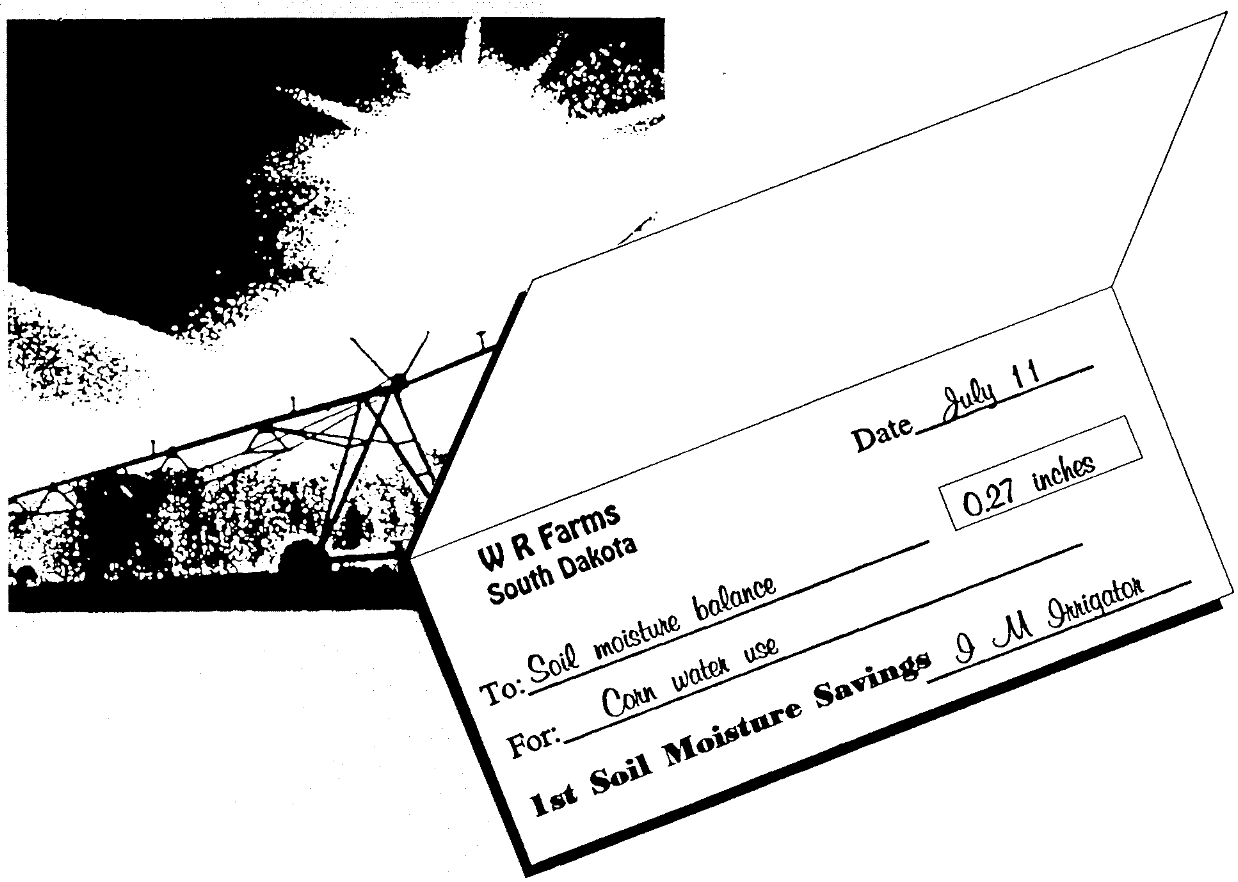
EC 897
May 1993

Checkbook Irrigation Scheduling

Irrigation Management Manual For South Dakota



Cooperative Extension Service
South Dakota State University
U.S. Department of Agriculture

COOPERATIVE EXTENSION SERVICE
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Checkbook Irrigation Scheduling

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Introduction

Irrigation scheduling is deciding when to irrigate and how much water to apply. Your experience and judgement uses information on the crops, soils, and weather to time water applications. You can choose one of many methods to schedule irrigations. This publication presents a method commonly referred to as “checkbook scheduling”.

Irrigation scheduling is becoming more important because of concerns for water quality and possible shortages of water in the future. Crop stress and yield loss can result from too little water. Too much water results in added pumping costs and may leach fertilizer from the root zone.

The checkbook method is quite simple and has been proven to be reliable in South Dakota and neighboring states. The procedure outlined in this publication uses a soil moisture balance worksheet. Information in this publication can be used without keeping the balance sheet. Some irrigators use the crop water use tables to keep a notebook or they simply record the crop water use on a home calendar.

This publication and others can be accessed electronically from the SDSU College of Agriculture & Biological Sciences publications page, which is at http://agbiopubs.sdstate.edu/articles/EC897.pdf

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1200 copies printed by CES at a cost of $1.16 each. June 1993; updated March 2002.

What is the Checkbook Method?

Checkbook irrigation scheduling is a way for you to plan irrigation water applications. The crop water use estimates from the checkbook method can be used to keep track of available soil moisture and help to schedule irrigations before crops become stressed.

The checkbook method is similar to balancing a checkbook. After determining an initial soil moisture deficit (current checkbook balance), daily adjustments are made on the soil moisture balance worksheet to account for crop water use (withdrawals) and rainfall or irrigation (deposits). You estimate crop water use from tables based on maximum daily air temperature and time since crop emergence. Crop water use increases the deficit while rainfall and irrigation reduce the deficit. Irrigations are scheduled so the soil moisture deficit won't reach a level that may stress the crop. The checkbook method should take only a few minutes each day for each field.

Suggested items for using the checkbook method are:

- **Rain gage(s)**
- **Maximum thermometer**
- **Soil moisture instrument(s)**
- **Crop water use tables**
- **Soil moisture balance worksheets**
- **Calculator is helpful**

The checkbook method involves keeping a soil moisture balance for one or more locations in the field. Several things influence the soil moisture balance including soil type, crop type and growth stage, and various weather factors. Since not all of these can be accounted for by using the checkbook method, it is important to use some type of instrument to measure soil moisture in the field. Extension Fact Sheet 876, Measuring Soil Moisture, covers several approaches to measuring soil moisture.

The advantage of the checkbook method compared to using only soil moisture readings for scheduling irrigations is that the crop water use tables can be used to plan future crop water use based on weather forecasts. In addition, you do not have to read the soil moisture as often since it is used primarily to verify the checkbook balance.

Using the Checkbook Method

Soil moisture balance worksheet

The soil moisture balance worksheet is used to record irrigation scheduling information (copies are at the back of this publication). It is handy for recording daily crop water use and soil moisture deficits along with dates, crop stage, rainfall, irrigation, and soil moisture. An example of the worksheet is shown in Figure 1. Discussion of each part of the worksheet is covered in later sections.

The top of the worksheet is used to record field information and the lower part of the worksheet is used to record information on crop water use and the soil moisture deficit. You do not have to fill out the worksheet beginning at “week 1” of the growing season. It is usually started whenever soil moisture instruments have been installed or irrigation is anticipated. For example, in Figure 1 the balance starts with week 6 on June 20.

