USE OF SOIL MOISTURE BUDGET SYSTEM TO ESTIMATE FIELD WORKDAYS FOR RILEY COUNTY, KANSAS WITH IMPLICATIONS FOR MACHINERY SIZES

by

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CHAPTER I

INTRODUCTION

Historical Background

Agricultural producers have traditionally sustained an awkward and risky relationship with the weather. The precise effect is difficult to measure and predict. Timeliness in completing tillage operations is a critical element in successful farming. Farmers complain that in some years little or no time is available to perform the different tillage operations. The impact of available time varies from complete failure to variable amount of yield reduction if tillage operations are not performed at the optimum time. Several technological innovations in agriculture have given farmers a slight measure of control over their environment or improved their ability to react more quickly and favorably. However, regardless of the innovations, weather remains important in decision making and operational activities.

Variation in time available for various operations creates important management problems with timely tillage operations. Timeliness is a function of acres and type of farm operation, *quantity* of the labor available, size of power and equipment, and number of field "workdays." The absolute amount of time available for performing given operations is influenced by weather. Some farm operations spend enormous amounts of capital on large farm machines to complete their operations assuming the most adverse weather. Therefore, they are extremely over equipped in years with average or better weather conditions.

To maximize returns over a period of years, the manager must balance the cost of being over equipped in favorable years with the increased return incoming from having the necessary capacity to complete the job in the least favorable years. Therefore, plans involving farm size and enterprise combinations, farm labor availability, and farm machinery and equipment inventories need to be considered within the framework of available time suitable for tillage operations and the extent of limitation on the days available for each period.

Despite the importance of timeliness in planning a farm organization and operation, little formal attention has been given to the question of time suitable for fieldwork. Often studies have used informal estimates or completely ignored the problem when specific information was required.

Timeliness of field operations is important for producing high yields. Investment in machinery is inversely related to time available for fieldwork with a specified acreage and labor availability. Consequently, an attempt has been made to secure information on the restrictions imposed by weather for the major tillage operations and explain the results in a manner that can be used by Riley county farmers in planning their equipment size, costs, and labor needed.

Objective of the Study

The objective of this study is to evaluate the effectiveness of Baier's soil moisture budget system for estimating soil moisture which is used to predict the available number of field workdays. Soil moisture estimates are affected by physiological factors as crop stages, vegetative cover, soil characteristics, and drainage and climatological factors as precipitation and pan evaporation. Estimates of workdays for particular tillage operations are based on daily estimates of soil moisture. The number of available workdays and their frequency of occurrence are used to study size of machines for each operation in producing wheat, grain sorghum, and grain sorghum silage in Riley County, Kansas.

CHAPTER II

REVIEW OF LITERATURE

One of the major uncertainties of agriculture which has persistently plagued the farmer is weather. Weather is one important variable needed to compute the timeliness of completing field operations. However, only scattered information has been recorded on field conditions, making an evaluation of workdays difficult. The available records can not be used for different areas since soil and weather conditions vary. Consequently, it is not surprising that literature is limited.

In 1960, Sitterley and Bere[1] predicted days available for tillage operations in Ohio. They used three classifications of water removal (drainage) as their comparison data for the project. Each classification estimated evaporation from the soil surface and transpiration from plants as a constant daily amount. This constant amount was altered only when daily mean temperature varied significantly from the average. Different daily evaporation and transpiration constants were obtained monthly between March and July. The drying rates for the study were determined by drainage, evaporation from the soil surface, and transpiration. The model was examined for a twenty year period, 1938-57. From the results an analysis of crop operations was made.

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[1] John H. Sitterley and Richard Bere, The Effect of Weather on the Days Available to Do Selected Crop Operations, Department of Agricultural Economics and Rural Sociology, Ohio State University, Mimeographed Bulletin No. 313 (August, 1960).

Shaw[2] estimated the effect of moisture on field workdays for selected soils in Iowa using a constant daily soil moisture loss for drying days. A second procedure added cloud cover to the previous procedure. Field operations were concerned only with bare soil surfaces. Drying capabilities were obtained from information on the soil moisture capacity in the top six inches of the soil surface, air temperature, and precipitation data. Shaw's first procedure assumed a constant rate of evaporation. The second procedure made a distinction among drying potentials for clear, partly cloudy, and cloudy days. The days were classified as field workdays when estimates were below an experimental constant. Special conditions concerning the amount of precipitation were used in the study.

Bolton, Penn, Cooke, and Heagler[3] used a computerized moisture balance system for estimating days suitable for fieldwork in the Mississippi River Delta. Estimates of field workdays were based on a soil moisture accounting system involving the surface six inches of the soil and the assumption that field operations could not be performed when soil moisture estimates were above a specific value. Data were examined for "clay" and "sandy" soils. Dissipation of soil moisture in the program was estimated by modifying pan evaporation readings and adjusting the reading of air temperature and time of the year through a trial and error process. These two types of soil were examined in four different percentile levels. In 1972, Cooke, Anderson, and

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[2]R. H. Shaw, "Estimation of Field Working Days in the Spring from Meteorological Data," Iowa State Journal of Science, (May 15, 1965), pp. 393-402.

[3]Bill Bolton, J. B. Penn, Fred T. Cooke, Jr., and Arthur M. Heagler, Days Suitable for Fieldwork, Mississippi River Delta Cotton Area, Department of Agricultural Economics and Agribusiness, Louisiana State University, Research Report No. 384, (November, 1968).

Heagler[4] used this moisture system to improve production practices and decrease costs of producing crops in the Delta. They found that using calculated numbers of workdays, more efficient producers could ". . . achieve similar yields of cotton with from $13.01 to $14.06 per acre less input costs than the usual producer."[5]

McQuigg, Maunder, and Johnson[6] used soil moisture measurements from road construction logs. Since records of available field workdays were not recorded for Missouri soils, excellent long term daily engineering records were combined with soil moisture and precipitation measurements from neighboring meteorological stations. This moisture system used monthly and seasonal data of road building activity for a forty-eight year period. The estimate of workdays was based upon a second-order Markov probability chain. The moisture model requires input obtained from prior information developed by Maunder, Johnson, and McQuigg.[7] The moisture system classified workdays as full workdays, partial workdays and as no workdays. These classifications are limited because of the functional relationships needed to convert information on road construction to agricultural operations. Recognizing these

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[4]Fred T. Cooke, Jr., J. M. Anderson, and Arthur M. Heagler, Crop Budgets and Planning Data for Major Farm Enterprises in the Yazoo-Mississippi Delta, Mississippi Agricultural and Forestry Experiment Station, Bulletin No. 794 (July, 1972).

[5]Ibid., p. 51.

[6]W. J. Maunder, Stanley R. Johnson, and J. D. McQuigg, "The Effect of Weather on Road Construction: Applications of a Simulation Model," Monthly Weather Review, CIX, No. 12 (December, 1971), pp. 946-953.

[7]W. J. Maunder, Stanley R. Johnson, and J. D. McQuigg, "A Study of the Effect of Weather on Road Construction: A Simulation Model," Monthly Weather Review, CIX, No. 12 (December, 1971), pp. 939-945.

limits McQuigg[8] applied the model to spring corn planting problems. The study determined the value of an extra day and the value of field operations per acre needed to escape a serious infestation of Southern Corn Leaf Blight.

Tulu, Holtman, Fridley, and Parsons[9] pooled previous information to estimate working days for selected Michigan soils. Link[10] estimated workday probabilities from a time series of farm workday records. Shaw[11] provides a tested workday model. Selirio and Brown[12] developed estimates for field tractiability using various soil moistures. However, the refined model by Tulu, Holtman, Fridley and Parsons[13] incorporated the soil moisture budget by Baier and Robertson.[14] Computing evaporation, runoff, and infiltration on a daily basis the moisture budget demonstrated that timeliness losses ranged from 5.0 to 19.8 bushels per acre. Therefore, a seven to ten percent

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[8]J. D. McQuigg, "Simulation Model STudies of the Impact of Weather Factors on Road Construction and the Movement of Heavy Equipment in Agricultural Operations," Weather Forecasting for Agriculture and Industry, pp. 147-154.

[9]M. Y. Tulu et al., "Timeliness Costs and Available Working Days--Shelled Corn," Paper presented at the winter meeting of the American Society of Agricultural Engineers, Chicago, Illinois, 11-14 December 1973.

[10]D. A. Link, Weather Probabilities Affecting Machine System Capabilities, Unpublished Ph.D. Thesis, Agricultural Engineering Department, Iowa State University of Science and Technology (1962).

[11]R. H. Shaw, "Estimation of Field Working Days in the Spring from Meteorological Data," Iowa State Journal of Science (May 15, 1965), pp. 393-402.

[12]I. S. Selirio and D. M. Brown, "Estimation of Spring Workdays from Climatological Records," Canadian Agricultural Engineering, XIV, No. 2 (December, 1972), pp. 78-81.

[13]Tulu, "Costs and Available Working Days," pp. 1-9.

[14]W. Baier and George W. Robertson, "Estimation of Latent Evaporation from Simple Weather Observations," Canadian Journal of Plant Science, XXXXV, pp. 276-284.

increase would be achieved in southeast Michigan by converting from a three bottom plow system to a six bottom plow system for two hundred acres of corn. Similar results led to the following factors affecting timeliness costs for grain corn planting.

(1) Available working days as influenced by the climate and soil type
(2) Yield-planting date relationships
(3) Daily effective field capacity per acre for the spring pre-plant and planting operations.[15]

The soil moisture budget of Baier and Robertson[16] proved to be reasonably accurate in studies of southeast Michigan. This program accounts for factors of soil type, vegetative cover, and provides a unique method for examining the different soil depths. However, the soil moisture program developed by Baier, Chaput, Russello, and Sharp[17] provides a more generalized formula for a greater variety of soils and cropping conditions. This model's components are described in Chapter III. Although the soil budget does contain detailed input it provides a clearer and more logical understanding of soil moisture dissipation.

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[15] Tulu, "Costs and Available Working Days," p. 9.

[16] Baier and Robertson, "Estimation of Evaporation," pp. 276-284.

[17] Wolfgang Baier, D. Z. Chaput, D. A. Russello, W. R. Sharp, Soil Moisture Estimator Program System, Canada Department of Agriculture, Technical Bulletin 78 (1971), pp. 1-55.

CHAPTER III

THE MOISTURE BALANCE SYSTEM

The Model - A Basic Understanding

The soil moisture estimator system tested was the Versatile Soil Moisture Budget by Baier, Chaput, Russello, and Sharp.[1] The system demands a basic knowledge of climatology and soil physics to estimate daily soil moisture in various zones of the soil profile. Daily values of precipitation and potential evapotranspiration for input are required by the program. In describing the Versatile Budget, Baier remarked,

> The Versatile Budget was specifically developed to accept daily data of precipitation (P) and estimates of Potential Evapotranspiration (PE) for simulating variations in daily soil moisture content by making use of physical and biological concepts of water movement into the soil and water loss from the soil through actual evaporation from an uncropped soil surface or through evapotranspiration from crops (AE).[2]

The Model - Its Internal Structure

Actual Evapotranspiration

The major structure of the soil moisture program is the daily dissipation of soil moisture by actual evapotranspiration (AE). Since only bare soil was examined, AE is actual evaporation and actual evapotranspiration. Daily estimation of actual evapotranspiration from each of the zones of the soil profile incorporated the following equation.

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[1] Baier and others, Soil Moisture Estimator Program System, pp. 1-55.

[2] Ibid., p. 4.

$$AE_i = \sum_{j=1}^{n} k_j \frac{S'_j(i-1)}{S_j} \cdot Z_j \cdot PE_i \cdot e^{-w(PE_i - \overline{PE})}$$

where,

AE_i = actual evapotranspiration for day i

$\sum_{j=1}^{n}$ = summation carried out for zone j=1 to zone j=n

k_j = crop coefficient for jth zone

$S'_j(i-1)$ = available soil moisture in the jth zone at the end of day i-1

S_j = capacity for available water in the jth zone

Z_j = adjustment factor for different types of soil dryness curves

PE_i = potential evapotranspiration for day i

w = adjustment function accounting for effects of varying PE rates on the AE:PE ratio

$\overline{PE}$ = long-term average daily PE for the month or the season[3]

Soil Moisture Zones

Each zone is defined as a specific percentage of the total soil moisture. Unlike the studies of Sitterley[4] and Bolton,[5] zones were estimated in percentages of the total soil moisture because the depth of zones differ, but not the percentage of the total soil moisture. Moisture zones expressed as a percentage make it possible to shift from various soil types and use the

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[3]Baier and others, Soil Moisture Estimator Program System, p. 4.

[4]Sitterley and Bere, Effect of Weather.

[5]Bolton and others, Days Suitable for Fieldwork.

same crop coefficients. The percentages for the six zones were:

Zone 1: 5.0%
Zone 2: 7.5%
Zone 3: 12.5%
Zone 4: 25.0%
Zone 5: 25.0%
Zone 6: 25.0%[6]

The capacities for each zone were approximated by:

(1) Observed experimental results taken at 9:00 A.M. after a rain that saturated the soil

(2) Comparison of results of Zone 1 with data collected by Hanks[7] and Noreno[8]

(3) Adjusting remaining zones with Zone 1 as the base

From these data the amount of soil moisture (bulk density/particle density) at .1 bars soil water potential for each zone is:

Zone 1: 1.35 inches
Zone 2: 2.03 inches
Zone 3: 3.38 inches
Zone 4: 6.75 inches
Zone 5: 6.75 inches
Zone 6: 6.75 inches

Crop Coefficients

Robertson[9] developed a mathematical model that related the rate of crop development of photoperiod, minimum air temperatures, and day-length. The relationship was transferred into crop coefficients by Baier which

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[6]Baier and others, Soil Moisture Estimator Program System, p. 4.

[7]Ronald J. Hanks, "Field Moisture Capacity, Field Determination and Laboratory Approximation," (Ph.D. dissertation, University of Wisconsin, 1953), pp. 1-42.

[8]Aldo L. Noreno, "A Formula to Express Evapotranspiration as a Function of Soil Moisture and Evaporation Demands of the Atmosphere," (Ph.D. Dissertation, Utah State University, 1969), pp. 1-113.

