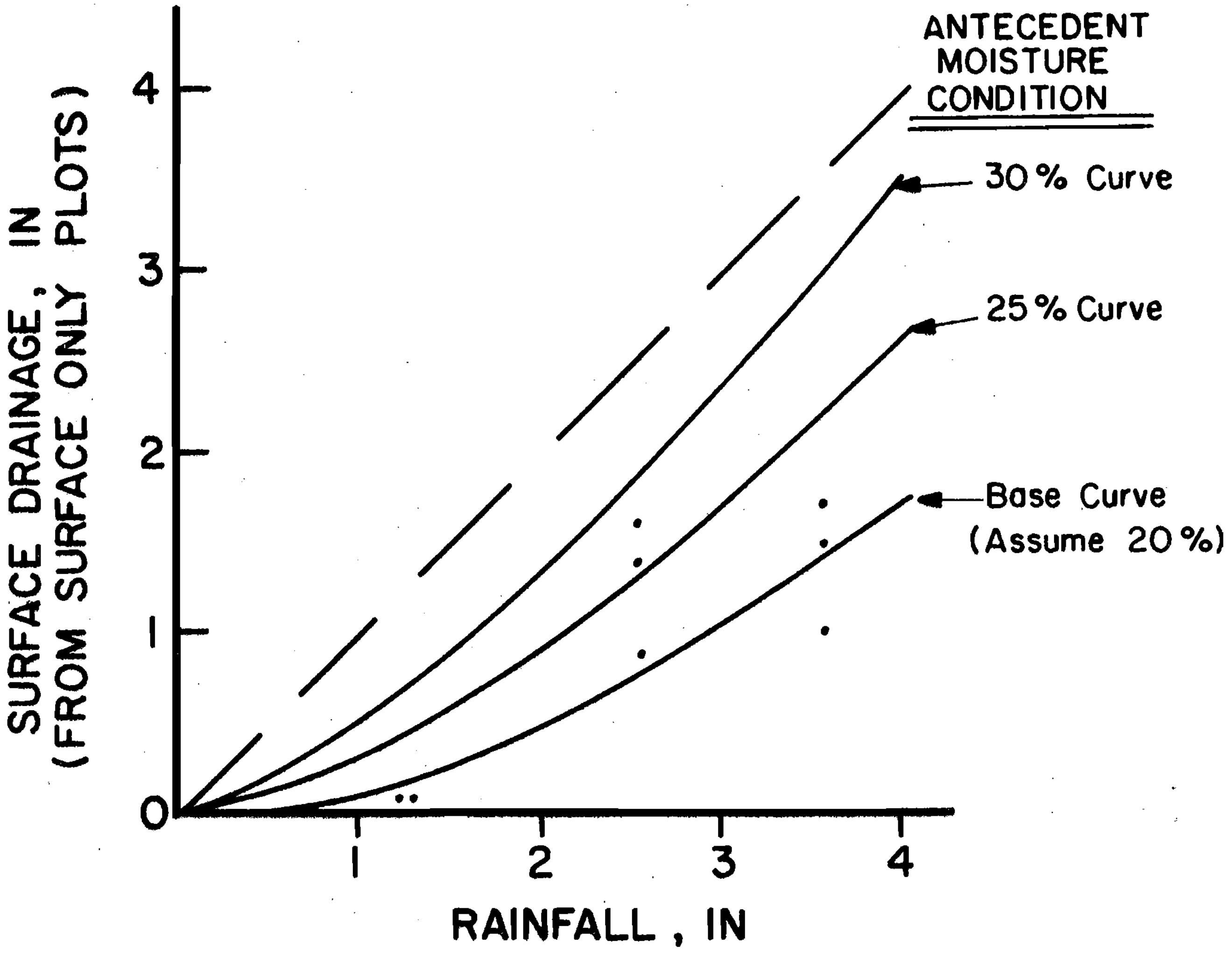
The above equations were developed by Dale and others (1979) for poorly drained and well-drained soils from three years of data taken at West Lafayette, Indiana. The crop development factor and the moisture stress factor were developed from literature and modified to fit the particular situation.

DRAINAGE

A model specific to the research plots was developed by treating each runoff event as a single unit, with the independent variables being drainage type, antecedent moisture, and rainfall amount. There were only a few runoff events, so the model is at best tenuous. The drainage models representing the four drainage types are shown in Figures 11-14.

IRRIGATION

There were two types of irrigation components to the model. One was used when the soil moisture model was being used to check the model against the data collected in the field. The other was used when the long-term effects of the treatments were predicted using historical data for which there were no corresponding field data. To check the model against field moisture measurements, actual irrigation amounts and times were used. When using historical weather data, the irrigation was modeled to be one inch of water applied whenever the soil moisture dropped below 28%.

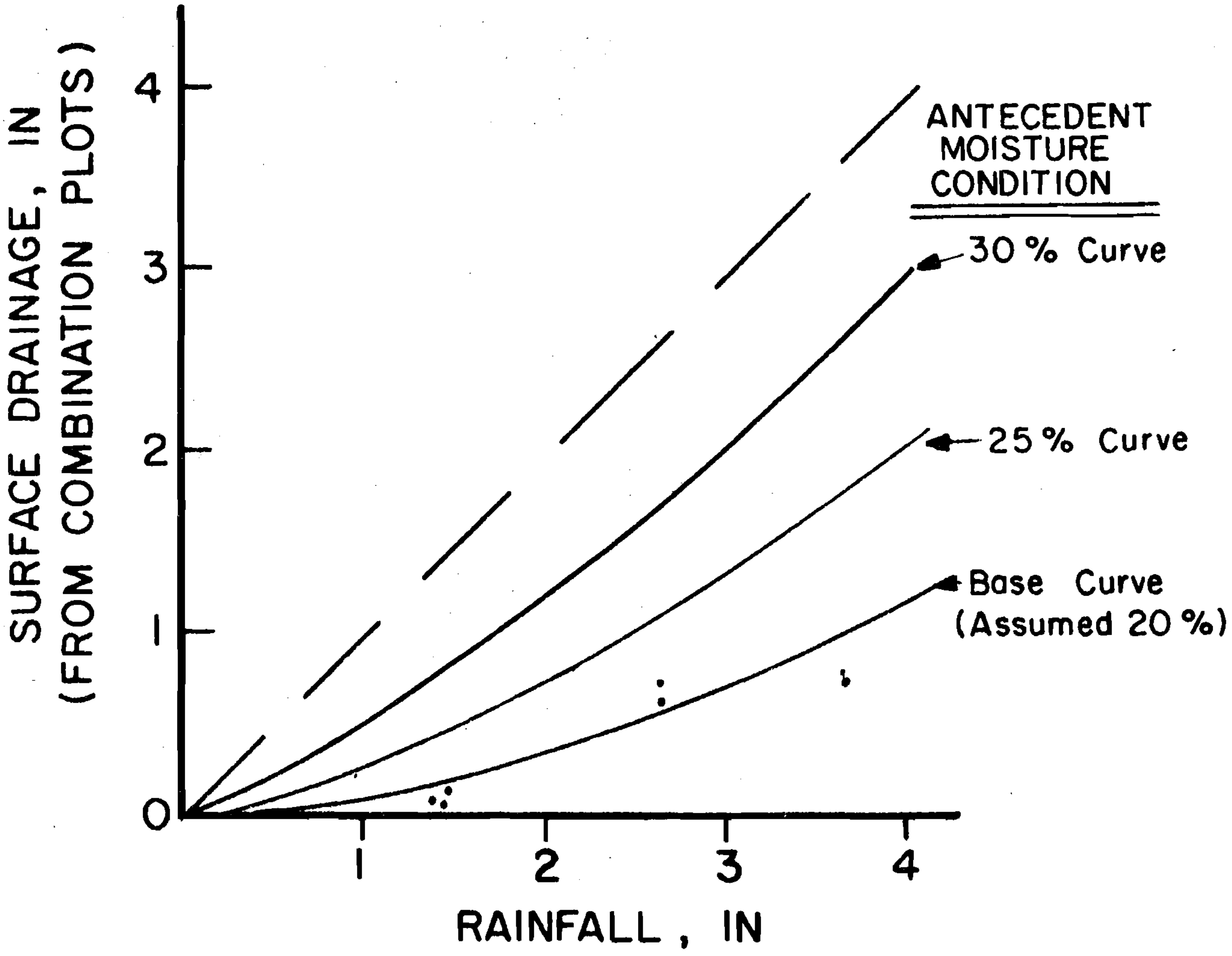


Drain = Base + Shift

where: $$\text{Base} = \frac{\text{Rain}}{-0.862 - 0.226(\text{Rain})} + \text{Rain}$$

$$\text{Shift} = 0.18(\text{Soil Moisture} - 20)\ \frac{\text{Rain}}{4.0}$$

Figure 11. Surface drainage from surface-drainage-only plots.

