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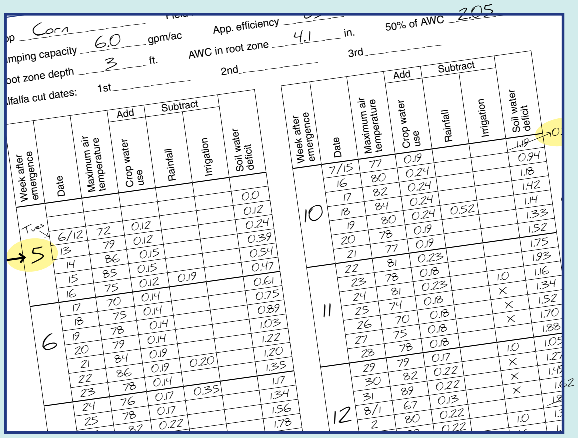

Irrigation Scheduling by the Checkbook Method

Revised by

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With variable rain events and a mixture of soil types, determining when to irrigate and how much water to apply during the growing season can be a challenge. With too little water, the crop is stressed, while with too much water, crops are stunted and fertilizer is leached below the root zone, and pumping costs are increased. Either way, the crop suffers and reduces the yield.

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Definitions

(Adapted from American Society of Agricultural and Biological Engineers (ASABE) Standard S526.4, used with permission)

Available soil water, more commonly called available water capacity (AWC): The portion of soil water that plant roots of most crops can absorb readily; expressed in millimeters (mm) of water per mm of soil (inches per inch, inches per foot or total inches) for a specific soil depth. It is the amount of water stored in the soil between field capacity (FC) and permanent wilting point (WP). It typically is adjusted for salinity (electrical conductivity) and rock fragment content. In some texts it also is called available water-holding capacity (AWHC).

Crop evapotranspiration (ETc): The amount of water used by the crop in transpiration and building of plant tissue, and that evaporated from adjacent soil or was intercepted by plant foliage. It is expressed as depth in mm (inches, or as the volume-depth ratio of acre-inches per acre) and can refer to daily, peak, design, monthly or seasonal quantities. Sometimes referred to as consumptive use (CU).

Crop water use: Calculated or measured water used by plants; expressed in mm per day (inches per day). Same as ETc except it is expressed as daily use only.

Deficit irrigation: An irrigation water management alternative where the soil in the plant root zone is not refilled to field capacity in all or part of the field.

Field capacity (FC): Amount of water remaining in a soil when the downward water flow due to gravity becomes negligible. An estimate of field capacity ranges between soil water contents at matric potentials of minus 10 to minus 33 kilopascal (kPa) (minus 0.1 to minus 0.33 bar).

Irrigation scheduling: The process of determining when to irrigate and how much water to apply based upon measurements or estimates of soil moisture or water used by the plant.

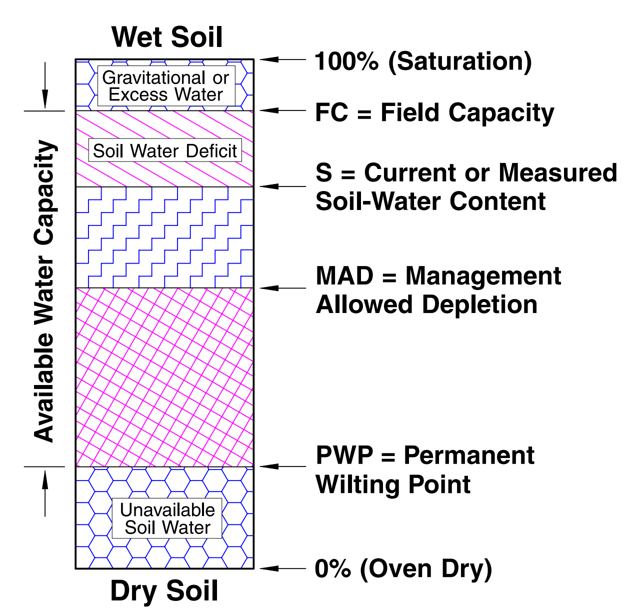
Management-allowed depletion (MAD): The desired soil-water deficit at the time of irrigation.

Permanent wilting point (PWP): Soil water content below which plants cannot readily obtain water and permanently wilt. Sometimes called "permanent wilting percentage," or WP. Often estimated as the water content corresponding to a matric potential of minus 1.5 megapascal (MPa) (minus 15 bar).

Soil-water deficit: Amount of water required to raise the soil-water content of the crop root zone to field capacity. It is measured in mm (inches) of water. Also called soil-water depletion.

Water application efficiency: Ratio of the average depth of water infiltrated and stored in the root zone to the average depth of water applied.

Water-holding capacity (WHC): Total amount of water held in a freely drained soil per increment of depth. It is the amount of water held between field capacity and the oven-dry moisture level; expressed in centimeters/centimeters (cm/cm) (inches/inch), centimeters/meter (cm/m) (inches/foot) or total centimeters (inches) for a specific soil depth. Sometimes called total water-holding capacity.



Adapted from Steele et.al. 2010, Applied Engineering in Agriculture with permission from ASABE

A system for scheduling irrigation using the “checkbook” method is outlined in this publication. It’s called the checkbook method because it operates just like a bank checking account. Rain and irrigation are deposits to the soil and the crop withdraws water from the root zone.

During the critical growth periods, the checkbook requires almost daily updates by the irrigator and, if used properly, it is a proven tool for irrigation scheduling.

Quick Start to Using the Checkbook

To use the checkbook method, the irrigation manager needs to obtain the maximum daily air temperature and have at least one and preferably two accurate rain gauges in or near the field being irrigated. Using the maximum daily air temperature, crop water use can be estimated from tables in this publication. The daily water use is entered into a soil water balance sheet to determine the amount of soil water removed from the root zone and the soil water deficit.