[9]George W. Robertson and D. A. Russelo, Astrometeorological Estimator, Agrometeorology Section, Plant Research Institute, Canada Department of Agronomy, Technical Bulletin 14 (1968).

expressed the amount of water used by plants. Each coefficient represents the proportion of actual evapotranspiration allocated to each zone. The coefficients used in the soil moisture budget for bare soil conditions were:

Zone 1: .60
Zone 2: .15
Zone 3: .05
Zone 4: .00
Zone 5: .00
Zone 6: .00[10]

Z-Tables

Under field conditions, actual evapotranspiration (AE) depends upon the available energy, as reflected in potential evapotranspiration (PE) and the soil moisture conditions. The relationship between available moisture in the soil and the AE/PE ratio depends upon the soil type, frequency of rainfall, and drainage. This relationship is summarized in the z-tables. Other tables are available as reported by scientists completing experiments under various field conditions.

The z-table expressed in graphical form in Figure 1 and transposed into input form in Table 1, demonstrates the decreasing exponential form of the AE/PE ratio in relation to available soil moisture. This decrease is described by Lemon as:

> In the first stage, the moisture loss proceeds at the potential rate as long as moisture is available at the plant roots, or at the soil surface in the case of bare soil, to meet the evaporative demand. In the second stage, when the soil begins to dry and moisture is not conducted to the interface fast enough to meet the atmospheric demand, the relative evapotranspiration rate declines rapidly as the moisture content decreases. The drying curves are exponential in

[10]Baier and others, Soil Moisture Estimator Program System, p. 6.

Figure 1: Proposal for the Relationship Between AE:PE Ratio and Available Soil Moisture[11]

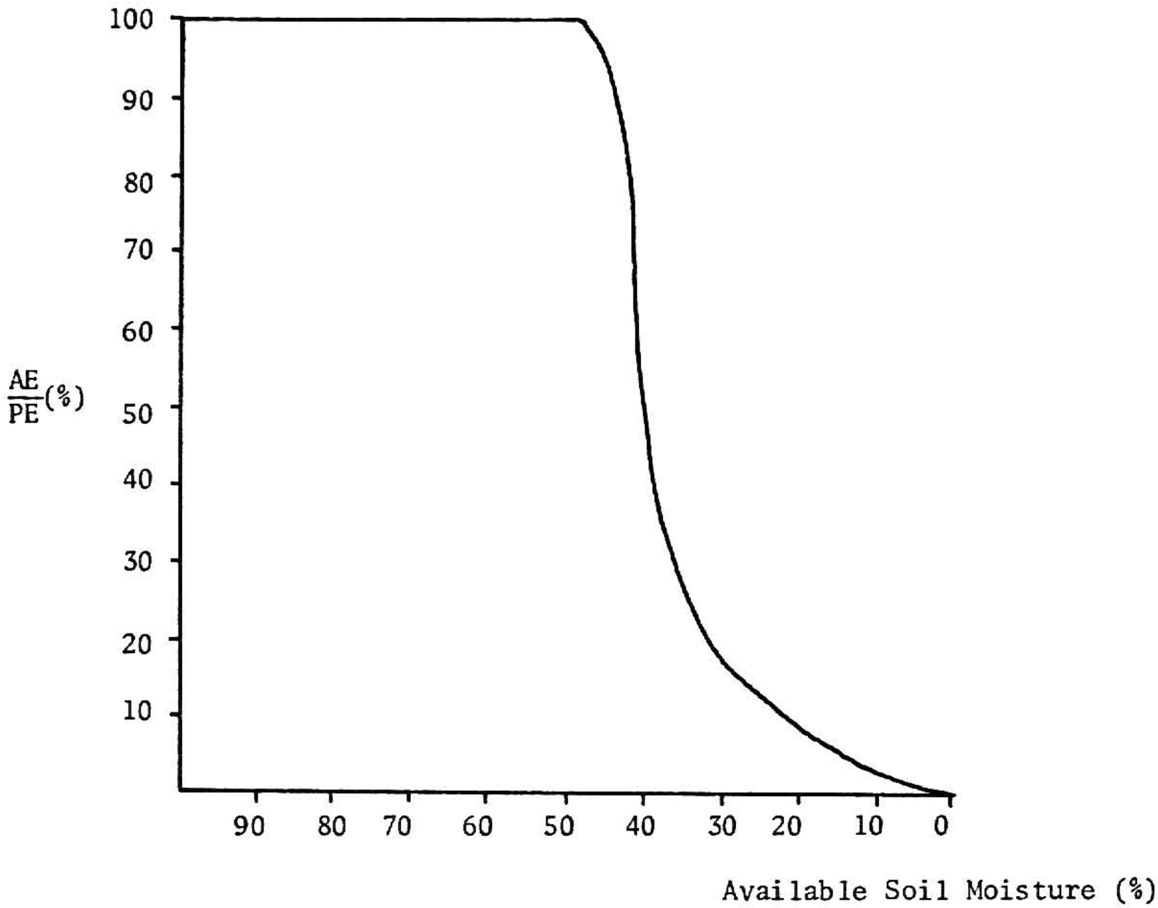

Table 1: Z - Table Used in the Soil Moisture Balance System[12]

.02	.04	.06	.08	.10	.12	.14	.16	.18	.20
.21	.23	.25	.27	.29	.31	.32	.34	.36	.38
.40	.42	.44	.46	.48	.50	.52	.54	.56	.60
.65	.65	.70	.71	.74	.78	.81	.91	1.05	1.25
1.34	1.43	1.63	1.82	2.00	2.00	2.00	2.00	2.00	2.00
1.96	1.92	1.89	1.85	1.82	1.79	1.75	1.72	1.69	1.67
1.64	1.61	1.59	1.56	1.54	1.52	1.49	1.47	1.45	1.43
1.41	1.39	1.37	1.35	1.33	1.32	1.30	1.28	1.27	1.25
1.23	1.22	1.20	1.19	1.18	1.16	1.15	1.14	1.12	1.11
1.10	1.09	1.08	1.06	1.05	1.04	1.03	1.02	1.01	1.00[13]

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[11] Baier and others, Soil Moisture Estimator Program System, p. 6.

[12] Ibid., p. 11.

[13] The upper left-hand corner of Figure 1 corresponds to the lower right-hand corner of Table 1.

> general shape. In the third stage, the moisture loss by vapour diffusion is very slow and takes part only from the dry surface layers of the soil.[14]

This explanation was confirmed under high evaporative conditions for corn by Denmead and Shaw[15] and low evaporative conditions in growth chamber experiments with bare soil and oats by Holmes and Robertson.[16] Since it was assumed that homogenous soil existed throughout the six zone profile, one z-table was used.

Potential Evapotranspiration

Twenty years ago, Penman defined potential evapotranspiration as, "The amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water."[17] Since Penman's definition there have been voluminous amounts of articles written on potential evapotranspiration using various numbers of input variables. Several empirical relationships are available such as those suggested most

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[14] E. R. Lemon, "The Potentialities for Decreasing Soil Moisture Evaporation Loss," Procedures of the Soil Science Society of America, XX (1956), pp. 120-125.

[15] O. T. Denmead and R. H. Shaw, "Availability of Soil Water to Plants as Affected by Soil Moisture Content and Meteorological Conditions," Agronomy Journal, LIV (1962), pp. 385-390.

[16] R. M. Holmes and G. W. Robertson, "Application of the Relationship between Actual and Potential Evapotranspiration in Dry Land Agriculture," Transaction of the American Soceity of Agricultural Engineers, VI, No. 1 (1963), pp. 65-67.

[17] H. L. Penman, "Evaporation: An Introductory Survey," Netherland Journal of Agricultural Science, IV, No. 1 (1956), p. 9.

commonly by Penman,[18] Van Bavel,[19] and Blaney and Criddle.[20] Also, there exist several direct measurement methods and physical approaches using the energy balance system for estimating potential evapotranspiration. These methods and systems have been described by Rosenberg.[21]

However, there are only two methods available that effectively estimate potential evapotranspiration using at most only air temperature as input.

(1) Thornthwaite Method - "requires air temperature as input"
(2) Pan evaporation - "does not require air temperature as input"

Thornthwaite and Mather[22] stated that no relation existed between potential evapotranspiration and expressions relating to the evaporating power of the air for their study. The major problems of the Thornthwaite method is that it underestimates the potential evapotranspiration throughout the year, particularly during the growing season in their studies.

However, McGuinness and Bordne[23] demonstrated that pan evaporation is

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[18]Ibid., pp. 9-29.

[19]C. H. M. van Bavel, "Potential Evaporation: The Combination Concept and its Experimental Verification," Water Resources Research, III (1956), pp. 455-467.

[20]H. F. Blaney and W. D. Criddle, Determining Water Requirements in Irrigated Areas from Climatological and Irrigated Data, United States Department of Agriculture Soil Conservation Service, Technical Paper 96 (1950), pp. 1-48.

[21]Norman J. Rosenberg, Hoyt E. Hart, Kirk W. Brown, Evapotranspiration, Nebraska Water Resources Research Institute, MP 20 (November, 1968), p. 38.

[22]C. W. Thornthwaite and J. R. Mather, "The Water Balance," Climatology VIII, Drexel Institute of Technology (1955), pp. 1-104.

[23]J. L. McQuinness and Erich F. Bordne, A Comparison of Lysimeter-Derived Potential Evapotranspiration with Computed Values, United States Department of Agriculture Agricultural Research Service, Technical Bulletin No. 1452 (March, 1972), pp. 1-24.

closer to the direct measurement of evapotranspiration by lysimeters than any empirical method. Even though evaporation pans can be affected by inadequate instrument exposure, errors in operation, and maintenance, the pan evaporative method was chosen because:

(1) The results by this method have been realistic and sufficiently accurate.[24]

(2) Data of measurements are available. (As shown in Figure 2, there are twenty-four stations in Kansas presently reporting pan evaporation to the U.S. Weather Bureau.)

Daily pan evaporation data needed to estimate actual evapotranspiration was obtained from data gathered at the Manhattan Agronomy Farm[25] during the period April 1, 1951 through August 11, 1959. Pan evaporation data from August 12, 1959 to October 31, 1970 and from April 1974 to July 1974 was obtained from Tuttle Creek Dam Station.[26]

Adjustment Function

Stanhill[27] stated that the evaporating power of the atmosphere must be taken into account. The moisture balance system in its estimation of actual evapotranspiration includes evaporating power as a correcting factor. The soil moisture stress, "w", on the proceeding day is calculated from a graph of Shaw's as:

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[24] E. I. Mukammal, "Evaporation Pans and Antometers," Evaporation, Proceedings of Hydrology Symposium No. 2 (1961), pp. 84-105.

[25] Climatological Data - Kansas, U.S. Weather Bureau, Vol. 65-73.

[26] Climatological Data - Kansas, U.S. Weather Bureau, Vol. 73-84.

[27] G. Stanhill, "The Effect of Differences in Soil Moisture Status in Plant Growth: A Review and Analysis of Soil Moisture Regime Experiments," Soil Science, LXXXIV (1957), pp. 205-214.

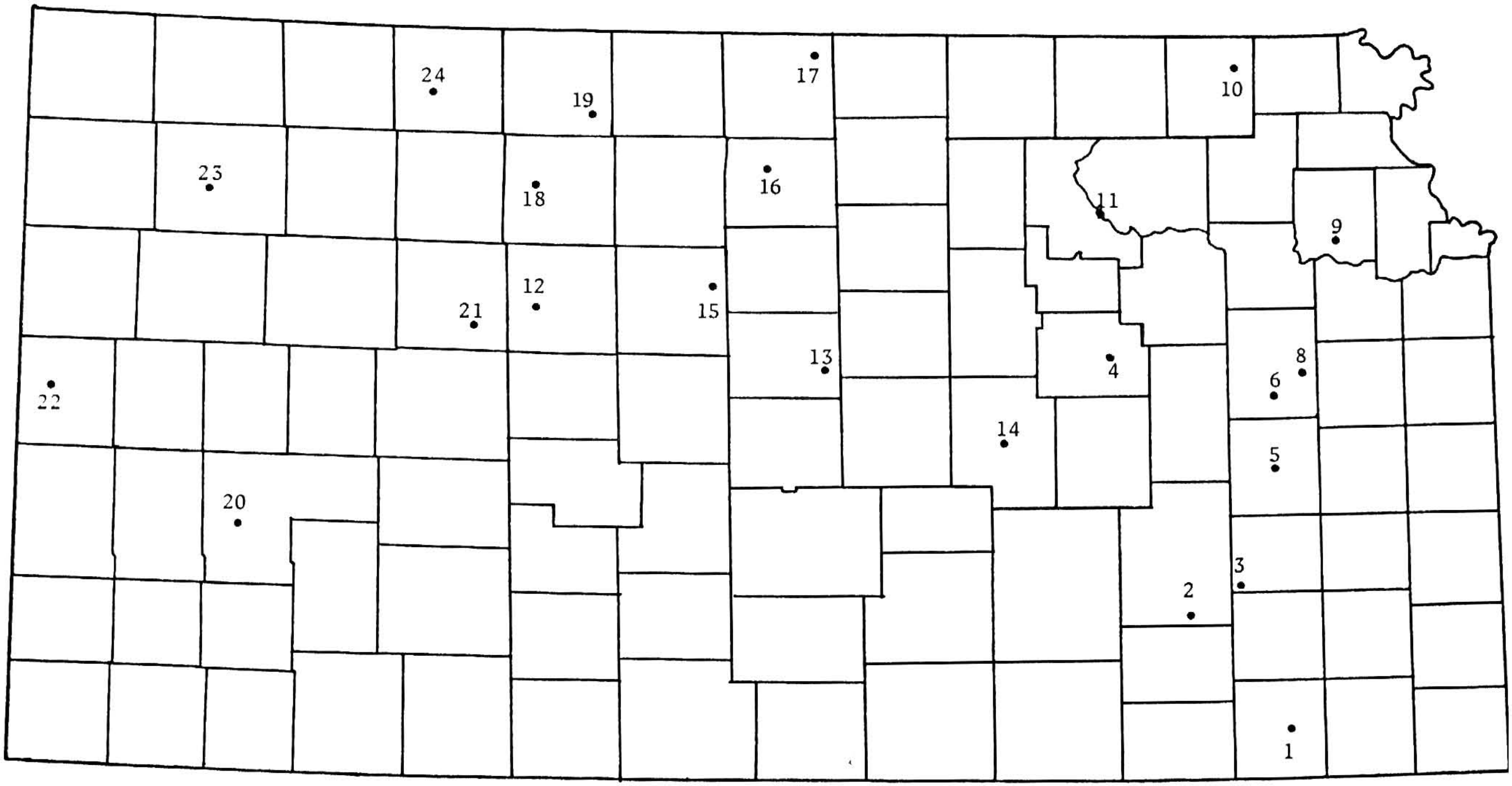

Figure 2: Collection Sites for Pan-Evaporation
in Kansas

Southeast

1) Elk City Dam

2) Fall River Dam

3) Toronto Dam

East Central

4) Council Grove Dam

5) John Redmond Dam

6) Melvern Lake

7) Milford Lake

8) Pomona Dam

Northeast

9) Perry Lake

10) Sabetha Lake

11) Tuttle Creek Dam

South Central

Central

12) Hays

13) Kanopolis Dam

14) Marion Dam

15) Wilson Lake

North Central

16) Glen Elder Dam

17) Lovewell Dam

18) Webster Dam

19) Kirwin Dam

Southwest

20) Garden City Exp. Station

West Central

21) Cedar Bluff

22) Tribune

Northwest

23) Colby

24) Norton Dam

Index of the Collection
of Sites
for Pan-evaporation in
Kansas
(Figure 2)

$$w = (7.91 - .11\, S'_{j(i-1)} S_j) \times 100$$

where,

S_j = capacity for available water in the jth zone[28]

Mean PE ($\overline{PE}$)

Mean PE ($\overline{PE}$) is the average monthly potential evapotranspiration during the period examined. Mean PE is part of the correcting factor for actual evapotranspiration. It enables the program to respond to large abnormal potential evapotranspiration fluctuations during the observed period.