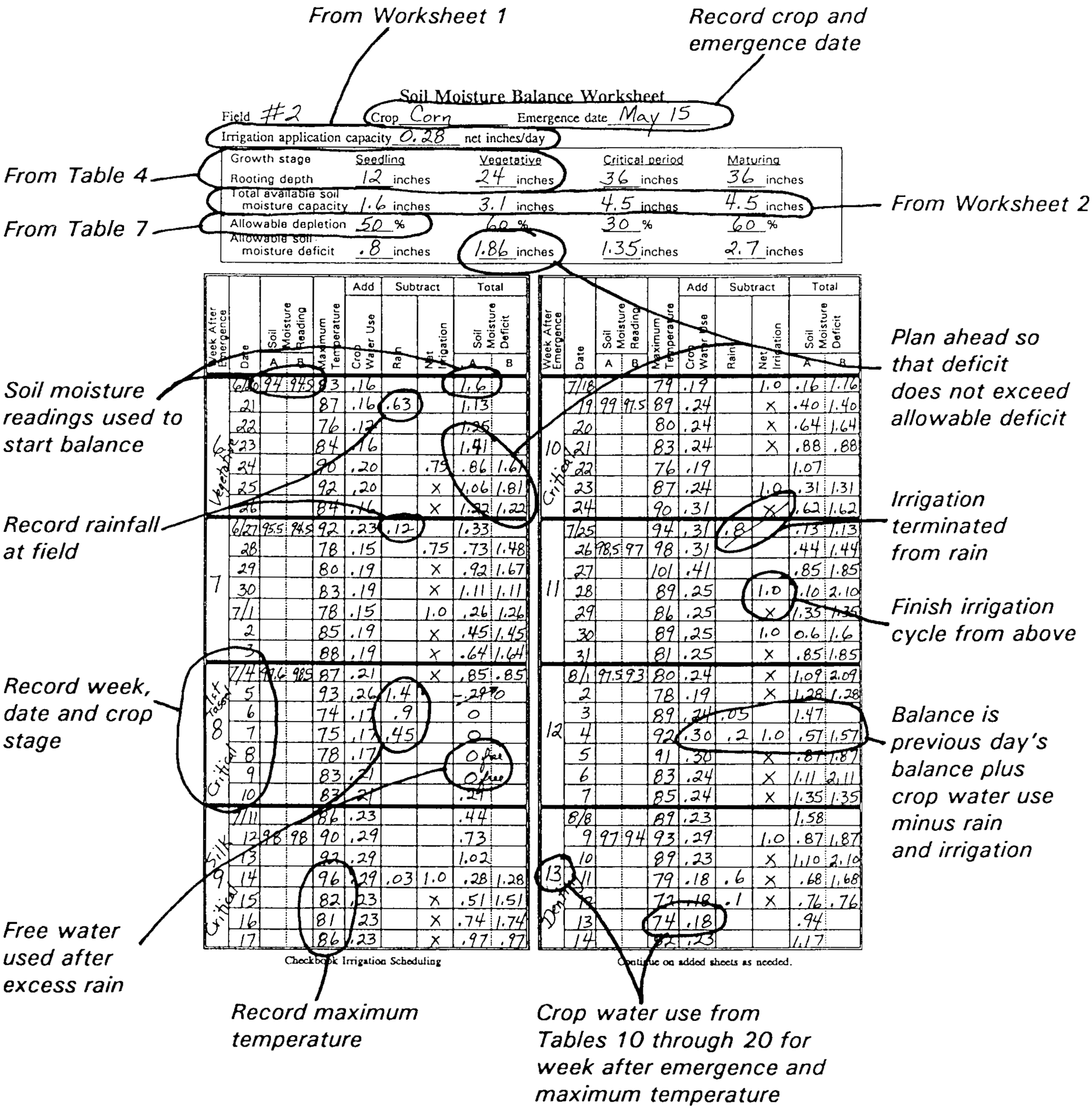
It is important to fill in the information at the top of the worksheet. Emergence date helps to place the crop at the right stage of growth and week of the season. Irrigation capacity is used to determine the irrigation amount that can be applied, especially when using center pivots. The available moisture capacity of the soil and allowable deficit are useful to determine when to irrigate and how much water to apply with each irrigation.

For each day, record maximum daily air temperature on the worksheet. Crop water use is read from the water use table for that crop (Tables 10 to 20) corresponding to the weeks after emergence. Any rainfall and irrigation is recorded. The soil water deficit is calculated by adding the crop water use and subtracting rain and irrigation from the previous day's deficit.

If rain overfills the soil profile more than field capacity, the calculated deficit may show less than zero (negative values). Always set the deficit to zero when this happens. You may want to keep the deficit at zero for one or two days after an excessive rain to account for the crop using percolating (free) water during that time.

To decide when to start irrigating, you compare the soil moisture deficit in the last column of the worksheet to the allowable deficits at the top of the sheet for the current crop stage. Start irrigation soon enough to allow coverage of the entire field before the current deficit exceeds the maximum allowable deficit. Maintain the soil water deficit less than the allowable deficit for all parts of the field.

Figure 1. Example Checkbook Method worksheet.



The irrigation amount should not overfill the available soil moisture capacity (making deficits less than zero). Whenever possible, it is desirable to leave a portion of the soil water deficit unfilled to allow for beneficial use of any rain fall that might come.

Since several factors used to obtain the soil moisture deficit are only estimates, regular field checks are necessary to insure that the existing balance is the best estimate possible. Use soil moisture instrument readings to update the soil moisture deficit if the two do not agree. Also adjust the weeks after emergence versus date if the actual crop stage of growth is different than the worksheet indicates.

Two columns with four weeks per column are included on one worksheet. Each page can keep the soil moisture balance for up to eight weeks for one crop, for four weeks for two locations in the same field, or for two separate crops. You also may maintain two separate balances on the same worksheet using the A and B designation, where A is the deficit for the start of the field and B is the deficit for the end of the field. For additional weeks during the growing season or for more crops, simply make photocopies of the blank worksheet.

Field #2 Crop Corn Emerge

Irrigation application capacity 0.28 net inches/day

Growth stage	Seedling	Vegetative
Rooting depth	12 inches	24 inches
Total available soil moisture capacity	1.6 inches	3.1 inches
Allowable depletion	50 %	60 %
Allowable soil moisture deficit	.8 inches	1.86 inches

Irrigation application capacity

The irrigation capacity is the rate the water can be delivered to the field, often given as GPM/acre (gallons per minute per acre). Table 1 gives the irrigation capacity in GPM/acre for various water delivery rates and acres. It also can be calculated by simply dividing the total GPM by the acres irrigated. An accurate measurement of the water delivery rate (GPM or CFS) is needed to compute the irrigation capacity. To convert CFS (cubic feet per second) to GPM, multiply by 449.

Irrigation application capacity defines the ability of the irrigation system to meet crop water use and refill the soil profile. Table 2 gives the net application capacities in inches per day for various irrigation capacities. Since irrigation is not 100 percent efficient, irrigation

Table 1. Irrigation capacity for various irrigated acreages and delivery rates.

Delivery Rate (GPM)	Gross irrigation capacity (GPM/acre) assuming no losses. Irrigated area (acres) 80	100	130	160	Delivery Rate (CFS)
400	5.0	4.0			0.88
500	6.3	5.0	3.9		1.11
600	7.5	6.0	4.6	3.8	1.33
700	8.8	7.0	5.4	4.4	1.56
800	10.	8.0	6.2	5.0	1.78
900		9.0	6.9	5.6	2.0
1000		10.	7.7	6.3	2.22
1200			9.2	7.5	2.67

efficiencies muse be estimated to account for water losses. Losses can be from evaporation, field runoff, and deep leaching.

Different system types have different irrigation efficiencies based on the nature of the system and the mode of operation. For example, center pivots are about 85% efficient while other sprinkler systems often are less. Flood irrigation often is considered to be 55-65 % efficient when managed properly. The nee application capacities are based on 24 hours of operation every day during the irrigation cycle and need to be adjusted if operating less than full time (Table 3). Worksheet 1 is an example of how to determine the irrigation application capacity.

Sprinkler irrigation average application rates also can be estimated by using several rain gages. Measure the total depth of water applied and divide by the number of days in the irrigation cycle. For example, 0.80 of net irrigation with a three day cycle would be 0.27 inches per day.

Table 3. Adjustment factor to change application capacity for hours of pumping.

24 hours/day	1.0
22 hours/day	0.92
20 hours/day	0.83
18 hours/day	0.75
16 hours/day	0.67
12 hours/day	0.50

Table 2. Application rates for irrigation capacities and application efficiencies.

Irrigation Capacity (GPM/acre)	Average application rates (net inches per day) 55% eff	65% eff	75% eff	85% eff
4	.12	.14	.16	.18
5	.15	.17	.20	.23
6	.18	.21	.24	.27
7	.21	.24	.28	.32
8	.23	.28	.32	.36
9	.26	.31	.36	.41
10	.29	.35	.40	.45

Equation: 0.0533 X GPM/acre X efficiency (in decimal form) = inches per day

Worksheet 1. Example: determining irrigation application capacity.

