IRRIGATION SCHEDULING AND UNIFORMITY FOR IMPROVED WATER MANAGEMENT

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Introduction

Irrigation is an important tool for reducing risks, increasing yields and producing higher quality crops. Ideally, we would like to keep the crops grown from being water stressed by maintaining the soil moisture in the root zone at a level that allows the plant roots to freely extract waters as needed. This paper will take you through the steps to determine the water holding capacity of soils, the water used by the plants and evaporation from the soil and discuss a methodology for estimating the available moisture remaining in the soil. An irrigation system will ideally apply water equally across the soil surface but in reality it doesn't happen. Gross variation can affect crop yields and effect the utilization of fertilizers and pesticides. A test method and equipment for determining the uniformity of water application is presented. The rate at which water is being applied to the field is often assumed based on the designed well pumping capacity. Periodic testing of the well pump is recommended to ensure it can supply the necessary water and it is operating efficiently. The paper will finish with a brief discussion of some energy saving opportunities that will reduce irrigation costs without reducing water being applied.

Soil Moisture determination

Plants require water, nutrients and mineral from the substrate their roots are growing in for survival and growth. For optimal growth, all nutrients and water need to be readily available. Water that is available in the soil for plant growth can is called "Total Available Water", refer to Figure 1. There is some water that is unavailable to plants because it is held tightly to the soil particles. The amount varies with soil type. After a long period of rain fall the ground would be considered "Saturated". An example of this would be water is a foot print after stepping on ground that had no visible water at the surface. After the excess water has drain from the soil profile the soil would be at "Field Capacity". As water evaporates from the soil surface or is used by the plants the soil moisture will decrease. If the soil moisture continues to decrease, eventually there will be a point at which the plant will not be able to uptake water as fast as it is used which will slow growth. A continued decrease in the soil moisture will lead to a slow down in photosynthesis in the plant and if the soil moisture decreases to the permanent wilt point the plant will die. If using a irrigation system to supplement crop water needs, the soil moisture is typically maintained above 50% of the "Total Available Water" (TAW) and is termed the "Maximum Allowable Depletion".

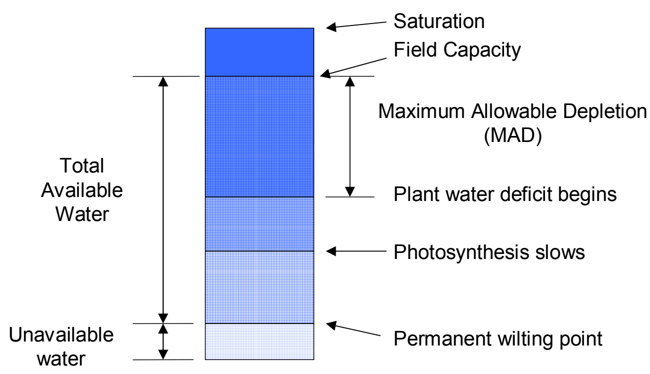

Figure 1: Soil Moisture Profile

Studies of water consumption by plants indicates that 40% of the water is extracted from the top 25%

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of the plant's root zone, 30% is extracted from the second 25% of the root zone and 30% is extracted by the bottom 50% of the root zone. The depth and distribution of roots varies greatly from cucumbers that have very shallow roots, most in the first 12 inches of the soil, to corn and alfalfa which may have roots 7 to 9 feet in depth. The root depth can be limited by things such as high water tables, rock, severe compaction or dry soils. Depending on the crop's root depth, we can manage some portion of that to ensure that plant growth is not limited by water. For most crops we will manage the upper 50% of the root zone where 70% of the water is extracted from the soil. This could vary from about 6 to 12 inches for turf grass to 36 to 48" for field corn. The maximum allowable depletion, the point at which we'd want to add supplemental water is typically 50% of TAW but for some moisture sensitive crops such as potatoes it could be as low as 30 to 35%. Some crops can benefit from changing the percent of the TAW maintain in the soil based on the stage of crop growth.

