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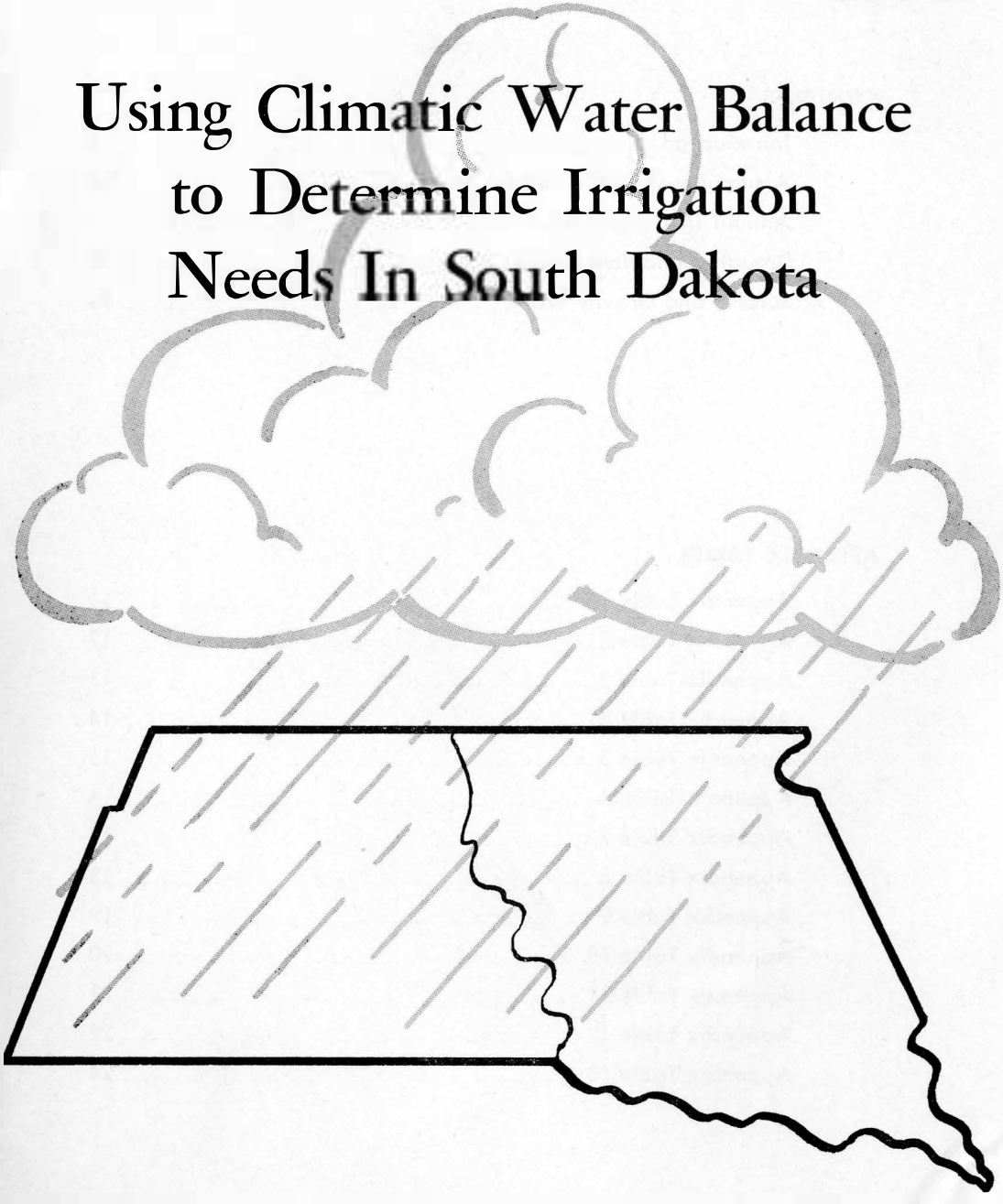

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CONTENTS

APPENDIX TABLES

Using Climatic Water Balance to Determine Irrigation Needs in South Dakota

By Ray F. Pengra[1]

Estimates of average soil moisture and the amount of irrigation water required to maintain a definite soil moisture level are of particular value for planning irrigation projects for large areas or for individual farms.

The purpose of this study was to develop information that would be of value to technicians in planning irrigation for the different areas of South Dakota. The method can also be used to develop irrigation needs for individual farms.

The use of historical data was necessary to determine needs during past years as an estimate of probable future needs. The study points out the portion of the growing season during which irrigation was needed, the frequency of irrigation, and the total amount of irrigation water that would have been needed to maintain soil moisture above the drought point during previous years. Weather data were used from 1930 to 1946 in order to include years both below as well as some above normal or average precipitation. This information for the drought years of the 1930's would be an indication of the maximum amount of water needed during dry years. The use of both dry and wet years indicates the extremes in the amount of irrigation water needed during different years.

The stations of Brookings, Redfield, and Newell were selected to represent the eastern, central, and western portions of the state. Location of the stations is shown in Figure 1.

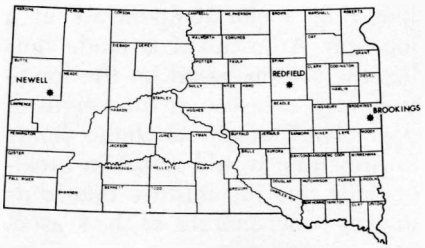

Figure 1. Location of stations used in this study.

Precipitation data have been available from the U. S. Weather Bureau for many years. These data have been of considerable value as indicators of soil moisture content and growing conditions. However, a part of this moisture is lost through runoff, some evaporates, and some is lost as a result of tran-

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spiration through vegetation. As a result precipitation alone does not provide satisfactory data for determining the soil moisture available for vegetation growth or the amount of irrigation water needed.

Temperature is an important factor affecting evaporation and transpiration. A method has been developed by Thornthwaite which uses temperature to estimate the loss of soil moisture at any location.

Thornthwaite's method of estimating soil moisture is based on what he calls potential evapotranspiration (PE). This factor is his estimate of the amount of evaporation and transpiration through vegetation that would occur at a particular location when the soil moisture is at full capacity. This figure is adjusted on the basis of the long-time mean temperature at a location. Adjustment is made during the season based on the longitude as a measure of the length of day. The longer daylight hours during June would result in greater daily loss of moisture than during the other months of the season. Appendix Table 1 presents the daily potential evapotranspiration figures as developed for South Dakota.

In estimating the daily loss of moisture by the Thornthwaite method, the actual evapotranspiration is considered to be proportional to the percentage of full capacity of the soil moisture remaining from the previous day. That is, if the soil moisture remaining 1 day was at half of full capacity, the actual evapotranspiration for the following day would be at only half or 50% of the potential.

The daily change in soil moisture when no moisture is recieved is secured by dividing the soil moisture remaining from the previous day by the soil capacity. This would give the percentage of capacity. This percentage is then multiplied by the potential evapotranspiration to secure the soil moisture change from the previous day. The result is then subtracted from the soil moisture remaining the previous day to secure the day's soil moisture. The difference between the potential evapotranspiration (PE) and soil moisture change is called the moisture deficit. When new moisture is received in excess of the PE figure for any day, the excess of the new moisture is added to the amount of soil moisture remaining the previous day. If the total exceeds the soil capacity, that day's soil moisture is considered to be at capacity and the excess is surplus.

ASSUMPTIONS USED IN THIS STUDY

As soil moisture and irrigation water needs were estimated by using only precipitation and temperature data, certain assumptions were necessary.

First, it is well known that the rate of growth of crops is reduced when soil moisture falls below a certain level. When the rate of growth of crops is seriously limited due to a lack of moisture, a drought may be said to exist. To simplify the procedure used in this study, a drought was defined as any period

during which the soil moisture in the crop root zone was less than 50% of soil moisture capacity.

Second, soil moisture capacity was arbitrarily assumed to be 4.00 inches and drought was assumed to exist when soil moisture fell to, or below, 2.00 inches.

Third, it was assumed that soil moisture does not change from October 31 to March 1 of the following year. This is a reasonable assumption because the soil in South Dakota is generally frozen during this period. In Iowa there was a loss of 0.2 inches of moisture from the soil between November 15, 1954, and April 15, 1955, on corn ground despite the fact that 5.3 inches of moisture was received during this period.[2]

This assumption made it possible to reduce the time required for analysis by 33% since no analysis was necessary from October 31 to March 1. The soil moisture carried over from the previous year and accumulated between March 1 and the start of the crop season on April 5 (or May 10 for corn) forms the starting point for the analysis of each crop season.

Fourth, the Thornthwaite formula as used with the IBM equipment corrects itself during a period of excessive moisture or drought. There is usually one or more such periods each year. Correction in daily soil moisture content would be made when a period of excessive moisture or drought occurred.

Fifth, to determine the number of irrigations and the amount of water that would have been necessary to prevent a drought, a hypothetical irrigation was introduced to bring the soil moisture up to full capacity each March 30. Subsequent hypothetical irrigations to bring soil moisture up to full capacity were made every time the soil moisture fell to the drought level during the crop season. Thus except for the March 30 irrigation, the irrigations were all 2.00 inches.