Crop water use increases the deficit, but rain and irrigation reduce the deficit. When a predetermined soil water deficit is reached, irrigation should be started.

To start, study the example soil water balance sheet and then begin your own checkbook using the blank copies at the end of this publication.

Soil Water-holding Capacity

The checkbook method is a root-zone soil-water accounting method. The amount of water plant roots can extract is a soil’s available water capacity. This is the difference in water content between a wet soil at field capacity and a dry soil at the permanent wilting point.

Soil texture is the major factor affecting soil water-holding capacity. Texture refers to the relative amounts of sand, silt and clay particles in the soil. The available water-holding capacity of the soil must be determined prior to the start of irrigation scheduling.

The available water capacity of soils in the field can be estimated using the values shown in Table 1. If more than one soil type is present in the field, the soil with the lowest water-holding capacity should be used for scheduling irrigations. However, if that soil type covers a relatively small area, the soil type covering the largest area should be used.

More accurate estimates for field soils can be found in the county soil survey books or on the Natural Resources Conservation Service (NRCS) Web Soil Survey website: https://websoilsurvey.sc.egov.usda.gov.

Table 1. Range of plant-available water for different soil textures.

Soil Texture	Inches of Water per Inch of Soil	Inches of Water per Foot of Soil
Coarse sand and gravel	0.02 to 0.06	0.2 to 0.7
Sands	0.04 to 0.09	0.5 to 1.1
Loamy sands	0.06 to 0.12	0.7 to 1.4
Sandy loams	0.11 to 0.15	1.3 to 1.8
Fine sandy loams	0.14 to 0.18	1.7 to 2.2
Loams and silt loams	0.17 to 0.23	2.0 to 2.8
Clay loams and silty clay loams	0.14 to 0.21	1.7 to 2.5
Silty clays and clays	0.13 to 0.18	1.6 to 2.2

The Root Zone

Assuming no subsurface restrictions, at maturity, each crop has a typical fully developed root zone depth. The root zone determines to what depth the plant can extract water from the soil.

The root zone of annual crops may not fully develop until eight weeks after the crop emerges. However, established perennials such as alfalfa and forage grasses will start with deeper roots.

Plant roots extract the greatest amount of soil water from the upper part of the root zone, and each crop is different. Generally, for all the crops shown in Figure 1, more than 90 percent of the water extracted from the root zone during the growing season will come from the depth shown as shaded.

Therefore, a depth less than a fully developed root zone can be used for irrigation management purposes. Fully developed root zone depths, along with irrigation management depths, are shown in Table 2.

At the beginning of crop emergence and growth, having the soil water-holding capacity in the total root zone at or near field capacity is important. Moist soil is necessary for germination and proper root development.

However, low previous autumn rainfall, no winter snow accumulations and less spring rain may result in dry subsoil below about 2 feet. Under these conditions, irrigating prior to or after planting to store water in the lower part of the root zone may be necessary.

Roots will not grow through or into a dry layer of soil, and a reduced root depth will result. Thus, checking the soil moisture to at least the 3-foot depth prior to or at planting time is important.

Table 2. Typical range of crop root depths in deep soils, along with the recommended irrigation water management depth.

Crop	Depth of Fully Developed Root Zone (inches)	Depth of Root Zone for Irrigation Water Management (inches)
Potatoes	24 to 30	18
Soybeans, dry edible beans	30 to 36	24
Wheat, barley, oats	42 to 48	36
Corn, sugar beets, sunflowers	48 to 54	36
Established alfalfa and forage grasses	60 to 72	48