	Example	Your system
(1) Water delivery rate	800 gpm	________
(2) Acres covered	130	________
(3) GPM/acre (Table 1 or (1) ÷ (2))	6.3	________
(4) Type of system	center pivot	________
(5) Application efficiency	85%	________
(6) Irrigation application capacity		
(a) from Table 2	________	________
or (b) from equation		
0.0533 X GPM/acre X appl. eff.		
0.0533 X 6.3 X .85	.286	________
(7) Adjustment for average hours of pumping		
Hours per day (Table 3) ÷ 24 X (6)	24 hr	________

Crop rooting depth

Irrigation application capacity 0.28 net inches/day		
Growth stage	Seedling	Vegetative
Rooting depth	12 inches	24 inches
Total available soil moisture capacity	1.6 inches	3.1 inches
Allowable depletion	50 %	60 %
Allowable soil moisture deficit	.8 inches	1.86 inches

Each crop has a rooting depth that governs how much water can be used from the soil. Table 4 gives some approximate rooting depths used for irrigation management, even though roots may go deeper. Plants use most of their water from the upper soil layers, where possible. For example, about 70% of the water is used from the top 50% of the crop rooting depth.

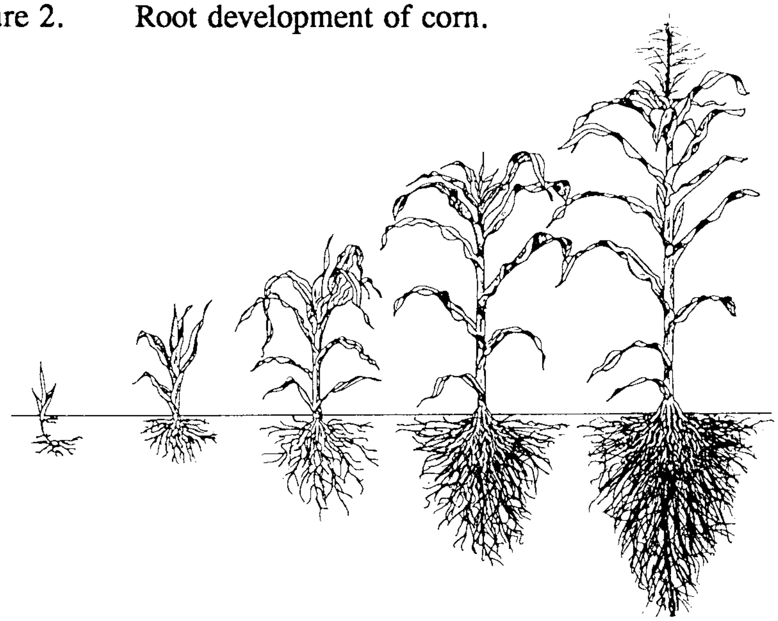
Table 4. Irrigation management depths for various crops.

	Irrigation management depths (inches)			
Annual crops	Seedling	Vegetative	Flowering	Mature
Corn	12	24	36	36
Soybeans	12	18	24	30
Potatoes	12	18	24	24
Small grains	12	18	24	30
Field beans	12	18	24	24
Sugar beets	12	18	24	30
Sorghum	12	24	30	36
Annual vegetables	6 to 12	18	24	24

Perennial crops	Seedling	Establishment	Mature
Alfalfa	6 to 12	24 to 36	48 to 72
Turf and lawns	6	12	12
Grass and pasture	6	12	24
Asparagus	12	24	36

The root zone of annual crops develops at about the same rate as top growth (Figure 2). Full root depth usually occurs before flowering or when full canopy cover is achieved. When planning early season irrigation, only consider the active root depth to calculate the maximum allowable soil moisture deficit. For example, during the seedling stage the roots may be only several inches deep as compared to later in the growing season.

Figure 2. Root development of corn.



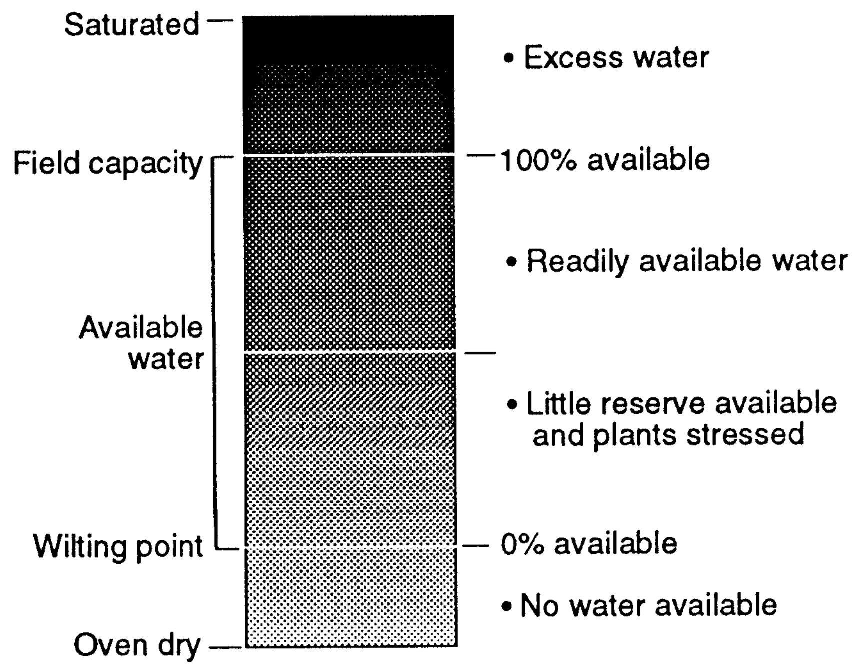
Note that the irrigation management depths in Table 4 are for deep soils that do not have restrictive layers. Adjust rooting depth if the soil is shallow or a restrictive layer prevents rooting depth. Always make sure that the root zone is moist throughout as the crop develops. If a dry layer of soil exists in the root zone, plant roots cannot grow through it and root depth is reduced.

Soil moisture capacity

Growth stage	Seedling	Vegetative
Rooting depth	12 inches	24 inches
Total available soil moisture capacity	1.6 inches	3.1 inches
Allowable depletion	50 %	60 %
Allowable soil moisture deficit	.8 inches	1.86 inches

Soil moisture capacity is the water in the soil that is available to the crop. It is the amount of water stored in the soil between wet soil at field capacity and dry soil at permanent wilting point. Soil moisture capacity is often referred to as available moisture. See Figure 3. Soils that are wetter than field capacity lack aeration and may result in crop stress. They also are subject to leaching of nutrients or chemicals below the root zone. But the closer the soil moisture content is to the wilting point, the harder it is for a crop to extract water. This results in crop stress.

Figure 3. Available soil moisture.



Different soil types have different available moisture capacities, and there are differences within fields even with the same soil type. Soil texture is the pr~mary factor that affects soil moisture capacity. Soil texture is determined by the relative amounts of sand, silt and clay in the soil volume. Soil surveys are one source of information on the available moisture capacity of soils. In fields with more than one soil type, manage your irrigation for the soil with the lowest moisture capacity as long as it is a significant part (30-50%) of the field. Worksheet 2 is an example of information from a soil survey, calculating the available moisture for a 3-foot root depth.

In the absence of specific soil moisture capacity information, use Table 5 to estimate the available moisture capacity. If there are layers of different texture in the soil, calculate a value for each layer and obtain a total for the profile. To arrive at estimates for the various crop growth stages, use layers that match the rooting depth at each stage.

Worksheet 2. Calculation of available moisture capacity.

Example

Soil type Lowry silt loam Root zone depth 3 ft

Soil depth	Available moisture inches per inch of soil		Available moisture capacity inches of water
0-8 in	0.22	8 X .22	1.76
8-13 in	0.20	5 X .20	1.00
13-36 in	0.16	23 X .16	3.68
		Total	6.44

Field #1

Soil type ____________ Root zone depth ____________

Soil depth	Available moisture inches per inch of soil		Available moisture capacity inches of water
		Total	

Field #2

Soil type ____________ Root zone depth ____________

Soil depth	Available moisture inches per inch of soil		Available moisture capacity inches of water
		Total	

Table 5. Available water capacities for various soil types.