Procedure

To determine the amount of irrigation water needed and the frequency of irrigation it was necessary to first determine the available soil moisture. In this study daily soil moisture was estimated at three weather stations using an adaptation of the method developed by Thornthwaite.[3] This method uses temperature to estimate potential evapotranspiration or PE. The PE then is used to determine the daily loss of soil moisture, the soil moisture available for plant growth, and the amount of irrigation water needed to avoid drought conditions.

International Business Machines (IBM) were used to make the daily soil moisture calculations. While the 650 and other large machines can be used, the calculation of soil

[2]R. H. Shaw and J. R. Runkles, "Soil Moisture and Water Utilization in Iowa," Agronomy Journal, Vol. 48, p. 313-318, 1956.

[3]C. W. Thornthwaite and J. R. Mather, "The Water Balance," *Publications in Climatology*, Vol. 8, No. 2, 1955. The adaptation is that of W. C. Palmer and A. V. Havens "A Graphical Technique for Determining Evapotranspiration by the Thornthwaite Method," *Monthly Weather Review*, Vol. 86, No. 4, April 1958.

moisture reported here was made by the smaller, less costly 602A.[4]

To illustrate the calculations of daily soil moisture, data for 1 month at Redfield, South Dakota, are presented in Appendix Table 2. Column 1 lists the days of the month. Column 2 is the precipitation received. Column 3 is the mean daily temperature. Column 4 is the potential evapotranspiration (PE) developed graphically by the Thornthwaite method. The PE figure (see Appendix Table 1) based on daily mean temperatures reported at the station, adjusted for length of day during the season. Column 5 is the difference between PE and new moisture with a minus sign for all days during which PE exceeded new moisture. Column 6 is the daily estimate of soil moisture storage. Note that soil moisture never exceeds 4.00 inches, since this is the assumed capacity of the soil.

The method of calculating the daily soil moisture depends upon whether precipitation minus potential evapotranspiration (P-PE) is positive or negative. When P-PE is positive it is added to the soil moisture of the previous day. For example, on June 18 there was a net gain of moisture of 1.03 inches. This amount was added to the 2.42 inches of the previous day and gives a total of 3.45 inches. On the next day, June 19, there was a net gain of .69 inches of moisture. When this is added to the moisture of the previous day the total is 4.14 inches. Of this amount 4.00 inches is recorded in column 6 and .14 inches in column 9 as moisture surplus.

To calculate the soil moisture in column 6 when P-PE is negative, the first step is to find the percent that the previous day's soil moisture was of soil capacity. This percentage is then multiplied by P-PE and the result subtracted from the previous day's soil moisture. This is necessary because as the soil becomes drier the actual water loss becomes less than is indicated by P-PE in column 5. For instance, if the previous day's soil moisture was only half of the capacity figure, then the decrease would be only half or 50% of the potential evapotranspiration (P-PE) shown in column 5. Thus, on June 10, P-PE was -.23 and the previous day's moisture was 2.00 inches or 50% of capacity. Hence, **with no irrigation** there is a storage change of only -.12 inch in column 7. **With 2.00 inches of irrigation** the previous day's moisture becomes 4.00 and the actual evapotranspiration is 100% of the potential evapotranspiration of column 5 or -.23 inches (see column 11). The moisture deficiency (column 8) is the difference between P-PE (column 5) and storage change (column 7). This is the decrease in evapotranspiration due to less than full field capacity of 4.00 inches of soil moisture.

[4]For a detailed explanation of how this was done see "Determination of the Climatic Water Balance by Machine Methods," by Ray F. Pengra and Howard H. Engelbrecht, *Publications in Climatology*, Vol. XIV, No. 3, C. W. Thornthwaite Associates, Centerton, New Jersey, 1961.

The method illustrated in Appendix Table 2 was used to calculate the daily soil moisture of each crop season for the 17 years, 1930-46. The same method permitted the calculation of the time of irrigation and the amount of irrigation water needed.

The irrigations such as that shown following June 9 in Appendix Table 2 were purely hypothetical. Yet they served the purpose of indicating the number of irrigations and the amount of water that would have been necessary to prevent the soil moisture from falling below the drought level.

The manner in which the "irrigations" were introduced into the data was as follows: IBM Calculating Punch 602A was used in making the calculations of daily soil moisture shown in Appendix Table 2, columns 1-9. As this daily soil moisture was punched on the card it also appeared on the storage drum of the 602A. By watching the storage drum it was possible to tell when the soil moisture reached the level defined as drought conditions. At that point the machine was stopped and an "irrigation card" was inserted into the deck of cards being run. This card had punched into it the amount of moisture needed to bring soil moisture up to full capacity. In the case of Appendix Table 2 this was 2.00 inches of soil moisture.

The effect of this hypothetical irrigation on the subsequent soil moisture is shown in columns 10, 11, 12, and 13 of Appendix Table 2. Until June 10, these figures are the same as those in columns 6, 7, 8, and 9. Without irrigation, crops suffered 5 days of drought from June 10-14. But a series of rains increased soil moisture to full capacity and as a result from June 20 to the end of the month there are again no differences in the two sets of figures since no further irrigations were needed to avoid drought conditions of 2.00 inches or less of soil moisture.

ANNUAL IRRIGATION NEEDS 1930-46

Calculations like those illustrated by Appendix Table 2 were made for each day of the growing season for the 17 years, 1930-46. From such calculations the moisture deficiency and the moisture surplus for each crop season have been secured for both "without irrigation" and "with irrigation" conditions. Also calculated were the number of drought days and the total amount of irrigation water needed to prevent drought conditions. These data are presented in Appendix Tables 3-11.

Calculations were made for three crop seasons as follows:

(1) Full growing season, April 5 to October 31.

(2) Corn season, May 10 to September 5.

(3) Small grain season, April 5 to July 18.

DROUGHT CONDITIONS AND IRRIGATIONS

Selected Years

Severe drought conditions existed in South Dakota in 1934 and 1936, and frequent "irrigations" would have been necessary to prevent the soil moisture from falling below 50% of soil capacity. The number of irrigations varies with the amount of precipitation. To maintain soil mois-

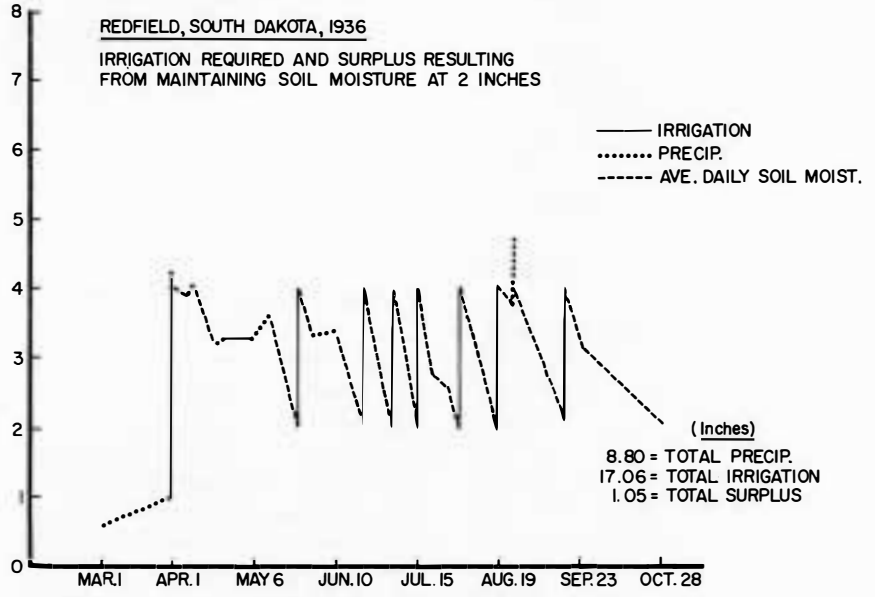
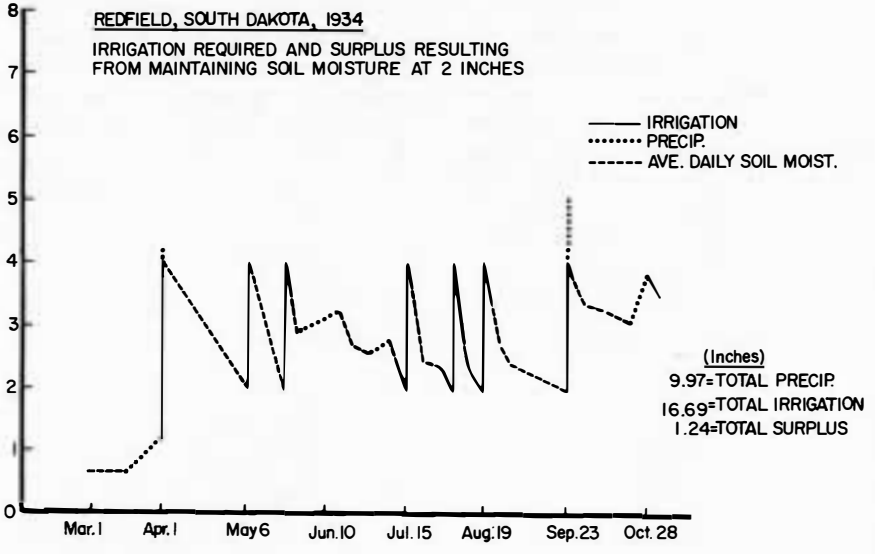


Figure 2-A (above), 2-B (below).



ture at 2.00 inches, six irrigations would have been required in 1934. This is shown in Figure 2, which also illustrates the following three points:

1) Six irrigations were needed in 1936 in order to maintain soil moisture at or above 2 inches.