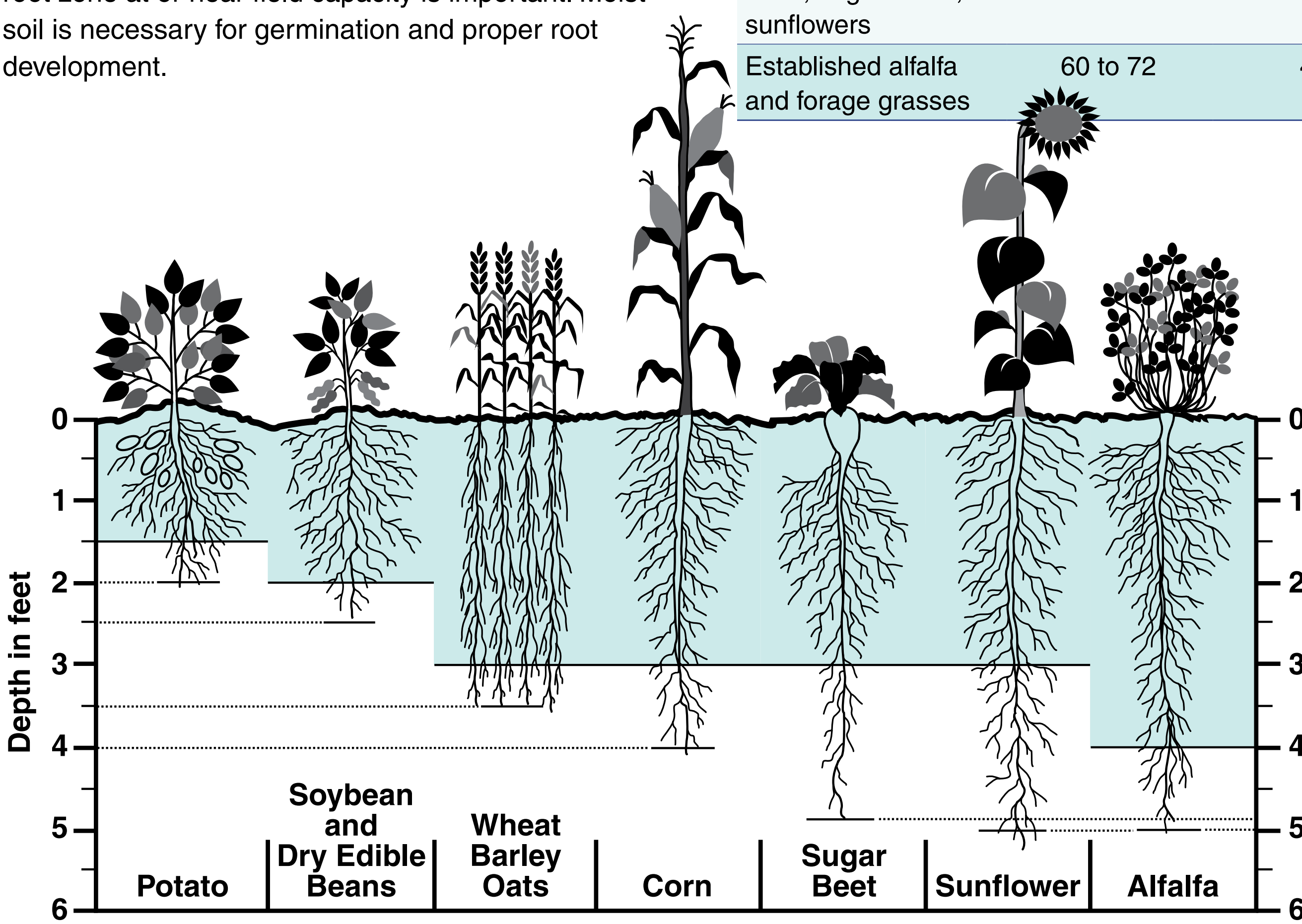


Figure 1. Typical fully developed root zone depths for the commonly irrigated crops in North Dakota. The shaded area is the irrigation water management depth.

Crop Water Use

During a particular day, water use is dependent on the type of crop, stage of growth, air temperature, solar radiation (sunshine), wind speed, relative humidity and soil water content in the root zone. These are a lot of variables, and determining water use may seem complicated.

However, based on many years of research, the estimation of crop water use has been simplified for North Dakota conditions. This publication includes tables for estimating each crop's water use based solely on daily maximum air temperature and stage of growth.

Tables 6 through 14 give the estimated water use in inches per day for the most commonly irrigated crops in North Dakota. The daily crop water use can be obtained by recording the maximum daily air temperature to within 10 F and knowing the date of crop emergence.

The date of crop emergence is when you can see about half the plants have emerged. Critical crop growth stages also are indicated on the lower part of the tables. Sometimes, due to variable weather conditions, the critical crop growth stage should determine the number of weeks past emergence, rather than the calendar.

Maximum daily air temperature is available for any location in North Dakota on TV weather broadcasts, many internet weather sites and from the local North Dakota Agricultural Weather Network station (NDAWN, www.ndawn.org).

Table 3. System pumping capacity in gallons per minute per acre for common irrigated areas under center pivots for various pumping rates assuming no evaporation or wind drift losses.

Pumping Rate (gpm)	Irrigated Area (acres)				
	80	100	125	132	154
400	5.00	4.00	3.20	3.03	2.60
500	6.25	5.00	4.00	3.79	3.25
600	7.50	6.00	4.80	4.55	3.90
700	8.75	7.00	5.60	5.30	4.55
800	10.00	8.00	6.40	6.06	5.19
900	11.25	9.00	7.20	6.82	5.84
1,000	12.50	10.00	8.00	7.58	6.49
1,100	13.75	11.00	8.80	8.33	7.14
1,200	15.00	12.00	9.60	9.09	7.79

Pumping Capacity

The pumping capacity determines the application rate of the irrigation system. Pumping capacity often is referred to in units of gallons per minute (gpm) per irrigated acre. For example, a 750 gpm pumping rate used to irrigate 125 acres has a 6 gpm/acre pumping capacity (750 ÷ 125). A 500 gpm pumping rate used to irrigate 100 acres has a 5 gpm/acre pumping rate (Table 3).

Water Application Efficiency

Sprinkler irrigation is not 100 percent efficient. Due to evaporation and wind drift, not all pumped water gets into the soil for plant growth.

The amount of water that does not infiltrate into the soil determines the application efficiency of the system. For example, if the irrigation system is set to apply 1 inch of water but only 0.85 inch infiltrates into the soil, the application efficiency is (0.85 ÷ 1.0) x 100, or 85 percent. However, application efficiency can vary from about 50 percent during a hot, windy afternoon to more than 95 percent with calm winds after dark.

For good irrigation water management, the pumping capacity should match the average peak water use of the crop. For example, the **seasonal average** peak water use of corn is about 0.27 inch per day, although the **daily** peak water use may exceed 0.30 inch per day.

Therefore, the minimum pumping capacity should be able to apply the seasonal average peak amount of water with the understanding that on some days, the crop water use will be greater. Replacing 0.27 inch used by the corn in one day requires a pumping rate of 6 gpm/acre, assuming 85 percent application efficiency (Table 4).

With sprinklers mounted on the top of the center pivot span pipe, the **average** annual application efficiency is about 85 percent when applying 1 inch of water or more, but it drops to 80 percent when applying ½ to ¾ inch. Why? Because most of the pumped water that doesn't get to the soil is lost to water that wets the plants and evaporates. The same amount is lost whether 1 inch or ½ inch is applied.