Soil type	Inches water per foot of soil
Fine sands	0.7 - 1.0
Loamy sands	0.9 - 1.5
Sandy loams	1.3 - 1.8
Loams	1.8 - 2.5
Silt loams	1.8 - 2.6
Clay loams	1.8 - 2.5
Clays	1.8 - 2.4

Allowable soil moisture deficit

Growth stage	Seedling	Vegetative
Rooting depth	12 inches	24 inches
Total available soil moisture capacity	1.6 inches	3.1 inches
Allowable depletion	50 %	60 %
Allowable soil moisture deficit	.8 inches	1.86 inches

The allowable soil moisture deficit is the maximum amount of water that can be depleted from the root zone without seriously affecting production. It is obtained by multiplying total available moisture capacity by the allowable depletion. Worksheet 3 illustrates the calculations to get the allowable soil moisture deficit. As shown on the top of the example on Figure 1, the allowable deficit may change for different growing stages. The later section on irrigation management strategies outlines allowable depletions for various crops and growth stages.

Week after emergence

Week After Emergence	Date	Soil Moisture Reading A	Soil Moisture Reading B	Maximum Temperature	Crop Water Use	Rain	Net Irrigation	Soil Moisture Deficit A	Soil Moisture Deficit B
	6/20	94	94.5	83	.16			1.6	
	21			87	.16	.63		1.13	
	22			76	.12			1.25	
6	23			84	.16			1.41	
	24			90	.20		.75	.86	1.61

You need to know the week after emergence to read crop water use from the tables. Locate the emergence date on a calendar and count the number of weeks to get the week and date when you start the checkbook. Record the week number and date on the balance sheet. It is not necessary to start the balance at week one.

Worksheet 3. Calculation of allowable soil moisture deficit.

	Example	Your field
Crop	Corn	
Stage of growth	silking	
Soil type	sandy loam	
Rooting depth	3	
Available moisture per ft (Soil survey or Table 5)	1.5	
Total available moisture	3 X 1.5 = 4.5	
Allowable depletion (Table 7)	40%	
Allowable soil moisture deficit	4.5 X .40 = 1.80	

Week After Emergence	Date	Soil Moisture Reading A	Soil Moisture Reading B	Maximum Temperature	Add: Crop Water Use	Subtract: Rain	Subtract: Net Irrigation	Total: Soil Moisture Deficit A	Total: Soil Moisture Deficit B
	6/20	94	94.5	83	.16			1.6	
	21			87	.16	.63		1.13	
	22			76	.12			1.25	

Crop water use

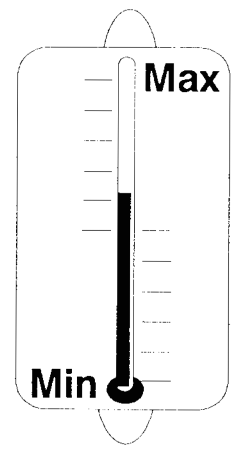
Crop water use increases the soil moisture deficit on the balance worksheet. This checkbook method estimates crop water use from the maximum daily air temperature and the crop's growth stage. Crop water use also is called evapotranspiration (ET). It includes both evaporation from the soil surface and transpiration from the plant leaves. It depends on crop type, stage of growth, sunshine, temperature, wind, humidity, and soil moisture.

Tables 10 through 20 give estimated crop water use values for the most common irrigated crops in South Dakota. Some of the crops have different tables for different areas of the state (Figure 9). Select the table for the crop you are irrigating based on where you are in the state. After determining the weeks after emergence and the maximum temperature, the crop water use can be read from the tables.

For seasons when the growing conditions may speed-up or slow-down crop development (such as 1992), it is important to match the week after emergence to the growth stage of the crop. Growth stages are indicated on the tables and should be used to adjust the week after emergence value to correspond with the actual growth stage and date. For example, it may only be 8 weeks after emergence, but if the corn is already fully tasseled and silking, then week 9 would be the week after emergence value to use. (See Table 10)

Obtain maximum daily air temperature from a maximum-minimum thermometer or from a local weather reporting station. Place the thermometer in a representative location out of direct sunlight. Don't measure temperature out in the irrigated field since the irrigation may create an oasis effect.

Figure 4. Maximum thermometer.



Rain fall and irrigation

Rainfall and irrigation reduce the soil moisture deficit on the balance worksheet. Accurate measurements of both rain and irrigation are essential to the checkbook balance. Rain gages can be used to measure rain and also sprinkler irrigation. More than one rain gage is needed to get a reasonable estimate of sprinkler irrigation water applications.

Soil Moisture Reading		Maximum Temperature	Add	Subtract		Total	
			Crop Water Use	Rain	Net Irrigation	Soil Moisture Deficit	
A	B					A	B
94	94.5	83	.16			1.6	
		87	.16	.63		1.13	
		76	.12			1.25	

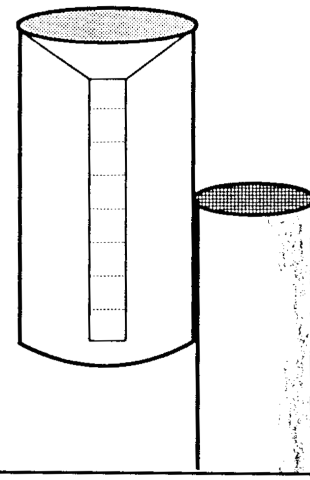
Week After Emergence	Date	Soil Moisture Reading	
		A	B
	7/18		
	19	99	97.5
	20		

The irrigation application capacity (net inches per day from Table 2) can be used to estimate the application depth for all types of irrigation including flood. Enter into the worksheet either the total depth of water applied or multiply the irrigation application capacity by the number of days in the irrigation cycle.

It also is helpful to mark on the balance sheet the number of days to complete an irrigation. See Figure 1 for an example.

The net irrigation should be less than the soil moisture deficit, where possible, to allow for a soil storage reserve for rainfall. For some coarse textured soils that have low moisture capacity, irrigation may need to be started with little allowance for rainfall storage in order to complete the irrigation cycle without stressing crops at the end of the cycle.

Figure 5. Rain gage.



Soil moisture deficit

The checkbook balance of the soil moisture deficit on the worksheet is an estimate of water that has been removed from the soil by the crop. Crop water use increases the deficit while rain and irrigation decrease the deficit.

B Reading	Maximum Temperature	Add: Crop Water Use	Subtract: Rain	Subtract: Net Irrigation	Total: Soil Moisture Deficit A	Total: Soil Moisture Deficit B	Week After Emergence	Date	Soil Moisture Reading A	Soil Moisture Reading B	Maximum Temperature
75	83	.16			1.6			7/18			79
	87	.16	.63		1.13			19	99	97.5	89
	76	.12			1.25			20			80

Use the soil moisture deficit to help schedule irrigations. Comparing the deficit to the maximum allowable deficit on the upper part of the worksheet, start irrigation so that the irrigation cycle can be completed before the maximum deficit occurs on any part of the field. Irrigation amounts or depths should be less than the soil moisture deficit to prevent over-watering and loss of fertilizer by deep percolation.

It is recommended that a soil moisture balance be kept for the start and end of the field or irrigation cycle. The A and B approach can be used where A is the start and B is the finish of the field, or separate copies of the worksheet can be kept.

After a heavy rainfall, the soil may have excessive water and the soil moisture deficit may show negative. Set the deficit to zero when this happens. But you may want to keep the deficit at zero for one or two days after an excessive rain to account for the crop using percolating (free) water during that time.

Starting the worksheet balance

To start the checkbook balance, estimate the soil moisture deficit for that date and enter it into the soil moisture deficit column on the worksheet. An excellent time to start the balance is immediately following a large, early-season rainfall that has refilled the soil profile. Then the soil moisture deficit is set to zero and the balance proceeds from that point. But do not postpone starting the balance until too late into the growing season while waiting for a large rainfall.