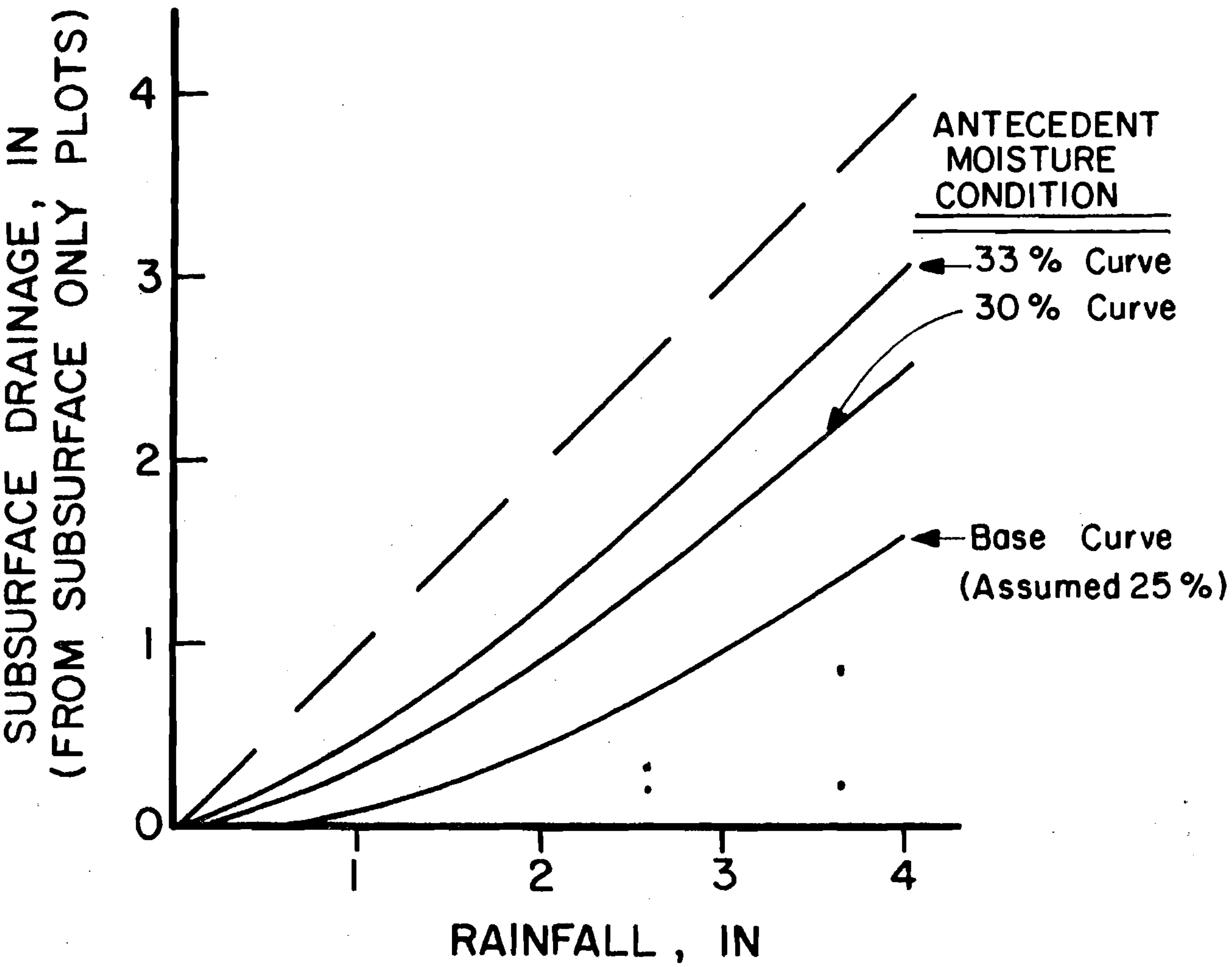


Drain = Base + Shift

$$\text{where:} \quad \text{Base} = \frac{\text{Rain}}{-0.984 - 0.111(\text{Rain})} + \text{Rain}$$

$$\text{Shift} = 0.18(\text{Soil Moisture} - 20)\ \frac{\text{Rain}}{4.0}$$

Figure 12. Surface drainage from combined drainage plots.

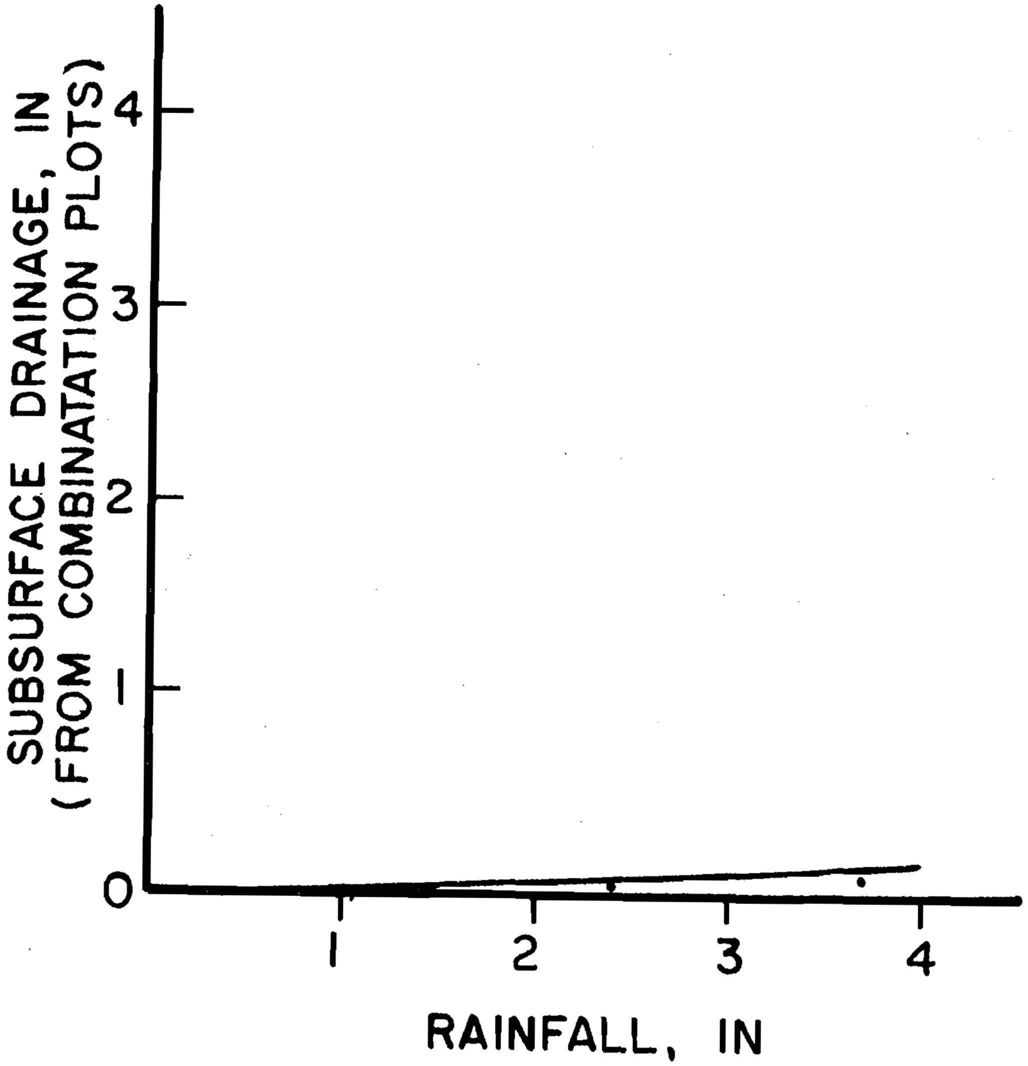


Drain = Base + Shift

$$\text{where:}\quad \text{Base} = \frac{\text{Rain}}{-0.986 - 0.176(\text{Rain})} + \text{Rain}$$

$$\text{Shift} = 0.18(\text{Soil Moisture} - 25)\ \frac{\text{Rain}}{4.0}$$

Figure 13. Subsurface drainage from subsurface-drainage-only plots.



Drain = -0.0475 + 0.0560(Rain)

Figure 14. Subsurface drainage from combined drainage plots.