With sprinklers mounted on drop pipes, the application efficiency can be greater than 85 percent because less foliage is wetted. The pumping capacity shown in Table 3 can be translated into equivalent daily infiltrated depths for the various application efficiencies shown in Table 4.

For example, a center pivot with a 5.5 gpm/acre pumping capacity has an application efficiency of 85 percent. If the percent timer on the center pivot is set to apply 0.9 inch, making a revolution will take slightly more than three days (obtain 0.29 inch from the last column in Table 4, then 0.9 inch ÷ 0.29 inch/day = 3.1 days).

But only 85 percent of 0.9 inch, or 0.76 inch, actually will infiltrate into the soil for plant use. Thus, the net applied amount is 0.76 inch, or approximately 0.25 inch/day, as shown in the 85 percent column in Table 4.

Table 4. Pumping capacity represented as an equivalent daily infiltrated depth assuming 24-hour-per-day pumping.

	Application Rate (inches/day)				
Pumping Capacity (gpm/acre)	80 % Efficiency	85 % Efficiency	90 % Efficiency	95% Efficiency	100 % Efficiency, No Water Loss to Evaporation
4	0.17	0.18	0.19	0.20	0.21
4.5	0.19	0.20	0.21	0.23	0.24
5	0.21	0.22	0.24	0.25	0.26
5.5	0.23	0.25	0.26	0.28	0.29
6	0.25	0.27	0.29	0.30	0.32
6.5	0.28	0.29	0.31	0.33	0.34
7	0.30	0.31	0.33	0.35	0.37
7.5	0.32	0.34	0.36	0.38	0.40
8	0.34	0.36	0.38	0.40	0.42

Determining Soil Water Deficit

The checkbook expresses the soil water content in terms of deficit, which is the difference between the soil water content at field capacity and the current soil water content in the root zone. It is presented as inches of water deficit or as a percentage of the available water capacity.

Think of it as the amount of water required to fill the root zone to field capacity or the point of zero deficit. One way to picture this concept is to imagine a tube that contains 4 inches of water when full, but if it only contains 3 inches of water, then it is one-fourth low, or it has a deficit of 1 inch of water, or 25 percent. To fill the tube, 1 inch must be added.

To begin the checkbook method of scheduling, you must determine the soil water content in the field at the start of the growing season (day of emergence). The initial soil water content can be determined with soil moisture sensors, but the easiest way is to use a soil probe to obtain samples from several areas of the field. Pay particular attention to areas with the coarsest soil textures.

Estimate the soil water deficit using the "Feel Method" outlined in Table 5. Soil samples should be taken in 6-inch increments to the depth used for water management (Table 2). Brochures with pictures showing the feel method for various soil textures can be found on the internet by doing a search using "soil water by the feel method" or go to the website listed in the section titled Additional Irrigation Scheduling Resources for North Dakota

Standard soil probe. (Tom Scherer, NDSU)

Testing soil moisture in the top 6 inches with a soil probe. (Tom Scherer, NDSU)

Wet soil that forms a tight ball and indicates more than 75 percent available water. (Tom Scherer, NDSU)

Dry soil with less than 50 percent of available water. (Tom Scherer, NDSU)

The total root zone deficit is computed by adding the deficits for each foot. The example below shows the procedure to estimate the soil water deficit in a 3-foot root zone. This should be done at the start of the growing season and about every two weeks after emergence, depending on rain events.

Example: Estimating Soil Water Deficit	Corn was planted and has a 3-foot water management root zone (from Table 2).

Soil Water-holding Capacity at One Location in the Field		
Soil Depth	**Soil Texture**	**Average Water-holding Capacity (Table 1)**
0 to 1 foot	Fine sandy loam (fsl)	0.16 inch per inch
1 to 3 feet	Loamy sand (ls)	0.09 inch per inch

Estimated Deficit			
Soil Depth	**Water-holding Capacity (Table 1)**	**Estimated Percent Deficit from Field Measurements (Table 5)**	**Deficit (inches)**
0 to 6 inches	6 in x 0.16 in/in = 0.96	x 50 %	= 0.48
6 to 12 inches	6 in x 0.16 in/in = 0.96	x 40 %	= 0.38
12 to 24 inches	12 in x 0.09 in/in = 1.08	x 30 %	= 0.32
24 to 36 inches	12 in x 0.09 in/in = 1.08	x 20 %	= 0.22
Total	4.1		1.4
		Percent Deficit	**34**

Table 5. Guide for judging how much water has been removed from the soil. The numbers in each box are approximate inches of water deficit in 1 foot of soil depth. Divide the numbers by 2 for 6-inch soil layers. Note: A ball is formed by firmly squeezing a handful of soil. A ribbon is formed by squeezing some soil between the thumb and forefinger and pushing forward.

Soil Water Deficit	Fine Sands and Loamy Sands	Sandy Loams and Fine Sandy Loams	Loams, Silt Loams, Silty Clay Loams	Clay Loams, Silty Clays and Clay
0% to 5% (about) (field capacity)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand, 0.0	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand, 0.0	Upon squeezing, some free water appears on soil with wet outline of ball left on hand, 0.2	Upon squeezing, some free water appears on soil with wet outline of ball left on hand, 0.3
5–25% - Wet	Forms a weak ball under pressure with water staining on fingers, 0 to 0.2	Forms a weak ball and makes a weak ribbon that breaks easily, 0 to 0.4	Forms a ball; very pliable that ribbons easily, 0.0 to 0.5	Forms a ball, ribbons easily and has a slick feeling, 0 to 0.6
25–50% - Moist	Forms a weak ball; will not ribbon but some water staining on fingers, 0.2 to 0.5	Forms a ball under pressure with light staining on fingers, 0.4 to 0.8	Forms a ball that is somewhat plastic and forms a weak ribbon, 0.5 to 1.0	Forms a smooth ball and ribbons, 0.6 to 1.2
50–75% - Slightly Moist	Appears to be dry but will form a weak ball when squeezed, 0.5 to 0.8	Forms a weak ball with finger marks but not much staining on fingers, 0.8 to 1.2	Forms a weak ball but holds together with pressure and no water staining on fingers, 1 to 1.5	Forms weak ball; somewhat pliable but no water stains on hand, 1.2 to 1.9
75–100% - Dry (100% soil water deficit results in permanent wilting)	Dry, loose and single grains flow through fingers, 0.8 to 1	Forms a very weak ball and soil grains break away easily, 1.2 to 1.5	Dry and sometimes slightly crusted; clods crumble with pressure, 1.5 to 2	Baked hard; clods are hard to crumble with pressure, 1.9 to 2.5