Where flood irrigation refills the soil profile, you can reset the soil moisture deficit to zero after an irrigation.

Often, for many parts of South Dakota, irrigation is needed and the worksheet must be started without the chance of a large rainfall to refill the soil profile. Using soil moisture instruments is recommended. Install instruments early in the growing season so that the readings can be used to initialize the soil moisture deficit. The next section discusses how to use soil moisture instruments to help with irrigation scheduling.

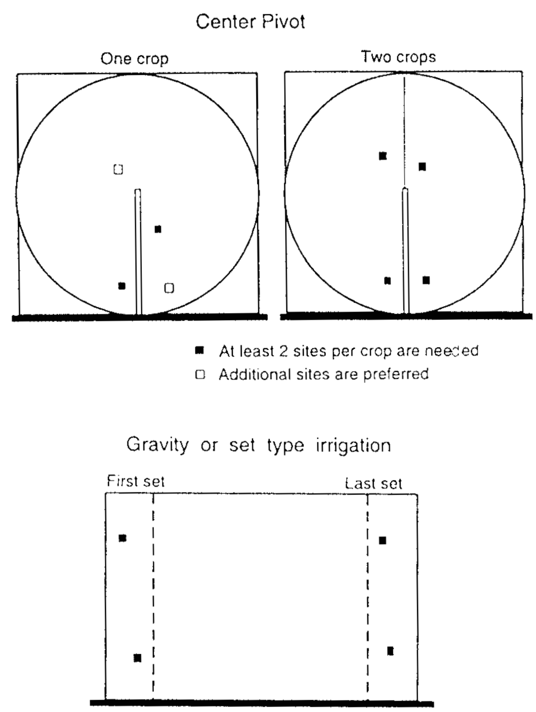
Soil moisture measurement

Measuring soil moisture benefits irrigation water management by giving more accurate soil moisture information. Soil moisture instrument readings are very helpful when starting the checkbook method at the beginning of the irrigation season. They also can provide corrections or adjustments to the soil moisture deficit throughout the season.

Soil moisture can be measured or estimated in a variety of ways including the simple, low cost “feel” method to more accurate, expensive, neutron probe units. For most irrigation scheduling uses, tensiometers or one of the several resistance block types is recommended. A more complete discussion of measuring soil moisture is in Fact Sheet FS 876 available from your county Extension office.

Select at least two sites in each crop or field to install soil moisture sensors (Figure 6). It is good to have one near the start of the irrigation cycle and one near the end. When the field contains more than one soil type, locate sensors in the predominant soil type. Avoid locations that are not representative of the field such as low areas or hilltops.

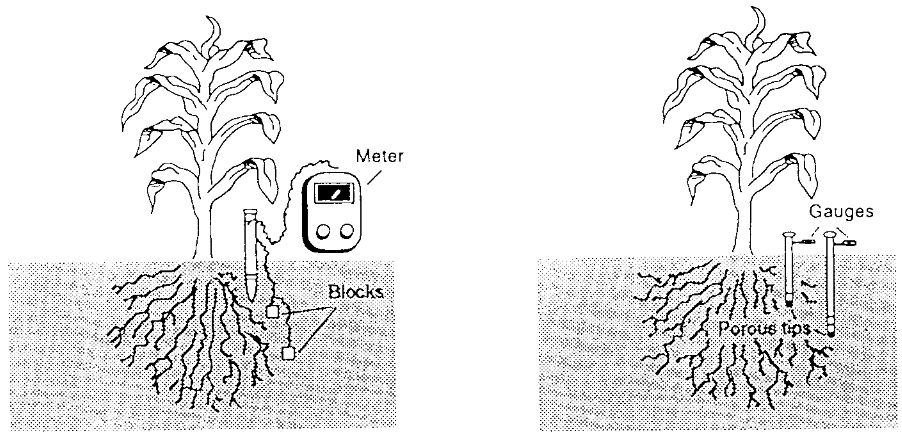
Figure 6. Locating soil moisture sites in the field.



Install at least two soil moisture sensors at each site except for shallow-rooted crops or for very shallow soil. Place the sensors at 1/3 and 2/3 of the crop rooting depth (Figure 7). Use the shallow sensor to judge when to start irrigating and the deep sensor to judge how much water to apply. If readings of the deep sensor rise faster than the shallow sensor readings, apply more water each irrigation. If readings of the deep sensor remain wet, apply less water during each irrigation since there is more chance for loss of water through the root zone.

Install the soil moisture sensors early in the growing season. Place them where they will be accessible from a road or trail. It is very important to place sensors where they can be found easily for reading.

Figure 7. Placing soil moisture sensors in the root zone.



For row crops, place the blocks or tensiometers between plants in the row. Avoid locations where field or irrigation equipment could damage the sensors. Mark the locations well with flags or stakes.

Use the soil moisture readings to start the soil moisture deficit on the balance worksheet. Table 6 can be used to estimate the soil moisture deficit from tensiometer and common resistance block values. For a given reading, follow across to the column for the dominant soil type and find the soil moisture deficit in inches per foot of soil. For example, with three feet of loam soil and an average KS-D1 reading of 94, the total soil moisture deficit would be 3 times 0.8 or 2.4 inches.

Irrigation management strategy

Irrigation management involves decision-making every day during the crop season. Any management strategy considers many factors ranging from crop water needs to pumping costs to protecting the environment. Decision-making is more complex now than when the only concern was how to get the highest yield.

In the past, irrigators were given the rule-of-thumb to maintain at least 50% available soil moisture. However, research has shown that depleting the soil moisture only to 30 to 40% will give the best yields, but more water is used and there is greater potential to leach nutrients out of the root zone. According to recent studies it is possible to produce nearly the same yields with less water by using flexible

Table 6. Soil moisture deficit in inches per foot for soil moisture readings.

Soil Tension	Tensiometer	Watermark Digital	Delmhorst KS-D1	Delmhorst KS-2	Sands	Sandy Loams	Loams	Silt and Clay Loams
10	10	10	99	90	0	0	0	0
20	20	20	98	80	0.2	0.3	0.35	0.4
30	30	30	96	70	0.3	0.5	0.6	0.7
40	40	40	94	60	0.4	0.65	0.8	0.9
50	50	50	91	51	0.5	0.8	1.0	1.1
60	60	60	88	43	0.55	0.9	1.1	1.3
70	70	70	86	38	0.6	1.0	1.18	1.4
80	80	80	84	34	0.64	1.05	1.25	1.47
90		90	80	29	0.67	1.1	1.33	1.53
100		100	77	25	0.7	1.2	1.4	1.6
200		200	52	9	0.78	1.3	1.6	1.8
500			32	4	0.9	1.5	1.9	2.2
*1500			10	0	1.0	1.7	2.2	2.6

* Permanent wilting point.

irrigation schedules and changing soil moisture depletions. Figure 8 illustrates how the allowable depletion might change during the growing season for corn. Letting soil moisture deplete to 60 to 70% both early and late in the growing season while maintaining moisture levels in the 30 to 50% range during critical stages has been successful.

Table 7 gives general depletion allowance guidelines for crops based on stages of growth. Select depletions from the appropriate column to use in the top of the soil moisture balance worksheet. (See Figure 1 for an example.) Table 8 lists the critical growth period for crops when they are most sensitive to water stress. Table 8 also gives water use efficiency both for the season and for critical periods. Remember that stress during those critical stages can substantially reduce crop yields as shown by the water efficiency column in Table 8.

The depletion allowances from Table 7 are given for normal growing conditions. During periods of above normal temperature, reduce the depletion allowance to minimize stress on the crop. Conversely for periods of below normal temperature, the depletion allowance can be increased without seriously affecting the crop. Table 9 illustrates the impact of temperature on the allowable soil moisture depletion to minimize crop stress and yield reductions.

Figure 8. Example of changing allowable depletions during the growing season for corn.