OTHER CONSIDERATIONS

Deep percolation was assumed to be zero because of the restrictive claypan layer associated with Cisne Association soils. The season's initial moisture content (volumetric) is assumed to be equal to 45% in the top 18 inches of the soil profile approximately sixteen days before planting.

SOIL MOISTURE MODEL RESULTS

The accuracy of this model may be judged by comparing the soil moisture content predicted by the model with the moisture levels measured by the neutron probe and the tensiometers during the 1979 season. Figures 15 through 17 are plots of predicted and measured soil moistures on various plots during the growing season. Included on these plots are actual neutron probe moisture readings at the 6-in and 1-ft depths and tensiometer moisture readings at the 1-ft depth. These figures indicate that the model does predict values of soil moisture within the ranges indicated by the various moisture-measuring devices as described earlier. However, one can see that these ranges, in some instances, are rather large.

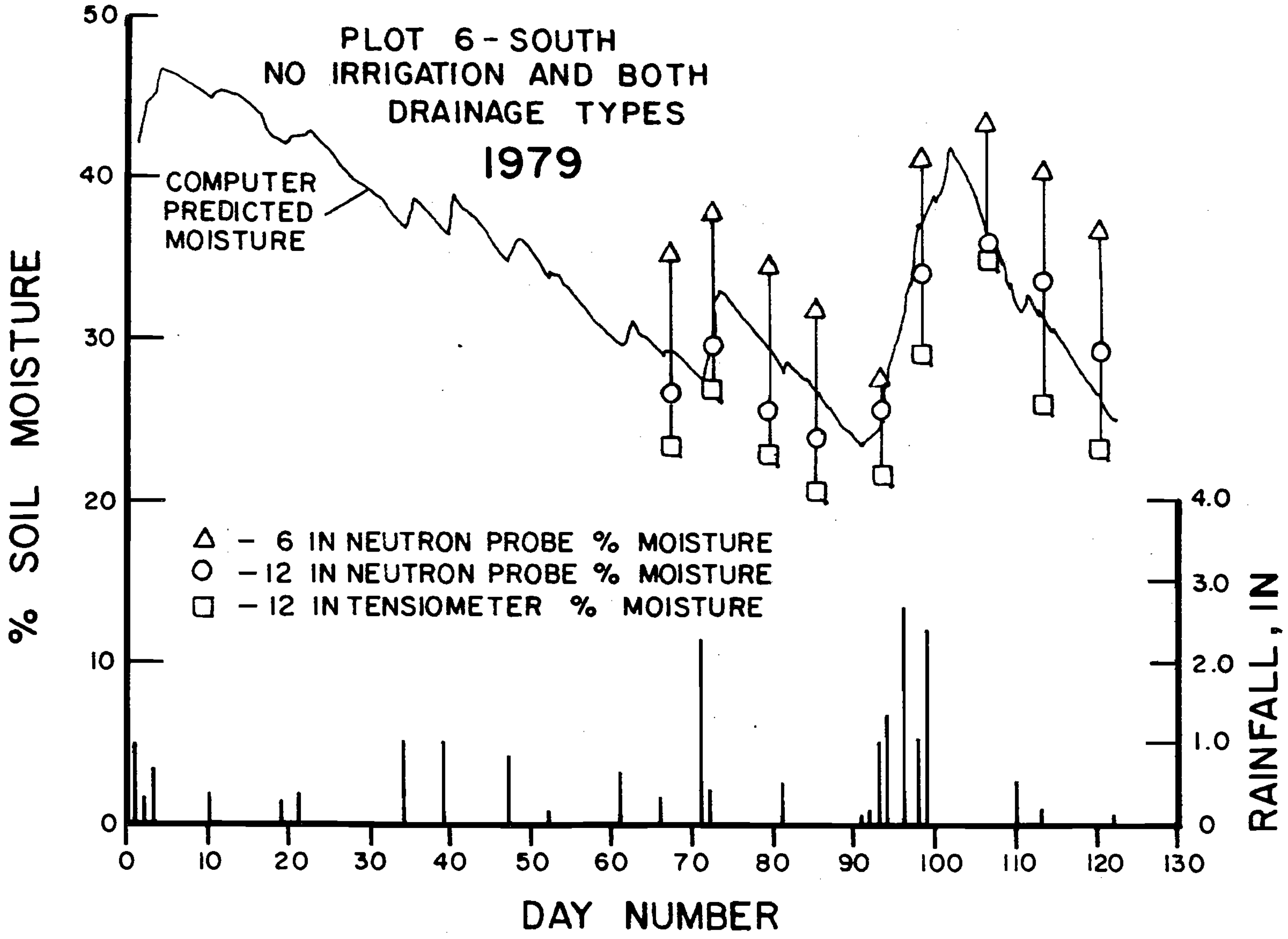


Figure 15. Results of soil moisture simulation model for plot 6-S.

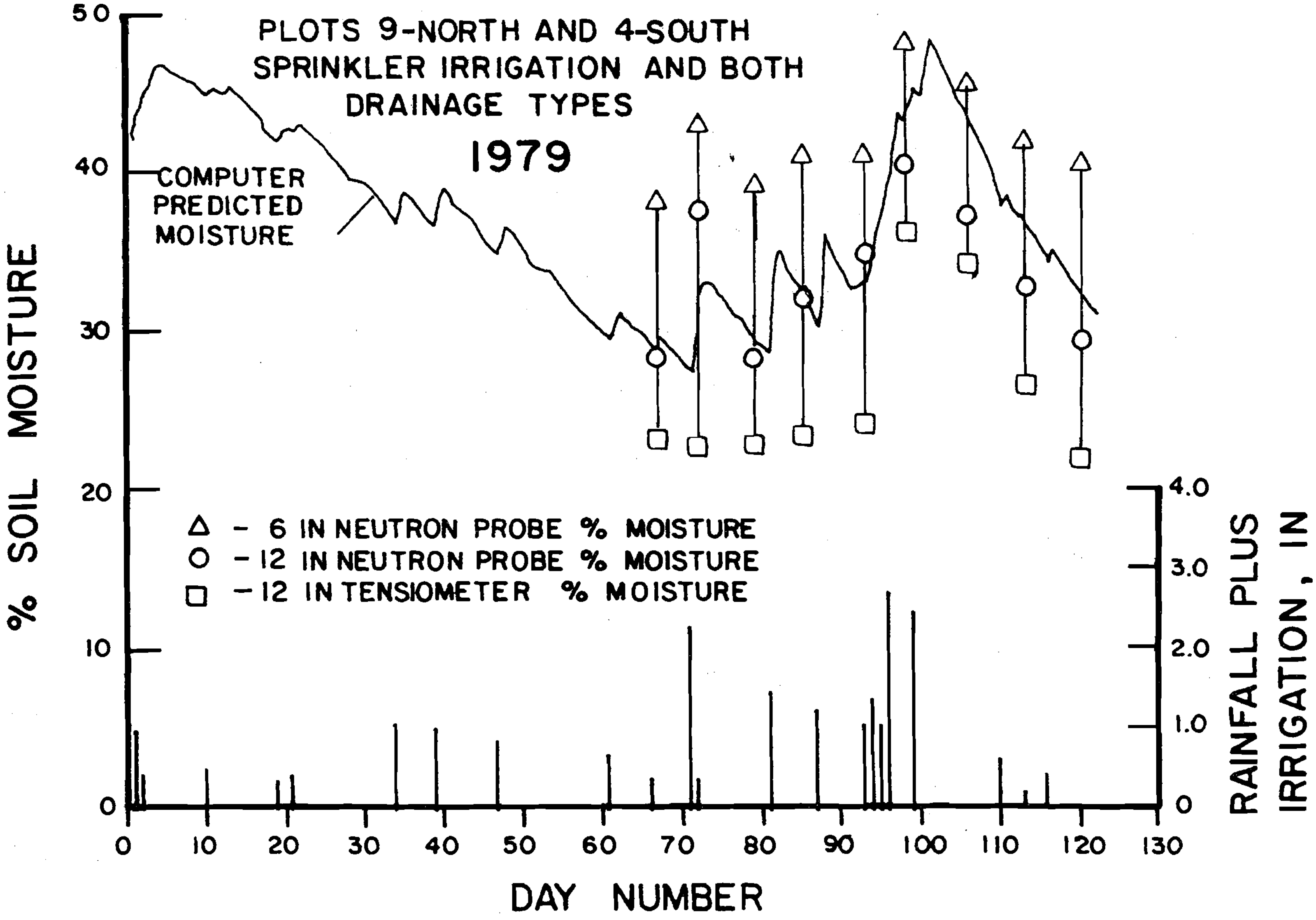


Figure 16. Results of soil moisture simulation model for plots 9-N and 4-S.