2) During relatively "wet" years, such as 1942 and 1946, the number of irrigations and the amount of irrigation water needed to avoid drought was greatly reduced.

3) In some cases, precipitation was received within the week that irrigation had been made. When this occurred, the precipitation line in each case extends above the soil capacity line, indicating a surplus of moisture.

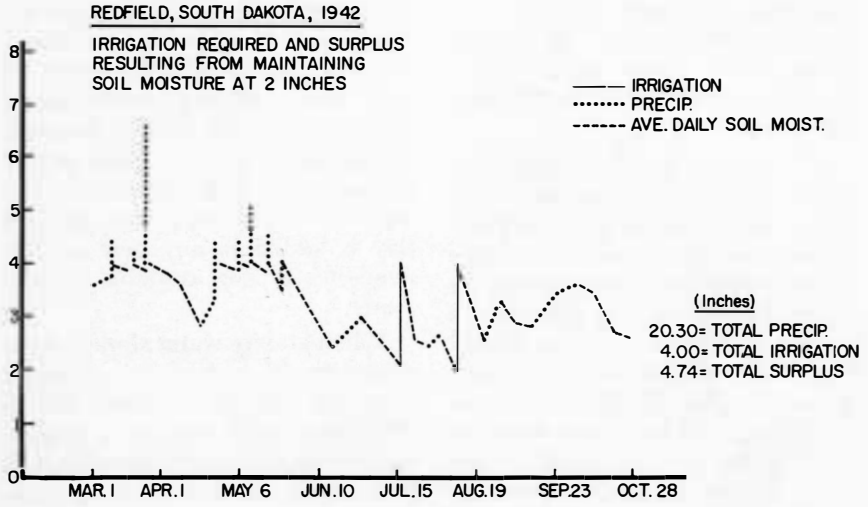
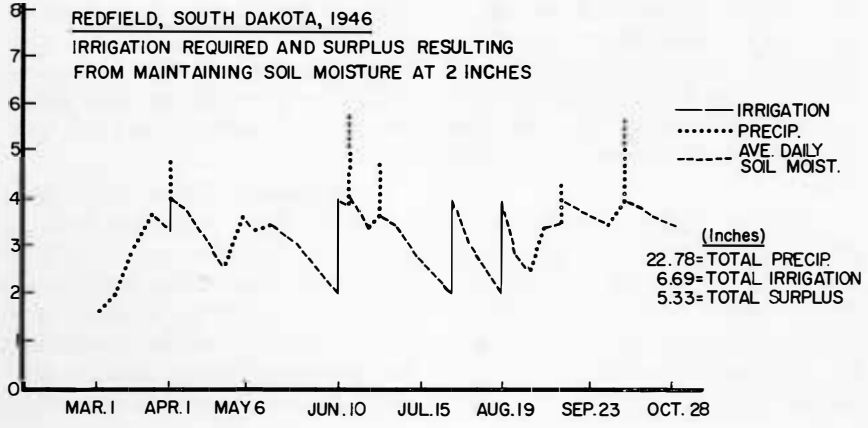


Figure 2-C (above), 2-D (below).



SURPLUS AND GRAVITY WATER

As noted above, in this study soil capacity within the root zone was assumed to be 4.00 inches. The excess, if any, above the 4.00 inches has been called "surplus." This surplus is not all lost immediately. Some of it runs off and the balance goes into the subsoil. It has been estimated that only 10% of gravity water will be lost during 1 day, while 90% will remain in the soil as gravity water storage. In regions where there is an aquifer layer in the soil, part of the surplus may replenish it.

As shown in the Appendix Tables, a "soil water balance" consists of soil moisture plus the gravity water storage for each day. Since the soil moisture storage would be at full capacity any day there was a surplus, a 1.00 inch surplus would give a soil water balance of 4 inches of capacity plus 90% of the 1.00 inch surplus, or 4.90 inches. In case the P-PE figure for the following day was —.15, the soil moisture storage would be 4.00, —.15, or 3.85 inches. Available gravity water from the previous day would be .90 inches, of which 90% would remain during the following day. This would be .81 inch. The soil water balance for that day would therefore be 3.85 plus .81 gravity storage water, or 4.66 inches.

Appendix Table 12 shows how the soil moisture and soil water balance were computed by IBM machines. Appendix Table 12 is a copy of the tabulation sheet. On March 12, soil moisture storage was 3.90 inches (column 5). On the 13th the P-PE figure was +.07 and the soil moisture and soil water balance were each 3.97. March 14 P-PE was +.30. This amount, when added to 3.97 inches from the previous day, totals 4.27. Of this amount, 4.00 inches or soil capacity is put in column 5, with .27 inch in column 8 as surplus. Since there was no carry-over of gravity water storage, the .27 inch was the available gravity water for that day (column 9). Water that remained longer than 1 day was .24 inch (90% of the .27 inch) and is listed as gravity water storage in column 10. Soil moisture of 4.00 inches plus .24 gives us 4.24 inches as soil water balance in column 10. The gravity storage each day is added to any new surplus available to get available gravity water.

When gravity water storage is reduced to .05 inches, it is dropped from the calculations, since 90% of .05 is too small to show a change and as a result the .05 inches would be carried indefinitely in the machine calculations. Because this is too small to be significant, the machine is set so that it is dropped whenever it appears. This is what happened, for example, in Appendix Table 12, when on April 25 the .05 was not carried over to April 26.

In Appendix Tables 2-11, it is assumed that irrigation started when soil moisture reached 2.00 inches. For some crops, such as pasture and forage crops, a higher level of soil moisture can be maintained than for annual grain crops; so computations also were made of irriga-

tion needed to maintain soil moisture at or above 2.50 inches. In Appendix Table 13, a comparison is made of the results of irrigation needed to maintain soil moisture at both levels, 2.00 inches and 2.50 inches, at the Redfield Station, for the period from 1930 through 1946.

Appendix Table 1. Daily Mean Temperatures and PE Figures (South Dakota)

Temp.	PE Figures Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
32	00	00	—	—	—	—	—	—
33	00	00	—	—	—	—	—	00
34	00	01	01	—	—	—	—	00
35	01	01	01	—	—	—	—	01
36	01	02	02	—	—	01	01	01
37	01	02	02	—	—	01	01	01
38	02	02	02	02	02	02	02	02
39	02	02	02	02	02	02	02	02
40	02	02	03	03	03	03	02	02
41	03	03	03	03	03	03	02	02
42	03	03	03	03	03	03	03	02
43	03	04	03	04	03	03	03	03
44	04	04	04	04	04	04	03	03
45	04	04	04	04	04	04	03	04
46	04	04	05	05	05	04	04	04
47	05	05	05	05	05	05	04	04
48	05	05	06	06	06	05	05	04
49	05	06	06	06	06	06	05	05
50	06	06	06	06	06	06	05	05
51	06	06	07	07	07	07	06	05
52	06	07	07	07	07	07	06	06
53	06	07	08	08	08	08	07	06
54	07	08	08	09	09	08	07	06
55	07	08	09	09	09	09	07	07
56	08	09	09	10	09	09	08	07
57	08	09	10	10	10	09	08	07
58	08	09	10	11	10	10	09	08
59	09	10	11	11	11	10	09	08
60	09	10	11	12	12	11	10	09
61	10	11	12	12	12	11	10	09
62	10	11	12	13	13	12	10	09
63	10	12	13	13	13	12	11	10
64	11	12	13	14	14	13	11	10
65	11	13	14	14	14	13	12	10
66	12	13	14	15	15	13	12	11

Temp.	PE Figures Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
67	12	13	15	15	15	14	12	11
68	12	14	15	16	16	14	13	12
69	13	14	16	16	16	15	13	12
70	13	15	16	17	17	15	14	12
71	14	15	17	18	17	16	14	13
72	14	16	17	18	18	16	15	13
73	15	16	18	19	18	17	15	14
74	15	17	19	19	19	18	16	14
75	16	18	19	20	20	18	16	14
76	16	18	20	20	20	19	17	15
77	16	19	20	21	21	19	17	15
78	17	19	21	22	21	20	18	16
79	17	20	21	22	22	20	18	16
80	18	20	22	23	23	21	19	16
81	—	—	22	23	23	21	19	17
82	—	—	23	24	24	22	20	17
83	—	—	24	24	24	23	20	18
84	—	—	24	25	25	24	21	19
85	—	—	25	25	26	24	21	20
86	—	—	25	26	27	25	22	—
87	—	—	26	27	27	25	22	—
88	—	—	27	28	28	26	23	—
89	—	—	28	29	28	26	23	—
90	—	—	29	29	29	26	24	—
91	—	—	—	30	29	27	25	—
92	—	—	—	30	30	27	26	—
93	—	—	—	31	30	28	27	—
94	—	—	—	31	31	28	28	—
95	—	—	—	32	32	29	—	—
96	—	—	—	33	33	—	—	—
97	—	—	—	—	33	—	—	—
98	—	—	—	—	34	—	—	—
99	—	—	—	—	35	—	—	—
100	—	—	—	—	36	—	—	—
101	—	—	—	—	36	—	—	—
102	—	—	—	—	37	—	—	—