Soil Water Balance

The soil water balance uses a checkbook like accounting procedure to show the amount of water removed from the soil profile (the deficit). Crop water use removes water from the soil and increases the deficit on a daily basis, while irrigation and/or rain add water to the soil and decrease the deficit. The purpose of irrigation scheduling is to:

- Prevent the soil water deficit from becoming excessive, causing plant stress
- Restrict irrigation when the deficit is very small

The amount of irrigation should not be greater than the deficit amount because this leads to leaching of nutrients and deep percolation below the root zone. Also, you must leave some room for rain to reduce runoff potential.

An important aspect of scheduling irrigations is to look several days into the future to determine when irrigation may be needed. For example, a center pivot can take three days or more to make a complete revolution and cover a field. The checkbook can be used to project and estimate what the soil water deficit will be on the last irrigated sector of the field to help determine when to start the irrigation system.

Irrigation Trigger Points Based on Soil Water Deficit

In general, annually planted crops are most sensitive to water stress in the reproductive stage of growth (flowering or early seed fill). They are less sensitive to water stress early in the growing season and later when approaching physiological maturity.

The most common scheduling guideline is to prevent the soil moisture deficit from exceeding 50 percent in the root zone. This is a general recommendation and applies to most agronomic crops such as corn, soybean, alfalfa and dry bean.

However, potato quality is very sensitive to water stress, and most growers do not want the deficit to be greater than 35 to 40 percent. On the other hand, sunflower and some forage crops can withstand a slightly higher deficit than 50 percent. Corn and soybean can withstand deficits up to 60 percent during vegetative growth, but with the onset of tasselling or blossoms, they should be irrigated to maintain a deficit of 50 percent or less.

Soil Water Balance Sheet

A completed soil water balance sheet example and blank copies are included in this publication. The irrigation manager should keep a balance sheet for each individual irrigated field. Keeping a soil water balance between zero and the allowable deficit for the specific crop in the field is the goal of irrigation scheduling.

Recording Rain and Irrigation Amounts

To use the balance sheet, the dates and measured amounts of irrigation and rain must be recorded. Rain is so variable over the landscape that two easily accessible rain gauges should be located in or near each irrigated field. Ideally, rain gauges should be located as shown in Figure 2.

The rain gauges should be at least 3 inches in diameter for accuracy. The standard 4-inch-diameter National Weather Service rain gauge that records rain events to 0.01 inch is highly recommended.

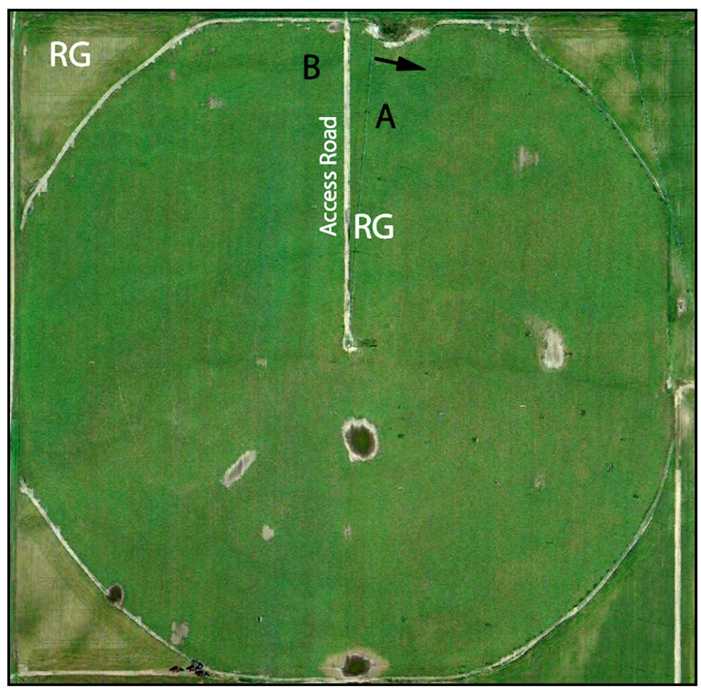


Figure 2. Ideally, each center pivot should have two rain gauges, one in the dryland corner and one along the access road about halfway to the pivot point. Soil moisture deficit should be measured near the starting point of the center pivot (A) and near the last part of the field to be irrigated (B).

Daily Crop Water Use Estimates

Tables 6 through 14 provide estimates of water use for the major irrigated crops in North Dakota. To use the tables, you need to know the daily maximum air temperature and the number of weeks after emergence. To make the process easy, the maximum air temperature for a day has to be only within a 10-degree range. As an illustration, on the example soil water balance sheet, the maximum temperature on July 11 was 85 degrees.

To obtain a crop water use estimate for corn, look on Table 6 under the ninth week after emergence in the row for the range of 80 to 90 degrees to find a crop water use estimate of 0.25 inch. Estimating alfalfa water use is different because alfalfa is cut several times during the growing season and water use is reduced after cutting. The additional tables that accompany Table 14 can be used to estimate alfalfa water use the first three weeks after cutting.