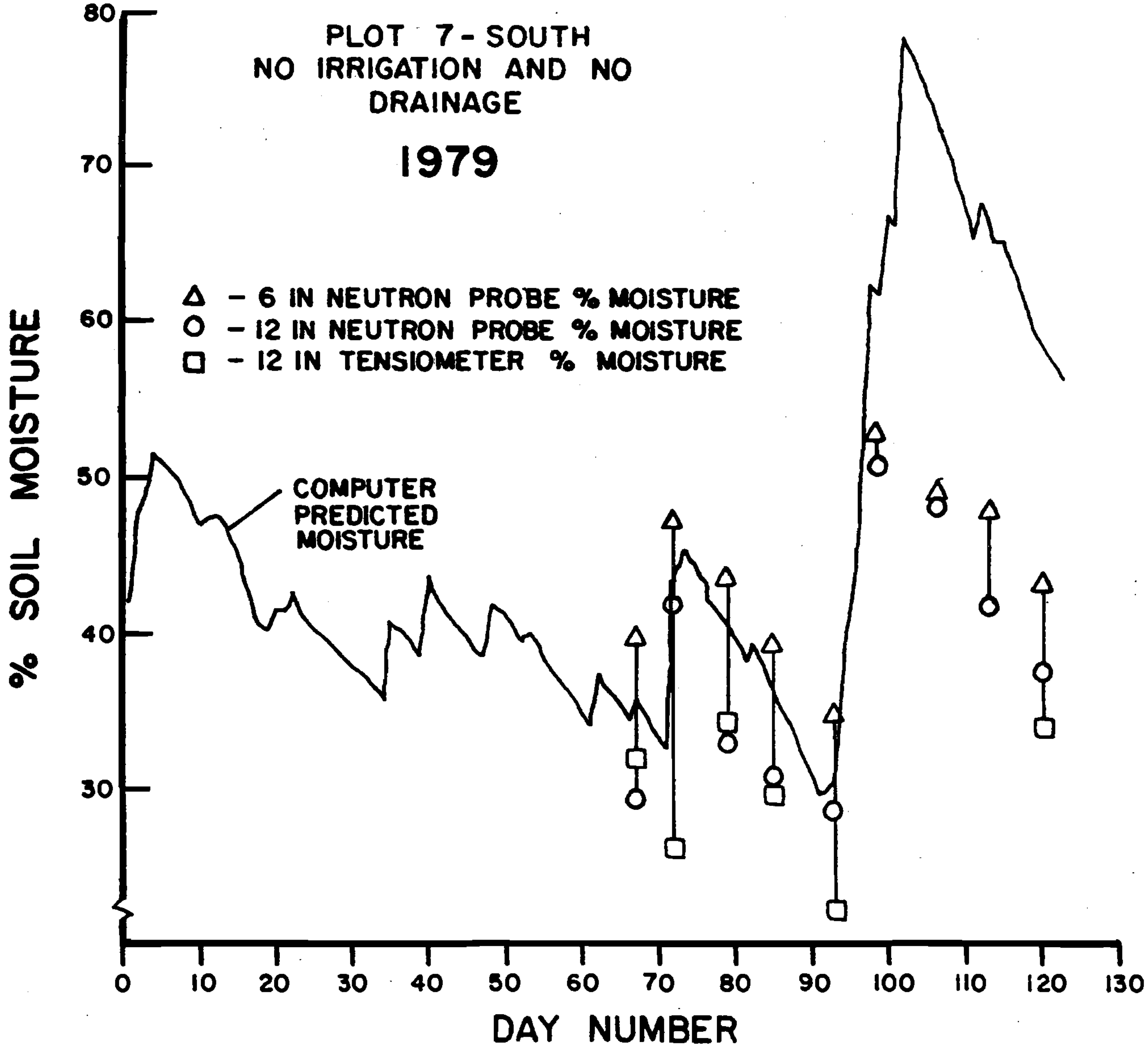


Figure 17. Results of soil moisture simulation model for plot 7-S.

YIELD MODEL DEVELOPMENT

Predicting yield from crop-related variables, because of the number of possible variables, is a very difficult process. Meteorological variables, including radiation, maximum and minimum temperatures, relative humidity, wind travel, and others, could all be used in the development of a model. Soil moisture, leaf water potential, evapotranspiration, and growth stage also have their various effects on final crop yield. Timeliness of planting date has an important effect on yield and therefore should be included in the complete yield model.

PLANTING DATE CORRECTION

Timeliness of planting date (yield reduction resulting from delaying planting after the optimum date) varies greatly from region to region. Wendte (1975) reported the great diversity of yields resulting from various planting dates in Missouri, Ohio, Indiana, and Illinois. Results varied from large reductions in yield if planting was delayed until after May 10 in Missouri to reductions of 4 to 6 bushels per acre if planting was delayed until early May in Ohio. Wendte also reported that research done at the University of Illinois indicated a 1.6 bu/acre/day reduction for planting after April 30.

The American Potash Institute (1965) found that May 8 was the optimum planting date for corn in the Midwest (Figure 18). If planting is accomplished either before or after this date, a reduction in yield is experienced. DeKalb Research (1979) reported the advantages of early planting based on work at their research plots at DeKalb, Illinois. Figure 19 is a plot of the results of their study; it includes the effect of switching to a short-season hybrid if planting has not taken place by May 25. If a short-season hybrid is not used after May 25, the yield-reduction effect of late planting greatly increases. The relationship shown in Figure 19 does not picture this increase in yield loss because, for modeling purposes, it is assumed that the farmer would automatically switch to a shorter-season hybrid after May 25. Both the DeKalb Research model and the American Potash Institute model have similar reductions for long planting delays except during the early season. They both, however,

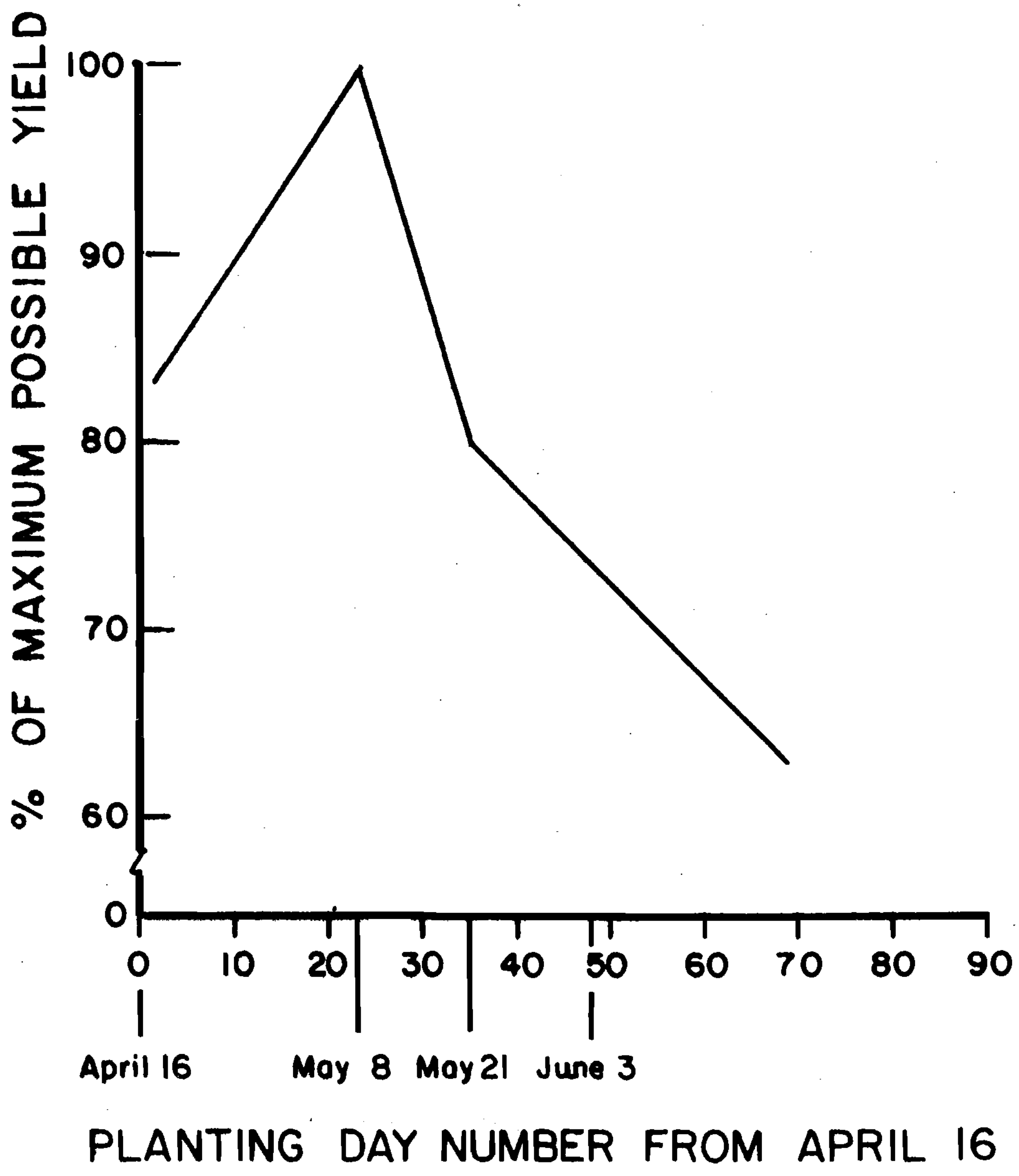


Figure 18. American Potash Institute planting date correction factors.