The field capacity or total available water will vary with soil type. The US Department of Agriculture Soil Conservation Service publishes a survey of soil types by county that is available from the Farm Service Agency in your county. The publication has maps of different sections of the county with topographical lines depicting the approximated locations of different soil types. First one needs to locate the field on the maps where the irrigated crops are being grown and note the soil type abbreviations. Then referring to table 8, Estimated Soil Properties, the available water capacities are listed for the different soil types in "inches of water per inch of soil". Most soil types will have a number of layers that have to be added up to get the total available water capacity for the root zone to be managed. For example, a Pecatonica soil would be expected to be made up of 10 inches of silt loam, from 10" to 21" is a silty clay loam, from 21" to 37" is a sandy clay loam and from 37" to 60" it is a sandy loam. The available water capacity is given as a range for each of these soil layers, for example the silt loam is estimated to have a water holding capacity of 0.18 to 0.22 inches of water per inch of soil while the silty clay loam layer has a water holding capacity of 0.16 to 0.20 inches of water per inch of soil. The water holding capacity for an 18" root zone would be determined as follows:

Silt Loam	10" @ 0.20 inches of water per inch of soil	2.00 inches of water
Silty clay loam	8" @ 0.18 inches of water per inch of soil	1.44 inches of water

In this case the total available water in the root zone would be 3.4 inches. If the crop grown used a maximum allowable depletion (MAD) of 40%, then we would try to maintain the soil moisture between field capacity and 2.0" TAW for a MAD of 1.4 inches of water. Many fields will encompass several soil types that may vary in the water holding capacities. You will have to make a decision if you want to irrigate for the soil that holds the least amount of water or for the average of all soil types found in the field.

Plant Water Consumption

There have been a large number of studies over the years to determine the water use by different plants under different conditions. This work has resulted in a number of different equations to estimate the water use by plants based on air temperature, humidity level, solar radiation, soil temperature. The UW-Madison Soil Science Department publishes the estimated ET values daily during the growing season that would estimate the water use by a crop with ample soil moisture and a canopy that covers 80% of the ground. The ET values are available on-line at www.soils.wisc.edu/wimnext/water.html or they can be emailed to you daily by sending an email to fewayne@facstaff.wisc.edu with the latitude and longitude of your farm. You can find the latitude and longitude of your farm by going to www.census.gov/cgi-bin/gazetteer and entering your town and state or your zip code and clicking on "search". The search will provide you with the latitude and longitude for the post office(s) or the center of the municipality. If you want to get a more precise latitude / longitude, click on the "Map" link and a map will appear. The red pin indicates the location of the latitude/longitude indicated at the bottom of the map. Use the "+", "-" and compass below the map to find your farm's location. Then click on "Place Marker" in the top of the blue box to the right of the map, place the curser over your farm's location on the map and click; the latitude and longitude for the location you selected will appear under the map. ET values in Wisconsin in June, July and August can reach 0.28" per day for several days. The ET values have to be adjusted for the amount the crop canopy covers the ground. This is done by referring to the Table 1 and looking up the adjusted ET value based on % canopy cover and ET value.

Figure 2: Low Evaporation Rain gauge

Water Measurement

Rain gauges should be located in each field to record rainfall and irrigation water applied. Gauges should have an opening of at least 3-1/2" for the most accuracy. Evaporation from rain gauges can affect the accuracy of the data if they are not read shortly after a rain event unless a low evaporation type gauge is used. The rain gauge pictured in Figure 2, design by Kansas State University, has a weekly evaporation rate of less than 1% and is low cost to build. It is recommended that three gauges be used in each field to determine the average water applied to the field by rainfall and irrigation.

Irrigation Scheduling

The checkbook method of irrigation scheduling is like balancing your checking account at the bank; rainfall and irrigation events are deposits and ET values are withdrawals. The objective is to keep adequate soil moisture in the plant's root zone, maximize the use of rain water and minimize leaching events. The soil moisture can not exceed the water holding capacity of the soil profile. If the total water holding capacity of the managed root zone is estimated at 2.5" and there is 1.75" of water content in the soil and a rainfall event or a combination of a rainfall event and irrigation exceeds 3/4" (2.5"-1.75"=3/4") of water, the excess will move through the managed root zone and out of reach of the plant's roots. This is termed a leaching event because the water will take water soluble nutrients with it such as nitrogen. The amount of water from the above example that can be credited to the checkbook water balance is 3/4". Ideally, one would like to keep the soil moisture level low enough to take advantage of rain fall and reduce leaching events but high enough to keep the plants growing without water being the limiting factor. The water balance can be done manually or there are programs and spreadsheets available to automate some of the record keeping.