Appendix Table 2. How Precipitation and Temperature Were Used to Estimate Soil Moisture and Irrigation Water Needs at Redfield, South Dakota, June, 1946

					Without irrigation				With irrigation assumed			
(1) Day of month	(2) P	(3) M-temp. degree F°	(4) PE	(5) P-PE	(6) Daily soil moisture	(7) Moisture change	(8) Moisture deficiency	(9) Moisture surplus	(10) Daily soil moisture	(11) Moisture change	(12) Moisture deficiency	(13) Moisture surplus
1	.00	46	.05	−.05	2.73*	−.04	.01	.00	2.73*	−.04	.01	.00
2	.00	51	.07	−.07	2.68	−.05	.02	.00	2.68	−.05	.02	.00
3	.00	55	.09	−.09	2.62	−.06	.03	.00	2.62	−.06	.03	.00
4	.00	68	.16	−.16	2.52	−.10	.06	.00	2.52	−.10	.06	.00
5	.00	72	.18	−.18	2.41	−.11	.07	.00	2.41	−.11	.07	.00
6	.00	80	.23	−.23	2.27	−.14	.09	.00	2.27	−.14	.09	.00
7	.00	73	.19	−.19	2.16	−.11	.08	.00	2.16	−.11	.08	.00
8	.00	63	.13	−.13	2.09	−.07	.06	.00	2.09	−.07	.06	.00
9	.00	72	.18	−.18	2.00†	−.09	.09	.00	2.00†	−.09	.09	.00
Irrigation‡		—	—	2.00‡	—	—	—	—	4.00‡	2.00	.00	.00
10	.00	81	.23	−.23	1.88	−.12	.11	.00	3.77	−.23	.00	.00
11	.00	71	.18	−.18	1.80	−.08	.10	.00	3.60	−.17	.01	.00
12	.26	67	.15	.11	1.91	.11	.00	.00	3.71	.11	.00	.00
13	.00	68	.16	−.16	1.83	−.08	.08	.00	3.56	−.15	.01	.00
14	.00	75	.20	−.20	1.74	−.09	.11	.00	3.38	−.18	.02	.00
15	.72	77	.21	.51	2.25	.51	.00	.00	3.89	.51	.00	.00
16	.00	73	.19	−.19	2.14	−.11	.08	.00	3.70	−.19	.00	.00
17	.46	71	.18	.28	2.42	.28	.00	.00	3.98	.28	.00	.00
18	1.13	56	.10	1.03	3.45	1.03	.00	.00	4.00	.02	.00	1.01
19	.76	51	.07	.69	4.00	.55	.00	.14	4.00	.00	.00	.69
20	.20	56	.10	.10	4.00	.00	.00	.10	4.00	.00	.00	.10
21	.00	66	.15	−.15	3.85	−.15	.00	.00	3.85	−.15	.00	.00
22	.00	75	.20	−.20	3.66	−.19	.01	.00	3.66	−.19	.01	.00
23	.00	84	.25	−.25	3.43	−.23	.02	.00	3.43	−.23	.02	.00
24	.17	79	.22	−.05	3.39	−.04	.01	.00	3.39	−.04	.01	.00
25	.07	69	.16	−.09	3.31	−.08	.01	.00	3.31	−.08	.01	.00
26	.06	74	.19	−.13	3.20	−.11	.02	.00	3.20	−.11	.02	.00
27	.16	77	.21	−.05	3.16	−.04	.01	.00	3.16	−.04	.01	.00
28	.50	72	.18	.32	3.48	.32	.00	.00	3.48	.32	.00	.00
29	.00	75	.20	−.20	3.31	−.17	.03	.00	3.31	−.17	.03	.00
30	.78	70	.17	.61	3.92	.61	.00	.00	3.92	.61	.00	.00

*Soil moisture on March 31 was 2.78 inches

†Soil moisture capacity is assumed to be 4.00 and a drought is assumed to exist when soil moisture falls to 50% of capacity or 2.00 inches.

‡A hypothetical irrigation of 2.00 inches was introduced at this point as explained in the text.

Appendix Table 3. Brookings, South Dakota Data for Full Growing Season April 5 to October 31. Soil Capacity 4 Inches Comparison of Soil Moisture Content Without and With Irrigation to Keep Soil Moisture Above 2 inches

			Without irrigation					With irrigation							
Year	Precip.	PE	Soil moisture 4/5	No. of drought days	Deficit	Surplus	Soil moisture 10/31	Soil moisture 4/5	Irrig. 3/30	Irrig. 4/5 10/31	Total irrig.	Irrig. and precip.	Deficit	Surplus	Soil moisture 10/31
1930	11.96	25.72	3.65	87	13.04	.25	2.68	3.65	0	12.00	12.00	23.96	4.98	3.65	3.22
1931	12.20	27.93	2.90	149	14.72	.00	1.89	3.99	1.25	12.00	13.25	25.45	5.50	2.71	3.05
1932	15.36	25.52	2.55	73	9.98	.00	2.37	4.00	2.03	8.00	10.03	25.39	4.72	3.92	2.64
1933	10.46	27.40	3.09	121	15.31	.00	1.46	3.86	.78	12.00	12.78	23.24	5.78	1.45	3.25
1934	16.34	27.87	1.79	131	12.77	.00	3.03	3.94	2.25	10.00	12.25	28.59	5.04	4.19	3.26
1935	13.55	24.47	4.00	104	10.05	2.17	.96	4.00	0	8.00	8.00	21.55	4.34	2.86	2.56
1936	13.42	28.26	1.82	140	14.99	.85	1.12	4.00	2.36	10.00	12.36	25.78	5.92	2.20	2.88
1937	11.92	26.23	3.57	138	13.90	1.84	1.32	4.00	.89	12.00	12.89	24.81	4.97	3.20	3.46
1938	11.17	27.20	1.97	143	14.56	.00	.50	4.00	2.03	10.00	12.03	23.20	5.45	1.31	2.11
1939	15.04	27.71	.51	173	13.59	.00	1.43	3.82	3.47	10.00	13.47	28.51	5.36	3.18	3.33
1940	14.34	25.96	3.78	90	9.50	.16	1.50	3.78	0	10.00	10.00	24.34	4.63	4.22	2.57
1941	17.43	26.86	1.93	118	13.63	2.14	3.99	4.00	2.24	10.00	12.24	29.67	5.14	5.72	3.99
1942	21.53	23.28	3.79	49	6.30	6.25	2.09	3.79	0	4.00	4.00	25.53	3.55	6.82	2.77
1943	22.96	23.77	2.64	26	5.80	3.63	4.00	3.59	1.15	6.00	7.15	30.11	3.96	8.74	4.00
1944	24.73	24.21	4.00	33	5.36	7.74	2.14	4.00	0	2.00	2.00	26.73	3.74	8.12	2.14
1945	17.42	21.72	2.32	57	6.84	3.08	1.78	3.93	1.71	4.00	5.71	23.13	3.18	4.25	2.56
1946	24.09	23.60	3.49	48	6.81	6.97	3.82	4.00	.72	6.00	6.72	30.81	3.59	10.26	3.82
Average	16.11	25.75	2.81	98	11.01	2.06	2.12	3.91	1.23	8.59	9.82	25.93	4.70	4.52	3.03
Av. 1932-36	13.83	26.70	2.65	114	12.62	.60	1.79	3.96	1.48	9.60	11.09	24.91	5.16	2.92	2.92
Av. 1942-46	22.15	23.31	3.25	43	6.22	5.53	2.77	3.87	.72	4.40	5.11	27.26	3.60	7.65	3.06
Highest	24.09	27.93	4.00	173	15.31	7.74	4.00	4.00	3.47	12.00	13.47	30.81	5.92	10.26	4.00
Lowest	10.46	21.72	.51	26	5.36	.00	.50	3.59	0	2.00	2.00	21.55	3.18	1.31	2.11

Appendix Table 4. Brookings, South Dakota Data for Small Grain Period April 5 to July 18. Soil Capacity 4 Inches Comparison of Soil Moisture Content Without and With Irrigation to Keep Soil Moisture Above 2 Inches