The following monthly mean PE data obtained from the Manhattan Weather Station for the period 1951-1970 were:

April	-.22 (inches)
May	-.25
June	-.30
July	-.34
August	-.30
September	-.23
October	-.17

Precipitation

Annual daily rainfall data for the period April 1 - October 31 between 1951 and 1970 were obtained from the Department of Physics at Kansas State University as collected at the Manhattan Weather Station. Using the data described, the soil moisture budget to increase soil moisture estimates from two factors, infiltration and runoff.

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[28] R. H. Shaw, "Prediction of Soil Moisture Under Meadow," Agronomy Journal, LVI (1964), pp. 320-324.

Water Infiltration

In the soil moisture system used in this study, water infiltrated into the top zone until it neared saturation (-.1 atmospheres soil water potential). This estimate of available infiltrating capacity is based upon my field research and the work presented by Cavazza, Comegna, and Linsalata.[29] After filling the top zone, water infiltrates into Zone 2 until all available water is exhausted or Zone 2 is brought to capacity. The infiltration process for remaining water is completed in all zones until all water is used or all of the zones are brought to capacity. Consequently, drainage, excessive infiltration, occurs when precipitation exceeds total actual evapotranspiration, runoff, and the sum of moisture deficits for all of the zones. The infiltration rate described was taken from a study by Kinsley, Kohler, and Paulus.[30] The model specifies infiltration as a function of precipitation in the previous 24-hour period and soil moisture content in Zone 1 the day before precipitation.

Runoff

Depending upon the rainfall and soil conditions, not all precipitation infiltrates into the soil below. The runoff and infiltration was summarized by Baier as,

> On days with precipitation less than or equal to one inch, the total amount of precipitation is considered to infiltrate into the soil.

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[29] L. Cabazza, V. Comegna, and D. Linsalata, "Correlation of Field Capacity between Open Field and Laboratory Determinations," Physics of Soil Water and Salts, ed. by A. Hadas and others, 1973, pp. 187-193.

[30] R. K. Linsley, M. A. Kohler, and J. L. H. Paulhus, Applied Hydrology, McGraw-Hill Book Co. Inc. (1949).

On days with precipitation greater than or equal to one inch, runoff is estimated from Equation (4).

$$Runoff_i = RR_i - I \qquad \text{Equation (4)}$$

where,

I = amount of water infiltrating into the soil

$$I = .9177 - 1.811 \log RR_i - .0097 \log RR_i \frac{S'_{j(i-1)}}{S_j} \times 100$$

RR_i = rainfall in inches for the 24 hour period ending the morning of day (i-1)

$\frac{S'_{j(i-1)}}{S_j} \times 100$ = available soil moisture in percent of capacity (S_j) in the top zone at the end of day (i-1)[31]

Estimation of Field Workdays

The soil moisture budget by Baier[32] did not designate days as "workdays" or "no workdays" based on soil moisture estimates. This decision section was added after examining plot data. Since there is much variability among soils, previous literature has not specified marginal soil moisture levels that will allow fieldwork.

With plot data gathered from Manhattan Agronomy Farm during April 1974 to July 1974 a value of .77 inches or more of moisture in Zone 1 was considered a "no workday" when tillage operations could not be accomplished. When this decision value is incorporated into the program, results as reported in Table 2 were obtained.

[31] Baier and others, Soil Moisture Estimator Program System, p. 13.

[32] Ibid., pp. 1-55.

CHAPTER IV

VALIDATING THE SOIL MOISTURE ESTIMATOR MODEL

Results of soil moisture estimator were compared with measured soil moisture to evaluate the reliability of the model. Comparisons were made using a plot near Manhattan, Kansas for measured soil moisture, rainfall and pan evaporation data at the Manhattan Weather Station for the model from April 25, 1974 to July 31, 1974.

Collection of Data

Soil moisture samples were obtained on level silt loam soil at the Agronomy Research Farm northwest of Manhattan, Kansas. The site of the observations was a tract of land measuring approximately twenty feet by thirty feet. Three samples per day were taken at 9:00 A.M. A three-fourth's inch diameter probe was used to obtain samples three inches deep. Previous soil moisture work had been completed at the tract by the Department of Agronomy which provided preliminary data.

The daily samples were taken immediately to the soil laboratory, weighed to obtain their "wet weight" and placed in an oven at 105 degrees Centigrade. Each sample was allowed to dry for seventy-two hours. After drying, they were removed from the oven and weighed to measure their "dry weight." This process of drying was used to obtain "dry soil" as described by Hillel,

> The term "dry soil" is generally defined as a soil dried to equilibrium in an oven at 105° C, though clay will often contain appreciable quantities of water at that state of dryness and at higher

> temperatures. Soil dried in "ordinary" air will generally contain several percent more water than oven-dry soil, a phenomenon due to vapor absorption and often referred to as soil "hygroscopicity."[1]

Plot Data Recorded

A daily record was kept with the following information.

(1) "Dry" soil
(2) "Wet" soil
(3) Brief explanation of the weather conditions, soil conditions and plant growth taking place since the last period
(4) Classification of field conditions as "Workday" or "No Workday"

The log of daily conditions at the plot was helpful for explaining discrepancies between recorded observations and estimates by the soil moisture budget system.

Field conditions at the plot were declared "workdays" by the criteria used by Selirio and Brown[2] and by Allman and Konke,[3]

> . . . a soil was considered dry enough to plow when freshly cut surface did not glisten with moisture, kneading by hand showed no evidence of free water or when it scoured free from the moldboard, and when it was friable enough to break into aggregates instead of large chunks.

The declaration of "workdays" for all tillage operations used the condition that it must be able to be broken into aggregates. Marginal workdays were

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[1]Daniel Hillel, Soil and Water, Physical Principles and Processes, Academic Press (1971), p. 12.

[2]I. S. Selirio and D. M. Brown, "Estimation of Spring Workdays from Climatological Records," Canadian Agricultural Engineering, XIV, No. 2 (December, 1972), p. 79.

[3]M. S. Allman and H. Konke, The pF of the Soil Moisture at the Wet Limit of the Plowing Range, Proceedings of the Soil Science Society of America, XII (1947), pp. 22-23.

classified as "no workdays."

Calculation of Soil Moisture

After collecting the plot data, the following formula was used to convert data into "moisture content in inches." This enabled a direct comparison between plot data and the computer soil moisture budget output.

$$\text{Moisture Content} = \frac{M_w}{M_s} \times \frac{M_s}{V_a + V_w + V_s} \times \text{depth (in.)}$$

where,

M_w = mass of water

M_s = mass of solids

V_a = volume of air

V_w = volume of water

V_s = volume of solids

Depth = depth of sample (inches)[4]

In the formula M_w/M_s expresses "gravimetric water content" which is the mass of water relative to the total mass of dry soil. The dry bulk density, $M_s/(V_a + V_w + V_s)$, relates the total mass of dry soil relative to the total volume of the soil. Dry bulk density of soil from the plot was 1.35 gm./cm.[3] Since the samples were taken from a three inch depth, the calculated formula was,

$$\text{Moisture Content (in.)} = M_w/M_s \times 1.35 \times 3$$

$$= M_w/M_s \times 4.5$$

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[4]Daniel Hillel, Soil and Water, pp. 9-14.

Comparison of Plot Data with the Soil Moisture Budget Estimator

Data collected were divided into three periods.

(1) April 25 to May 15
(2) May 16 to July 4
(3) July 5 to July 31

During the first period days were categorized as either "workdays" or "no workdays" with no moisture samples taken. Moisture measurements and workday classifications were estimated for the second period. The third period recorded only workday classifications with soil moisture estimates influenced by soybeans growing on the plot. Data were not collected for several days between June 16 and July 2. Since June 15 was classified as a "workday" and no precipitation was recorded during the period, all unobserved days between June 16 and July 2 were recorded as "workdays," Figure 3.

As shown in Figure 3 and Table 2, there are days in which differences between reported field conditions and the results estimated by the soil moisture budget occur. These differences can possibly be explained by,

(1) A difference in the amount of rainfall recorded at the Manhattan Weather Reporting Station and the experimental site.

(2) The upward movement of soil water to Zone 1 caused by surface soil water depletion producing a negative hydraulic gradient in the soil profile.

The program does not take into account the second possibility because of the high variability among soils and the difficulty in obtaining estimates of field soil water flow.

The first type of difference will always be present when on site rainfall recordings are not available. As seen in Figure 3, differences in recorded rainfall affected May 21 and June 23 estimates. The errors in the

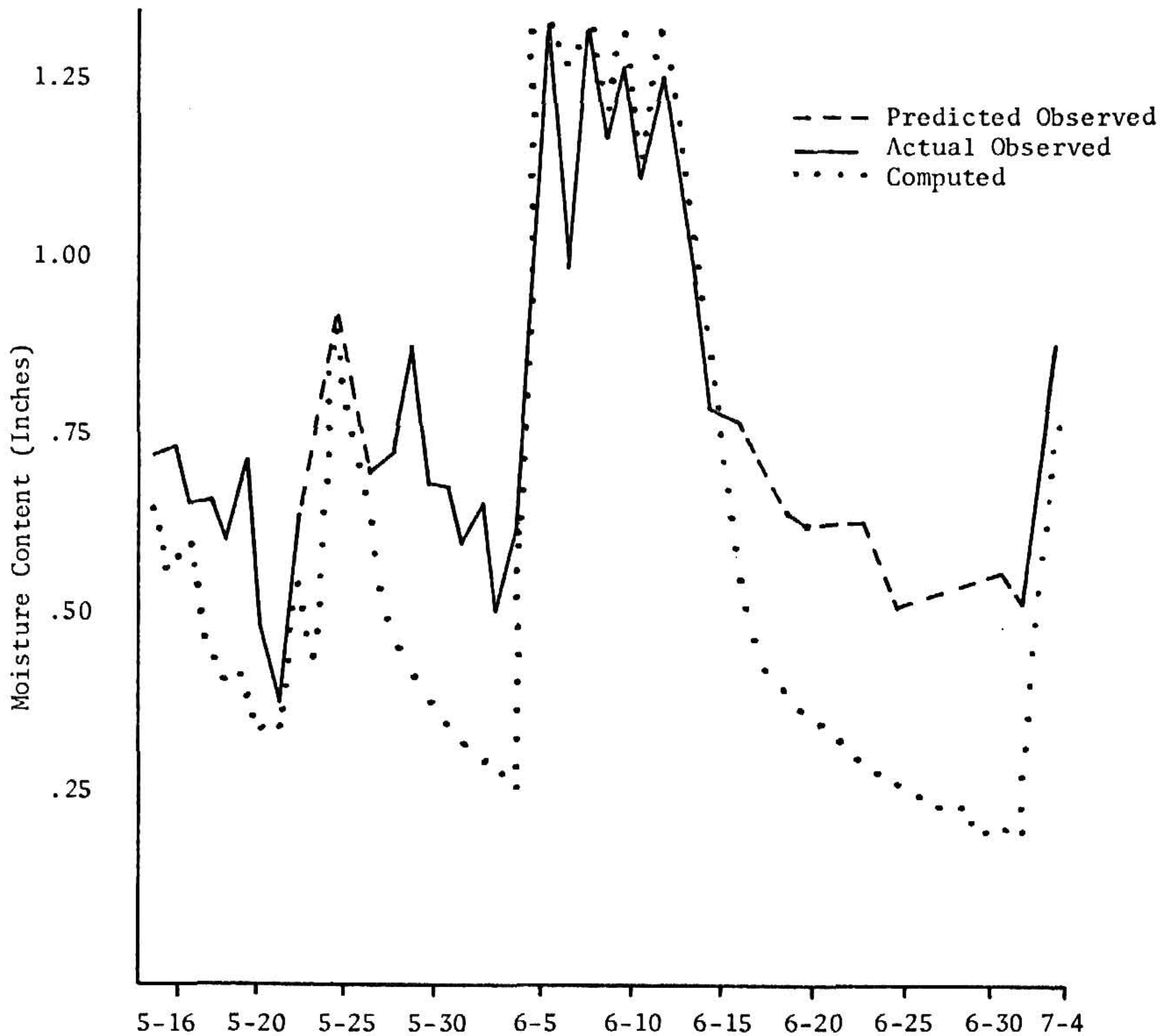

Figure 3: Observed and Computed Values for Moisture Content in Zone 1, at Manhattan, Kansas (May 16, 1974-July 4, 1974)

Table 2: Verification of Observations and Model Estimates

Date	Prec.	Evaporation	Model Estimate*	Observations*
Period 1				
4/25/74	.0	.25	1	1
4/26/74	.0	.24	1	1
4/27/74	.0	.18	1	1
4/28/74	.0	.27	1	1
4/29/74	1.29	.17	0	0
4/30/74	1.32	.10	0	0
5/01/74	.0	.20	0	0
5/02/74	.0	.18	0	0
5/03/74	.0	.23	0	0
5/04/74	.0	.21	0	0
5/05/74	.0	.15	1	1
5/06/74	.0	.20	1	1
5/07/74	.0	.23	1	1
5/07/74	.0	.26	1	1
5/08/74	.0	.26	1	1
5/09/74	.40	.24	0	0
5/10/74	.31	.17	0	0
5/11/74	.14	.24	0	0
5/12/74	.0	.28	0	1
5/13/74	.0	.17	1	1
5/14/74	.36	.12	0	0
5/15/74	.0	.26	0	1
Period 2				
5/15/74	.0	.25	1	1
5/16/74	.06	.20	1	1
5/18/74	.12	.13	1	1
5/19/74	.0	.22	1	1
5/20/74	.0	.35	1	1
5/21/74	.0	.35	1	1
5/22/74	.0	.24	1	1
5/23/74	.0	.25	1	1
5/24/74	.25	.10	1	1
5/25/74	.0	.27	1	1
5/26/74	.45	.04	0	0
5/27/74	.0	.22	0	0
5/28/74	.07	.34	1	1
5/29/74	.0	.27	1	1
5/30/74	.0	.25	1	1
5/31/74	.0	.35	1	1

*A 1 denotes a day on which work was possible. A 0 denotes a day on which tillage was not possible.