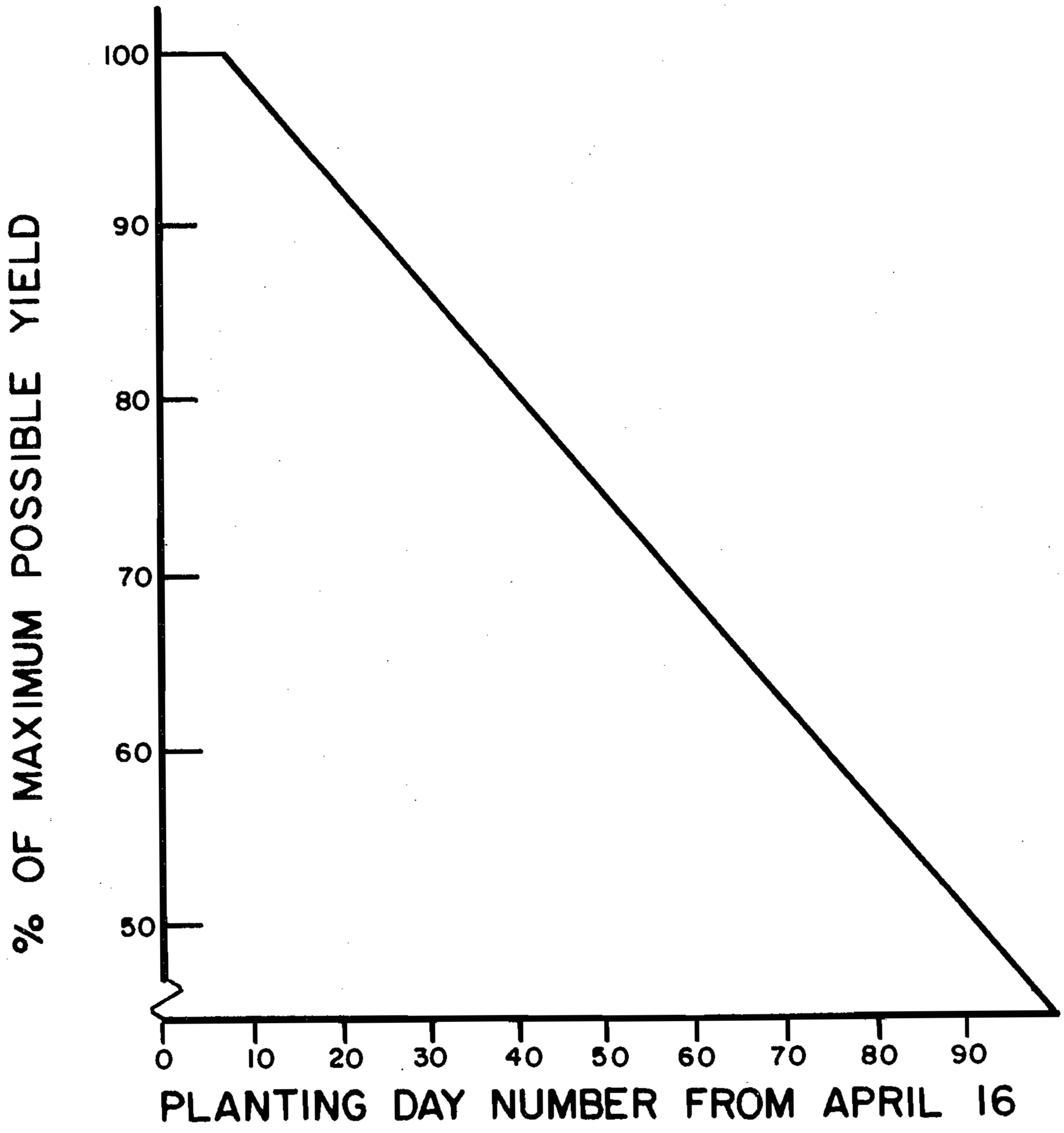


Figure 19. DeKalb Research planting date correction factors.

follow the trend suggested by the University of Illinois of 1.6 bu/acre/day reduction after April 30 (Pendleton and Egli 1969). Therefore, both the DeKalb Research and the American Potash Institute reduction models were included in the computer model for comparison purposes.

ANTHESIS DATE PREDICTION

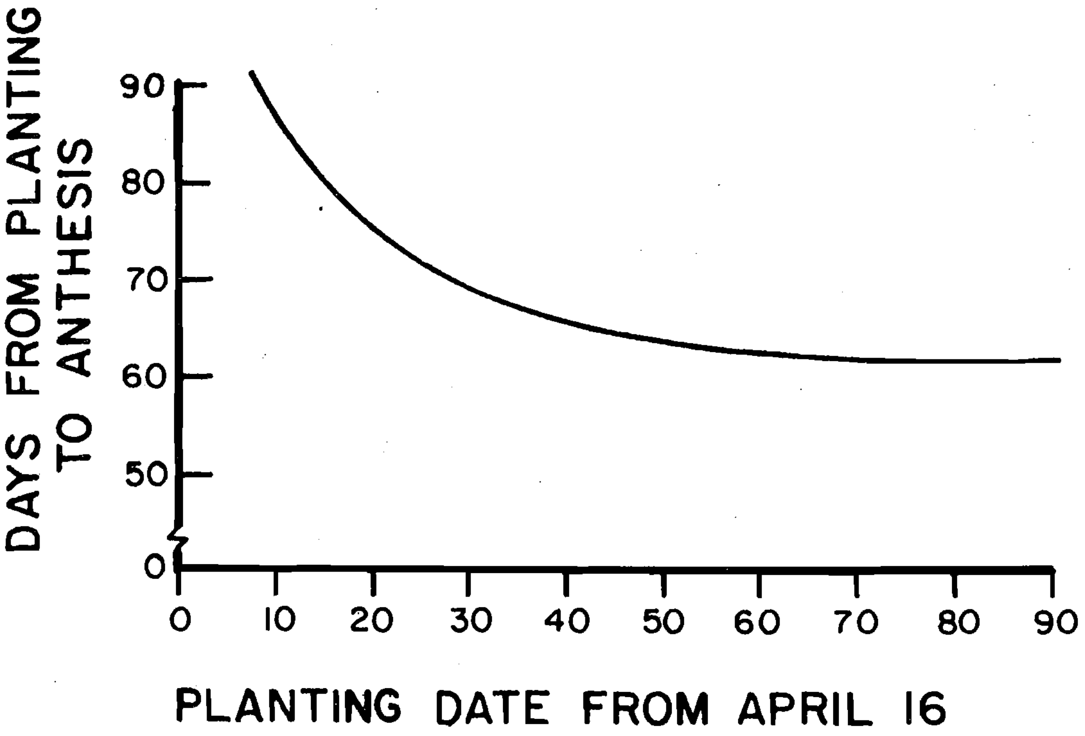
The soil moisture model, developed in an earlier section, bases some of the equations for predicting evapotranspiration on silking date. Silking date can be estimated by the date of planting, as indicated by Runge and Odell (1958) from research work done at the University of Illinois Agronomy South Farm. The relationship and corresponding equation are shown in Figure 20. This relationship enables the growing season to be broken into stages of growth, which greatly facilitates the development of a yield model.

YIELD MODEL PERIODS

Runge (1968) divided the growing season into 8-day periods from 50 days before to 14 days after anthesis. Mak (1978) used two 32-day periods, the planting season and the pollination season. Mak based these periods on calendar dates, with the planting season running from May 1 through June 1 and the pollination season extending from June 30 through July 31.