Site-specific and more accurate crop water use values can be obtained by accessing the North Dakota Agricultural Weather Network website at www.ndawn.org. Look under “Applications” in the left-hand menu. To obtain the water use estimates, select the nearest weather station on the network, the crop, emergence date and time period.

To use the balance sheet, enter the estimated water use and add this to the previous day’s soil water deficit. For the first day after emergence, enter the estimated deficit from the field measurements. Subtract rain and/or irrigation for that day and record the new soil water deficit amount.

Standard 4-inch-diameter National Weather Service rain gauge

Compare this to the 50 percent deficit point shown at the top of the balance sheet (2.05 inches on the example balance sheet) to determine when irrigation is needed. Of course, check weather reports to see if rain is forecast for the area where the field is located.

Remember, the soil water deficit never can be less than zero because zero indicates the soil is at field capacity. If a negative deficit is calculated for a particular day, enter zero in the deficit column.

To ensure the checkbook is tracking the soil water deficit accurately, the field should be probed to root zone depth about every two weeks at several locations. If the checkbook is different from the field measurements, enter the measured deficit value for that day.

Additional Irrigation Scheduling Resources for North Dakota

- An Excel spreadsheet version of this checkbook that can be used in North Dakota and Minnesota has been developed. It can be downloaded, along with a users manual, from this website: www.ag.ndsu.edu/irrigation/irrigation-scheduling.
- A site-specific irrigation-scheduling program for North Dakota also is available in the “Applications” section of the NDAWN website. This program automatically imports the soil properties for your specific field. It is updated automatically every day using weather data from the nearest NDAWN station. A users manual for this program can be found at: www.ag.ndsu.edu/irrigation/irrigation-scheduling.
- A pictorial-based version of estimating soil water by the feel method can be found at: www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_051845.pdf.

Acknowledgments

The first version of this publication was authored by Darnell R. Lundstrom and Earl C. Stegman in 1976, reprinted in 1983 and revised in 1988. This publication is a revision and update of the 1988 version. We are indebted to these gentlemen for coining the term “Checkbook Method,” which is used throughout the U.S. to refer to soil water accounting methods for irrigation scheduling.

Sample Soil Water Balance Sheet

Soil Water Balance Sheet

Crop: Corn Field name: SW 23 Emergence date: 5/15/18

Table 4 → Pumping capacity: 6.0 gpm/ac App. efficiency: 85 % Net irrig.: 0.27 in/day

Table 2 → Root zone depth: 3 ft. AWC in root zone: 4.1 in. 50% of AWC: 2.05 in.

Alfalfa cut dates: 1st ______ 2nd ______ 3rd ______

Week after emergence	Date	Maximum air temperature	Add	Subtract		Soil water deficit
			Crop water use	Rainfall	Irrigation	
Tues						0.0
5	6/12	72	0.12			0.12
	13	79	0.12			0.24
	14	86	0.15			0.39
	15	85	0.15			0.54
	16	75	0.12	0.19		0.47
6	17	70	0.14			0.61
	18	75	0.14			0.75
	19	78	0.14			0.89
	20	79	0.14			1.03
	21	84	0.19			1.22
	22	86	0.19	0.20		1.20
	23	78	0.14			1.35
7	24	76	0.17	0.35		1.17
	25	78	0.17			1.34
	26	82	0.22			1.56
	27	85	0.22			1.78
	28	89	0.22			2.00
	29	80	0.22	0.47		1.75
	30	76	0.17		0.75	1.17
8	7/1	81	0.24		X	1.41
	2	83	0.24		X	1.65
	3	83	0.24	0.42		1.47
	4	77	0.19	0.48		1.18
	5	77	0.19			1.37
	6	82	0.24	0.43		1.18
	7	92	0.30			1.48
9	8	84	0.25	0.11		1.62
	9	82	0.25			1.87
	10	86	0.25	4.93		0.0
	11	85	0.25			0.25
	12	81	0.25			0.50
	13	87	0.25			0.75
	14	89	0.25			1.00

Week after emergence	Date	Maximum air temperature	Add	Subtract		Soil water deficit
			Crop water use	Rainfall	Irrigation	
10	7/15	77	0.19			~~1.19~~ → 0.70
	16	80	0.24			0.94
	17	82	0.24			1.18
	18	84	0.24			1.42
	19	80	0.24	0.52		1.14
	20	78	0.19			1.33
	21	77	0.19			1.52
11	22	81	0.23			1.75
	23	78	0.18			1.93
	24	81	0.23		1.0	1.16
	25	74	0.18		X	1.34
	26	70	0.18		X	1.52
	27	75	0.18		X	1.70
	28	78	0.18			1.88
12	29	79	0.17		1.0	1.05
	30	82	0.22		X	1.27
	31	89	0.22		X	1.49
	8/1	67	0.13		X	1.62
	2	80	0.22			~~1.84~~ → 2.1
	3	88	0.22		1.0	1.32
	4	89	0.22		X	1.54
13	5	80	0.21		X	1.75
	6	79	0.17		X	1.92
	7	88	0.21		1.0	1.13
	8	88	0.21		X	1.34
	9	88	0.21		X	1.55
	10	91	0.26		X	1.81
	11	93	0.26		1.0	1.07
14	12	99	0.25		X	1.32
	13	84	0.20		X	1.52
	14	71	0.16		X	1.68
	15	81	0.20			1.88
	16					
	17					
	18					

Week after emergence → 5

Add 0.61 to 0.14 to get 0.75

Maximum daily air temp is recorded and estimated crop water use is taken from Table 6

Rain amount exceeds previous days deficit plus today's crop water use

Irrigation is started so deficit does not exceed 50% of AWC. The pivot timer is set to apply 0.75 inches in 3 days

Soil water deficit is corrected by probing the field using the soil feel method (Table 5)

Rain and irrigation are subtracted from previous days deficit

Checkbook is up to date

Soil Water Balance Sheet

Crop ______________________ Field name ______________________ Emergence date ____________

Pumping capacity ___________ gpm/ac App. efficiency __________ % Net irrig. ___________ in/day

Root zone depth ____________ ft. AWC in root zone ____________ in. 50% of AWC ___________ in.