Table 2: Verification of Observations and Model Estimates (cont.)

Date	Prec.	Evaporation	Model Estimate*	Observations*
6/01/74	.0	.21	1	1
6/02/74	.0	.23	1	1
6/03/74	.0	.35	1	1
6/04/74	.0	.27	1	1
6/05/74	.0	.25	1	1
6/06/74	1.27	.19	0	0
6/07/74	1.82	.28	0	0
6/08/74	.02	.12	0	0
6/09/74	1.84	.01	0	0
6/10/74	.0	.16	0	0
6/11/74	.48	.25	0	0
6/12/74	.0	.30	0	0
6/13/74	.41	.27	0	0
6/14/74	.0	.23	0	0
6/15/74	.0	.31	0	0
6/16/74	.0	.31	0	0
6/17/74	.0	.33	1	1
6/18/74	.0	.13	1	1
6/19/74	.0	.35	1	1
6/20/74	.0	.36	1	1
6/21/74	.0	.60	1	1
6/22/74	.0	.40	1	1
6/23/74	.0	.36	1	1
6/24/74	.0	.30	1	1
6/25/74	.0	.25	1	1
6/26/74	.0	.27	1	1
6/27/74	.0	.34	1	1
6/28/74	.0	.42	1	1
6/29/74	.0	.41	1	1
6/30/74	.0	.51	1	1
7/01/74	.0	.26	1	1
7/02/74	.0	.48	1	1
7/03/74	.0	.52	1	1
7/04/74	.58	.48	0	0
Period 3				
7/05/74	.0	.27	1	1
7/06/74	.0	.25	1	1
7/07/74	.0	.43	1	1
7/08/74	.0	.51	1	1
7/09/74	.0	.62	1	1

*A 1 denotes a day on which work was possible. A 0 denotes a day on which tillage was not possible.

Table 2: Verification of Observations and Model Estimates (cont.)

Date	Prec.	Evaporation	Model Estimate*	Observations*
7/10/74	.0	.50	1	1
7/11/74	.0	.31	1	1
7/12/74	.0	.58	1	1
7/13/74	.0	.45	1	1
7/14/74	.0	.35	1	1
7/15/74	.0	.39	1	1
7/16/74	.0	.39	1	1
7/17/74	.0	.38	1	1
7/18/74	.0	.54	1	1
7/19/74	.0	.52	1	1
7/20/74	.0	.40	1	1
7/21/74	.0	.43	1	1
7/22/74	.0	.44	1	1
7/23/74	.0	.39	1	1
7/24/74	.0	.45	0	0
7/25/74	2.00	.45	0	0
7/26/74	.55	.54	0	0
7/27/74	.0	.51	0	0
7/28/74	.0	.49	1	1
7/29/74	.0	.39	1	1
7/30/74	.0	.36	1	1
7/31/74	.0	.19	1	1

*A 1 denotes a day on which work was possible. A 0 denotes a day on which tillage was not possible.

estimator caused by the second type of error are not as significant since they occur after the decision making point between "workdays" and "no workdays."

The only differences of classifying workday decisions were in the April 25 to May 15 period. For May 12 and May 15, the soil moisture estimates indicated "no workdays"; the observed data reported these as "workdays," see Table 2. On May 9, 10, and 11, measurable rainfall was reported at the Manhattan Weather Station. May 12 was recorded as a "workday" by the estimator. This discrepancy is believed to be caused by differences in rainfall between the weather station and plot site. On May 13, rainfall occurred at 8:00 P.M. The program recorded this rainfall on May 14. This presented an erroneous estimation of field workdays on May 15. Therefore, time of rainfall presents another problem which if coupled with precipitation differences explains the second error.

The period May 16 to July 4 did not have any classification differences, see Table 2, but the period did have large differences between soil moisture as estimated by the model and actual soil samples. These deviations were possibly caused by upward soil water flow.

For the final period, July 5 to July 31, there was no difference in classifying workdays. This period had a long dry spell, with rain reported on July 25. Since a soybean crop was growing on the site, no samples were collected after July 31.

The soil moisture system, Table 2, estimates sixty-eight workdays for the ninety-eight day period. Observations taken at the site estimated seventy workdays. This is a difference of 2.04 percent for the entire period. The two differences occurred in May. Therefore, during May, a difference of 6.45 percent existed between computer estimates and actual observations, see Table 2.

CHAPTER V

ESTIMATED SOIL MOISTURE DATA FOR RILEY COUNTY

The Program

Using the soil moisture budget system, "workdays" and "no workdays" were calculated for each day between April 1 and October 31 for the twenty year period, 1951 - 1970. From this computer data, the accumulated percentage of at most any selected number of available workdays was divided into one-half month periods, Figures 4 through 10. For example, Figure 4 shows that ten percent of the years had an estimated five or fewer workdays. Figures 11 through 15 presented the accumulated percentages of "workdays" for combined periods of particular crop operations. These crops and their particular tillage operations are presented in Table 4.

Unlike previous studies, Sundays, except for those during June 15-30, were declared a "no workday." Sundays in the June 16-30 period were declared "workdays" if they met moisture requirements because of the high probability for severe thunderstorms partially or completely destroying a wheat crop. Work on Sunday during the wheat harvest was allowed if soil moisture permitted, but not during fall harvest.

Sitterley and Bere[1] used a constant correcting percentage to exclude Sundays as "workdays." The error caused by this procedure is shown in Table 3. This error is due to the seasonal rains in Riley County. During years

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[1]Sitterley and Bere, <u>Effect of Weather</u>, p. 5.

Table 3: Total Days in a Year that are Declared "Workdays" on Sunday (Manhattan, Kansas April 1, 1951 to October 31, 1970)

Period	Total Sundays Deleted as "Workdays"[a]	Twenty Year Mean	Twenty Year Median	Percentage Difference
April (1-15)	31	1.55	1.5	10.3%
April (16-30)	30	1.50	2.0	10.0%
May (1-15)	28	1.40	1.0	9.3%
May (16-31)	23	1.15	1.0	7.2%
June (1-15)	18	.90	1.0	6.0%
June (16-30)	25	1.25	1.0	8.3%
July (1-15)	33	1.65	2.0	11.0%
July (16-31)	29	1.45	1.5	9.4%
August (1-15)	32	1.60	2.0	10.7%
August (16-31)	31	1.55	1.5	9.7%
September (1-15)	27	1.35	1.5	9.0%
September (16-30)	24	1.20	1.0	8.0%
October (1-15)	24	1.20	1.0	8.0%
October (16-31)	29	1.45	1.5	9.1%
Total Per Year		1.38		9.1%
Cumulative Total		17.95	18.5	

[a]Summation of all Sundays meeting moisture requirements as "workdays" in the twenty years examined

Figure 4: Accumulated Percentage of April Workdays by 1/2 Month for Daily Intervals (Considering Sunday as a "No Workday")

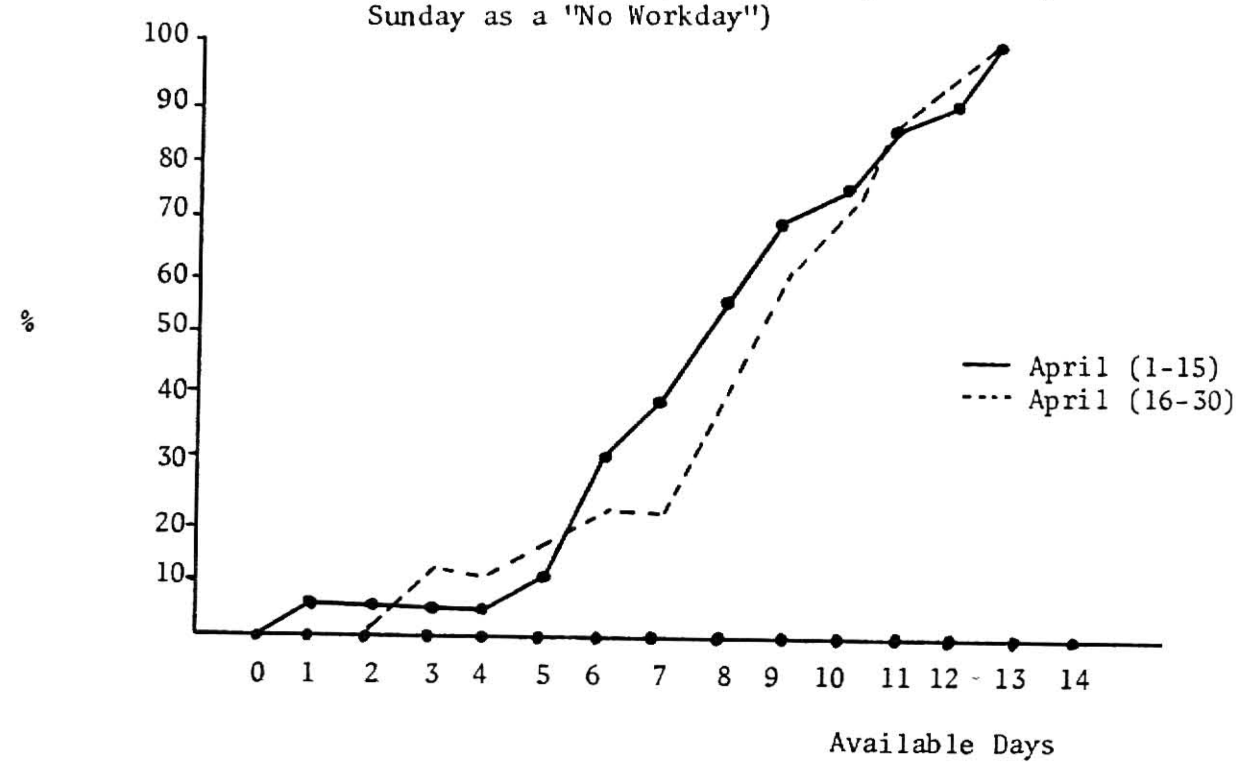


Figure 5: Accumulated Percentage of May Workdays by 1/2 Month for Daily Intervals (Considering Sunday as a "No Workday")

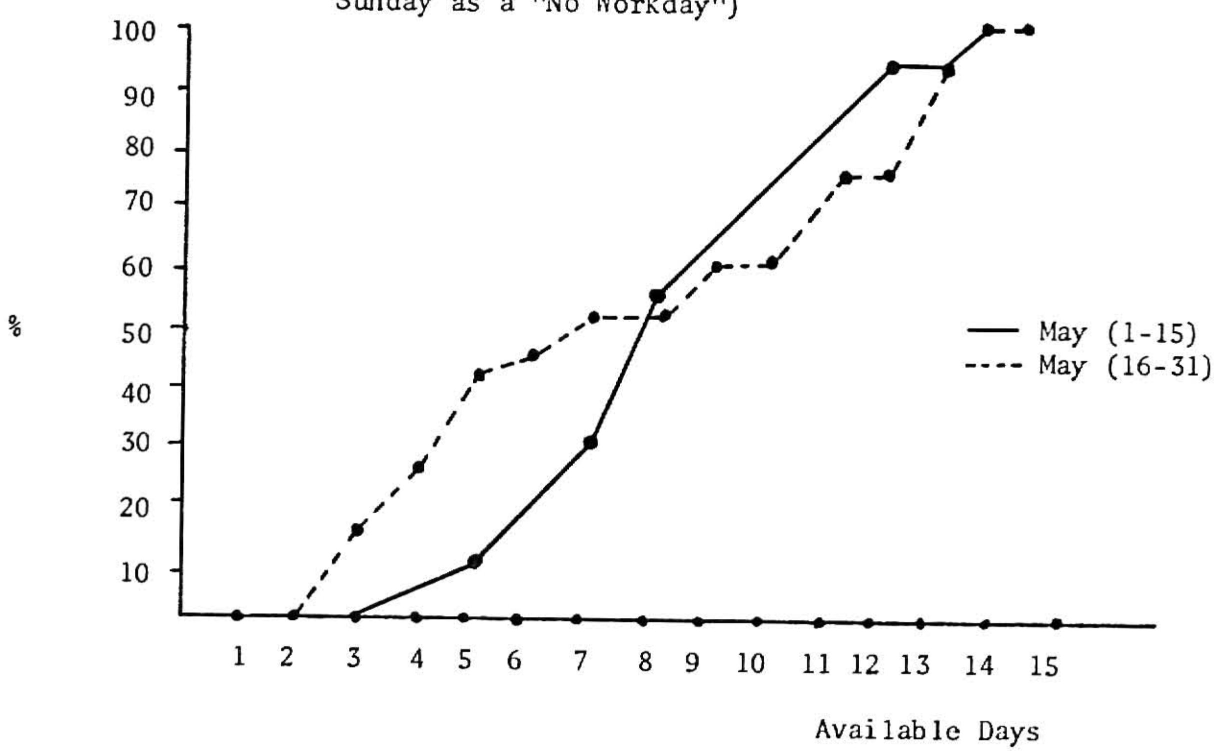


Figure 6: Accumulated Percentage of June Workdays by 1/2 Month for Daily Intervals (Considering Sunday as a "No Workday" during June 1-15)