			Without irrigation					With irrigation							
Year	Precip.	PE	Soil moisture 4/5	No. of drought days	Deficit	Surplus	Soil moisture 7/18	Soil moisture 4/5	Irrig. 3/30	Irrig. 4/5 7/18	Total irrig.	Irrig. and precip.	Deficit	Surplus	Soil moisture 7/18
1930	5.23	12.96	3.65	32	4.96	.25	.63	3.65	0	4.00	4.00	9.23	2.58	.27	2.23
1931	5.78	14.11	2.90	54	6.40	.00	.97	3.99	1.25	4.00	6.25	12.03	2.83	.39	2.10
1932	7.38	13.53	2.55	39	4.85	.00	1.25	4.00	2.03	4.00	6.03	13.41	2.36	1.07	3.14
1933	3.94	14.68	3.09	47	8.08	.00	.43	3.86	.78	6.00	6.78	10.72	3.33	.17	2.28
1934	9.78	15.50	1.79	67	6.53	.00	2.60	3.94	2.25	6.00	8.25	18.03	2.49	3.43	3.28
1935	7.94	11.59	4.00	13	2.91	2.17	1.09	4.00	0	2.00	2.00	9.94	1.98	2.17	2.16
1936	7.98	14.68	1.82	47	6.24	.85	.51	4.00	2.36	6.00	8.36	16.34	2.52	2.09	3.73
1937	6.90	12.86	3.57	33	4.90	1.84	.67	4.00	.89	6.00	6.89	13.79	2.35	2.97	3.42
1938	7.72	13.09	1.97	39	5.27	.00	1.87	4.00	2.03	4.00	6.03	13.75	2.21	1.21	3.63
1939	8.74	14.44	.51	77	6.37	.00	1.18	3.82	3.47	4.00	7.47	16.21	2.47	1.87	2.72
1940	7.55	12.20	3.78	8	2.56	.16	1.53	3.78	0	4.00	4.00	11.55	1.87	1.97	3.03
1941	10.65	13.32	1.93	40	4.28	2.07	1.47	4.00	2.24	4.00	6.24	16.89	2.41	4.24	3.50
1942	14.71	12.19	3.79	3	1.72	6.25	1.78	3.79	0	2.00	2.00	16.71	1.56	6.25	3.62
1943	10.48	12.14	2.64	8	2.74	.95	2.77	3.59	1.15	2.00	3.15	13.63	2.08	2.19	3.82
1944	14.91	12.79	4.00	14	2.11	6.13	2.10	4.00	0	2.00	2.00	16.91	1.36	6.18	3.30
1945	10.82	9.87	2.32	1	1.71	3.08	1.90	3.93	1.71	2.00	3.71	14.53	1.12	4.20	3.80
1946	11.19	12.51	3.49	7	2.40	1.97	2.60	4.00	.72	2.00	2.72	13.91	1.60	3.68	2.60
Average	8.92	13.08	2.81	31	4.35	1.51	1.49	3.90	1.23	3.76	5.05	13.97	2.18	2.61	3.08
Av. 1932-36	7.40	13.99	2.65	42	5.72	.60	1.18	3.96	1.48	4.80	6.28	13.69	2.53	1.78	2.92
Av. 1942-46	12.42	11.90	3.25	7	2.13	3.67	2.23	3.87	.71	2.00	2.71	15.14	1.54	4.51	3.43
Highest	14.91	15.50	4.00	67	8.08	6.25	2.77	4.00	3.47	6.00	8.36	18.03	3.33	6.25	3.82
Lowest	3.94	9.87	.51	1	1.71	.00	.43	3.59	.00	2.00	2.00	9.23	1.12	.17	2.10

Appendix Table 5. Brookings, South Dakota Data for Corn Season May 10 to Sept. 5. Soil Moisture Capacity 4 Inches Comparison of Soil Moisture Content Without and With Irrigation to Keep Soil Moisture Above 2 Inches

			Without irrigation					With irrigation							
Year	Precip.	PE	Soil moisture 5/10	No. of drought days	Deficit	Surplus	Soil moisture 9/5	Soil moisture 5/10	Irrig. 3/30	Irrig. 5/10 9/5	Total irrig.	Irrig. and precip.	Deficit	Surplus	Soil moisture 9/5
1930	5.65	19.17	3.43	81	11.62	.25	1.28	3.43	0	10.00	10.00	15.65	4.57	.77	3.71
1931	7.63	20.47	2.74	97	11.19	.00	1.09	3.38	1.25	10.00	11.25	18.88	4.34	2.11	2.77
1932	10.78	19.70	2.69	66	8.12	.00	1.89	3.64	2.03	4.00	6.03	16.81	3.90	.24	2.38
1933	7.63	21.27	3.10	91	13.20	.00	2.66	3.63	.78	10.00	10.78	18.41	4.74	1.33	3.40
1934	10.32	20.78	1.81	83	10.13	.00	1.48	2.89	2.25	10.00	12.25	22.57	4.00	3.52	2.91
1935	9.95	18.59	3.60	53	7.35	.00	2.31	3.60	0	6.00	6.00	15.95	3.26	.68	3.54
1936	10.04	21.90	2.64	66	11.73	.85	1.66	3.76	2.36	8.00	10.36	20.40	4.55	1.93	2.52
1937	6.61	20.37	3.44	82	11.34	.00	1.02	3.44	.89	10.00	10.89	17.50	4.17	.90	2.95
1938	7.44	19.51	2.22	84	10.21	.00	.36	3.28	2.03	8.00	10.03	20.84	3.90	.89	2.22
1939	10.81	20.75	1.53	82	9.43	.00	1.02	2.82	3.47	8.00	11.47	22.28	4.12	2.18	2.82
1940	11.42	19.11	3.35	44	7.01	.16	2.51	3.35	0	8.00	8.00	19.42	3.30	4.08	2.90
1941	5.75	19.90	3.10	87	11.40	.00	.35	3.10	2.24	10.00	12.24	17.99	4.39	.21	3.13
1942	14.91	17.30	3.74	36	4.67	4.51	1.51	3.74	0	4.00	4.00	18.91	2.63	5.08	2.90
1943	18.46	18.26	1.95	10	3.82	3.53	2.44	2.57	1.15	6.00	7.15	25.61	3.10	7.87	4.00
1944	19.04	18.83	3.75	33	4.43	4.98	3.41	3.75	0	2.00	2.00	21.04	2.81	5.36	3.41
1945	13.09	16.48	3.04	31	4.81	3.08	1.38	3.59	1.71	4.00	5.71	18.80	2.56	3.52	3.24
1946	10.82	17.36	2.97	46	6.10	1.96	.56	3.24	.72	6.00	6.72	17.54	3.12	3.75	2.07
Average	10.61	19.40	2.89	63	8.63	1.14	1.58	3.37	1.23	7.29	8.52	19.32	3.73	2.61	2.99
Av. 1932-36	9.74	20.45	2.77	72	10.11	.17	2.00	3.50	1.48	7.60	9.08	18.83	4.09	1.54	2.95
Av. 1942-46	15.26	17.65	3.09	31	4.77	3.61	1.86	3.38	.71	4.40	5.11	20.38	2.84	5.12	3.12
Highest	19.04	21.90	3.75	97	13.20	4.98	3.41	3.76	3.47	10.00	12.25	22.57	4.74	7.87	4.00
Lowest	5.75	16.48	1.81	10	3.82	.00	.35	2.57	.00	2.00	2.00	15.65	2.56	.24	2.07

Appendix Table 6. Redfield, South Dakota Data for Full Growing Season, April 5 to October 31. Soil Capacity 4 Inches Comparison of Soil Moisture Content Without and With Irrigation to Keep Soil Moisture Above 2 Inches

			Without irrigation					With irrigation							
Year	Precip.	PE	Soil moisture 4/5	No. of drought days	Deficit	Surplus	Soil moisture 10/31	Soil moisture 4/5	Irrig. 3/30	Irrig. 4/5 10/31	Total irrig.	Irrig. and precip.	Deficit	Surplus	Soil moisture 10/31
1930	18.48	26.75	3.31	96	13.43	4.87	3.60	3.72	.47	10.00	10.47	28.95	4.71	6.56	3.60
1931	9.93	29.15	4.00	136	17.75	.86	1.67	4.00	.00	14.00	14.00	23.93	6.16	1.46	3.48
1932	14.79	26.88	1.79	147	12.02	.00	1.72	3.83	2.14	8.00	10.14	24.93	5.01	1.10	3.65
1933	11.22	27.93	3.22	132	14.17	.00	.68	3.81	.62	12.00	12.62	23.84	5.51	1.49	3.12
1934	9.03	28.72	1.42	194	20.40	.00	2.13	3.97	2.69	14.00	16.69	25.72	6.28	1.12	3.44
1935	13.72	25.59	4.00	130	13.24	4.76	.61	4.00	.77	12.00	12.77	26.49	5.05	5.43	3.75
1936	8.26	29.85	1.07	205	21.05	.00	.53	4.00	3.06	14.00	17.06	25.32	6.61	.92	2.10
1937	10.66	28.59	2.80	131	15.86	.00	.73	4.00	1.73	12.00	13.73	24.39	6.11	1.44	2.74
1938	14.62	28.57	1.28	132	13.91	.24	1.00	3.98	2.72	10.00	12.72	27.34	5.32	2.59	2.76
1939	12.92	28.48	.85	178	16.54	.81	1.02	3.77	3.10	12.00	15.10	28.02	5.49	2.53	3.17
1940	14.97	27.78	2.95	117	12.58	1.30	1.42	3.96	1.04	12.00	13.04	28.01	5.83	5.06	3.92
1941	18.43	28.39	2.06	91	12.48	.92	3.66	3.98	2.34	10.00	12.34	30.77	4.94	5.30	3.66
1942	17.27	24.52	3.82	59	7.87	2.37	2.07	3.82	.00	4.00	4.00	21.27	4.48	2.42	2.63
1943	15.27	25.93	1.79	156	11.13	.00	2.26	3.71	2.07	6.00	8.07	23.34	5.07	.61	3.51
1944	17.56	25.47	2.51	56	7.96	.81	1.75	3.96	1.46	4.00	5.46	23.02	5.29	3.23	2.11
1945	16.81	23.07	1.72	105	8.84	2.80	1.50	3.87	2.22	6.00	8.22	25.03	3.70	4.74	2.57
1946	19.04	24.95	3.96	53	7.45	1.97	3.53	3.96	.69	6.00	6.69	25.73	4.03	4.55	3.53
Average	14.29	27.10	2.50	125	13.33	1.28	1.76	3.90	1.59	9.76	11.36	25.63	5.27	2.97	3.16
Av. 1932-36	11.40	27.79	2.30	162	16.18	.95	1.13	3.92	1.86	12.00	13.86	25.26	5.69	2.01	3.21
Av. 1942-46	17.19	24.79	2.76	86	8.65	1.59	2.22	3.86	1.28	5.20	6.49	23.68	4.51	3.11	2.87
Highest	19.04	29.85	4.00	205	21.05	4.87	3.66	4.00	3.10	14.00	17.06	30.77	6.61	6.56	3.92
Lowest	8.26	23.07	.85	53	7.45	.00	.53	3.71	.00	4.00	4.00	21.27	3.70	.61	2.10