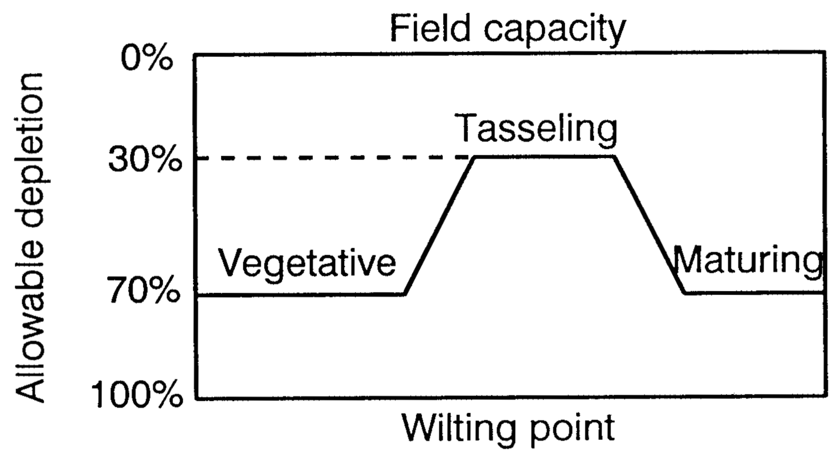


Table 7. Guidelines for soil moisture depletion allowances for irrigation management.

Crop	Depletion allowances for various crop stages			
	Seedling	Vegetative	Critical period	Maturing
Corn	50%	50-70%	30-50%	60-70%
Soybeans	50%	60-70%	40-50%	60-70%
Potatoes	50%	40-60%	20-40%	60%
Small grain	50%	60-70%	40-50%	60-70%
Field beans	50%	50-70%	30-50%	60-70%
Sorghum	50-60%	60-70%	40-60%	60-70%
Alfalfa	30-40%	40-60%		60%*

* Late season depletion

Early season irrigation

Make sure that there is adequate soil moisture for the crop to get a good start. If the soil is dry in the surface layer, one irrigation may promote rapid, uniform germination. As the crop develops, moist soil is needed for root development. Check your fields by probing to insure no dry soil layers are present. You may need to irrigate to wet the soil

Table 8. Crop water use and critical growth stages.

Crop	Water use Inches/year	Water efficiency Yield/inch of water	Growth period most sensitive to water stress
Corn	18 to 24	5 to 20 bu/inch	Tassel through pollination
Soybeans	17 to 23	2 to 4 bu/inch	Flowering through pod fill
Potatoes	17 to 24	15 to 25 cwt/inch	Tuberization
Wheat	14 to 20	4 to 5 bu/inch	Boot through flowering
Field beans	15 to 20	1 to 2 cwt/inch	Flowering through pod fill
Sorghum	17 to 23	5 to 8 bu/inch	Boot through heading
Alfalfa	22 to 30	.2 to .25 Ton/inch	Seedling

Table 9. Allowable soil moisture depletions to minimize crop stress.

Temperature	Corn	Soybeans	Potatoes	Alfalfa
60°F	92%	87%	99%	97%
70°F	80%	75%	89%	86%
80°F	60%	56%	44%	64%
90°F	29%	29%	0%	25%
100°F	0%	0%	0%	0%

for the rooting depth development at that stage of growth. You also can use irrigation to activate certain preplant or post emergence herbicides.

Perennial forage crops such as alfalfa often will need supplemental irrigation early in the season. Use the checkbook tables along with measuring soil moisture to judge soil moisture levels. First-crop hay yields often can be increased with early irrigations. Be prepared to irrigate early if little precipitation came over the winter and spring.

Critical period irrigation

For many annual crops in South Dakota, the first irrigation may come with the approach of a critical growth stage. Table 8 lists the growth period where crops are most sensitive to water stress. Typically, this also is the hottest and driest time of the summer. Depletion allowances are lower while at the same time crop water use is higher.

Most irrigation systems in the state cannot keep up with crop water demands during critical periods. Water is used from the soil moisture reserve. Plan ahead using temperature forecasts to judge when to start the irrigation so that the soil moisture deficit does not drop below the depletion allowance. This is especially important if your irrigation system has a low irrigation application capacity (low GPM/acre). For fields with low soil moisture capacity and with limited irrigation capacity, you may want to start irrigating as soon as the there is adequate soil moisture capacity (soil moisture deficit) to hold the irrigation amount.

Late season irrigation

As the crop matures soil moisture depletion allowances can be greater. Most crops are less susceptible to stress, and crop water use is usually less. Many soils have storage reserves of 2 to 4 inches of water before they reach the 60 to 70% depletion. Make use of more soil moisture to minimize risk of leaching any left-over nutrients from the profile. You also can take advantage of any off-season precipitation.

Rather than terminating irrigation at a given date, monitor the crop stage and soil moisture with an eye to the weather forecast before deciding when to quit irrigating. It is common to have very hot, dry conditions late in the growing season that can reduce yields if soil moisture is not available. Terminating irrigation early does not promote early maturing and dry-down of the grain.

Do not water stress alfalfa late in the season. Adequate moisture promotes good fall regrowth and gives it a better start in the spring.

Other management considerations

When using chemigation to apply liquid nitrogen or other chemicals, you may not need water at the time that you want to apply the chemicals. Apply the chemicals in a timely fashion, but use the least amount of water possible. It helps to have high capacity injection equipment along with an irrigation system that can cover the field in the shortest time possible.

Certain crops require more intensive water management to maintain both high yields and high market quality. Potatoes and other vegetable crops are examples. In general, they require a lower soil moisture depletion and more uniform irrigation throughout the season.

Many irrigators take advantage of electric load management programs through their electric supplier. Even though the control periods are not usually excessive, they can occur daily. It is important to reflect a lower irrigation application capacity to account for the fewer hours of operation per day (Table 3). Keep in mind that the load control periods often come during critical periods when crop water demands are highest.

> Irrigation management is an art, even though you need to consider a wide variety of scientific inputs to do the best job possible. ~ *A good rule to follow: if you would like to have a rain, irrigate.*

Definition of terms

Available soil moisture (water): the amount of water held in the soil between field capacity and wilting point. Available moisture often is expressed as inches of water per inch of soil or per foot of soil. Not all available moisture is equally available to the plant, with the moisture closest to field capacity most available.

Allowable deficit (depletion allowance): the percent of the total available soil moisture that can be depleted without seriously affecting crop production. The depletion allowance can change during the growing season based on the vulnerability of the crop to water stress.

Chemigation: the application of any chemical, including fertilizers, with the irrigation water. Normally the chemical is injected into the irrigation water.

Crop water use: the amount of water used by the crop during a given period (often daily). Crop water use is considered the same as evapotranspiration.

Emergence date: the date when about 50% of the plants have germinated and emerged through the soil surface.

Evapotranspiration: the amount of crop water use; a combination of both evaporation from the soil surface and transpiration from the plants.

Field capacity: the amount of water held in the soil when most of the free (gravitational) water has drained.

Irrigation application capacity (irrigation capacity): the rate that irrigation water can be delivered to the field, often expressed as GPM/acre. Irrigation capacity determines the ability of the irrigation system to keep up with the crop water needs. Higher capacities are needed where crop water demands are high and/or soil moisture capacity is low. High capacities also permit irrigating the field faster.

Irrigation (application) efficiency: the amount of water available for crop water use versus the total volume of water pumped. Efficiency is expressed as a % or a decimal; for example, 85% is the same as 0.85.

Irrigation management depth: the amount or depth of water applied during each irrigation. The depth should always be less than, or equal to, the soil moisture deficit.

Maximum temperature: the highest air temperature during a given 24 hour period. Place the thermometer to avoid direct sunlight and away from things that could cause false readings.

Net irrigation: the irrigation depth after accounting for application losses. The net irrigation is always less than the total water delivered to the field.

Soil moisture capacity: the ability of the soil to store water for crop water use. The soil moisture capacity of coarse textured soil generally is less than for fine textured soils.

Soil moisture deficit (soil moisture balance): the amount of moisture that has been used from the root zone. A rainfall or irrigation amount equal to the deficit would refill the available soil moisture to field capacity.

Soil texture: the relative amount of sand, silt, and clay in the soil volume. Coarse-textured soils have more sand while fine-textured soils have more clay.