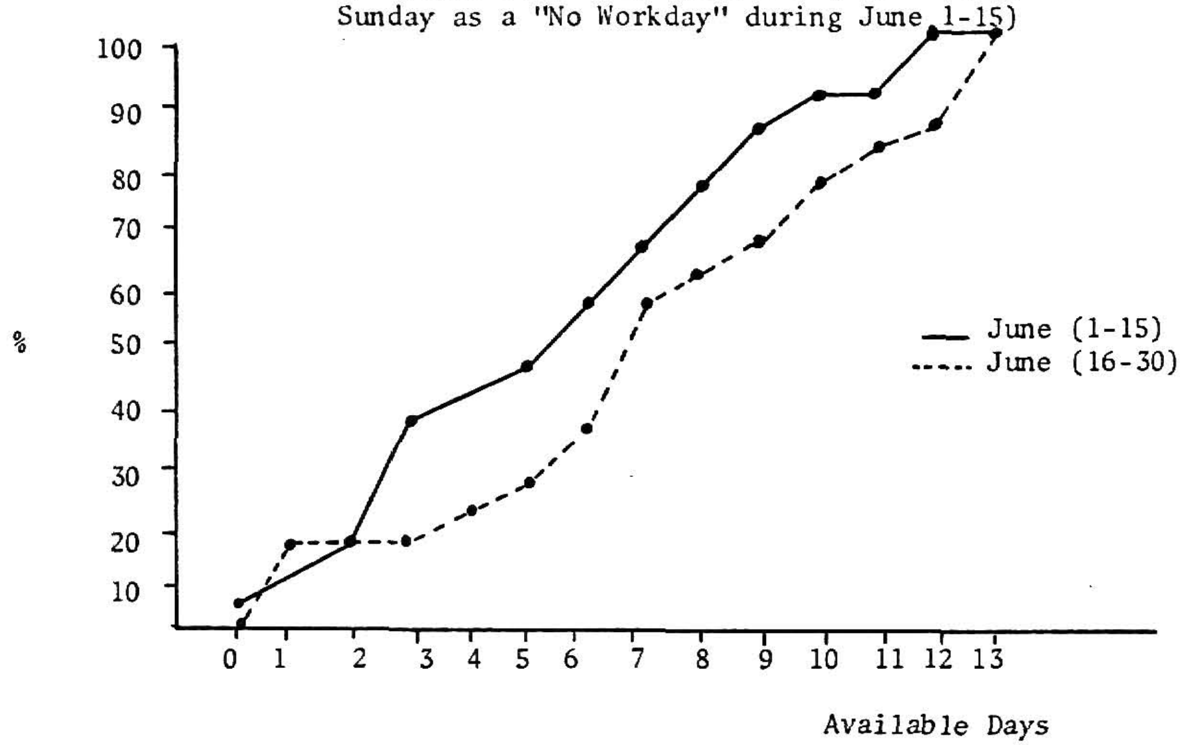


Figure 7: Accumulated Percentage of July Workdays by 1/2 Month for Daily Intervals (Considering Sunday as a "No Workday")

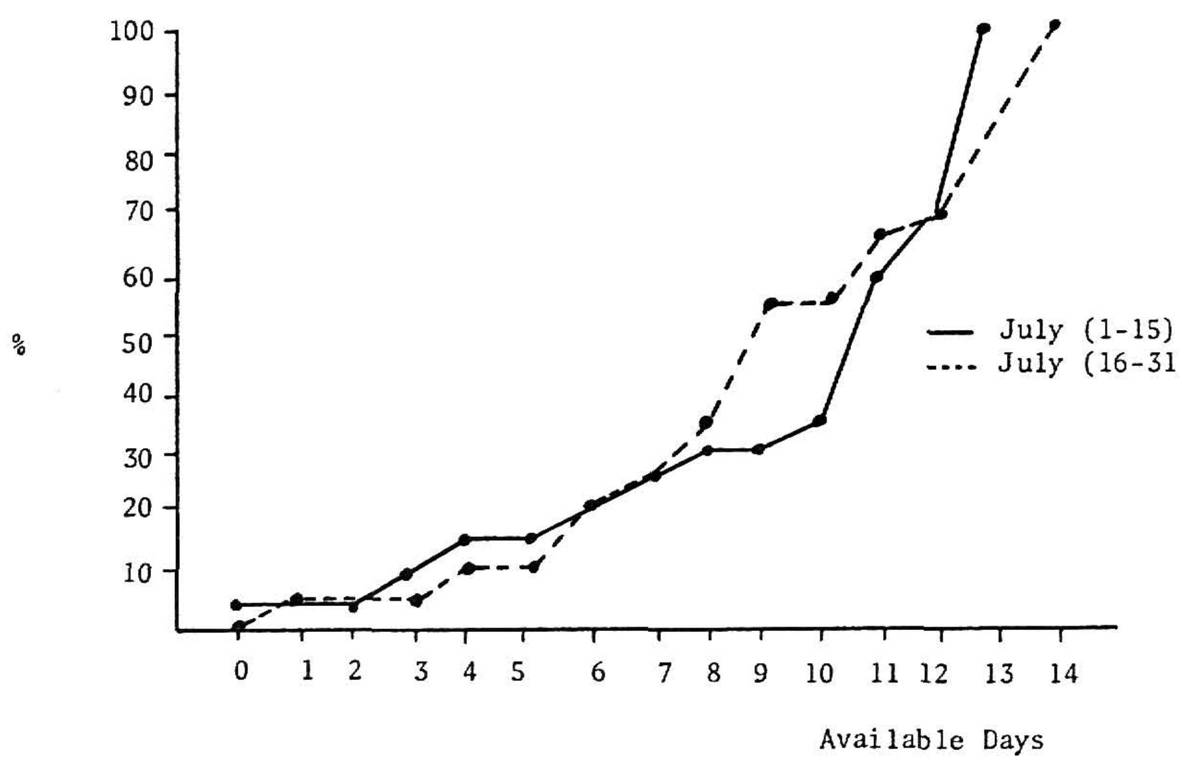


Figure 8: Accumulated Percentage of August Workdays by 1/2 Month for Daily Intervals (Considering Sunday as a "No Workday")

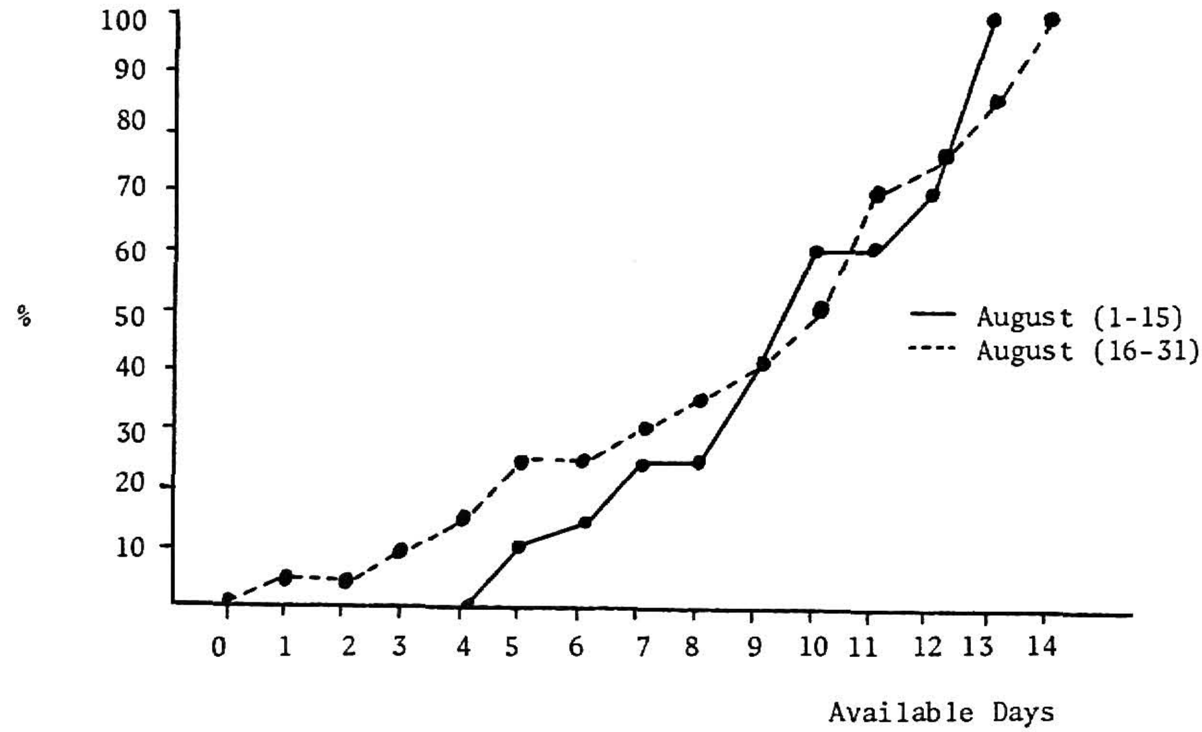


Figure 9: Accumulated Percentage of September Workdays by 1/2 Month for Daily Intervals (Considering Sunday as a "No Workday")

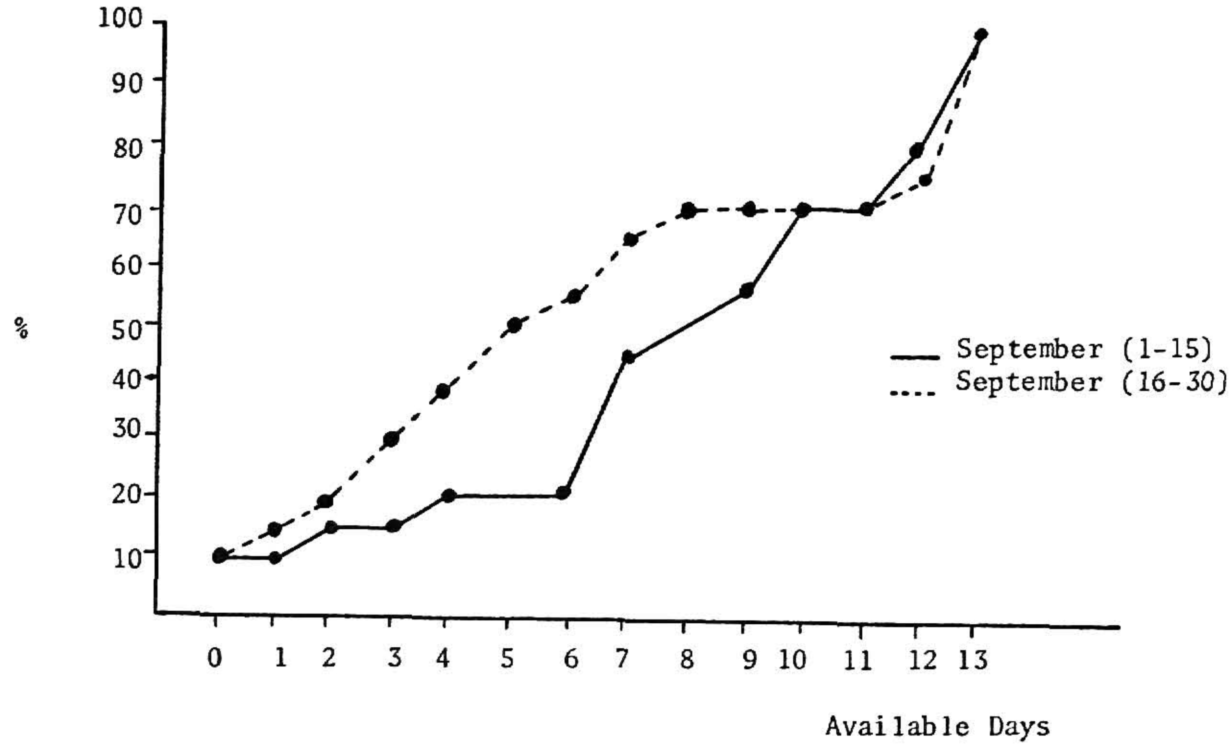


Figure 10: Accumulated Percentage of October Workdays by 1/2 Month for Daily Intervals (Considering Sunday as a "No Workday")

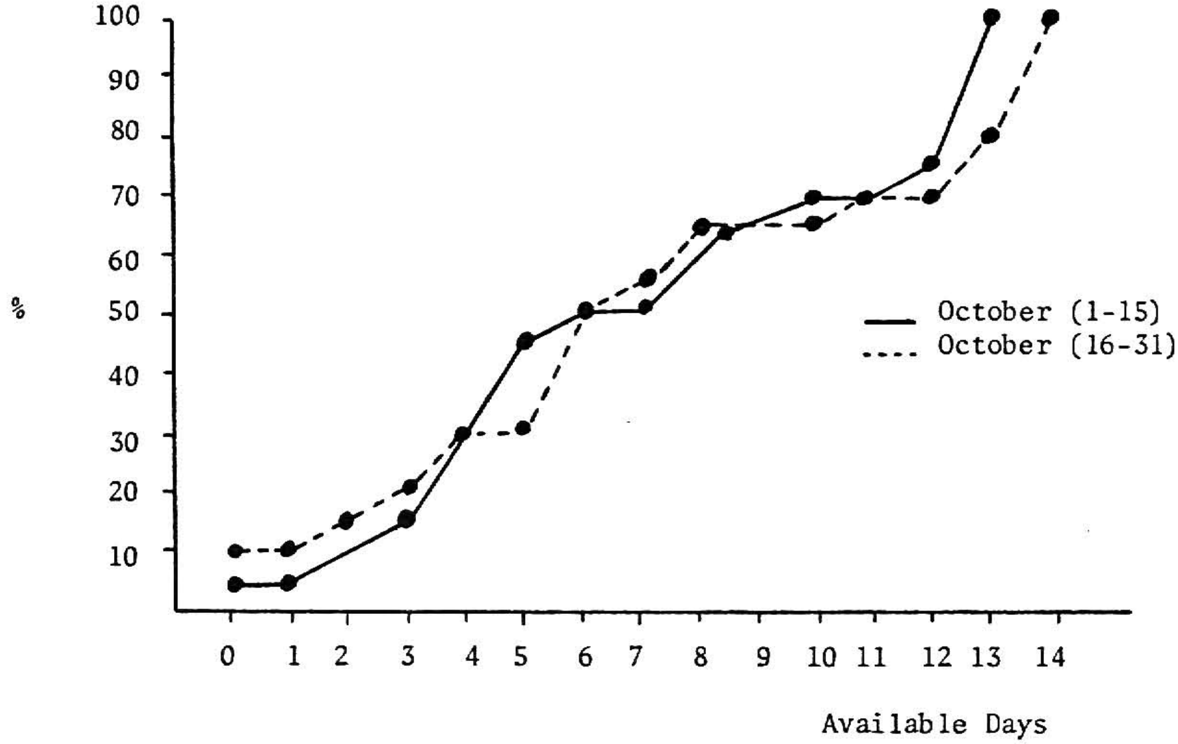


Figure 11: Accumulated Percentage of April 1 to May 15 Workdays by Daily Intervals (Considering Sunday as a "No Workday")