Soil Moisture Sensors

The checkbook is only a good approximation of the soil moisture and needs to be checked and adjusted on occasion particularly if there has been a long period without a rain event that has saturated the soil. Checking the soil moisture with sensors or probes will provide the information to make adjustments. There are many types of soil moisture sensors that use a number of different technologies to sense the soil moisture. Some are probes that have a maximum depth of up to 8

Appendix Table C. Evapotranspiration (ET) estimates adjusted for % crop canopy cover (for use with WISP)

ET estimate in inches	% crop cover								
	0	10	20	30	40	50	60	70	80
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.02	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02
0.04	0.00	0.00	0.01	0.02	0.03	0.03	0.04	0.04	0.04
0.06	0.00	0.01	0.02	0.03	0.04	0.05	0.05	0.06	0.06
0.08	0.00	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08
0.10	0.00	0.02	0.04	0.05	0.07	0.08	0.09	0.10	0.10
0.12	0.00	0.03	0.05	0.06	0.08	0.09	0.11	0.11	0.12
0.14	0.00	0.03	0.05	0.07	0.09	0.11	0.12	0.13	0.14
0.16	0.01	0.04	0.06	0.08	0.11	0.13	0.14	0.15	0.16
0.18	0.01	0.04	0.07	0.09	0.12	0.14	0.16	0.17	0.18
0.20	0.01	0.05	0.08	0.11	0.13	0.16	0.18	0.19	0.20
0.22	0.01	0.05	0.08	0.12	0.15	0.17	0.19	0.21	0.22
0.24	0.01	0.06	0.09	0.13	0.16	0.19	0.21	0.23	0.24
0.26	0.01	0.06	0.10	0.14	0.17	0.20	0.23	0.25	0.26
0.28	0.01	0.06	0.11	0.15	0.19	0.22	0.25	0.27	0.28
0.30	0.01	0.07	0.12	0.16	0.20	0.23	0.26	0.28	0.30
0.32	0.02	0.07	0.12	0.17	0.21	0.25	0.28	0.30	0.32
0.34	0.02	0.08	0.13	0.18	0.23	0.26	0.30	0.32	0.34
0.36	0.02	0.08	0.14	0.19	0.24	0.28	0.32	0.34	0.36

*To use this table, you must have an estimate of the current % crop canopy cover and the ET estimate provided by University of Wisconsin-Extension, Cooperative Extension. You can obtain the ET estimate by calling the toll-free IPM PEST Phone at (800) 236-4264. Outside Wisconsin, call (608) 262-4264.

To adjust the ET estimate for canopy cover, select the appropriate % crop cover value. Move right to the column headed by the ET estimate. The value at the intersection is the adjusted ET estimate.

inches ideal for turf grass, others have to be buried at the depth that the soil moisture measurement is desired. One of the newest moisture sensors can take readings at four different depths with the same probe. For monitoring a field, it is recommended that measurement be taken at a minimum of two locations and two depths. The first location should be at the beginning of a center pivot's rotation and the other location should be near the end. If using a different type of irrigation system, one location should be at the first area to be irrigated and the other at the last area to be watered. This provides the extremes of the soil moisture in the field. The first sensor should be placed at about 25% of the managed root zone depth and the second at 80 to 90% of the managed root zone depth. The upper sensor is in the root zone where 40% of the water is extracted by the plant while the deeper sensor will indicate leaching events and provide feed back on how deep the irrigation water is getting. Some growers who have started using moisture sensors have found that the amount of irrigation water that was being applied was insufficient to fill the managed root zone.

