Irrigation Scheduling For Field Crops and Vegetables
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Irrigation Scheduling For Field Crops & Vegetables

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The primary purpose of irrigation is to improve yield and/or crop quality. In addition, vegetable growers may irrigate to 1) start small seedlings such as lettuce and carrots, 2) moisten and firm soil around transplants until they develop more roots, 3) reduce wind erosion on sandy and muck soils, 4) prevent burn-off of small seedlings on organic soils, and 5) control temperature (frost protection and temporary cooling during hot summer days).

In Michigan, irrigation is most frequently confined to sandy or organic soils where high value crops such as fruit and vegetables are produced. Irrigation of corn, soybeans, alfalfa, and other crops, however, is increasing. Michigan has nearly 3 million acres of sandy soils in crop production which could benefit from irrigation. Since a wide variety of crops are grown on sandy soils and there is interest in irrigation of fine textured soils, information is needed on scheduling irrigation for many crops grown on all soil types.

Evapotranspiration

One of the most important factors affecting the amount of water needed and the frequency of application is evapotranspiration. Evapotranspiration is the sum of water lost by evaporation from soil and transpiration from plants. It is directly related to temperature, light intensity, wind, humidity, level of soil moisture, and plant vegetable cover. An increase in all factors except humidity causes an increase in evapotranspiration.

Water lost by evaporation from an open pan of water is closely related to evapotranspiration. The average water lost from bare soil is approximately 30% of that lost from an open pan. As the vegetable cover increases, so does the rate of evapotranspiration until it equals 80 to 85% of open pan evaporation. Figure 1 shows long time average open pan evaporation and rainfall on a weekly basis at three locations in Michigan. The weekly water deficit (difference between open pan evaporation and rainfall) for mid-July is twice as great at East Lansing as Seney, Michigan in the Upper Peninsula.

Assuming evapotranspiration is 80% of open pan evaporation (1.75, from Figure 1) and rainfall is normal (.75) in mid-July at East Lansing, 0.8 inches (1.75 − .75 = 1.0 × 80%) of water will be needed weekly to replace evapotranspiration losses. If no rain occurs, 1.4 inches will be required (1.75 × 80%).

Table 1 provides information on average daily evapotranspiration values for three locations in Michigan as affected by percent crop cover. These values may be used as a general guide for scheduling irrigation when using the water balance sheet (see Table 8).

Available Soil Moisture

The water holding capacity of a soil is closely related to soil texture. Fine textured soils will hold more water than sandy soils, but not all of the water held by clay is available for plant use. Water held by the soil and available for plant use is called available water. Knowing the amount of available soil moisture is very important to the irrigator in determining the amount of water to apply and the frequency of application.

Some average values for available soil moisture held by various soil types are given in Table 2. These values will later be used to determine the carrying capacity of a soil.

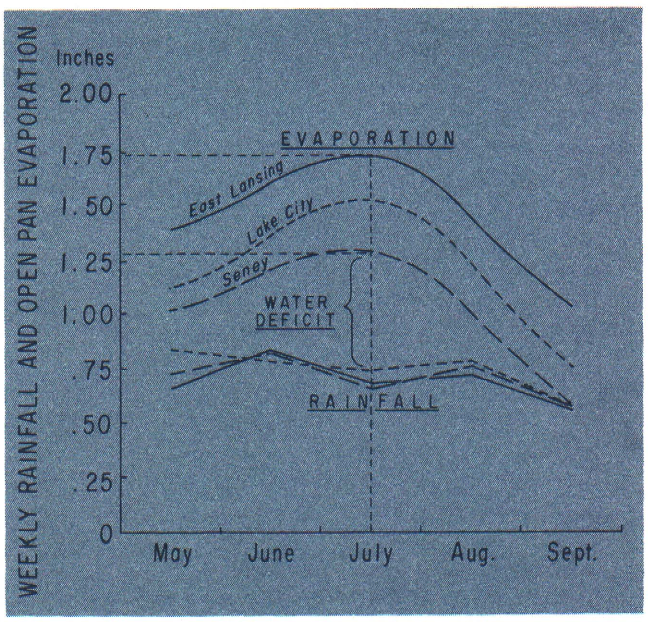

Figure 1. Weekly rainfall and open pan evaporation throughout the growing season for three locations in Michigan (Data from Nurnberger, Fred V., 1976 Summary of Evaporation in Michigan, M.D.A., Michigan Weather Service, 1407 S. Harrison Road, E. Lansing, MI).