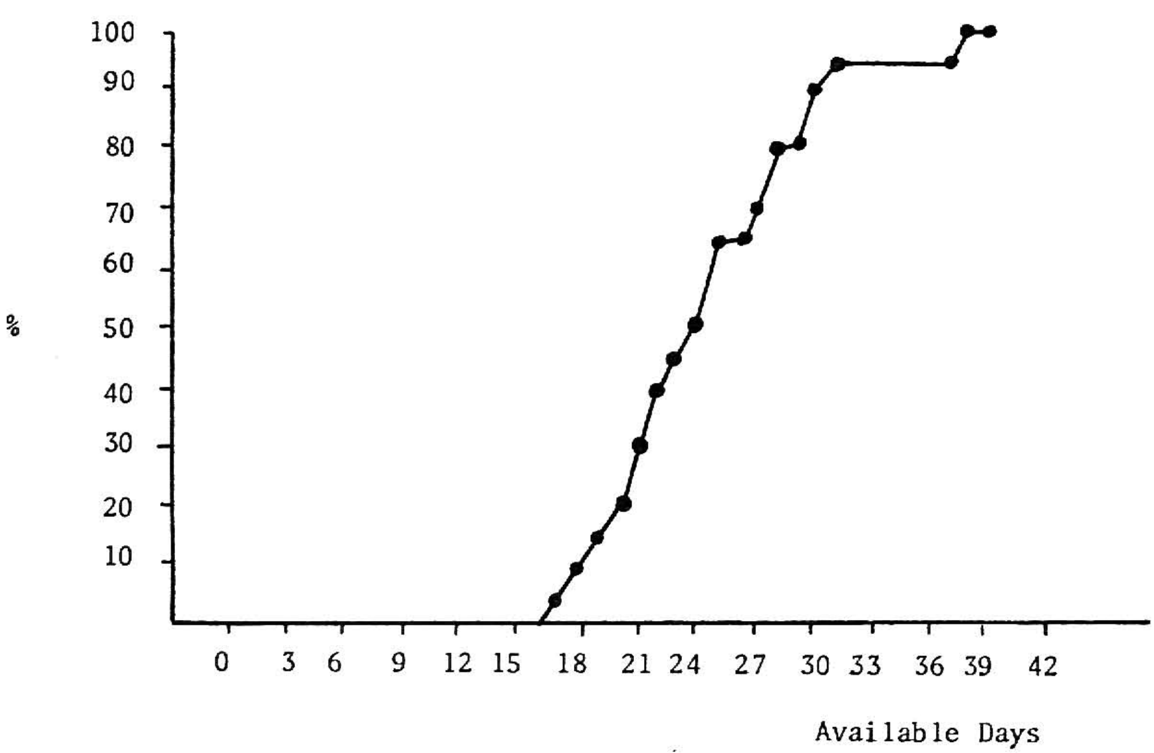


Figure 12: Accumulated Percentage of June 16 to July 31 Workdays by Daily Intervals (Considering Sunday as a "No Workday")

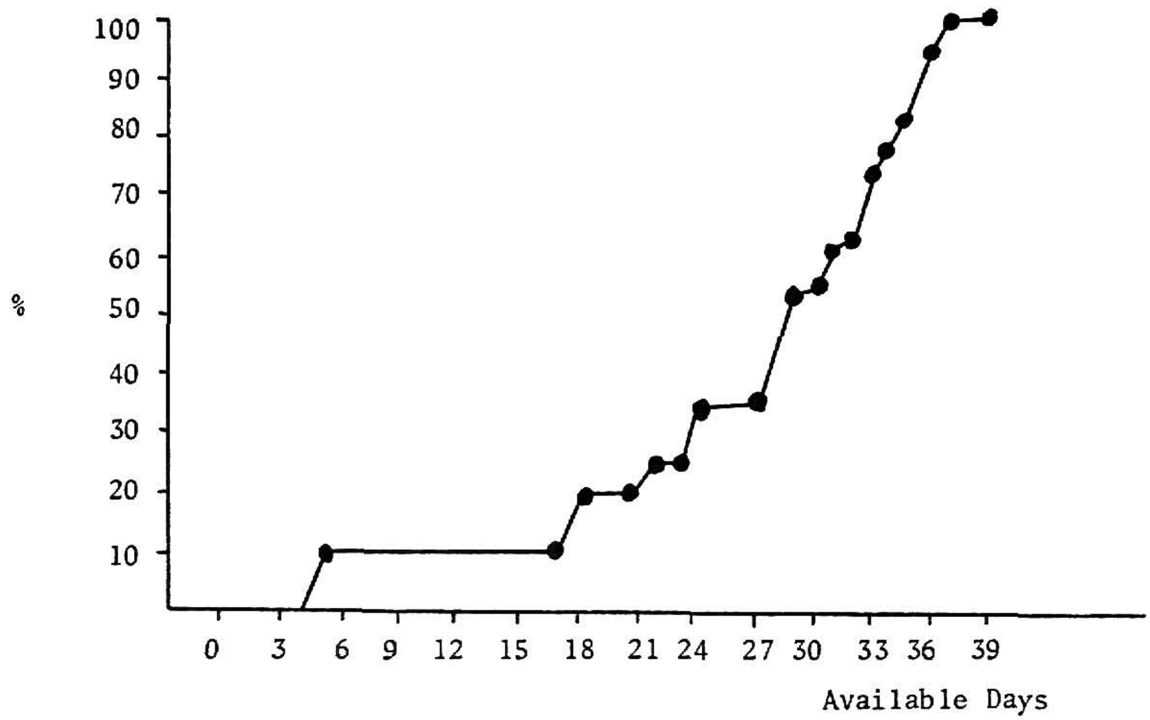


Figure 13: Accumulated Percentage of July 1 to July 31 Workdays by Daily Intervals (Considering Sunday as a "No Workday")

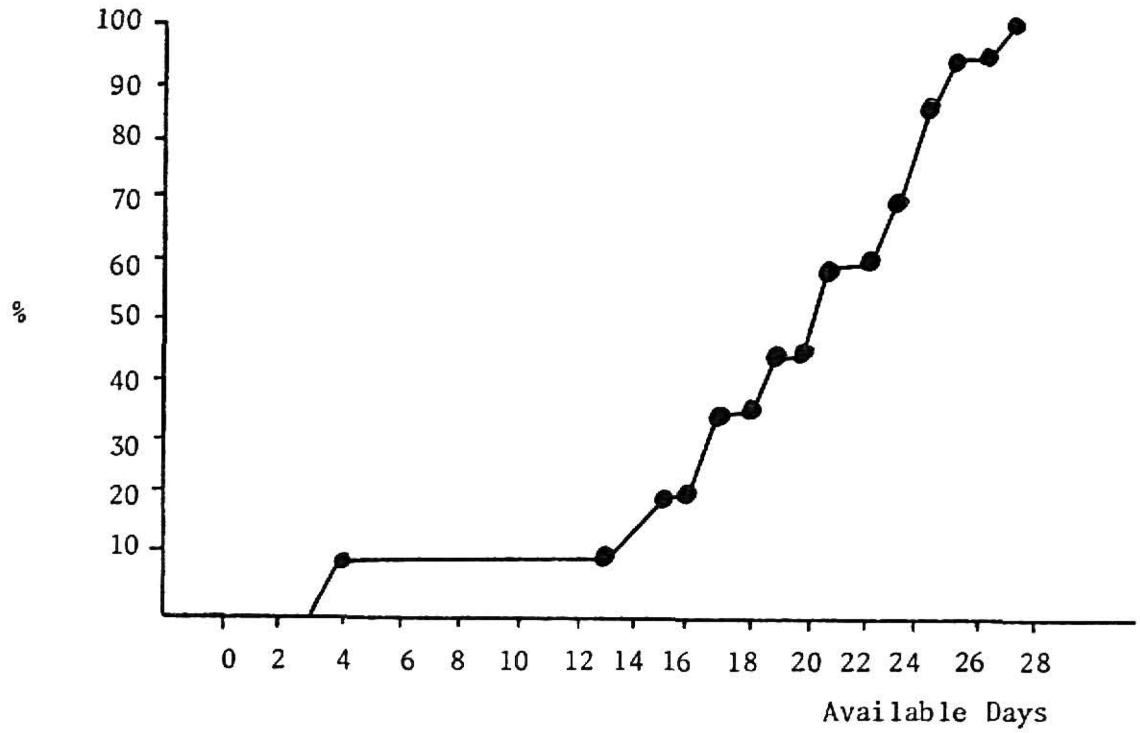


Figure 14: Accumulated Percentage of September 16 to October 31 Workdays by Daily Intervals (Considering Sunday as a "No Workday")

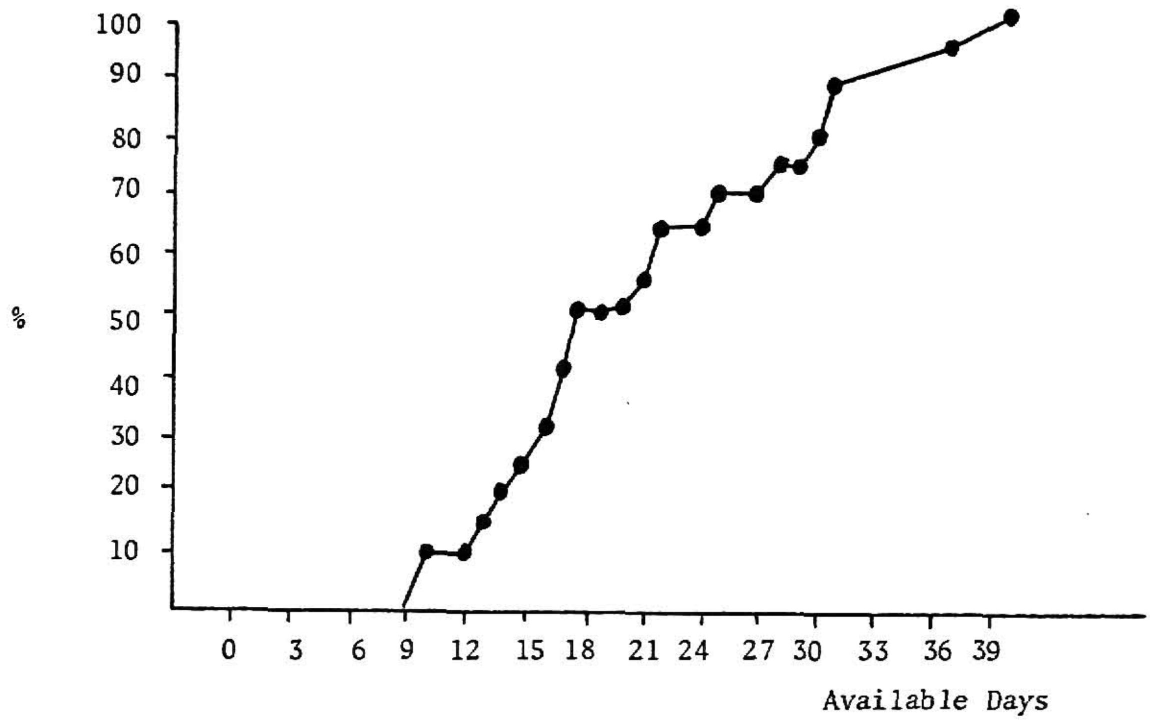
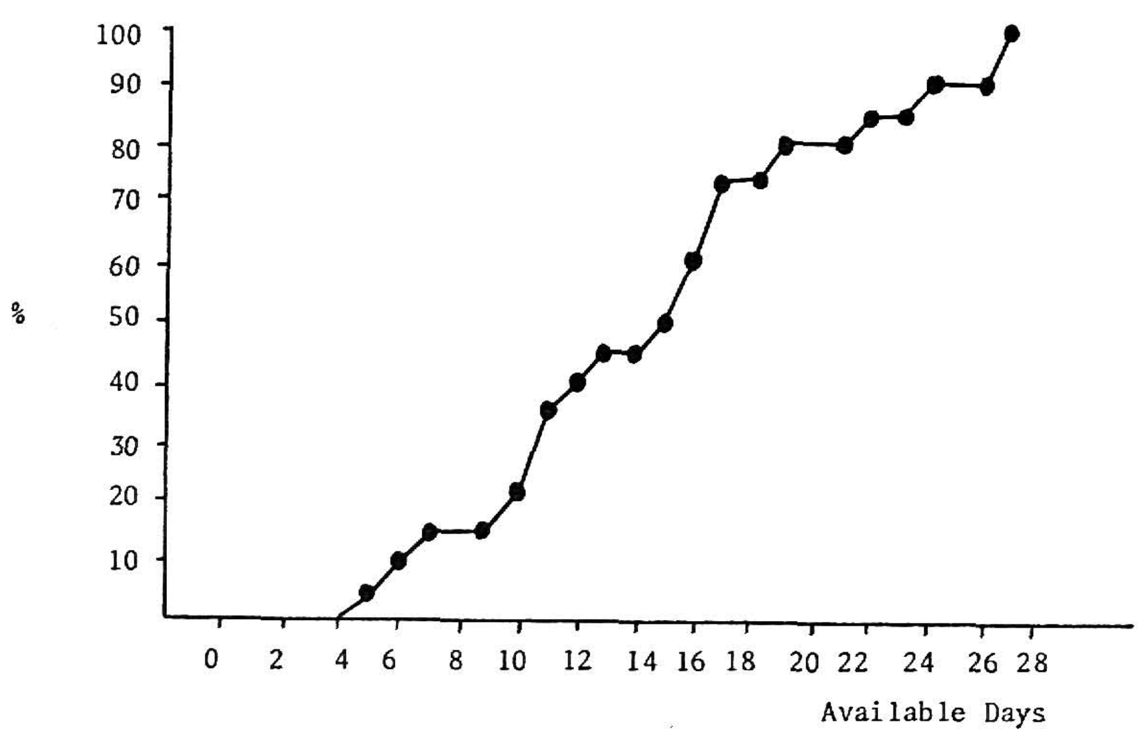


Figure 15: Accumulated Percentage of October 1 to October 31 Workdays by Daily Intervals (Considering Sunday as a "No Workday")



that are very dry, too many "workdays" on Sunday are deleted. Whereas, in very wet years too few were deleted.