Appendix Table 7. Redfield, South Dakota Data for Corn Period May 10 to September 5. Soil Capacity 4 Inches Comparison of Soil Moisture Content Without and With Irrigation to Keep Soil Moisture Above 2 Inches

			Without irrigation					With irrigation							
Year	Precip.	PE	Soil moisture 5/10	No. of drought days	Deficit	Surplus	Soil moisture 9/5	Soil moisture 5/10	Irrig. 3/30	Irrig. 5/10 9/5	Total irrig.	Irrig. and precip.	Deficit	Surplus	Soil moisture 9/5
1930	7.72	19.99	3.94	82	12.07	1.97	1.77	3.94	.47	10.00	10.47	18.19	4.00	2.67	3.00
1931	5.97	21.53	3.40	80	13.15	.86	.13	3.40	.00	12.00	12.00	17.97	4.82	1.46	3.20
1932	10.93	20.64	2.29	72	8.94	.00	1.52	3.57	2.14	6.00	8.14	19.07	4.02	.83	3.05
1933	8.32	21.49	3.19	76	10.42	.00	.44	3.58	.62	10.00	10.62	18.94	4.46	1.09	3.78
1934	5.20	21.56	.80	119	15.83	.00	.27	4.00	2.69	10.00	12.69	17.89	4.76	.06	2.34
1935	7.57	19.67	3.62	74	9.78	.00	1.30	3.62	.77	8.00	8.77	16.34	3.82	.66	2.68
1936	6.90	23.27	1.43	114	16.14	.00	1.20	3.05	3.06	12.00	15.06	21.96	5.07	.81	2.94
1937	6.93	21.90	3.20	75	12.48	.00	.71	3.29	1.73	10.00	11.73	18.66	4.89	.63	2.58
1938	8.25	20.61	3.58	80	10.58	.24	1.56	3.67	2.72	8.00	10.72	18.97	4.21	.32	3.20
1939	10.25	21.31	.85	87	11.30	.81	.28	2.17	3.10	10.00	13.10	23.35	4.09	2.17	3.03
1940	11.17	20.39	3.21	64	9.36	1.05	2.30	3.21	1.04	8.00	9.04	20.21	4.29	3.98	2.30
1941	8.06	21.23	3.25	69	10.85	.00	.93	3.25	2.34	10.00	12.34	20.40	4.30	1.16	3.22
1942	11.83	18.17	3.72	48	6.14	1.50	2.02	3.72	.00	4.00	4.00	15.83	3.43	1.55	3.26
1943	12.74	19.44	1.18	66	7.30	.00	1.78	2.28	2.07	4.00	6.07	18.81	3.46	.61	2.43
1944	12.27	19.71	3.71	30	6.02	.00	2.29	3.71	1.46	4.00	5.46	17.73	4.00	1.12	3.15
1945	12.52	17.49	2.39	49	6.35	2.80	.97	3.59	2.22	6.00	8.22	20.74	3.11	4.39	3.34
1946	10.68	18.35	3.42	46	6.03	1.06	.72	3.42	.69	6.00	4.69	15.37	3.24	2.65	2.34
Average	9.25	20.40	2.78	72	10.16	.61	1.19	3.38	1.60	8.12	9.60	18.85	4.12	1.54	2.93
Av. 1932-36	7.78	21.33	2.27	91	12.22	.00	.95	3.56	1.86	9.20	11.06	18.84	4.43	.69	2.96
Av. 1942-46	12.01	18.63	2.88	48	6.37	1.07	1.56	3.34	1.29	4.80	5.68	17.70	3.45	2.06	2.90
Highest	12.74	23.27	3.94	119	16.14	2.80	2.30	4.00	3.10	12.00	15.06	23.35	5.07	4.39	3.78
Lowest	5.20	17.49	.80	30	6.02	.00	.13	2.17	.00	4.00	4.00	15.37	3.11	.06	2.30

Appendix Table 8. Redfield, South Dakota Data for Small Grain Period April 5 to July 18. Soil Capacity 4 Inches Comparison of Soil Moisture Content Without and With Irrigation to Keep Soil Moisture Above 2 Inches

			Without irrigation					With irrigation						
Year	Precip.	PE	Soil moisture 4/5	No. of drought days	Deficit	Surplus	Soil moisture 7/18	Soil moisture 4/5	Irrig. 3/30	Irrig. 4/5 7/18	Total irrig.	Irrig. and precip.	Deficit	Surplus	Soil moisture 7/18
1930	8.54	13.24	3.31	37	5.61	3.72	.50	3.72	.47	6.00	6.47	15.01	2.39	4.12	3.29
1931	6.56	14.70	4.00	31	5.68	.86	.68	4.00	.00	6.00	6.00	12.56	3.02	1.45	3.43
1932	9.01	14.23	1.79	46	4.82	.00	1.39	3.83	2.14	2.00	4.14	13.15	2.38	.00	2.99
1933	7.70	14.91	3.22	36	5.63	.00	1.65	3.81	.62	4.00	4.62	12.32	2.60	.95	2.26
1934	3.98	15.91	1.43	105	10.95	.00	.44	3.97	2.69	8.00	10.69	14.67	3.34	.05	3.33
1935	8.90	12.01	4.00	25	4.61	4.76	.74	4.00	.77	4.00	4.77	13.67	2.33	5.08	2.14
1936	4.17	16.06	1.07	100	11.03	.00	.21	4.00	3.06	8.00	11.06	15.23	3.43	.10	3.44
1937	6.92	13.89	2.80	26	5.36	.00	1.19	4.00	1.73	4.00	5.73	12.65	2.75	1.39	2.39
1938	9.82	13.83	1.28	42	4.25	.24	1.28	3.98	2.72	4.00	6.72	16.54	2.05	2.44	3.58
1939	10.11	14.64	.85	73	6.03	.81	1.54	3.77	3.10	4.00	7.10	17.21	2.29	2.42	3.11
1940	6.71	13.35	2.95	36	5.22	.25	1.28	3.96	1.04	6.00	7.04	13.75	2.54	2.24	3.62
1941	10.25	14.30	2.06	20	4.00	.78	1.23	3.98	2.34	4.00	6.34	16.59	2.41	3.74	2.60
1942	10.48	12.75	3.82	5	2.41	2.37	1.59	3.82	.00	2.00	2.00	12.48	1.95	2.41	3.09
1943	8.51	12.81	1.79	61	4.24	.00	1.73	3.71	2.07	2.00	4.07	12.58	2.40	.24	3.57
1944	11.52	13.25	2.51	0	2.67	.81	2.64	3.96	1.46	.00	1.46	12.98	2.52	2.11	2.64
1945	10.46	10.53	1.72	16	2.65	2.80	1.50	3.87	2.22	2.00	4.22	14.68	1.24	4.04	3.00
1946	10.99	13.38	3.96	5	2.33	1.06	2.84	3.96	.69	2.00	2.69	13.68	1.89	2.62	2.84
Average	8.50	13.75	2.50	39	5.15	1.09	1.32	3.90	1.59	4.00	5.59	14.09	2.44	2.08	3.01
Av. 1932-36	6.75	14.62	2.30	62	7.41	.95	.89	3.92	1.86	5.20	7.06	13.81	2.82	1.24	2.83
Av. 1942-46	10.39	12.54	2.76	17	2.86	1.41	2.06	3.86	1.29	1.60	2.89	13.28	2.00	2.28	3.03
Highest	11.52	16.06	4.00	105	11.03	4.76	2.84	4.00	3.10	8.00	11.06	17.21	3.43	5.08	3.62
Lowest	3.98	10.53	.85	0	2.33	.00	.21	3.71	.00	.00	1.46	12.32	1.24	.00	2.14

Appendix Table 9. Newell, South Dakota Data for Full Season April 5 to October 31. Soil Capacity 4 Inches Comparison of Soil Moisture Content Without and With Irrigation to Keep Soil Moisture Above 2 Inches