Table 1. **Estimated average daily evapotranspiration for three Michigan locations for three levels of crop cover.**[1]

Month	East Lansing Percent Cover 0-30	30-70	70-100	Lake City Percent Cover 0-30	30-70	70-100	Seney Percent Cover 0-30	30-70	70-100
				Average Daily Evapotranspiration (inches)					
May	.08	.12	.16	.06	.09	.12	.06	.09	.12
June	.09	.13	.18	.08	.11	.15	.07	.10	.13
July	.10	.15	.19	.08	.12	.17	.07	.11	.14
August	.08	.12	.16	.07	.10	.14	.06	.09	.11
September	.06	.09	.12	.04	.06	.08	.03	.05	.07

[1]*Estimated from open pan evaporation measurements at each location using efficiency factors of 40, 60 and 80 percent for the 0-30, 30-70 and 70-100 percent cover, respectively. (Data from Nurnberger, Fred V. 1976. Summary of Evaporation in Michigan, M.D.A. Michigan Weather Service, 1407 S. Harrison Road, E. Lansing, MI.)*

Table 2. Available Soil Moisture for Various Soils.

Soil Type	Available Soil Moisture
	inches/foot of depth
Sands	0.5
Loamy Sands	1.0
Sandy Loams	1.5
Loams	2.0
Silt and Clay Loams	2.5
Clays	2.0

Table 3. Available soil moisture in the upper six feet of a Montcalm and McBride sandy loam soil.

Soil depth inches	Texture	Available soil moisture: inches/ inch of depth	inches/ horizon
	Montcalm sandy loam		
0-24	Sandy loam	.12	2.88
24-31	Sandy loam	.13	.91
32-72	Sand	.04	1.60
		Total	5.39
	McBride sandy loam		
0-16	Sandy loam	.13	2.08
16-38	Sandy clay loam	.15	3.30
38-48	Sandy loam	.12	1.20
48-72	Sandy loam	.10	2.40
		Total	8.98

Available soil moisture often varies with depth as does soil texture. Examples of two common soils used in Michigan for irrigated potatoes and the associated available moisture in the upper six feet of the profile are shown in Table 3. The subsoil texture of these two soils is quite different making the total available moisture in the profile considerably different. Specific information on other soil types may be obtained from your local Soil Conservation District (SCS) office. The district soil conservationist can help you determine the various soil types on your farm and get a more accurate estimate of available soil moisture.

Estimating Available Moisture

There are three well-known ways to determine available soil moisture in the field. Unless you are an experienced irrigator, any one method in itself may be insufficient for determining soil moisture. Using one method to check the other is generally more successful.

The **feel method** is probably the most common field method of determining available moisture. You must, however, develop your own sense of feel. Table 4 gives some idea of the available moisture content of several soil types.

The **water balance sheet** is another method which can be used in conjunction with the feel method to evaluate available soil moisture content. This method allows you to schedule irrigation water based on evapotranspiration and rainfall. The most important step in this procedure is estimating the total available moisture in the soil profile at the beginning of the season. In Michigan, this is generally not a real problem if you start the record early enough in the season when the profile is full of water. A large rain in May or June will usually fill the soil profile with moisture on most sandy soils and the record may be started the following day. From that point on it's a matter of keeping a record of rainfall, evapotranspiration and irrigation. Rainfall can be easily measured with a rain gauge set up in the field. Evapotranspiration can be estimated from measurements of open pan evaporation as in Table 1.

The third method of estimating available soil moisture is with **soil tensiometers or moisture blocks**. Once again, to be effectively used, they should be checked against the feel method or used with the water balance sheet. The difficulty in using these instruments is that readings on the instrument vary with soil type. It is best to use two or three instruments at one site. One should be placed in the center of the root zone and another at the lower end of the effective rooting zone. Instruments which are placed near the surface will show wide fluctuations in the readings and it is easy for these devices to become inoperable if the soil becomes too dry.

Table 4. Practical interpretation chart of soil moisture for various soil textures and conditions.