Applying Results

Results of "workday" estimates were applied to an average Riley County farm to study the effect on machinery size requirements. The total cropland acreage of the average Riley County farm, excluding prairie hay and alfalfa acres, according to Kansas Farm Management records in 1973 were:

Grain Sorghum	175 Acres
Wheat	135 Acres
Grain Sorghum Silage	45 Acres[2]

Crop and Tillage Practices

Planting dates and estimates for periods of specific tillage operations were obtained from several sources. The major sources included the Kansas Cooperative Extension Service,[3] Walther and Wilson,[4] the United States Department of Agriculture Reporting Service,[5] and visits with local Riley County farmers. These sources were used to estimate tillage practice dates when tillage operations are to be completed for the major crops, Table 4.

Section I of Table 4 contains the tillage dates which if there are a

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[2] Farm Management Summary and Analysis Report, 1973, Cooperative Extension Service, Kansas State University (April, 1974), pp. 34-35.

[3] Planting Crops in Kansas, Cooperative Extension Service, Kansas State University (May, 1970).

[4] Wilbert H. Walther and John L. Wilson, Planting, Development, and Harvest of Major Kansas Crops, Topeka, Kansas: State Printing Office (February, 1963), pp. 1-60.

[5] Cropping Operation - Times Over, United States Department of Agriculture (1967).

Table 4: Cropping Operations and Operational Dates

Operation	Wheat		Grain Sorghum and Grain Sorghum Silage	
	Recommended Dates		Recommended Dates	
	Earliest	Latest	Earliest	Latest
Section I				
Disc			April 1	April 15
Chisel			April 1	April 30
Disc			May 1	May 15
Plant (Lister)			May 16	May 31
Cultivate			June 1	June 15
Harvest	June 16	June 30		
Plow	July 1	July 31		
Cultivate			July 1	July 31
Disc	August 1	August 15		
Springtooth	August 16	August 31		
Springtooth	September 1	September 15		
Plant (Drill)	September 16	September 30		
Harvest			October 1	October 31
Section II				
Disc, Chisel, and Disc			April 1	May 15
Springtooth and Plant (Lister)			May 16	June 15
Harvest and Plow	June 16	July 31		
Cultivate (twice)			June 16	July 31
Disc	August 1	August 15		
Springtooth	August 16	August 31		
Springtooth and Plant (Drill)	September 16	October 31		
Harvest			September 16	October 31

sufficient number of working days in all periods, the farmer could expect to complete his field work.

Section II contains dates which are the latest that a farmer will wait to do a particular operation. It is the time periods in which local farmers stated that ". . . work has to be done by then."

Calculation of Field Machinery Size

Machinery width estimates were made using information in the KSU Farm Management Guide[6] and compared to estimates used by the Economic Research Service of the United States Department of Agriculture.[7] Also, information from a small survey of Riley County farmers was incorporated. Two major variables in determining width were speed and efficiency which were determined for the following machines by Krenz as:[8]

Machine	Speed	Efficiency
Chisel	4.1	.80
Combine	3.0	.67
Cultivator	3.8	.76
Disc	4.8	.83
Drill	4.0	.72
Forage Cutter	3.0	.63
Lister (Planter)	5.0	.67
Plow	4.5	.80
Springtooth	5.3	.70

The estimates for speed and efficiency were applied to the formula

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[6]Leo Figurski and Mark D. Shrock, Determining Field Capacity of Farm Machinery, Manhattan, Kansas: Kansas State University Cooperative Extension Service, Farm Management Guide No. 256 (September, 1973)

[7]Ronald D. Krenz, "Crop Budgets for Kansas," Budgets used in the Firm Enterprise Data System, October 1974 (Mimeographed).

[8]Ibid.

developed by Frisby[9] to obtain the size of equipment.

$$\text{Width in Feet} = \frac{(\text{Actual Field Capacity}) \times 8.25}{(\text{Speed}) \times (\text{Field Efficiency})}$$

The acreage capacity (actual field capacity) was calculated using the following formula:

$$\text{Acreage Capacity} = \frac{\text{Total Acreage of a Particular Crop}}{(\text{No. of Workdays in a Period}) \times (\text{No. of Hrs. in a "Workday"})}$$

The acreages for each crop are described on page thirty-nine. Each "workday" was assumed to be ten hours. The estimate of the number of "workdays" in a period were from the soil moisture budget model.

After obtaining the average width for a given type of operation, Frisby's width formula was transformed into the following formula:

$$\text{No. of Field Workdays} = \frac{\text{Total Acreage of a Particular Crop} \times 8.25}{(\text{No. of Hrs. in a Workday}) \times \text{Width} \times \text{Speed} \times \text{Efficiency}}$$

In this formula the width of the machines specified are in actual sizes that machines are sold. Consequently, when estimating the machinery size needed for a particular time period, the calculated field workdays required must be less than or equal to the estimated number of field workdays for the period. For a period with tillage practices requiring more than one type of machinery the sum of the field workdays required for all operations has to be less than or equal to the total field workdays available.

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[9] James C. Frisby, Machinery Management IV--Using Weather Data to Size Tillage Implements, Science and Technology Guide, Agricultural Engineering (October, 1969), pp. 1203-1204.

CHAPTER VI

ANALYSIS OF DAYS AVAILABLE FOR FIELDWORK IN RILEY COUNTY, KANSAS

Spring Tillage

The spring tillage period, April 1 to May 15, is used to prepare the soil for planting sorghum crops. It is assumed that the acreage used for the planting of sorghum crops is cleared with a field chopper prior to April 1.

Table 5: Days Available for Spring Tillage

	Probability of "Workdays"[a]				
	.95	.85	.75	.65	.50
Section I					
April 1-15	5 days	6 days	6 days	7 days	9 days
April 16-30	3 days	6 days	8 days	9 days	9 days
May 1-15	4 days	6 days	6 days	7 days	7 days
Section II					
April 1 to May 15	18 days	20 days	22 days	23 days	25 days

[a]The probability of "Workdays" describes the phenomenon that at least the specified number of "Workdays" were available in a particular percentage of the years examined. Sundays were excluded.

As shown in Figures 4, 5, and 6, all three periods of Section I have at least six workdays in eighty-five percent of the years examined. However, there is a greater total number of workdays for the combined one-half month periods in Section II at the eighty-five percent probability level. The reason the total "workdays" in Section II differs from the sum of "workdays" of the periods in Section I is that the number of "workdays" in any other period are independent, in a probability sense.[1] Years when April 1-15 had five days, the April 16-30 period had eleven "workdays." It is highly improbable that a year with the least number of "workdays" in any one period would also have the least number of "workdays" in every period.

Table 6: Size of Machinery to Complete 220 Acres for Spring Tillage by Designated Periods

	Percentage of Years Required to do Fieldwork				
	95%	85%	75%	65%	50%
Section I[a]					
April 1-15	10 ft.	8 ft.[c]	8 ft.	8 ft.	8 ft.
April 16-30	2-10 ft.	10 ft.[c]	10 ft.	10 ft.	10 ft.
May 1-15	12 ft.	8 ft.[c]	8 ft.	8 ft.	8 ft.
Section II[b]					
April 1 to	8 ft.[c]	8 ft.	8 ft.	8 ft.	8 ft.
May 15	10 ft.[c]	10 ft.	10 ft.	10 ft.	10 ft.

[a]April 1-15 one discing operation, April 16-30 one chiseling operation, and May 1-15 one discing operation.

[b]April 1 to May 15 uses a 8 ft. disc and a 10 ft. chisel.

[c]A smaller size of machine is not available for study.

Using the probability of "workdays" reported in Table 5, the size of disc and chisel needed to complete tillage of 220 acres by period from April 1 to May 15 was calculated and reported in Table 6. Discing and chiseling as designated by period requires a twelve foot disc and two ten foot chisels to finish work in ninety-five percent of the years examined if tillage must be completed in the designated periods. However, size of disc and chisel can be

[1]Although the total days of the period are the sum of the three mutually exclusive periods, it is assumed that occurrence of "workdays" in a section is independent to the number of "workdays" in comparative sections.

reduced to eight feet and ten feet, respectively if completing tillage in eighty-five percent of the years is adequate.

Relaxing the rigid time periods, as in Section I, and assuming the necessary discing or chiseling can be done anytime from April 1 to May 15, an eight foot disc and ten foot chisel are adequate for ninety-five percent of the years examined.

Spring Planting

The number and percent of field workdays for May 15 to June 15 decreases compared with the previous period, Figures 5 and 6. A problem of size for equipment to plant 220 acres for most years becomes more important. In all periods, Section I, forty-five percent of the years contained five "workdays" or less. This explains why some of the local farmers recommended to begin planting after the danger of frost is no longer present to allow more time for planting and cultivation before the wheat harvest.

If the two periods in Section I, Table 7 are combined as recommended by several Riley County farmers, the total number of "workdays" for the two operations increases, Section II.

Table 7: Days Available for Spring Planting of Sorghums

	Probability of "Workdays"				
	.95	.85	.75	.65	.50
Section I					
May 16-31	2 days	3 days	4 days	4 days	8 days
June 1-15	1 day	3 days	3 days	4 days	6 days
Section II					
May 16 to June 15	6 days	10 days	10 days	12 days	14 days

The problem of few "workdays" during May 16 to June 15 may cause a yield loss if a crop is planted late. Strickler[2] studied the effect of late planting in the Manhattan area using research test plots. He found that for the period 1958 to 1962 the average yield for eight types of grain sorghum planted at three different dates was:

May 20 - 88.1 bushels
June 10 - 68.1 bushels
June 30 - 37.1 bushels

This is a large reduction in the yield with later planting and must be taken into consideration when estimating the optimum size of machinery, Table 8.

Table 8: Size of Machinery to Complete Spring Planting

	Percentage of Years Required to do Fieldwork				
	95%	85%	75%	65%	50%
Section I[a]					
May 16-31	1-10 row	1-8 row	1-6 row	1-6 row	1-4 row
June 1-15	2-8 row and 1-6 row	1-8 row	1-8 row	1-6 row	1-4 row
Section II[b]					
May 16 to June 15	1-16'11" 1-6 row or 2-16'11" 1-4 row	1-11'1" 1-4 row or 2-21 1/2' 1-2 row	1-11'1" 1-4 row or 1-26 1/2' 1-2 row	1-16'11" 1-2 row	1-11'1" 1-2 row

[a]May 16-31 incorporates a sorghum planter, June 1-15 investigates the size of a sorghum cultivator

[b]May 16-June 15 incorporates a springtooth expressed in feet and inches and a planter designated by the number of rows for width

[2]F. C. Strickler and A. W. Pauli, Yield and Yield Components of Grain Sorghum as Influenced by Date of Planting, Kansas State University, Agricultural Experiment Station, Technical Bulletin 130 (August, 1963), pp. 1-15.

The size of machinery in Section I of Table 8 demonstrates the lack of available "workdays." A 4-row planter and a 4-row cultivator is adequate size to complete planting and cultivation in only fifty percent of the years within the rigid time periods described in Section I, Table 7. With this period classification the size of machinery needed reaches unreasonable sizes in ninety-five percent of the years.

If springtoothing and planting is permitted anytime during May 16 to June 15, Section II contains a much more reasonable size of springtooth and planter which are adequate. Not only is the required size of the planter and springtooth smaller, but also a smaller tractor can be used. Although allowing the longer period to plant and harrow does lower the size of equipment, it introduces the possibility of loss in yield by as much as twenty-five percent because of late planting. Information from some Riley County farmers visited showed that their machinery is adequate to plant and cultivate 220 acres in eighty-five percent of the years considering the May 16 to June 15 period. Apparently these farmers consider the loss in yield, possible 15 percent of the time, less costly than owning larger equipment to get crops planted ninety-five percent of the time.

Wheat Harvest and After

Harvest Fieldwork

Since severe thunderstorms can destroy a wheat crop, the number of "workdays" in the June 16-30 period is extremely important. Twenty-five percent of the years studied had five "workdays" or less, including Sundays as a possible "workday." Fifteen percent of the years had one "workday" or less. Including July with the June 16-30 period greatly reduces the problem of limited "workdays." The July 1-31 period in Section I was not as restrictive in most years, with only ten percent of the years containing ten days or less. This demonstrates that July is either very dry or extremely wet and supports the farmers' concern about the effect of weather during the harvest period.

Finishing wheat harvest is usually the most important operation. Harvest will continue into July if needed. After completing harvest, row crops are cultivated, wheat stubble plowed, and row crops are cultivated a second time if "workdays" are available. Section II and Figure 12, show that there are two years in twenty which have 7.5 "workdays" or less. However, the remaining ninety percent of the years, the number of "workdays" available are adequate.

Table 9: Days Available for the Wheat Harvest and After Harvest Fieldwork

	Probability of "Workdays"				
	.95	.85	.75	.65	.50
Section I					
June 16-30[a]	1 day	4 days	6 days	7 days	7 days
July 1-31	4 days	15 days	17 days	19 days	21 days
Section II					
June 16 to July 31	5 days	18 days	24 days	28 days	29 days

[a]Sundays are "Workdays" if they meet soil moisture requirements.

The size of machinery necessary to harvest 135 acres of wheat is a problem at least five percent of the years. Four fourteen foot combines are needed to harvest 135 acres in one "workday," which occurred in five percent of the years examined during June 16-30. However, in eighty-five percent of the years, Section II, one fourteen foot combine was adequate to complete harvest during the same period. It is unreasonable to rationalize a farmer needing four combines to meet the demand of five percent of the years. For an average Riley County farmer a thirteen foot combine, a four row field cultivator, and a four bottom by sixteen inch moldboard plow would complete fieldwork in seventy-five percent of the years studied for the period June 16-30 and eighty-five percent of the years during the month of July, Table 10.