Alfalfa cut dates: 1st______________ 2nd______________ 3rd______________

Week after emergence	Date	Maximum air temperature	Add	Subtract		Soil water deficit
			Crop water use	Rainfall	Irrigation	

Week after emergence	Date	Maximum air temperature	Add	Subtract		Soil water deficit
			Crop water use	Rainfall	Irrigation	

Soil Water Balance Sheet

Crop ________________________ Field name ________________________ Emergence date _____________

Pumping capacity ____________ gpm/ac App. efficiency ___________ % Net irrig. ____________ in/day

Root zone depth _____________ ft. AWC in root zone _____________ in. 50% of AWC ____________ in.

Alfalfa cut dates: 1st_______________ 2nd_______________ 3rd_______________

			Add	Subtract		
Week after emergence	Date	Maximum air temperature	Crop water use	Rainfall	Irrigation	Soil water deficit

			Add	Subtract		
Week after emergence	Date	Maximum air temperature	Crop water use	Rainfall	Irrigation	Soil water deficit

Water Use Estimates for Irrigated Crops in North Dakota

Table 6. Average Corn Water Use (inches/day)

Week After Emergence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Date																	
Maximum Temperature 50-59°F	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.06	0.04	0.03
60-69°F	0.02	0.03	0.05	0.06	0.08	0.10	0.12	0.14	0.14	0.13	0.13	0.13	0.12	0.11	0.09	0.07	0.06
70-79°F	0.03	0.04	0.06	0.09	0.12	0.14	0.17	0.19	0.19	0.19	0.18	0.17	0.17	0.16	0.13	0.10	0.08
80-89°F	0.04	0.06	0.08	0.11	0.15	0.19	0.22	0.24	0.25	0.24	0.23	0.22	0.21	0.20	0.17	0.13	0.10
90-99°F	0.05	0.07	0.10	0.14	0.18	0.23	0.27	0.30	0.30	0.29	0.29	0.27	0.26	0.25	0.20	0.16	0.12

3 Leaf | 12 Leaf | Tassel | Silk | Pollinate | Blister Kernel | Early Dent | Dent | Black Layer

Table 7. Average Wheat Water Use (inches/day)

Week After Emergence	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date														
Maximum Temperature 50-59°F	0.01	0.03	0.04	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.04	0.03
60-69°F	0.02	0.04	0.07	0.10	0.12	0.13	0.14	0.14	0.14	0.14	0.12	0.10	0.07	0.04
70-79°F	0.03	0.06	0.10	0.13	0.17	0.19	0.19	0.19	0.19	0.19	0.17	0.14	0.10	0.06
80-89°F	0.04	0.08	0.12	0.17	0.22	0.24	0.24	0.25	0.25	0.25	0.22	0.17	0.12	0.08
90-99°F	0.05	0.10	0.15	0.21	0.26	0.29	0.30	0.30	0.30	0.30	0.27	0.21	0.15	0.09

2 Tiller | Joint | Boot | Heading | Flower | Early Milk | Early Dough | Hard Dough

Table 8. Average Barley Water Use (inches/day)

Week After Emergence	1	2	3	4	5	6	7	8	9	10	11	12	13
Date													
Maximum Temperature 50-59°F	0.02	0.03	0.05	0.06	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.04	0.02
60-69°F	0.03	0.05	0.08	0.10	0.13	0.13	0.13	0.14	0.14	0.12	0.09	0.06	0.03
70-79°F	0.04	0.07	0.11	0.14	0.18	0.18	0.19	0.19	0.19	0.17	0.13	0.08	0.04
80-89°F	0.05	0.09	0.13	0.19	0.23	0.23	0.24	0.24	0.25	0.22	0.17	0.11	0.05
90-99°F	0.06	0.10	0.16	0.23	0.28	0.29	0.29	0.30	0.30	0.27	0.20	0.13	0.06

4-5 Leaf | Heading | Milk

Table 9. Average Soybean Water Use (inches/day)

Week After Emergence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Date																
Maximum Temperature 50-59°F	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.08	0.08	0.07	0.07	0.06	0.05	0.04
60-69°F	0.02	0.03	0.05	0.07	0.09	0.11	0.12	0.13	0.13	0.13	0.13	0.12	0.11	0.10	0.08	0.06
70-79°F	0.03	0.05	0.07	0.09	0.12	0.15	0.17	0.19	0.19	0.18	0.17	0.17	0.16	0.14	0.11	0.08
80-89°F	0.04	0.06	0.09	0.12	0.15	0.19	0.22	0.24	0.24	0.23	0.22	0.21	0.20	0.18	0.14	0.10
90-99°F	0.05	0.07	0.11	0.15	0.19	0.23	0.27	0.29	0.29	0.29	0.27	0.26	0.25	0.22	0.17	0.13
				3rd Trifoliate				Flower				Upper Pod Fill			Leaf Drop	

Table 10. Average Sunflower Water Use (inches/day)