Available moisture in soil	Feel or appearance of soil: Coarse-textured soils	Moderately coarse textured soils	Medium-textured soils	Fine-and very fine-textured soils
0 percent	Dry, loose, and single-grained; flows through fingers	Dry and loose; flows through fingers	Powdery dry; in some places slightly crusted but breaks down easily into powder	Hard, baked, and cracked; has loose crumbs on surface in some places
50 percent or less	Appears to be dry; does not form a ball under pressure[1]	Appears to be dry; does not form a ball under pressure[1]	Somewhat crumbly but holds together under pressure[1]	Somewhat pliable; balls under pressure[1]
50 to 75 percent	Appears to be dry; does not form a ball under pressure[1]	Balls under pressure but seldom holds together	Forms a ball under pressure; somewhat plastic; slicks slightly under pressure	Forms a ball; ribbons out between thumb and forefinger
75 percent to field capacity	Sticks together slightly; may form a very weak ball under pressure	Forms weak ball that breaks easily; does not slick	Forms ball; very pliable; slicks readily if relatively high in clay	Ribbons out between fingers easily; has a slick feeling
At field capacity (100 percent)	On squeezing, no free water appears on soil, but wet outline of ball is left on hand	Same as for coarse-textured soils at field capacity	Same as for coarse-textured soils at field capacity	Same as for coarse-textured on soils at field capacity
Above field capacity	Free water appears when soil is bounced in hand	Free water is released with kneading	Free water can be squeezed out	Puddles; free water forms on surface

[1]*Ball is formed by squeezing a handful of soil very firmly.*
(Source the *National Engineering Handbook*, SCS, USDA, Section 15, Chapter 1)

Effective Rooting Zone

The amount of water needed for irrigation and the frequency of application also depends on the crop to be irrigated. Some crops, such as alfalfa, have a very extensive primary and secondary rooting system and penetrate to greater depth than other crops. The effective rooting depth of alfalfa will vary from 3 to 6 feet or more depending on soil physical properties and depth of the water table. Corn also has a very good branching root system and can effectively use water to a depth of 4 feet or more. Soybeans, however, have a tap root system with secondary branch roots and seldom use water effectively from more than 2 feet deep. Lettuce has a very shallow root system and will rarely use water below one foot. Table 5 gives some average rooting depths of a number of crops grown in Michigan. Shallow rooted crops must be irrigated frequently with small amounts of water while deep rooted crops may be irrigated with larger applications of water at less frequent intervals.

Table 5. Effective rooting depth of several crops.

Crop	Root Depth Feet	Crop	Root Depth Feet
Alfalfa	3 to 6	Pasture (grass)	1½ to 3
Cabbage	1½ to 2	Peas	1 to 2
Carrot	1½ to 2	Potato	1½ to 2
Corn	2½ to 4	Small grain	2 to 3
Cucumber	1½ to 2	Soybean	1½ to 2
Field bean	1 to 2	Strawberry	½ to 1
Lettuce	½ to 1	Sugar beet	2 to 3
Onion	1 to 1½	Tomato	1 to 2

Carrying Capacity

The carrying capacity of a soil is the time required by a crop to deplete 50% of the available soil moisture. It is affected by the rate of evapotranspiration, the effective rooting depth of the crop and the moisture-holding capacity of the soil. It can be calculated by the following equation. Carrying capacity (days) =

$$\frac{\text{avail. moisture/foot} \times \text{effective rooting depth (ft)} \times 50\%}{\text{evapotranspiration (inches/day)}}$$

Some calculated values for the carrying capacity of various soil types are shown in Table 6. Crops which

Table 6. Carrying capacity of a soil for several crop rooting depths and evapotranspiration rates.[1]

Soil Type	Evapotrans-piration	Effective rooting depth (feet) 1	2	3	4	5	6
	inches/day			*days*			
Sands	.10	2.5	5.0	.75	10.0	12.5	15.0
	.20	1.2	2.5	3.7	5.0	6.2	7.5
	.30	.8	1.6	2.4	3.3	4.1	.50
Loamy sands	.10	5.0	10.0	15.0	20.0	25.0	30.0
	.20	2.5	5.0	7.5	10.0	12.5	15.0
	.30	1.6	3.3	5.0	6.6	8.2	10.0
Sandy loams	.10	7.5	15.0	22.5	30.0	37.5	45.0
	.20	3.7	7.5	11.2	15.0	18.7	22.5
	.30	2.5	5.0	7.5	10.0	12.5	15.0
Loams and clays	.10	10.0	20.0	30.0	40.0	50.0	60.0
	.20	5.0	10.0	15.0	20.0	25.0	30.0
	.30	3.3	6.6	10.0	13.3	16.6	20.0
Silt and clay loams	.10	12.5	25.0	37.5	50.0	62.5	75.0
	.20	6.2	12.5	18.7	25.0	31.2	37.5
	.30	4.1	8.3	12.5	16.6	20.8	25.0