Managing Deep rooted crops versus shallow rooted crops

A deeper managed root zone depth, results in more total available water to manage. This can provide longer periods between irrigation events and the ability to utilize more rainfall events without leaching. Typically, the amount of irrigation per application should also be increased to provide for deeper penetration of the water. In arid area, continuous shallow irrigation, low water application depth, can cause root pruning and can lead to lodging of crops like corn.

Uniformity Testing

Can you look at an irrigation system and tell if it is applying water uniformly? Not likely. Gross problems can be seen visually, leaky pipes joints, nozzle not rotating or grossly plugged nozzles, but to determine if the water is being applied evenly to the soil surface across the irrigated area requires testing. Testing will provide an indication of areas of the irrigation system where water is being applied greater or less that the average. Ideally we'd like to have the water perfectly applied but this isn't practical but a well design and maintained system can achieve coefficients of uniformity of 90 to 95%. Nozzles do wear out over time, contrary to the belief of some growers. The nozzle will wear from particles in the water or may become restricted or plugged do to poor water quality. Testing can also provide information about the effect of pressure variations from end guns turning on and off or corner systems extending or wheel slippage. Uniformity testing is recommended every 3 to 5 years or sooner. Testing can also be used to check new center pivot irrigation systems that the nozzles have been placed in the correct order. Poor uniformity can affect crop yield because of too much or not enough water but also affects the utilization of fertilizers, herbicides and pesticides. Figure 3 below show a graph of the uniformity test data for a center pivot irrigation system. A system with a high coefficient of performance would have all measurements between the high and low deviation limit lines which represent a 10% plus or minus from the average.