Transpiration: the water that is used by the plant itself, most of which is used for cooling.

Wilting point: the point at which the amount of water in the soil can no longer sustain plant growth. It generally is considered to be at 15 bars of tension.

Conversion Factors

To convert from:	To:	Multiply by:
CFS	GPM	449
ac-in/hr	GPM	452
CFS	miner's inches	50
HP	KW	0.746
psi	ft of head	2.31
lps	GPM	15.85

Figure 10. Crop water use regions of South Dakota.

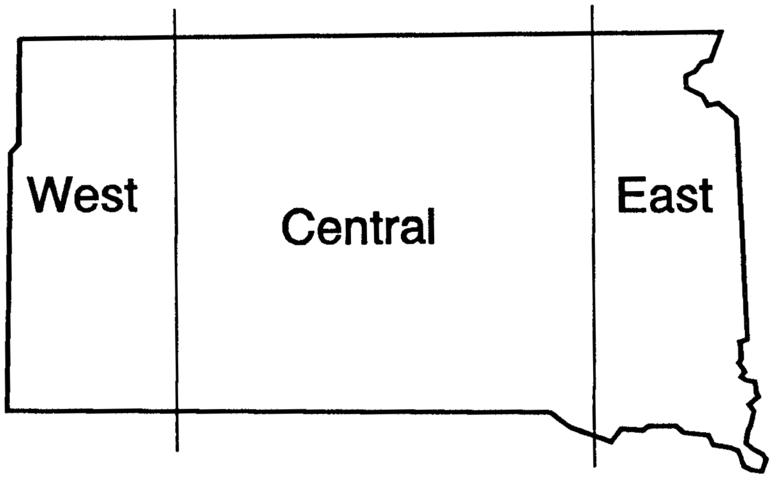


Table 10. Corn water use (inches per day) Western South Dakota

Maximum Temperature	Week after emergence																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
50 - 59°F	.02	.02	.03	.04	.05	.07	.08	.09	.10	.10	.10	.10	.10	.09	.07	.06	.05	.04
60 - 69°F	.03	.03	.04	.05	.07	.09	.11	.12	.14	.14	.14	.14	.13	.12	.10	.09	.07	.06
70 - 79°F	.04	.05	.06	.08	.10	.14	.16	.18	.20	.21	.22	.21	.20	.18	.15	.13	.11	.09
80 - 89°F	.06	.06	.08	.10	.14	.18	.22	.25	.27	.29	.29	.28	.27	.24	.20	.17	.14	.11
90 - 99°F	.07	.08	.09	.12	.17	.22	.27	.30	.33	.35	.35	.34	.32	.29	.25	.21	.17	.14
≥ 100°F	.08	.09	.11	.14	.20	.26	.31	.35	.39	.41	.41	.40	.38	.34	.29	.25	.20	.16
Corn growth stages			↑ 3 leaf		↑ 8 leaf			↑ 1st tassel	↑ silk		↑ blister kernel			↑ early dent			↑ black layer	

Table 11. Alfalfa water use (inches per day) Western South Dakota

Maximum Temperature	Weeks after new growth in the spring				Weeks after each cutting			For remainder of months not covered by other charts				
	1	2	3	4	1	2	3	May	June	July	Aug	Sept
50 - 59°F	.05	.07	.08	.09	.07	.09	.10	.09	.10	.11	.10	.08
60 - 69°F	.07	.10	.11	.13	.10	.12	.13	.13	.14	.15	.14	.11
70 - 79°F	.11	.15	.17	.19	.15	.18	.20	.19	.22	.22	.21	.17
80 - 89°F	.14	.20	.22	.25	.20	.24	.27	.25	.29	.29	.29	.22
90 - 99°F	.17	.24	.27	.31	.24	.29	.32	.31	.35	.36	.35	.27
≥ 100	.20	.28	.32	.36	.28	.34	.38	.36	.41	.42	.41	.32

<u>Central</u> South Dakota Crop Water Use Tables

Table 12. Corn water use (inches per day) — Central South Dakota

Maximum Temperature	Week after emergence 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
50 - 59°F	.02	.02	.03	.04	.05	.07	.08	.09	.10	.10	.10	.10	.10	.09	.07	.06	.05	.04
60 - 69°F	.03	.03	.04	.05	.07	.09	.11	.12	.14	.14	.14	.14	.13	.12	.10	.09	.07	.06
70 - 79°F	.04	.05	.05	.07	.10	.13	.16	.18	.19	.20	.21	.20	.19	.17	.15	.12	.10	.08
80 - 89°F	.06	.06	.07	.10	.13	.18	.21	.24	.26	.28	.28	.27	.26	.23	.20	.17	.14	.11
90 - 99°F	.07	.08	.09	.13	.17	.23	.27	.31	.34	.36	.36	.35	.33	.30	.26	.22	.18	.14
≥ 100°F	.09	.10	.12	.16	.22	.29	.34	.39	.43	.45	.45	.44	.42	.38	.32	.27	.22	.18
Corn growth stages			↑ 3 leaf		↑ 8 leaf			↑ 1st tassel	↑ silk		↑ blister kernel			↑ early dent			↑ black layer	

Table 13. Soybean water use (inches per day) — Central South Dakota

Maximum Temperature	Week after emergence 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
50 - 59°F	.02	.02	.02	.03	.04	.05	.07	.08	.10	.10	.10	.10	.09	.08	.06	.04	.03
60 - 69°F	.03	.03	.03	.04	.05	.07	.10	.12	.13	.14	.14	.14	.13	.11	.08	.05	.04
70 - 79°F	.04	.04	.05	.06	.08	.10	.14	.17	.19	.20	.21	.20	.19	.16	.11	.08	.06
80 - 89°F	.06	.06	.06	.08	.10	.14	.18	.23	.26	.28	.28	.27	.25	.21	.15	.10	.08
90 - 99°F	.07	.08	.08	.10	.13	.18	.24	.29	.33	.36	.36	.35	.33	.28	.20	.13	.10
≥ 100	.09	.10	.11	.13	.17	.23	.30	.37	.42	.45	.45	.44	.41	.35	.25	.17	.13
Soybean growth stages				↑ 3rd trifoliate V3				R1	↑ flower	R2		↑ upper pod fill R4				↑ leaf drop R7	

Table 14. Alfalfa water use (inches per day) — Central South Dakota

Maximum Temperature	Weeks after new growth in the spring 1	2	3	4	Weeks after each cutting 1	2	3	For remainder of months not covered by other charts May	June	July	Aug	Sept
50 - 59°F	.05	.07	.08	.09	.07	.09	.10	.09	.10	.11	.10	.08
60 - 69°F	.07	.10	.11	.13	.10	.12	.13	.13	.14	.15	.14	.11
70 - 79°F	.10	.14	.16	.18	.14	.17	.19	.18	.21	.21	.20	.16
80 - 89°F	.14	.19	.22	.24	.19	.23	.26	.24	.28	.28	.28	.22
90 - 99°F	.18	.25	.28	.32	.25	.30	.33	.32	.36	.37	.36	.28
≥ 100	.22	.31	.35	.40	.31	.37	.42	.40	.45	.46	.45	.35

Eastern South Dakota Crop Water Use Tables

Table 15. Corn water use (inches per day) Eastern South Dakota

Maximum Temperature	Week after emergence																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
50 - 59°F	.02	.02	.02	.03	.04	.06	.07	.08	.09	.09	.09	.09	.09	.08	.07	.06	.05	.04
60 - 69°F	.03	.03	.04	.05	.07	.09	.11	.12	.14	.14	.14	.14	.13	.12	.10	.09	.07	.06
70 - 79°F	.04	.04	.05	.07	.09	.12	.15	.17	.18	.19	.20	.19	.18	.16	.14	.12	.10	.08
80 - 89°F	.05	.06	.06	.09	.12	.16	.19	.21	.23	.24	.25	.24	.23	.21	.18	.15	.12	.10
90 - 99°F	.06	.07	.08	.11	.15	.20	.23	.26	.29	.31	.31	.30	.29	.26	.22	.19	.15	.12
≥ 100°F	.08	.09	.11	.14	.20	.26	.31	.35	.39	.41	.41	.40	.38	.34	.29	.25	.20	.16
Corn growth stages			↑ 3 leaf		↑ 8 leaf			↑ 1st tassel	↑ silk		↑ blister kernel			↑ early dent			↑ black layer	