[1] *Based on depletion of 50% of the available water.*

have a shallow root system have a shorter carrying capacity than deep rooting crops. Soils with a larger moisture-holding capacity have a large carrying capacity, but an increase in evapotranspiration shortens the carrying capacity of a soil.

The carrying capacity should be used in the design of an irrigation system. The design should not exceed the shortest carying capacity especially where high value, shallow rooting crops and crop quality are of concern. There is less flexibility in scheduling irrigation water for shallow rooting crops such as vegetables than for deep rooting crops such as corn or alfalfa. The longer the carrying capacity the greater the flexibility, and the more reliance that can be placed on rainfall to extend the carrying capacity.

Water Intake Rates

The intensity at which water can be applied is determined primarily by the basic rate of water infiltration of the soil. Some suggested maximum water intake rates for several soil types are given in Table 7. The actual intake rate varies with soil structure, organic matter level the amount of crop residue or crop cover. Soils with good soil structure, high organic matter and plenty of plant residues on the surface have higher rates of water intake than compact soils low in organic matter or without residues on the surface.

Irrigation Scheduling

It is important to develop an irrigation schedule or plan for irrigating. Now that we have a working knowledge of such things as soil moisture-holding capacity, effective rooting depth, water intake rates, evapotranspiration and carrying capacity of the soil, we can develop some guidelines for an irrigation schedule.

Table 7. Suggested maximum water intake rates for various soil types.

Soil type	Intake rate[1]
	inches/hour
Sands	2.0
Loamy sands	1.8
Sandy loams	1.5
Loams	1.0
Silt and clay loams	0.5
Clays	0.2

[1] *Assumes a full crop cover. For bare soil reduce the rate by one-half.*

When to start irrigating

Most crops grow best at 50 to 80% available moisture. Moisture stress begins to develop in plants when only 20% of the available water remains at which point plant growth rapidly declines. In order to maintain soil moisture above the 50% available level, you should *start irrigating when the effective rooting zone is slightly above the 50% available level.* This should allow you to get all of your acreage irrigated before any moisture stress occurs. For corn, it is very critical that adequate moisture be available early in the season at the tassel and early silk stage. Every effort should be made to see that the available moisture level is above 50% at this stage of corn development.

How much water in one application

This depends on the soil moisture level at the time of irrigation and the moisture-holding capacity of the soil. Since most crops desire a moisture level of 50 to 80% of available moisture, *the optimum application rate would be 30% (80% – 50%) of the total available water in the effective rooting zone of the crop.* For example, a potato crop with an effective rooting depth of 2 feet, growing on a sandy loam soil with a total available water-holding capacity of 3 inches (1.5 inches/ft × 2 ft), would have an optimum application rate of .9 inches (3 × 30%).

If the soil moisture level at the start of irrigation is less than 50% of available moisture, apply additional water to bring the total available water in the profile to 80%. If moisture stress occurs, the soil is at the 20% moisture level. In this situation you will need to make an application equivalent to 60% (80% – 20%) of the total available water in the profile. If time is critical, it may be better to irrigate all of the acreage with a smaller application in a shorter period and then follow with a larger application to get the soil to the 80% moisture level.

How often to irrigate

Frequency of irrigation depends in part upon the carrying capacity of the soil. Table 6 shows the time required to deplete 50% of the available moisture at three rates of evapotranspiration. Shallow rooted crops grown on sands will need to be irrigated more frequently with small amounts of water. Deep rooted crops on fine textured soils may need little or no irrigation water because of the large carrying capacity.

When to stop irrigating

Stop irrigating when the soil reaches 80 to 90% of the total water-holding capacity. This should prevent or minimize the leaching of nitrate-nitrogen from the soil profile in the event of rain.