			Without irrigation					With irrigation							
Year	Precip.	PE	Soil moisture 4/5	No. of drought days	Deficit	Surplus	Soil moisture 10/31	Soil moisture 4/5	Irrig. 3/30	Irrig. 4/5 10/31	Total irrig.	Irrig. and precip.	Deficit	Surplus	Soil moisture 10/31
1930	10.32	23.83	3.81	121	11.13	.13	1.30	3.81	0	8.00	8.00	18.32	4.80	.38	2.72
1931	6.52	25.80	2.23	187	17.87	.00	.82	3.98	1.86	12.00	13.86	18.52	6.19	.16	2.73
1932	17.72	23.86	1.50	123	9.10	2.71	1.75	3.94	2.76	6.00	8.76	26.48	3.83	4.51	3.12
1933	17.68	24.51	2.31	136	11.94	6.47	.95	3.91	1.69	10.00	11.69	29.37	4.30	8.46	2.92
1934	9.02	25.13	3.02	155	15.03	.00	1.94	4.00	2.27	12.00	12.27	21.29	5.19	1.77	3.31
1935	9.00	22.73	3.27	121	12.88	1.90	.52	4.00	1.13	10.00	11.13	20.11	4.59	2.68	2.18
1936	6.84	27.68	1.11	193	20.71	.00	.96	4.00	3.06	16.00	19.06	25.90	6.33	1.67	3.82
1937	15.35	24.78	2.63	106	10.24	2.17	1.27	4.00	2.39	10.00	12.39	27.74	4.77	5.86	3.48
1938	8.05	25.12	1.61	142	15.77	.00	.31	3.99	2.33	12.00	10.33	18.38	4.99	.91	3.00
1939	8.73	25.21	.55	207	16.99	.00	1.06	3.86	3.51	10.00	13.51	22.24	5.73	.30	2.81
1940	12.97	25.55	2.44	114	11.77	.82	.81	4.00	1.84	8.00	11.84	24.81	5.42	2.87	1.97
1941	20.16	23.90	1.54	70	9.96	5.41	2.35	3.98	2.58	6.00	8.58	28.74	4.55	7.88	2.91
1942	16.84	21.75	2.48	98	7.75	4.07	1.25	3.82	1.40	6.00	7.40	24.24	3.63	5.75	2.79
1943	9.91	23.33	1.76	173	13.06	.00	1.40	3.70	2.10	8.00	10.10	20.01	5.13	.01	3.40
1944	13.25	22.26	2.48	98	8.77	1.31	.93	3.96	1.57	6.00	7.57	20.82	4.02	2.44	2.53
1945	10.31	20.92	1.78	154	11.18	1.05	1.30	4.00	2.53	8.00	10.53	20.84	3.77	2.54	2.62
1946	24.02	21.82	3.35	49	7.13	8.69	3.99	3.97	1.60	6.00	7.60	31.62	3.08	11.26	3.99
Average	12.74	24.01	2.23	132	12.44	2.04	1.39	3.94	2.04	9.06	10.86	23.49	4.72	3.50	2.96
Av. 1932-36	12.05	24.78	2.24	126	13.93	2.21	1.22	3.97	2.18	10.80	12.58	24.63	4.85	3.82	3.07
Av. 1942-46	14.87	22.02	2.37	112	9.58	3.02	1.77	3.89	1.84	6.80	8.64	23.51	3.93	4.40	3.07
Highest	24.02	27.68	3.81	207	20.71	8.69	3.99	4.00	3.51	16.00	19.06	31.62	6.33	11.26	3.99
Lowest	6.52	20.92	.55	49	7.13	.00	.31	3.70	0	6.00	7.40	18.32	3.08	.01	1.97

Appendix Table 10. Newell, South Dakota Data for Corn Season May 10 to September 5. Soil Capacity 4 Inches Comparison of Soil Moisture Content Without and With Irrigation to Keep Soil Moisture Above 2 Inches

	Without irrigation							With irrigation							
Year	Precip.	PE	Soil moisture 5/10	No. of drought days	Deficit	Surplus	Soil moisture 9/5	Soil moisture 5/10	Irrig. 3/30	Irrig. 5/10 9/5	Total irrig.	Irrig. and precip.	Deficit	Surplus	Soil moisture 9/5
1930	6.65	17.97	3.48	65	8.65	.13	.68	3.48	.00	8.00	8.00	14.65	3.86	.38	3.64
1931	4.01	19.44	2.20	105	13.44	.00	.21	3.36	1.86	10.00	11.86	15.87	4.92	.11	2.74
1932	12.77	18.42	3.10	49	6.33	2.71	1.07	3.47	2.76	6.00	8.76	21.53	3.08	3.02	3.88
1933	11.79	19.02	4.00	80	9.42	4.90	1.29	4.00	1.69	8.00	9.69	21.48	3.42	5.39	2.80
1934	5.99	19.16	1.62	102	11.81	.00	.26	2.10	2.27	12.00	14.27	20.26	3.98	1.77	3.14
1935	7.82	17.32	2.91	65	9.09	1.90	.60	3.15	1.13	8.00	9.13	16.95	3.22	2.23	2.64
1936	3.27	21.80	2.50	112	16.37	.00	.34	3.31	3.06	14.00	17.06	20.33	5.25	.18	3.85
1937	12.47	18.89	2.01	66	7.88	2.17	1.30	2.94	2.39	8.00	10.39	22.86	3.84	5.66	2.70
1938	5.02	18.35	2.35	83	11.22	.00	.24	3.35	2.33	10.00	12.33	17.35	3.94	.11	3.85
1939	6.66	18.88	.58	116	12.29	.00	.65	2.48	3.51	8.00	11.51	18.17	4.50	.30	2.46
1940	8.79	18.99	3.17	58	8.30	.52	.75	3.17	1.84	8.00	9.84	18.63	4.23	3.16	2.04
1941	12.30	18.52	3.38	61	8.76	3.67	2.25	3.38	2.58	6.00	8.58	20.88	4.00	3.87	3.29
1942	10.74	16.16	3.75	42	5.19	2.63	.89	3.75	1.40	4.00	5.40	16.14	2.85	2.71	2.47
1943	7.82	17.27	1.39	82	8.60	.00	.54	2.56	2.10	6.00	8.10	15.92	3.70	.00	2.81
1944	10.18	17.00	3.27	42	5.67	1.31	.81	3.57	1.57	4.00	5.57	15.75	3.12	1.50	2.37
1945	7.58	16.20	1.38	63	8.54	1.05	.25	2.97	2.53	8.00	10.53	18.11	3.16	2.47	3.04
1946	13.50	16.39	3.76	46	5.04	6.43	.48	3.76	1.60	6.00	7.60	21.10	2.71	6.83	2.75
Average	8.65	18.22	2.64	73	9.27	1.61	.74	3.22	2.04	7.88	9.73	18.59	3.75	2.33	2.96
Av. 1932-36	8.32	19.14	2.83	82	10.60	1.90	.71	3.21	2.18	9.60	11.78	20.11	3.79	2.52	3.26
Av. 1942-46	9.96	16.60	2.71	55	6.81	2.28	.59	3.32	1.84	5.60	7.44	17.40	3.10	2.70	2.69
Highest	13.50	21.80	4.00	116	16.37	6.43	2.25	4.00	3.51	14.00	17.06	22.86	5.25	6.83	3.88
Lowest	3.27	16.16	.58	42	5.19	.00	.21	2.10	.00	4.00	5.40	14.65	2.71	.00	2.04

Appendix Table 11. Newell, South Dakota Data for Small Grain Season April 5 to July 18. Soil Capacity 4 Inches Comparison of Soil Moisture Content Without and With Irrigation to Keep Soil Moisture Above 2 Inches

			Without irrigation					With irrigation							
Year	Precip.	PE	Soil moisture 4/5	No. of drought days	Deficit	Surplus	Soil moisture 7/18	Soil moisture 4/5	Irrig. 3/30	Irrig. 4/5 7/18	Total irrig.	Irrig. and precip.	Deficit	Surplus	Soil moisture 7/18
1930	6.64	12.30	3.81	16	3.26	.13	1.28	3.81	.00	2.00	2.00	8.44	2.25	.18	2.22
1931	4.05	13.07	2.23	82	7.23	.00	.44	3.98	1.86	4.00	5.86	9.91	3.11	.09	1.98
1932	13.20	12.58	1.50	20	2.36	2.71	1.77	3.94	2.76	2.00	4.76	17.96	1.45	4.47	3.54
1933	13.62	12.53	2.31	31	4.20	6.47	1.13	3.91	1.69	4.00	5.69	19.31	1.84	8.15	2.69
1934	4.80	13.74	3.02	60	6.88	.00	.96	4.00	2.27	6.00	8.27	13.07	2.82	1.72	2.16
1935	7.10	10.52	3.27	16	2.97	1.90	.92	4.00	1.13	4.00	5.13	12.23	1.74	2.53	3.79
1936	3.74	14.75	1.11	88	10.20	.00	.30	4.00	3.06	8.00	11.06	14.80	3.29	1.49	2.79
1937	11.51	11.81	2.63	30	3.67	2.17	3.83	4.00	2.39	4.00	6.39	17.90	1.82	5.69	3.83
1938	5.77	12.16	1.61	37	5.44	.00	.66	3.99	2.33	4.00	6.33	12.10	2.00	.83	2.77
1939	4.85	13.04	.55	102	8.42	.00	.78	3.86	3.51	4.00	7.51	12.36	2.71	.26	2.12
1940	8.46	12.37	2.44	9	3.51	.82	1.22	4.00	1.84	4.00	5.84	14.30	2.57	4.21	2.45
1941	13.52	12.37	1.54	27	3.60	5.41	.88	3.98	2.58	4.00	6.58	20.10	2.02	7.72	3.43
1942	13.29	10.67	2.48	0	1.59	4.07	2.62	3.82	1.40	.00	1.40	14.69	1.28	5.10	2.62
1943	7.17	10.83	1.76	68	3.83	.00	1.93	3.70	2.10	.00	2.10	9.27	2.13	.00	2.17
1944	9.83	10.92	2.48	0	2.05	1.31	2.13	3.96	1.57	.00	1.57	11.40	1.60	2.34	2.13
1945	7.42	9.03	1.78	49	2.39	1.05	1.51	4.00	2.53	2.00	4.53	11.95	1.07	2.46	3.00
1946	16.60	11.38	3.35	1	1.59	7.73	2.43	3.97	1.60	2.00	3.60	20.20	1.32	8.51	4.00
Average	8.92	12.00	2.23	37	4.31	1.99	1.46	3.94	2.04	3.18	5.21	14.11	2.06	3.28	2.81
Av. 1932-36	8.49	12.82	2.24	43	5.32	2.22	1.02	3.97	2.18	4.80	6.98	15.47	2.23	3.67	2.99
Av. 1942-46	10.86	10.57	2.37	24	2.29	2.83	2.12	3.89	1.84	.80	2.64	13.50	1.48	3.68	2.78
Highest	16.60	14.75	3.81	102	10.20	7.73	3.83	4.00	3.51	8.00	11.06	20.20	3.29	8.51	4.00
Lowest	3.74	9.03	.55	.00	1.59	.00	.30	3.70	.00	.00	1.40	8.44	1.07	.00	1.98