Denmead and Shaw (1960) used a slightly different breakdown of the growing season, dividing the season into a vegetative, a silking, and an ear stage of growth. The vegetative growth stage extended from 30 days after planting to the beginning of visible tasseling. This period was taken to be exactly 30 days in length. The silking stage was only 17 days long, running from the end of the vegetative growth stage to 5 days after the plants were 75% silked. The ear stage extended from the end of the silking stage to 30 days after the silking stage.

After considering the other possibilities of growing season breakdown, a variation of the Denmead and Shaw model was used because of the widespread use of the model by other researchers. The growing season was broken into three 15-day periods. The first period began 22 days before



$$\text{Days from Planting to Anthesis} = 57.60456 + \frac{319.99123}{\text{Planting Date}}$$

$R^2 = 0.70262$

Figure 20. Days from planting day to anthesis as a function of planting date (from Runge 1968).

anthesis, the second began 7 days before anthesis, and the third began 8 days after anthesis. This breakdown allows simple computer modeling of the periods and reflects the variability of factors used in the model during the silking and seed-setting periods of growth.

SOIL MOISTURE AND EXCESS SOIL MOISTURE

Soil moistures were predicted by the soil moisture model, as previously discussed. Soil moisture may have both a positive and negative effect on crop yield. Low values of soil moisture will decrease yield, but excessive values of moisture will also decrease yield. To indicate this relationship, an excess soil moisture variable was also included in the model. Whenever soil moisture was greater than 38%, a variable, named SMG, was set equal to the soil moisture minus 38. For example, if the soil moisture was 42%, SMG was set equal to 4%. If the soil moisture was less than 38%, SMG was set equal to zero.

YIELD MODEL REGRESSION

Yield prediction equations were determined by regression analyses of the growing-season-period averages of evapotranspiration, soil moisture, and excess soil moisture. These equations were based on predicted values of these variables during 1977, 1978, and 1979 and actual corn yields from the twenty plots for each of those years. This means that 60 plot-years of actual yields, simulated soil moisture, and simulated evapotranspiration values were used. Before the regression analysis, each yield value was corrected to remove planting-date effect. Both the American Potash Institute and the DeKalb Research correction factors were used to modify the separate yield values from each year. For each of these possibilities, the inclusion of all plot yields except those from plot 1-S was also tried. For each of these possibilities, the regression analysis was also tried with the forced and nonforced inclusion of the excess soil moisture variables (SMG).

The regression analysis included all possible squared and cubed combinations of the evapotranspiration, soil moisture, and excess moisture variables. This analysis resulted in eight yield equations.

The regression coefficients (R^2 values) ranged from values of 0.87 to 0.95 (a value of 1.00 is defined as a perfect correlation between predicted and actual value). The resulting equations, their coefficients, and other information are shown in Table 7. After considering the performance of each model, the equations used for yield prediction of the twenty years of meteorological data were restricted to four of the models. Those models resulting from the exclusion of data from plot 1-S had slightly higher regression coefficients.

Table 8 lists the actual and predicted yields for 1977, 1978, and 1979 as indicated by the four yield models. The corresponding regression coefficients for each model are also shown. Model D57NF* results in the highest regression coefficient, but all of the models have relatively high values.

---

* D: DeKalb Research planting date correction
57: 57 data points (excludes plot 1-S)
NF: nonforced inclusion of the excess moisture variable

TABLE 7

Yield Model Prediction Equations

VARIABLES	AMERICAN POTASH INSTITUTE				DEKALB RESEARCH			
	ALL PLOTS		EXCLUDING 1-SOUTH		ALL PLOTS		EXCLUDING 1-SOUTH	
	FORCED INCLUSION	NON-FORCED	FORCED INCLUSION	NON-FORCED	FORCED INCLUSION	NON-FORCED	FORCED INCLUSION	NON-FORCED
SMG(3)	-4,6012		-2,6723		-5,9946		-5,6385	
SMG(3)^2								
SMG(3)^3								
SMG(2)	2,4433		2,4558		5,8058		4,8850	
SMG(2)^2								
SMG(2)^3								
SMG(1)	9,4421		-7,4844		-0,1809		3,7082	
SMG(1)^2								
SMG(1)^3								
SM(3)	8,1942	48,6324	50,5409	48,6446		17,0585		65,6055
SM(3)^2								
SM(3)^3		-0,0059	0,0098					
SM(2)	36,7622					19,4693		
SM(2)^2					0,0038			
SM(2)^3							0,0043	0,0021
SM(1)		-3,6010	-32,6301	-31,4754		-0,0013		
SM(1)^2								
SM(1)^3				0,0094				
ET(3)					875,3369		827,4577	
ET(3)^2								5634,288
ET(3)^3		-369,7781			-478,3013		-425,5923	
ET(2)								
ET(2)^2					-286,5526		-298,3418	
ET(2)^3								
ET(1)	-99,3651						-68,5008	-3359,578
ET(1)^2								
ET(1)^3								-3146,629
OTHER VARIABLES USED:								
SMG(2)*ET(2)								2,8610
SM(2)*ET(2)^2						-8,9919		
SM(3)*ET(3)^2						-0,0013		
ET(2)*SM(2)^2	-0,4594							
ET(3)*SMG(3)^2				-0,0406				
ET(3)*SM(3)^2			-0,5955	-0,5563				-0,8851
INTERCEPT	-910,599	-702,962	-310,419	-297,710	-299,863	-749,729	-257,447	-697,421
REGRESSION COEFFICIENT (R-SQUARED)	0,91	0,87	0,91	0,91	0,91	0,90	0,94	D,95

NOTE THAT THE NUMBERS IN PARANTHESIS AFTER EACH VARIABLE INDICATE WHICH PERIOD THE VARIABLE COMES FROM. PERIOD 1 INDICATES PRESILKING SEASON, 2 INDICATES SILKING PERIOD AND 3 INDICATES THE POST SILKING PERIOD.

Forced Inclusion -- Regression process carried out with the forced inclusion of variables SMG (1), SMG (2), and SMG (3).

Nonforced Inclusion -- Regression process carried out with no restraints.

TABLE 8

Values of Predicted and Actual Yields from Yield Models

		Potash Planting Correction			DeKalb Planting Correction		
Year	Plot	Actual Yield*	Model Yields		Actual Yield*	Model Yields	
			P57FR**	P57NF**		D57FR**	D57NF**
1977	1-N	63.2	80.8	79.2	61.0	74.3	65.5
1977	2-N	77.7	70.4	68.2	75.1	78.0	72.1
1977	3-N	156.6	146.7	147.2	151.2	137.3	147.3
1977	4-N	167.3	142.7	143.4	161.5	150.2	144.0
1977	5-N	74.9	75.7	71.2	72.3	61.2	66.0
1977	6-N	157.1	145.1	144.5	151.7	145.8	142.8
1977	7-N	62.9	76.3	74.5	60.8	61.3	67.3
1977	8-N	173.0	146.2	145.6	167.1	145.7	144.2
1977	9-N	161.9	142.1	142.1	156.4	146.1	141.5
1977	10-N	158.7	141.5	141.4	153.3	145.7	141.1
1977	1-S	15.8			15.3		
1977	2-S	136.1	145.1	144.5	131.5	145.8	142.8
1977	3-S	153.2	144.6	144.4	148.0	145.6	143.9
1977	4-S	153.4	145.2	145.0	148.2	146.0	144.2
1977	5-S	143.0	146.2	145.6	138.1	145.7	144.2
1977	6-S	67.3	76.3	74.7	65.0	61.3	67.3
1977	7-S	79.5	70.4	68.2	76.8	78.0	72.1
1977	8-S	71.1	80.8	79.2	68.7	74.3	65.5
1977	9-S	146.8	146.1	146.5	141.8	149.8	147.8
1977	10-S	142.3	153.4	153.6	137.5	139.1	149.9
1978	1-N	66.7	71.5	71.3	64.5	71.6	68.6
1978	2-N	64.8	77.6	77.6	62.7	83.5	71.9
1978	3-N	162.0	188.4	196.6	156.4	162.9	188.1
1978	4-N	148.3	147.0	157.7	143.5	127.3	142.0
1978	5-N	77.7	60.5	60.3	68.3	59.4	67.6
1978	6-N	125.8	135.1	137.5	121.7	126.0	127.1
1978	7-N	64.8	60.2	60.0	62.7	59.2	68.5
1978	8-N	139.1	135.2	137.5	134.5	126.1	126.7
1978	9-N	143.9	139.2	142.6	139.2	132.0	125.9
1978	10-N	113.7	139.6	143.0	109.9	131.4	127.0
1978	1-S	15.2			14.7		
1978	2-S	84.0	135.1	137.5	81.2	126.0	127.1
1978	3-S	144.4	143.9	148.6	139.7	132.0	127.8
1978	4-S	131.9	144.3	148.9	127.6	132.3	128.7
1978	5-S	120.0	135.2	137.5	116.1	126.1	126.7
1978	6-S	73.4	60.2	60.0	71.0	59.2	68.5
1978	7-S	65.4	77.6	77.6	63.2	83.5	71.9
1978	8-S	74.9	71.5	71.3	72.5	71.6	68.6
1978	9-S	164.2	155.1	160.0	158.8	128.4	148.9
1978	10-S	167.9	141.3	155.4	162.4	161.4	132.7