Irrigating near the end of the growing season may be just as critical for optimum crop production as earlier in the season. Quite often, adequate moisture during the final period of growth is the most important. Thus, *you should have adequate moisture in the soil to carry the crop to maturity.* If the soil approaches the 50% available level and the crop is not yet mature, you will need to make another application of water.

Water Balance Sheet for Irrigation Scheduling

The water balance sheet shown as Table 8 is an example of actual measurements made at East Lansing in 1974. A blank balance sheet is also provided for use on your field. Values for evapotranspiration can be obtained from Table 1. You may want to adjust these values for unusually hot or cool periods. Variations of 40% above or below the normal are possible for any one day. Weekly variation, however, will reflect smaller deviations from the average.

Table 8. Sample Water Balance Sheet.

Figures shown are examples — Record your own on the balance sheet below.

Field No. *1*
Soil Type *Sandy loam*
Crop *Potatoes*
Available Water Holding Capacity *1.5* inches per foot[1]
Effective Rooting Zone *2* feet[2]
Total Available Profile Moisture *3.0* inches for rooting zone[3]
Optimum Profile Moisture Range *1.5 - 2.4* inches for rooting zone[4]
Total Available Profile Moisture Today *3.0* inches for rooting zone[5]

Date	*Percent Crop Cover*	*Weekly[6] Evapotranspiration*	*Weekly[7] Rainfall*	*Weekly Irrigation*	*Rainfall Irrigation Minus Evapotranspiration*	*Profile Moisture*
5-27	30	—	—	—	—	3.0
6-2	40	.13 × 7 = .91	1.5	—	1.5 − .91 = +.59	3.0[8]
6-9	50	.14 × 7 = .98	.8	—	.8 − .98 = −.18	2.8
6-16	60	.16 × 7 = 1.12	.0	—	.0 − 1.12 = −1.12	1.7[9]
6-23	70	.18 × 7 = 1.26	.5	—	.5 − 1.26 = −.76	0.9
6-30	80	.18 × 7 = 1.26	1.0	1.0	2.0 − 1.26 = +.74	1.7
7-7	100	.19 × 7 = 1.33	0	2.0	2.0 − 1.33 = +.67	2.4

[1]*See Table 2.*
[2]*See Table 5.*
[3]*Available waterholding capacity multiplied by the effective rooting zone.*
[4]*Multiply total available profile moisture by 50% for lower limit and 80% for upper limit.*
[5]*Estimated or measured available moisture on the first day of recorded entry.*
[6]*Use Table 1 to help estimate average daily evapotranspiration values for your area. Remember that evapotranspiration may vary 20% above or below the average values for normal weather conditions. Multiply these values by 7 to get weekly loss.*
[7]*A rain gauge out in the open is needed. Summer rainfall is so variable that you need your own gauge.*
[8]*The soil has a maximum of 3.0 inches of available water, therefore, the excess (.59 inches) rainfall is leached out of the root zone.*
[9]*Begin irrigating when soil profile moisture approaches one-half the total (1.5 inches for this crop and soil).*

WATER BALANCE SHEET

Record your own figures in space provided.

Field No. __________
Soil Type__________
Crop __________
Available Water Holding Capacity __________ inches per foot[1]
Effective Rooting Zone __________ feet[2]
Total Available Profile Moisture __________ inches for rooting zone[3]
Optimum Profile Moisture Range __________ inches for rooting zone[4]
Total Available Profile Moisture Today __________ inches for rooting zone[5]

Date	Percent Crop Cover	Weekly[6] Evapotranspiration	Weekly[7] Rainfall	Weekly Irrigation	Rainfall Irrigation Minus Evapotranspiration	Profile Moisture

[1]*See Table 2.*
[2]*See Table 5.*
[3]*Available waterholding capacity multiplied by the effective rooting zone.*
[4]*Multiply total available profile moisture by 50% for lower limit and 80% for upper limit.*
[5]*Estimated or measured available moisture on the first day of recorded entry.*
[6]*Use Table 1 to help estimate average daily evapotranspiration values for your area. Remember that evapotranspiration may vary 20% above or below the average values for normal weather conditions. Multiply these values by 7 to get weekly loss.*
[7]*A rain gauge out in the open is needed. Summer rainfall is so variable that you need your own gauge.*

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