Appendix Table 12. Daily Soil Moisture Balance, 1942, Brookings, South Dakota. Soil Holds 4 Inches of Water at Field Capacity and Has 3.90 March 12. Ninety Percent of Available Gravity Water Held for Percolation of Each Succeeding Day. (All Values in Inches)

(1) Day	(2) Precip.	(3) Adj. PE	(4) P-PE	(5) Soil moisture storage	(6) Actual storage change	(7) Deficit	(8) Surplus	(9) Available gravity water	(10) Gravity water storage	(11) Soil water balance
					March					
12	—	—	—	3.90	—	—	—	—	—	—
13	.09	.02	+.07	3.97	+.07	.00	.00	.00	.00	3.97
14	.31	.01	+.30	4.00	+.03	.00	.27	.27	.24	4.24
15	.17	.00	+.17	4.00	.00	.00	.17	.41	.37	4.37
16	.00	.00	.00	4.00	.00	.00	.00	.37	.33	4.33
17	.00	.00	.00	4.00	.00	.00	.00	.33	.30	4.30
18	.00	.00	.00	4.00	.00	.00	.00	.30	.27	4.27
19	.01	.02	—.01	3.99	—.01	.00	.00	.27	.24	4.23
20	.37	.01	+.36	4.00	+.01	.00	.35	.59	.53	4.53
21	.00	.01	—.01	3.99	—.01	.00	.00	.53	.48	4.47
22	.00	.02	—.02	3.97	—.02	.00	.00	.48	.43	4.40
23	.00	.05	—.05	3.92	—.05	.00	.00	.43	.39	4.31
24	.00	.05	—.05	3.87	—.05	.00	.00	.39	.35	4.22
25	.89	.06	+.83	4.00	+.13	.00	.70	1.05	.95	4.95
26	.44	.02	+.42	4.00	.00	.00	.42	1.37	1.23	5.23
27	.04	.00	+.04	4.00	.00	.00	.04	1.27	1.14	5.14
28	.01	.00	+.01	4.00	.00	.00	.01	1.15	1.04	5.04
29	.01	.00	+.01	4.00	.00	.00	.01	1.05	.95	4.95
30	.00	.00	+.00	4.00	.00	.00	.00	.95	.86	4.86
31	.00	.00	.00	4.00	.00	.00	.00	.86	.77	4.77
					April					
1	.00	.04	—.04	3.96	—.04	.00	.00	.77	.69	4.65
2	.00	.04	—.04	3.92	—.04	.00	.00	.69	.62	4.54
3	.00	.05	—.05	3.87	—.05	.00	.00	.62	.56	4.43
4	.00	.08	—.08	3.79	—.08	.00	.00	.56	.50	4.29
5	.00	.02	—.02	3.77	—.02	.00	.00	.50	.45	4.22
6	.17	.00	+.17	3.94	+.17	.00	.00	.45	.41	4.35
7	.04	.00	+.04	3.98	+.04	.00	.00	.41	.37	4.35
8	.00	.01	—.01	3.97	—.01	.00	.00	.37	.33	4.30
9	.00	.03	—.03	3.94	—.03	.00	.00	.33	.30	4.24
10	.00	.02	—.02	3.92	—.02	.00	.00	.30	.27	4.19
11	.00	.02	—.02	3.90	—.02	.00	.00	.27	.24	4.14
12	.00	.06	—.06	3.84	—.06	.00	.00	.24	.22	4.06
13	.00	.09	—.09	3.75	—.09	.00	.00	.22	.20	3.95
14	.00	.11	—.11	3.64	—.11	.00	.00	.20	.18	3.82
15	.00	.13	—.13	3.52	—.12	.01	.00	.18	.16	3.68
16	.00	.10	—.10	3.43	—.09	.01	.00	.16	.14	3.57
17	.00	.06	—.06	3.38	—.05	.01	.00	.14	.13	3.51
18	.00	.08	—.08	3.31	—.07	.01	.00	.13	.12	3.43
19	.00	.07	—.07	3.25	—.06	.01	.00	.12	.11	3.36

(1) Day	(2) Precip.	(3) Adj. PE	(4) P-PE	(5) Soil moisture storage	(6) Actual storage change	(7) Deficit	(8) Surplus	(9) Available gravity water	(10) Gravity water storage	(11) Soil water balance
					(April, continued)					
20	.00	.06	—.06	3.20	—.05	.01	.00	.11	.10	3.30
21	.00	.08	—.08	3.14	—.06	.02	.00	.10	.09	3.23
22	.00	.10	—.10	3.06	—.08	.02	.00	.09	.08	3.14
23	.00	.13	—.13	2.96	—.10	.03	.00	.08	.07	3.03
24	.00	.11	—.11	2.88	—.08	.03	.00	.07	.06	2.94
25	.11	.11	.00	2.88	.00	.00	.00	.06	.05	2.93
26	.03	.09	—.06	2.84	—.04	.02	.00	.00	.00	2.84
27	.42	.08	+.34	3.18	+.34	.00	.00	.00	.00	3.18
28	.30	.09	+.21	3.39	+.21	.00	.00	.00	.00	3.39
29	.00	.12	—.12	3.29	—.10	.02	.00	.00	.00	3.29
30	.62	.13	+.49	3.78	+.49	.00	.00	.00	.00	3.78
					May					
1	.85	.11	+.74	4.00	+.22	.00	.52	.52	.47	4.47
2	.39	.04	+.35	4.00	.00	.00	.35	.82	.74	4.74

Appendix Table 13. Comparison of Results of Irrigating to Maintain Soil Moisture at or Above 2.00 Inches and 2.50 Inches at Redfield, South Dakota 1930-1946

Year	Inches precipitation	2.00 inches			2.50 inches		
		Irrigation	Deficit	Surplus	Irrigation	Deficit	Surplus
1930	18.48	10.47	4.71	6.56	13.97	3.48	8.83
1931	9.93	14.00	6.16	1.46	16.50	4.36	1.67
1932	14.79	10.14	5.01	1.10	11.14	3.29	.80
1933	11.22	12.62	5.51	1.49	14.12	3.97	2.07
1934	9.03	16.69	6.28	1.12	17.69	4.54	.44
1935	13.72	12.77	5.05	5.43	12.77	3.76	5.34
1936	8.26	17.06	6.61	.92	19.56	4.78	1.02
1937	10.66	13.73	6.11	1.44	15.23	4.30	1.41
1938	14.62	12.72	5.32	2.59	16.22	3.53	3.68
1939	12.92	15.10	5.49	2.53	19.60	3.98	5.37
1940	14.97	13.04	5.83	5.06	16.04	4.07	6.41
1941	18.43	12.34	4.94	5.30	12.84	3.81	4.67
1942	17.27	4.00	4.48	2.42	7.50	2.92	4.25
1943	15.27	8.07	5.07	.61	14.07	3.20	4.25
1944	17.56	5.46	5.29	3.23	8.96	3.52	4.30
1945	16.81	8.22	3.70	4.74	9.72	2.62	5.05
1946	19.04	6.69	4.03	4.55	9.69	2.91	6.43
Average	14.29	11.36	5.27	2.97	13.86	3.71	3.88
Av. 1932-36	11.40	13.86	5.69	2.01	15.06	4.09	1.93
Av. 1942-46	17.19	6.49	4.51	3.11	9.99	3.03	4.87
Highest	19.04	17.06	6.61	6.56	19.60	4.90	8.84
Lowest	8.26	4.00	3.70	.61	7.50	2.62	.80

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