Table 10: Size of Machinery Needed to Complete Fieldwork During and After Harvest

	Percentage of Years Required to do Fieldwork				
	95%	85%	75%	65%	50%
Section I[a]					
June 16-30	4-14'	1-14'	1-12'[c]	1-12'	1-12'
July 1-31	2 4-16"	1 3-16"	1 4-16"	1 3-16"[c]	1 3-16"
	1-10 row	1-4 row	1-2 row	1-2 row	1-2 row
		or			
		1 6-16"			
		1-2 row			
Section II[b]					
June 16 to July 31	3-19'	1-14'	1-14'	1-12'	1-12'
	3 5-16"	1 6-16"	1 3-16"	1 3-16"	1 3-16"
	3-6 row	1-6 row	1-4 row	1-4 row	1-4 row
		or			or
		1-19'			1-14'
		1 5-16"			1 6'16"
		1-6 row			1-2 row

[a]June 16-30 relates the size of combines needed, July 1-31 describes the number and size of sixteen inch moldboard plows and row sorghum cultivators needed.

[b]June 16 to July 31 incorporates a combine, sixteen inch moldboard plows, and row sorghum cultivators.

[c]A smaller sized machine is not available for study.

When selecting the appropriate section it should be remembered that row crops usually are cultivated once before wheat harvest if "workdays" are available. If pre-harvest cultivation is impossible, two cultivations are done in July. If wheat harvest is carried over into July, it is possible to have a shortage of "workdays" to plow wheat stubbel and to cultivate sorghums with the given rotational systems.

Summer Preparation of Wheat Ground

Workdays to prepare the seedbed for the winter wheat crop are adequate, Table 11. Seventy-five percent of the years examined had nine "workdays" or more in the first period of August. Sixty-five percent of the years had nine "workdays" or more in the second section of the month.

Table 11: Days Available for Summer Preparation of Winter Wheat Ground

	Probability of "Workdays"				
	.95	.85	.75	.65	.50
Section I					
August 1-15	5 days	7 days	9 days	9 days	10 days
August 16-31	3 days	5 days	7 days	9 days	11 days
September 1-15	0 days	3 days	7 days	7 days	8 days
Section II					
August 1-15	5 days	7 days	9 days	9 days	10 days
August 16-31	3 days	5 days	7 days	9 days	11 days

The only period of Section I which presents a serious problem is September 1-15. In five percent of the years examined, there are no field "workdays." Three years out of twenty have two "workdays" or less in the first part of September. However, seventy-five percent of the years have more than fifty percent of the available days as field workdays, Figure 8.

Section II is the same as Section I with the omission of September 1-15. Since fertilization was assumed, applied under contract, no other operation would be required in the period.

Size of disc and harrow need not be large to prepare 135 acres wheat ground for fall planting, except for the September period. Size of machinery for wheat ground tillage is smaller than required for sorghum ground tillage of 220 acres. Only in five percent of the years is there no possibility for work being completed.

Table 12: Size of Machinery Needed to Complete Fieldwork for Preparation of Winter Wheat Ground

	Percentage of Years Required to do Fieldwork				
	95%	85%	75%	65%	50%
Section I[a]					
August 1-15	8 ft.[c]	8 ft.	8 ft.	8 ft.	8 ft.
August 16-31	11'1"[c]	11'1"	11'1"	11'1"	11'1"
September 1-15	No Workdays	11'1"[c]	11'1"	11'1"	11'1"
Section II[b]					
August 1-15	8 ft.[c]	8 ft.	8 ft.	8 ft.	8 ft.
August 16-30	11'1"[c]	11'1"	11'1"	11'1"	11'1"

[a]August 1-15 investigates the size of discs; August 16-31 and September 1-15 examines the size of springtooths.

[b]August 1-15 investigates the size of discs; and August 16-31 examines the size of springtooths.

[c]A smaller sized machine is not available for study.

For the representative farms studied a fifteen foot springtooth and a twelve foot discs are adequate to prepare ground for sorghum and will also be more than adequate to prepare ground for wheat planting. However, omission of one springtooth operation increases needed "workdays" in the next operational period.

Sowing Wheat and Fall Harvest

The last fifteen days of September have more rainfall than the first half of the month when fifty percent of the years have less than six "workdays," Table 13 and Figure 9. Few "workdays" during the last half of September is a problem if the drilling of wheat is to be completed in this period.

October 1-31 has more "workdays" available. Ninety-five percent of the years examined during October had at least six "workdays" available for fieldwork.

Table 13: Days Available for Sowing Wheat and Fall Harvest

	Probability of "Workdays"				
	.95	.85	.75	.65	.50
Section I					
September 16-30	0 days	2 days	3 days	4 days	6 days
October 1-31	6 days	10 days	11 days	12 days	16 days
Section II					
September 16 October 31	10 days	14 days	16 days	17 days	21 days

Ninety-five percent of the years have at least twenty-six percent of the days available for fieldwork from September 16 through October 31. However, much delay in planting may require an extra field operation, spring-toothing. Section II combines all operations, thereby allowing for late sowing dates. The Kansas Cooperative Extension Service[3] recommends planting dates for this area are between September 15 to October 10.

The effect of late wheat planting was published by the Kansas Agriculture Experiment Station. The results of the study showed:

Planting Date		Yield
September 15	-	30.2 Bushels/Acre
September 22	-	30.6 Bushels/Acre
September 29	-	31.1 Bushels/Acre
October 6	-	30.3 Bushels/Acre
October 13	-	25.4 Bushels/Acre
October 20	-	21.5 Bushels/Acre
October 27	-	17.4 Bushels/Acre[4]

[3] Planting Crops in Kansas, Cooperative Extension Service.

[4] Growing Wheat in Kansas, Agriculture Experiment Station, Kansas State University, Bulletin 463 (January, 1964), p. 29.

Therefore, if the wheat is planted before October 6, there was less than a bushel difference in average yields comparing September 15 to October 6 plantings.

A 16 x 8 wheat drill is more than adequate to plant 135 acres of wheat in most years. Only in sixty-five percent of the years examined would drilling be completed in September. The month of October has a larger number of "workdays." However, due to the speed and width of the machines, only eighty-five percent of the years would field work be completed with the average machinery size in Riley County.

In Figure 14 and Table 14 every examined year has at least 7.5 "workdays" and twenty-five percent of the years had fifteen "workdays" or less. Only in fifteen percent of the years would the following size drills and field sorghum harvesters fail to complete wheat drilling and sorghum harvest by the end of October: a thirteen foot combine, a 16 x 8 drill, a fifteen foot springtooth, and one row forage cutter.

Table 14: Size of Machinery Needed for Sowing Wheat and Fall Sorghum Harvest

	Percentage of Years Required to do Fieldwork				
	95%	85%	75%	65%	50%
Section I					
September 16-30	No Workdays	2-16x8	1-20x8	1-16x8	1-12x8
October 1-31	1-19' 1-1 row 1-2 row	1-12' 1-2 row or 2-12' 1-1 row	1-12' 1-2 row or 1-19' 1-1 row	1-14' 1-1 row	1-12' 1-1 row
Section II					
September 16 to October 31	1-22 1/2' 1-20x8 1-19' 2-2 row or 1-14'7" 1-20x8 1-19' 3-2 row	1-14'7" 1-16x8 1-16' 1-2 row or 1-11'1" 1-16x8 1-16' 1-1 row	1-11'1" 1-12x8 1-14' 1-2 row	1-11'1" 1-12x8 1-12' 1-2 row	1-11'1" 1-12x8 1-12' 1-2 row

CHAPTER VII

SUMMARY AND CONCLUSION

Findings

The objective of this study was to evaluate the results of the soil moisture budget system to estimate field workdays and to incorporate the information into estimating the size of machinery needed for various tillage operations. Daily pan evaporation and rainfall records were obtained for twenty years between 1951-1970. These inputs supplied the moisture budget system information to estimate soil moisture. Data collected in 1974 showed that .77 inches of the soil moisture (one-half saturation) in the top five percent of the total soil moisture is the maximum moisture for "workdays." For 1974, the observed and calculated "workdays" agreed 97.96 percent of the time.

Using twenty year data from the Manhattan Weather Station, calculated "workdays" for each year were used to estimate probability of "workdays" for different months and weeks. With the estimated probabilities the size of machinery required to complete specified jobs on an average Riley County farm was calculated. Machinery size requirements are estimated two ways: (1) size required to do the job during favorable weather and (2) size required to do the job by the latest feasible day. The results provided the following information.

"Workdays" for spring tillage of the soil for sorghum crops are adequate in most years for average Riley County farms. In all of the one-half month periods the minimum size disc and chisel was adequate to do the required tillage in at least eighty-five percent of the years. Only in ten percent of the years was there a serious lack of "workdays" during April 16-30. In all of the years examined for April 1 to May 15, the minimum sized machinery fulfilled tillage requirements within the number of estimated field workdays.

Days available for spring planting decreases as the amount of rainfall increases. During the periods May 16-31 and June 1-15, thirty-five percent of the years had five "workdays" or less. Therefore, only in sixty-five percent of the years examined would average sized Riley County farms have machinery large enough to complete tillage operations. Since the periods are independent in a probability sense, with their present size of machinery Riley County farmers could complete spring planting in eighty-five percent of the years during May 16 to June 15.

The wheat harvest and after harvest fieldwork provides a greater "workday" problem. Since severe thunderstorms can destroy a crop, farmers try to complete harvest quickly and with reasonable sized machinery. Five percent of the years examined contained one "workday" or less for harvest during June 16-30. However, farmers could expect to finish harvest, plowing, and cultivation in sixty-five percent of the years examined, July 1-31. During June 16 to July 31 there is a large year to year difference in the number of "workdays" so that either the years are extremely wet or extremely dry.

"Workdays" available for tillage in preparation of the seedbed for the winter wheat crop are adequate. Only in ten percent of the years during the period September 1-15 was there a problem in "workday" availability.

The availability of "workdays" for sowing wheat and fall harvest of grain sorghums is of interest because of the increased rainfall and decreased evaporation during fall months. Between September 16-30, ten percent of the years had "no workdays." Therefore, local farmers had machinery of size adequate to finish their fieldwork in sixty-five percent of the years for September 16-30, seventy-five percent of the years for October 1-31, and sixty-five percent of the years for September 16 to October 31.

Sources of Error

The soil moisture budget system has not been tested for various soil situations. Further experimentation with different soil types and during the entire growing season, especially the fall, is needed. The model assumed a constant soil moisture level for estimating "workdays." With experimentation, the decision making value for the possibility of field operations should be adjusted for each separate crop operation.

Data of machinery size used in different regions is needed. The machinery speed and efficiency should relate to the types of soil, and the number of hours in a "workday" should be evaluated for each period.

Possibilities of Future Study

The potential of estimating field "workdays" has many economic ramifications. Not only can different sizes of presently operated farms be examined in Riley County, but for the entire state. Many farmers now receiving higher prices for their crops want to know if they should invest in machinery. Established and beginning farmers need to know the size of machinery required if they expand the size of their present enterprises. With accurate machine cost data, this program could be used to study the cost and risk of not getting the operation done. Consequently, this study expanded could be helpful to large and small farmers alike from the rainy cornfields of eastern Kansas to the arid wheat fields of western Kansas.

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USE OF SOIL MOISTURE BUDGET SYSTEM TO ESTIMATE FIELD WORKDAYS FOR RILEY COUNTY, KANSAS WITH IMPLICATIONS FOR MACHINERY SIZES

by

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The object of this study is to evaluate the effectiveness of Baier's soil moisture budget system for estimating soil moisture which is used to predict the available number of field "workdays" in Riley County, Kansas. The number of "workdays" was used to equate the size of machines for each selected crop operation.

The Baier soil moisture program considers crop stages, vegetative cover, soil characteristics, and drainage. These characteristics were combined with daily measurements of precipitation and pan evaporation to predict the number of "workdays" for each tillage operation.

Soil samples from a silt loam soil at the Agronomy Research Farm northwest of Manhattan, Kansas were taken and soil moisture was measured and "workdays" were identified. This data was compared with model estimates. "Workdays" were identified for ninety-eight days, April 25 through July 31, 1974. Estimates of "workdays" predicted from Baier's model agreed 97.96 percent of the days when compared with the collected data.

Using the Baier soil moisture estimator, days between April 1 to October 31 were designated as "Workdays" and "No Workdays" for the twenty year period, 1951 to 1970. All Sundays were designated as "No Workdays" except for those during June 15-30.

The results of the "workday" estimates were used to study machinery size required on an average Riley County farm consisting of 175 acres of grain sorghum, 135 acres of wheat, and 45 acres of grain sorghum silage. Two tillage programs were examined: (1) minimum periods to complete specific tillage practices, and (2) combined tillage practice periods, allowing tillage and planting to occur until the latest possible day. Size of machines needed to complete a specified job within a given number of "workdays" was estimated from the following formula:

$$\text{Width in Feet} = \frac{A \times 8.25}{Wd \times Hr \times S \times Fe}$$

where,

A = Total acreage of a particular crop
Wd = Number of "Workdays" in a period
Hr = Hours in a "Workday"
S = Speed
Fe = Field efficiency

Standard estimates for speed, field efficiency, and hours in a "workday" were used with daily "Workday" and "No Workday" estimates for twenty years. The average and cumulative distribution of "workdays" were calculated by month and one-half month periods.

Results showed "Workdays" for spring tillage of sorghum crops were adequate for average sized Riley County farms. If each half of April and the first half of May or all of April 1 to May 15 is considered, below average sized machinery could be used eighty-five percent of the years examined.

"Workdays" available for spring planting decreases. During each period, May 16-31 and June 1-15, forty-five percent of the years had five "workdays" or less. Only in fifty percent of the years examined would average sized machinery be large enough to complete tillage operations. However, if May 16 to June 15 is combined, Riley County farmers could complete spring planting in eighty-five percent of the years.

Rainfall in late June reduces "Workdays" available for the wheat harvest. Between June 16 to June 30, fifteen percent of the years examined had one "Workday" or less. However, farmers could expect to finish harvest, plowing, and cultivation in sixty-five percent of the years during July 1-31. During the combined section, June 16 to July 31, only ten percent of the years presented a serious problem.

Days available for tillage in preparation of the seedbed for the winter wheat crop are adequate. Only in ten percent of the years between September 1-15 was there any "workday" problem.

Ten percent of the years had zero "Workdays" between September 16-30 for sowing wheat. However, the size of machinery used by Riley County farmers between September 16-30 allows completion of fieldwork in sixty-five percent of the years. Also, they could finish fall harvest, October 1-31, in seventy-five percent of the years.