Continued on Next Page

Table 8 (continued)

		Potash Planting Correction			DeKalb Planting Correction		
Year	Plot	Actual Yield*	Model Yields		Actual Yield*	Model Yields	
			P57FR**	P57NF**		D57FR**	D57NF**
1979	1-N	165.0	170.1	168.9	180.5	198.1	190.7
1979	2-N	29.3	23.3	22.6	31.7	26.4	25.6
1979	3-N	3.0	5.6	7.8	3.3	9.2	0.7
1979	4-N	201.0	203.0	194.3	219.8	203.7	214.0
1979	5-N	141.0	156.3	158.6	154.2	165.0	166.7
1979	6-N	161.0	165.1	163.4	176.1	195.9	189.0
1979	7-N	148.0	152.3	153.8	161.9	141.1	158.4
1979	8-N	195.0	153.6	153.2	213.3	190.1	184.3
1979	9-N	194.0	167.3	163.4	212.2	197.6	189.1
1979	10-N	184.0	186.2	180.7	201.2	202.4	201.9
1979	1-S	93.0			101.7		
1979	2-S	173.0	165.1	163.4	189.2	195.9	189.0
1979	3-S	187.0	200.4	193.2	204.5	205.6	212.5
1979	4-S	179.0	178.1	172.8	195.8	200.6	196.1
1979	5-S	173.0	153.6	153.2	189.2	190.1	184.3
1979	6-S	152.0	152.3	153.8	166.2	141.1	158.4
1979	7-S	16.0	23.3	22.6	17.5	26.4	25.6
1979	8-S	157.0	170.1	168.9	171.5	198.1	190.7
1979	9-S	189.0	201.9	193.0	206.7	206.0	213.2
1979	10-S	16.0	12.7	10.9	17.5	10.1	19.4

* Actual yields are yields from plots corrected for the effect of planting date, using both sets of correction factors for comparison purposes.

** P57NF, P57FR, D57NF, D57FR are all codings for each specific regression model, the first letter indicating planting date correction (P--Potash Institute, D--DeKalb Research), the numbers indicating the number of data sets (57--yield set with all plots except plot 1 south), and the final two letters indicating whether or not SMG(1,2,and 3) were forceably included (FR--forced inclusion, and NF--nonforced inclusion).

Note: Treatment combination corresponding to the plot number is shown in Figures 3 and 4.

TESTING THE YIELD MODEL

The yield models were developed with the hope of allowing prediction of yield for any year in which the weather variables included in the model are available for the area of interest. The period between 1951 and 1971 was one such period, with data available from Vandalia, Illinois. This period was used by Mak in 1978. The data from 1959 were missing, however, so only 20 years from the period of 1951 to 1971 were used. Tables 9, 10, 11, and 12 show the predicted yields from each model for this twenty-year period. Model D57NF predicts yields completely out of the general range, with values from 1962 bushels per acre to zero bushels per acre. Models P57NF and P57FR both predict values in the acceptable range of yields, but Mak (1978) reported somewhat higher nonirrigated crop yields for this area than either of these models indicate. These models do, however, predict yields in the accepted range of 50 to 150 bushels per acre.

Model D57FR predicts yield within an even smaller range of yields and also includes some rather high yields of over the 200 bushel-per-acre mark in 1958, with adequate irrigation. This model indicates the increased yield possibilities with the addition of irrigation.

Model D57FR is therefore the best model developed, but it has many drawbacks. From the tables, one can notice that increasing the drainage has little or even a negative effect on yield. This may be caused by the inclusion of the no-drainage treatment, which the soil moisture model failed to model accurately.

TABLE 9

Predicted Yields for 1951-1971 for Each Treatment from Model D57FR

	IRRIGATION AND DRAINAGE TREATMENTS**									
YEAR	SPR SUR	SPR SUB	SPR COM	SPR NON	FUR SUR	FUR COM	NON SUR	NON SUB	NON COM	NON NON
1951	89.391	91.421	94.804	131.157	83.811	94.393	64.263	84.288	86.469	131.157
1952	83.053	106.397	75.005	0.000	66.613	62.295	16.486	51.105	27.580	0.000
1953	122.394	84.801	122.526	90.419	115.399	115.520	25.462	21.416	25.466	44.674
1954	94.918	73.729	94.804	113.670	98.203	98.235	107.719	56.991	107.642	128.378
1955	113.606	114.550	112.882	191.327	110.565	109.367	62.072	77.729	57.062	191.327
1956	122.722	125.288	121.940	204.158	119.437	118.143	67.053	85.016	61.641	204.158
1957	118.344	118.942	113.900	82.246	112.058	115.252	88.676	137.385	78.771	82.246
1958	207.093	219.093	199.316	82.246	196.093	201.682	155.177	253.066	137.844	82.246
1960	75.156	78.170	77.283	94.559	69.493	69.713	0.000	0.000	0.000	94.559
1961	88.158	108.613	65.070	114.891	82.503	63.709	0.000	65.737	0.000	114.632
1962	102.340	88.633	99.720	157.763	103.224	102.036	44.161	26.380	43.748	156.885
1963	102.340	88.633	99.720	157.763	103.224	102.036	44.161	26.380	43.748	156.885
1964	116.923	107.571	101.988	92.210	108.023	97.716	0.000	0.000	0.000	0.000
1965	109.059	91.651	103.468	136.981	100.981	102.078	45.228	95.412	50.410	120.389
1966	116.461	109.912	122.614	133.581	116.234	125.515	91.832	99.798	108.564	122.107
1967	84.410	117.358	84.542	120.216	82.747	84.769	42.195	23.252	56.790	34.885
1968	136.265	145.511	140.622	150.868	139.056	147.642	126.786	135.292	135.652	150.868
1969	105.032	105.286	104.125	96.998	103.560	102.352	95.684	61.502	89.161	122.039
1970	120.701	101.043	120.216	127.422	122.278	115.448	74.684	67.992	60.163	90.192
1971	149.804	127.210	148.151	157.032	151.762	142.275	92.691	85.600	74.144	111.150
TWENTY YEAR AVERAGE	112.909	110.191	110.135	121.775	109.263	108.509	62.216	72.717	62.243	106.939

**IRRIGATION TYPES: SPR=SPRINKLER, FUR=FURROW, NON=NO DRAINAGE,
DRAINAGE TYPES: SUR=SURFACE ONLY, SUB=TILE DRAINAGE ONLY, COM=BOTH SURFACE AND TILE DRAINAGE, NON=NO DRAINAGE

TABLE 10

Predicted Yields for 1951-1971 for Each Treatment from Model D57NF

	IRRIGATION AND DRAINAGE TREATMENTS**									
YEAR	SPR SUR	SPR SUB	SPR COM	SPR NON	FUR SUR	FUR COM	NON SUR	NON SUB	NON COM	NON NON
1951	190.124	0.000	197.955	0.000	0.000	55.123	0.000	0.000	0.000	0.000
1952	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1953	625.697	0.000	632.112	0.000	452.684	459.461	0.000	0.000	0.000	0.000
1954	837.065	0.000	833.112	1842.238	1068.735	1068.423	1443.737	0.000	1442.070	1961.729
1955	601.306	391.472	632.436	656.802	456.264	442.366	0.000	0.000	0.000	656.802
1956	649.554	428.170	683.182	700.852	492.875	477.862	0.000	0.000	0.000	700.852
1957	0.000	975.292	0.000	0.000	0.000	0.000	0.000	543.894	0.000	0.000
1958	0.000	1796.509	0.000	0.000	0.000	0.000	0.000	1001.864	0.000	0.000
1960	124.901	0.000	149.017	1049.838	0.000	0.000	0.000	0.000	0.000	1049.838
1961	0.000	0.000	448.268	0.000	0.000	396.044	0.000	0.000	0.000	0.000
1962	209.625	0.000	145.589	0.000	148.416	148.413	0.000	0.000	0.000	0.000
1963	209.625	0.000	145.589	0.000	148.416	148.413	0.000	0.000	0.000	0.000
1964	215.440	17.991	0.000	0.000	63.771	0.000	0.000	0.000	0.000	0.000
1965	541.039	0.000	649.511	530.780	330.033	450.095	0.000	155.768	0.000	0.000
1966	1201.109	1067.626	1345.780	1637.452	1307.234	1360.016	1125.114	1079.535	1224.944	1224.399
1967	144.221	783.165	148.704	956.755	37.289	88.825	266.820	0.000	429.591	0.000
1968	971.858	1176.258	1110.850	0.000	1143.909	1687.079	285.768	300.545	1001.856	0.000
1969	822.761	853.847	764.447	1521.565	827.880	747.534	854.071	467.590	782.947	398.558
1970	862.425	856.427	957.776	807.926	652.706	698.188	416.002	591.954	419.726	0.000
1971	1070.370	1078.218	1180.341	995.670	810.085	860.431	516.307	745.254	517.261	0.000
TWENTY YEAR AVERAGE	463.856	471.249	501.233	534.994	397.015	454.414	245.391	244.316	290.920	299.609