Table 16. Soybean water use (inches per day) Eastern South Dakota

Maximum Temperature	Week after emergence																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
50 - 59°F	.02	.02	.02	.03	.03	.05	.06	.08	.09	.09	.09	.09	.08	.07	.05	.03	.03
60 - 69°F	.03	.03	.03	.04	.05	.07	.10	.12	.13	.14	.14	.14	.13	.11	.08	.05	.04
70 - 79°F	.04	.04	.05	.06	.07	.10	.13	.16	.18	.19	.20	.19	.18	.15	.11	.07	.06
80 - 89°F	.05	.05	.06	.07	.09	.12	.16	.20	.23	.24	.25	.24	.22	.19	.14	.09	.07
90 - 99°F	.06	.07	.07	.09	.11	.16	.20	.25	.29	.31	.31	.30	.28	.24	.17	.11	.09
≥ 100	.08	.09	.10	.12	.15	.21	.27	.34	.38	.41	.41	.40	.37	.32	.23	.15	.12
Soybean growth stages				↑ 3rd trifoliate V3				↑ flower R1		R2		↑ upper pod fill R4				↑ leaf drop R7	

Table 17. Alfalfa water use (inches per day) Eastern South Dakota

Maximum Temperature	Weeks after new growth in the spring				Weeks after each cutting			For remainder of months not covered by other charts				
	1	2	3	4	1	2	3	May	June	July	Aug	Sept
50 - 59°F	.05	.06	.07	.08	.06	.08	.09	.08	.09	.09	.09	.07
60 - 69°F	.07	.10	.11	.13	.10	.12	.13	.13	.14	.15	.14	.11
70 - 79°F	.10	.13	.15	.17	.13	.16	.18	.17	.20	.20	.19	.15
80 - 89°F	.12	.17	.19	.22	.17	.20	.23	.22	.25	.25	.24	.19
90 - 99°F	.15	.21	.24	.27	.21	.26	.29	.27	.31	.32	.31	.24
≥ 100	.20	.28	.32	.36	.28	.34	.38	.36	.41	.42	.41	.32

General South Dakota Crop Water Use Tables

Table 18. Potato water use (inches per day)

Maximum Temperature	Week after emergence																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
50 - 59°F	.02	.03	.04	.05	.06	.08	.09	.10	.10	.10	.10	.10	.09	.08	.08	.07	.06
60 - 69°F	.03	.04	.06	.07	.09	.11	.13	.14	.14	.14	.14	.14	.13	.12	.11	.10	.08
70 - 79°F	.04	.05	.08	.10	.13	.16	.18	.19	.20	.20	.20	.19	.18	.17	.15	.14	.12
80 - 89°F	.06	.07	.10	.13	.16	.20	.23	.24	.25	.26	.25	.24	.23	.21	.19	.17	.15
90 - 99°F	.07	.09	.13	.16	.20	.26	.29	.31	.32	.33	.32	.31	.29	.27	.24	.22	.19
≥ 100	.10	.12	.18	.22	.28	.35	.40	.43	.44	.45	.44	.43	.40	.37	.33	.30	.26
Potato growth stage			7 inch	budding		full flower		tuber formation and development								maturing	

Table 19. Small grain water use (inches per day)

Maximum Temperature	Week after emergence														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
50 - 59°F	.02	.03	.04	.05	.07	.09	.10	.10	.10	.10	.09	.08	.07	.06	.05
60 - 69°F	.03	.04	.05	.07	.10	.12	.14	.14	.14	.14	.12	.11	.09	.08	.07
70 - 79°F	.04	.05	.07	.11	.14	.18	.20	.20	.20	.19	.18	.16	.13	.11	.10
80 - 89°F	.05	.07	.09	.13	.18	.22	.25	.26	.25	.24	.22	.20	.16	.14	.12
90 - 99°F	.06	.09	.12	.17	.23	.28	.31	.33	.32	.31	.28	.26	.21	.18	.15
≥ 100	.08	.11	.14	.21	.29	.35	.39	.41	.40	.39	.36	.32	.26	.23	.19
Small grain growth stages			tillering			jointing		heading		milk		early dough	hard dough		

Table 20. Field bean water use (inches per day)

Maximum Temperature	Week after emergence														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
50 - 59°F	.02	.03	.04	.05	.08	.10	.10	.10	.10	.10	.09	.07	.06	.05	.03
60 - 69°F	.03	.04	.06	.07	.11	.14	.14	.14	.14	.13	.12	.10	.08	.06	.05
70 - 79°F	.05	.06	.08	.11	.16	.20	.20	.20	.20	.19	.17	.14	.11	.09	.07
80 - 89°F	.06	.08	.10	.13	.20	.25	.26	.26	.25	.24	.21	.18	.14	.11	.09
90 - 99°F	.08	.10	.13	.17	.26	.31	.33	.33	.32	.31	.27	.22	.18	.14	.11
≥ 100	.10	.12	.16	.21	.32	.39	.41	.41	.40	.38	.34	.28	.22	.18	.14
Field bean growth stages				2nd trifoliate V3		flower R2			pod filling R5				leaf yellowing R8		

Soil Moisture Balance Worksheet

Field________________ Crop________________ Emergence date_______________

Irrigation application capacity__________ net inches/day

Growth stage	Seedling	Vegetative	Critical period	Maturing
Rooting depth	_____inches	_____inches	_____inches	_____inches
Total available soil moisture capacity	_____inches	_____inches	_____inches	_____inches
Allowable depletion	_____%	_____%	_____%	_____%
Allowable soil moisture deficit	_____inches	_____inches	_____inches	_____inches

Week After Emergence	Date	Soil Moisture Reading		Maximum Temperature	Add	Subtract		Total	
					Crop Water Use	Rain	Net Irrigation	Soil Moisture Deficit	
		A	B					A	B

Week After Emergence	Date	Soil Moisture Reading		Maximum Temperature	Add	Subtract		Total	
					Crop Water Use	Rain	Net Irrigation	Soil Moisture Deficit	
		A	B					A	B

Continue on added sheets as needed.

Soil Moisture Balance Worksheet

Field________________ Crop________________ Emergence date_______________

Irrigation application capacity__________ net inches/day

Growth stage	Seedling	Vegetative	Critical period	Maturing
Rooting depth	______inches	______inches	______inches	______inches
Total available soil moisture capacity	______inches	______inches	______inches	______inches
Allowable depletion	______%	______%	______%	______%
Allowable soil moisture deficit	______inches	______inches	______inches	______inches

Week After Emergence	Date	Soil Moisture Reading		Maximum Temperature	Add	Subtract		Total	
					Crop Water Use	Rain	Net Irrigation	Soil Moisture Deficit	
		A	B					A	B

Week After Emergence	Date	Soil Moisture Reading		Maximum Temperature	Add	Subtract		Total	
					Crop Water Use	Rain	Net Irrigation	Soil Moisture Deficit	
		A	B					A	B

Continue on added sheets as needed.

Soil Moisture Balance Worksheet

Field________________ Crop________________ Emergence date_______________

Irrigation application capacity__________ net inches/day

Growth stage	Seedling	Vegetative	Critical period	Maturing
Rooting depth	______inches	______inches	______inches	______inches
Total available soil moisture capacity	______inches	______inches	______inches	______inches
Allowable depletion	______%	______%	______%	______%
Allowable soil moisture deficit	______inches	______inches	______inches	______inches

Week After Emergence	Date	Soil Moisture Reading		Maximum Temperature	Add	Subtract		Total	
					Crop Water Use	Rain	Net Irrigation	Soil Moisture Deficit	
		A	B					A	B

Week After Emergence	Date	Soil Moisture Reading		Maximum Temperature	Add	Subtract		Total	
					Crop Water Use	Rain	Net Irrigation	Soil Moisture Deficit	
		A	B					A	B

Continue on added sheets as needed.