Week After Emergence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Date															
Maximum Temperature 50-59°F	0.01	0.03	0.05	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.04	0.03
60-69°F	0.02	0.05	0.08	0.10	0.12	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.10	0.07	0.04
70-79°F	0.03	0.07	0.11	0.15	0.17	0.19	0.19	0.19	0.19	0.18	0.17	0.16	0.13	0.10	0.06
80-89°F	0.03	0.09	0.14	0.19	0.22	0.25	0.25	0.25	0.24	0.23	0.22	0.21	0.17	0.13	0.07
90-99°F	0.04	0.11	0.17	0.23	0.27	0.30	0.30	0.30	0.29	0.29	0.27	0.26	0.21	0.15	0.09
						Bud		Ray Flower		100% Anther		Ray Petal Drop			Maturity

Table 11. Average Potato Water Use (inches/day)

Week After Emergence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Date															
Maximum Temperature 50-59°F	0.02	0.03	0.04	0.05	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.05	0.04
60-69°F	0.03	0.04	0.07	0.09	0.11	0.13	0.14	0.14	0.14	0.13	0.13	0.12	0.10	0.09	0.07
70-79°F	0.04	0.06	0.09	0.12	0.15	0.17	0.19	0.19	0.19	0.19	0.18	0.17	0.14	0.12	0.10
80-89°F	0.05	0.08	0.12	0.16	0.19	0.22	0.25	0.25	0.25	0.24	0.23	0.21	0.18	0.16	0.13
90-99°F	0.06	0.10	0.14	0.19	0.24	0.27	0.30	0.30	0.30	0.29	0.29	0.26	0.23	0.19	0.16
			7 Inch	Budding		Full Cover									

Water Use Estimates for Irrigated Crops in North Dakota

Table 12. Average Pinto Bean Water Use (inches/day)

Week After Emergence	1	2	3	4	5	6	7	8	9	10	11	12	13
Date													
Maximum Temperature 50-59°F	0.02	0.03	0.04	0.05	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.05
60-69°F	0.04	0.05	0.06	0.08	0.11	0.13	0.14	0.14	0.13	0.13	0.13	0.11	0.08
70-79°F	0.05	0.06	0.09	0.12	0.15	0.18	0.19	0.19	0.19	0.18	0.17	0.15	0.11
80-89°F	0.06	0.08	0.11	0.15	0.19	0.23	0.25	0.25	0.24	0.23	0.22	0.19	0.14
90-99°F	0.08	0.10	0.14	0.18	0.23	0.28	0.30	0.30	0.29	0.29	0.27	0.24	0.17

4 Leaf | Auxillary Bud | Flower | Podding | Initial Stripe | Leaf Yellow | Maturity

Table 13. Average Sugar Beet Water Use (inches/day)

Week After Emergence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Date																				
Maximum Temperature 50-59°F	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.05
60-69°F	0.02	0.04	0.05	0.06	0.08	0.10	0.11	0.13	0.14	0.14	0.13	0.13	0.13	0.12	0.11	0.10	0.10	0.09	0.08	0.08
70-79°F	0.03	0.05	0.07	0.09	0.11	0.14	0.16	0.18	0.19	0.19	0.19	0.18	0.17	0.17	0.16	0.15	0.14	0.13	0.12	0.11
80-89°F	0.04	0.06	0.09	0.12	0.15	0.17	0.20	0.23	0.24	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.17	0.16	0.15	0.14
90-99°F	0.05	0.08	0.11	0.14	0.18	0.21	0.25	0.28	0.30	0.30	0.29	0.29	0.27	0.26	0.25	0.23	0.21	0.20	0.18	0.17

4-6 Leaf | 10-12 Leaf | Full Cover

Table 14. Average Alfalfa Water Use (inches/day)

Week After May 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Date																						
Maximum Temperature 50-59°F	0.04	0.05	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.05
60-69°F	0.07	0.09	0.11	0.12	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.11	0.10	0.10	0.09	0.08	0.08
70-79°F	0.09	0.12	0.15	0.17	0.18	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.18	0.17	0.17	0.16	0.15	0.14	0.13	0.12	0.11
80-89°F	0.12	0.16	0.19	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.25	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.17	0.16	0.15	0.14
90-99°F	0.15	0.19	0.23	0.27	0.28	0.29	0.29	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.27	0.26	0.25	0.23	0.21	0.20	0.18	0.17

Use these tables for the first three weeks after cutting.

Week After 1st and 2nd Cut	1	2	3
Maximum Temperature 50-59°F	0.05	0.06	0.08
60-69°F	0.08	0.11	0.13
70-79°F	0.11	0.15	0.18
80-89°F	0.15	0.19	0.23
90-99°F	0.18	0.23	0.28

Week After 3rd Cut	1	2	3
Maximum Temperature 50-59°F	0.04	0.05	0.07
60-69°F	0.07	0.09	0.11
70-79°F	0.10	0.13	0.15
80-89°F	0.13	0.16	0.20
90-99°F	0.15	0.20	0.24

Worksheet to Estimate the Soil Water Deficit at One Location in the Field (see example on page 7)

Estimating Soil Water Deficit	Crop ________________	Root zone ________________ (from Table 2)

Soil Water-holding Capacity at One Location in the Field		
Soil Depth	**Soil Texture**	**Average Water-holding Capacity (Table 1)**

Estimated Deficit			
Soil Depth	**Water-holding Capacity (Table 1)**	**Estimated Percent Deficit From Field Measurements and Table 5**	**Deficit (inches)**
0 to 6 inches		x	=
6 to 12 inches		x	=
12 to 18 inches		x	=
18 to 24 inches		x	=
24 to 30 inches		x	=
30 to 36 inches		x	=
Total			
		Percent Deficit	

For more information on this and other topics, see www.ag.ndsu.edu/extension

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