**IRRIGATION TYPES: SPR=SPRINKLER, FUR=FURROW, NON=NO DRAINAGE.
DRAINAGE TYPES: SUR=SURFACE ONLY, SUB=TILE DRAINAGE ONLY, COM=BOTH SURFACE AND TILE DRAINAGE, NON=NO DRAINAGE

TABLE 11

Predicted Yields for 1951-1971 for Each Treatment from Model P57FR

IRRIGATION AND DRAINAGE TREATMENTS**

YEAR	SPR SUR	SPR SUB	SPR COM	SPR NON	FUR SUR	FUR COM	NON SUR	NON SUB	NON COM	NON NON
1951	90,053	5,011	81,015	76,831	76,109	74,447	28,735	0,000	31,496	76,831
1952	42,332	0,000	63,427	97.300	32,826	62,388	0,000	0.000	0,000	95,191
1953	94,198	131,376	94,215	88.402	86,359	86.439	0,000	16.851	0,000	24,896
1954	86,493	65,724	86,266	129,882	94,121	94,018	106,466	64,863	106,474	119,692
1955	126,919	120,668	127,178	167,007	120,774	120,130	55,597	62,563	49,794	167,007
1956	107,521	100,688	107,740	143,678	102,315	101,769	47,100	52.204	42,183	143.678
1957	69,000	0,000	75,292	0,000	64,712	63,942	31,816	38,865	23,536	0,000
1958	103,568	0,000	113,012	0,000	97,131	95.976	47,756	61,062	35,327	0,000
1960	86,692	76,860	85,844	76,707	77,820	76.076	0,000	0,000	0,000	76,707
1961	58,658	51,851	92,291	47,549	53,553	87,053	0,000	0,000	0,000	48,110
1962	83,743	117,966	88,453	89,871	92,555	90,781	2,655	62,916	,224	71,490
1963	80.129	111,909	84,636	87,503	88,560	86,863	2,540	59,685	,215	69,607
1964	122,470	129,039	124,688	142,055	124,044	130,528	0,000	0,000	0,000	23,599
1965	118,254	133,903	115,784	159,341	107,160	108,075	52,861	90,164	57,014	127.040
1966	105,880	104,744	105,274	115,974	107,748	99,808	93,812	99,671	84,062	97,897
1967	121,243	77,216	119,537	98,665	118,737	109,989	167,963	0,000	158,975	0,000
1968	118,528	143,993	117,201	90,197	133,986	124,080	96,730	130,296	108,143	90,197
1969	107,196	106,227	102,937	105,783	108,709	104.883	113,354	92,442	108,715	123,491
1970	136,250	130,224	141,354	151,832	137,130	142,245	104,187	126.251	104,346	128,867
1971	148,370	143,686	152,929	164,264	149,328	153,892	113,455	139,302	112,890	139,419
TWENTY YEAR AVERAGE	100,375	87,554	103,954	101,642	98,684	100,669	53,251	54,857	51,170	81,186

**IRRIGATION TYPES: SPR=SPRINKLER, FUR=FURROW, NON=NO DRAINAGE,
DRAINAGE TYPES: SUR=SURFACE ONLY, SUB=TILE DRAINAGE ONLY, COM=BOTH SURFACE AND TILE DRAINAGE, NON=NO DRAINAGE

TABLE 12

Predicted Yields for 1951-1971 for Each Treatment from Model P57NF

	IRRIGATION AND DRAINAGE TREATMENTS**									
YEAR	SPR SUR	SPR SUB	SPR COM	SPR NON	FUR SUR	FUR COM	NON SUN	NON SUB	NON COM	NON NUN
1951	79,036	80,218	72,707	131,888	64,358	65,591	15,598	54,911	21,587	131,888
1952	73,117	69,330	68,430	65,387	59,482	63,510	0,000	0,008	0,000	62,755
1953	88,851	115,866	88,905	91,157	80,768	80,883	0,000	6,530	0,000	25,122
1954	81,247	78,600	81,010	129,154	89,495	89,393	102,876	54,920	102,880	118,151
1955	118,992	110,428	119,402	157,665	112,358	111,694	45,367	50,332	39,639	157,665
1956	100,806	92,144	101,153	135,641	95,186	94,623	38,433	41,999	33,580	135,641
1957	96,315	47,632	101,457	27,136	91,677	90,388	58,476	87,000	49,271	27,136
1958	144,567	74,836	152,284	27,630	137,606	135,670	87,771	136,686	73,955	27,630
1960	77,910	85,868	77,285	79,113	68,507	66,884	0,000	0,000	0,000	79,113
1961	74,588	74,682	87,727	116,085	68,731	82,390	0,000	0,000	0,000	116,288
1962	76,240	102,867	81,208	101,568	84,758	83,561	0,000	45,078	0,000	82,916
1963	72,950	97,585	77,704	98,891	81,100	79,955	0,000	42,764	0,000	80,731
1964	116,066	121,642	115,554	126,323	117,108	121,993	0,000	0,000	0,000	6,758
1965	112,081	141,348	109,874	145,730	100,138	101,341	44,839	82,081	49,267	109,223
1966	100,873	99,274	100,309	112,319	102,712	94,903	88,787	94,740	79,513	92,658
1967	115,861	72,711	114,194	94,453	112,604	104,170	162,820	0,000	154,483	0,000
1968	108,749	133,382	110,169	160,698	124,894	119,654	84,806	115,410	101,153	160,698
1969	101,592	100,871	97,135	111,182	103,120	99,152	108,041	86,452	103,322	115,035
1970	130,293	123,230	135,161	144,848	130,298	135,014	97,413	118,690	97,236	118,899
1971	141,883	135,970	146,229	156,708	141,889	146,070	106,079	130,960	105,198	128,635
TWENTY YEAR AVERAGE	100,601	97,924	101,895	110,679	98,339	98,342	52,065	57,428	50,544	88,847

**IRRIGATION TYPES: SPR=SPRINKLER, FUR=FURROW, NON=NO DRAINAGE,
DRAINAGE TYPES: SUR=SURFACE ONLY, SUB=TILE DRAINAGE ONLY, COM=BOTH SURFACE AND TILE DRAINAGE, NON=NO DRAINAGE

CONCLUSIONS

The principal conclusion of this study must be drawn from the yield data. First, the data indicate that both irrigation and drainage are needed on claypan soils in humid climates. Corn yields were increased by 13 bu/acre by drainage alone and 50 bu/acre by irrigation alone. Second, the data indicate that irrigation and drainage increase yield synergistically, with an average 92 bu/acre increase when irrigation and drainage are used together. Third, the method of irrigation, whether sprinkler or furrow, has little effect on yield. And fourth, the drainage type (whether surface, subsurface, or both) appears to have little effect on crop yield.

The fact that subsurface drainage might work equally as well as surface drainage has an important potential effect on water quality. Surface water carries sediment with it. Subsurface drain water, on the other hand, is free from sediment--which means that there is the potential for improving water quality while still maintaining yield, by using subsurface rather than surface drainage.

The fact that irrigation and drainage have a synergistic effect on yield adds impetus to the prospect of improving water quality and water-use efficiency. While it is unquestioned that storing drainage water and later using it for irrigation would improve water-use efficiency and downstream water quality, there is little chance of this improvement being instituted unless the process is also economically attractive to the landowner. This synergistic effect enhances those economics benefits.

No definite conclusions can be drawn from the modeling portion of this study. The cutoff of promised funds eliminated the possibility of collecting, during this reporting period, a sufficient data base from which to develop a workable model. Still, the model methodology for predicting more accurate long-term estimates of treatment yields appears to be the best approach to the problem. Additional data are being collected in 1981, and the research will continue at least through 1982. Additional data should permit refinement of the models.

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