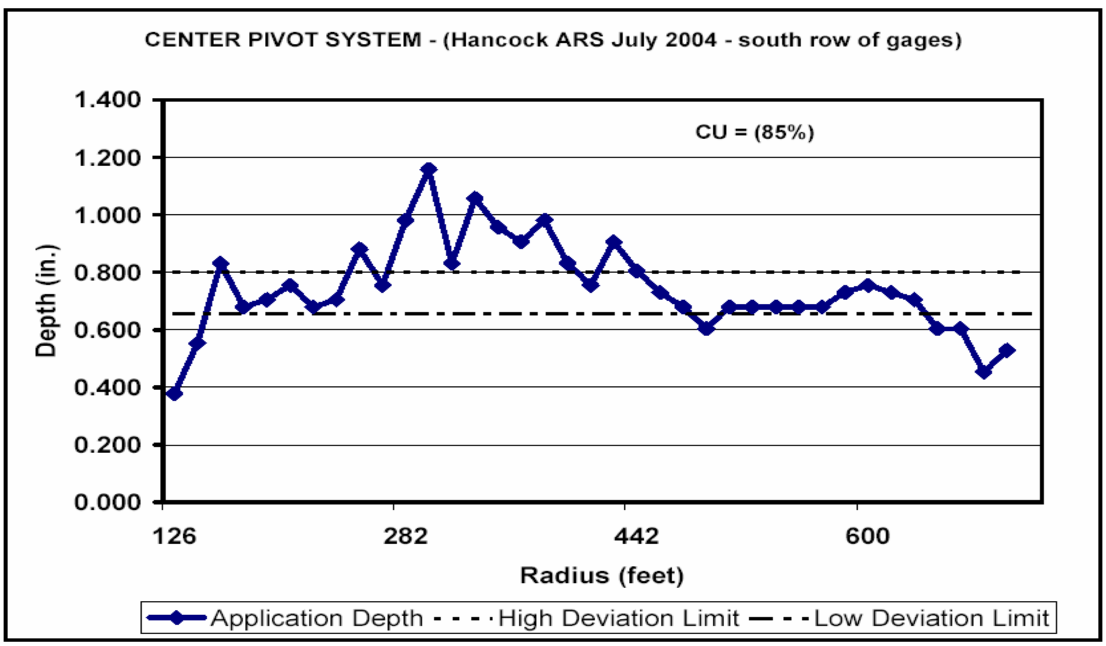

Figure 3: Gage data from uniformity test of center pivot irrigation system

Uniformity Test equipment

Uniformity testing requires a large number of identical collection cans with an opening diameter of at least 3.5" and a minimum depth of 7". The opening should have a sharp edge and be position so the opening is level during the test. The test involves setting up a row of rain gauges or cans at a distance between collection cans of no greater than 80% of the nozzle spacing or a maximum of 16 feet for impact sprinklers and 10 feet for spray nozzles. On large irrigation systems, this can amount to a considerable number of cans. To make it easier to do and to encourage uniformity testing, a test kit was put together in mid summer 2004. The kit contains 150 rain gages, stakes, measuring devices, instructions, data sheets and a spreadsheet program for data analysis. It is kept at the Hancock ARS and is available at no charge for Wisconsin growers. Contact Jeff at 715-249-5961 to reserve the kit.

Pump-Well testing

When a grower runs an irrigation system he is assuming some amount of water is being applied to the soil usually based on the design capacity of the pump-well system when it was installed or last refurbished. If the pump-well is not tested on a regular basis, every 2 or 3 years is recommended, the grower may not find out there is a problem until the crop starts to show sign of water stress. Testing typically costs between $150 to $300 per well and should include measurements of pump output versus pressure, drawdown level and energy consumption. If all of this data is collected then the pumping efficiency can be determined to compare the pump's performance to the Nebraska Performance Standard (NPS). Indirectly the test helps identify worn impellers, excessive impeller clearance, changes in water table levels, plugged well screens, insufficient net positive suction head and engine or motor issues. Studies in Wisconsin, Kansas and Nebraska indicated that pumping plants are typically operating at 75% of the NPS. A Kansas study estimated that 40% more fuel was being used than necessary if the irrigation equipment was properly sized, adjusted and maintained. A Nebraska study found that 57% of the pumping plants studied needed adjustment which resulted in a 14% cost savings. If a grower keeps accurate production records, the efficiency can be estimated from fuel or electric bills. Refer to KSU extension bulletin "Evaluating Pumping Plant Efficiency Using On-Farm Fuel Bills" (No. L-885) which can be found at www.oznet.ksu.edu/mil/toolkit.htm.

Other Cost Saving Opportunities

Lower system pressures
Lowering pivot pressure for an irrigation system from high pressure (80 psi +) to a lower pressure can reduce operating costs while providing the same amount of water. If the pressure was reduce from 80 to 50 psi, the savings would be approximately 25% while lowering the pressure to 30 psi can save up to 40% in energy costs. If your system is in need to new nozzles, you should consider the benefits of running at lower system pressures.

Time of Day Electric rates
Many electric utilities offer programs to encourage the use of electrical energy during off-peak hours, nights and weekends. If all irrigation can be moved to off-peak hours, a grower could reduce irrigation costs by 50% plus. This requires an irrigation system that can cover the irrigated area in 100 hours or less per week. Usually if 65% of the irrigation can be accomplished off peak, these programs will be advantageous to the grower.

Energy Conservation Grants

Focus on Energy is Wisconsin's energy conservation program that offers grants for conserving energy. The Agricultural program offers free energy audits using standardized audit tools to aid growers and producers in reducing energy costs. The program covers approximately 85% of Wisconsin's homes and businesses. The grants can be used to cover up to 25% of the cost of equipment and are based on the estimated first year energy savings. For irrigation system, the program covers the conversion of systems to lower pivot pressures and improving pumping plant efficiencies. For more information, call 1-800-762-7077 or access the web site at www.focusonenergy.com.

The 2002 Farm Bill also provides funds for renewable energy and energy efficiency projects. The Notice of Funding is usually published in May each year with applications due in mid-July. Grants cannot exceed 25% of total project costs and range from a minimum of $2500 to $500,000. Energy efficiency projects must demonstrate at least a 15% energy savings and an 11-year investment payback to be considered. Applications are handled by the USDA Rural Development office in each state. The Wisconsin office is located in Stevens Point and can be contacted at 715-345-7615. More information and applications can be found at www.elpc.org/farmenergy/9006FAQ.htm or www.rurdev.usda.gov/rbs/farmbill/index.html.

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