Agriculture Notes

Estimating vegetable crop water use with moisture - accounting method

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Abdi Qassim and Bill Ashcroft, Tatura

This Agriculture Note describes the use of the moisture-accounting method for estimating water requirements for vegetable crop production.

Introduction

Adequate irrigation design, good irrigation management and scheduling have long been recognised as keys to increasing vegetable production on a sustainable basis. Scheduling irrigation according to crop water needs minimises the chances of under or over watering. Consequently, there is less crop failure and leaching of fertilisers beyond the root-zone, and more profit for growers. This approach underpins the long-term viability of an efficient and sustainable production system for the irrigated vegetable industry. Weather data has been used for estimating crop water requirements for many years, and is a handy management tool when it is used in conjunction with scheduling methods. Nowadays, it is possible to download a set of climatic data onto a personal computer and use it for estimating crop water use.

The moisture-accounting method

The Moisture Accounting Method involves steps to estimate soil moisture content by using weather data. It is based on soil water balance. For instance, if the moisture content of a soil is known at any given time, the moisture content at any later time can be computed by adding water gains (effective rain and/or irrigation) and subtracting water losses (run-off, deep percolation and crop evapotranspiration - ET_c) during the elapsed period.

Keeping the daily water balance is a simple procedure, but it must be completed each day. By knowing the daily values for inflow (rainfall or irrigation) and outflow (crop water use), the daily balance can be calculated as shown in Table 4. As soon as the accumulated water deficit exceeds the value of the net irrigation application depth (ie the net amount of irrigation water applied), more irrigation water is supplied to maintain an optimum soil moisture content for plant growth.

Required data: crop, soil and climate

1. *Crop data*:

Crop data: Root depth, growth stages and Crop coefficient.

1.1 Root depth

Different irrigation systems influence root development by changing the availability of water at different depths in the soil profile. A healthy root system is essential for all crops because it facilitates the uptake of water and nutrients. In some vegetable crops, such as carrots and onions, healthy roots are even more important because roots are the harvested products.

It is important to consider aspects of the root zone at various stages of crop growth. Once you have a good idea of the size of the root system you can modify the irrigation depth and interval between irrigations to suit it. Shallow rooted crops can only extract water from a limited depth, and may require short and frequent irrigations. Deep rooted plants, on the other hand, are able to extract water from deep down but can be prone to root disease if the subsoil becomes saturated.

Rooting depth can be determined by digging out the whole plant, shaking the soil off or digging a soil pit and then measuring the depth of the root system. Table 1 shows the range of typical root depths for various vegetable crops. Rooting depth and depletion fraction (p), which is the fraction of total available water that can be depleted from the root zone before moisture stress occurs are vital factors in determining how much water should be applied and when.

Table 1. Root depth and depletion fraction of some selected vegetable crops (Source: Allen** et al.**, 1998).

Crop	**Tomatoes**	**Onions**		**Water melon**	**Carrot**	**Lettuce**	**Broccoli**	**Cabbage**
		Green	**Dry**					
Root depth (m)	0.5 - 1.5	0.3 - 0.6	0.3 - 0.6	0.8 - 1.5	05 - 1.0	0.3 - 0.5	0.4 - 0.6	0.5 - 0.8
Depletion fraction (p) [1]	0.4-0.5	0.3-0.4	0.3-0.4	0.4-0.5	0.4-0.5	0.3-0.4	0.4-0.5	0.4-0.5

[1] The values for depletion (p) apply when $ET_c \approx 5$ mm/day, otherwise p= p (table 4) + 0.04 (5 - ET_c).

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1.2 Growth Stages

The length of the total growing season and each growth stage of the crop are important when estimating crop water needs. The growth of an annual crop can be divided into four stages:

- *Initial (establishment)*: from sowing to 10% ground cover
- *Crop development* : from 10 to 70% ground cover
- *Mid-season* (fruit formation): including flowering and fruit set or yield formation
- *Late-season*: including ripening and harvest.

1.3 Crop coefficient (K_c)

A Crop coefficient is a factor for estimating crop water requirements based on reference crop evapotranspiration. Crop coefficients vary between crops and growth stages, which reflects the changing characteristics of a plant over the growing season. Crop type and growth stages are the major factors influencing the crop coefficient. As the crop grows, the ground cover, crop height and leaf area change. Differences in the crop's evapotranspiration rate over the various growth stages will change the crop coefficient as shown in Table 2.

A crop coefficient relates crop water use at a particular development stage to the amount of evapotranspiration (ET) calculated from weather data.

Crop Evapotranspiration (ET_c) =

Crop Coefficient (K_c) X Reference Evapotranspiration (ET_o)

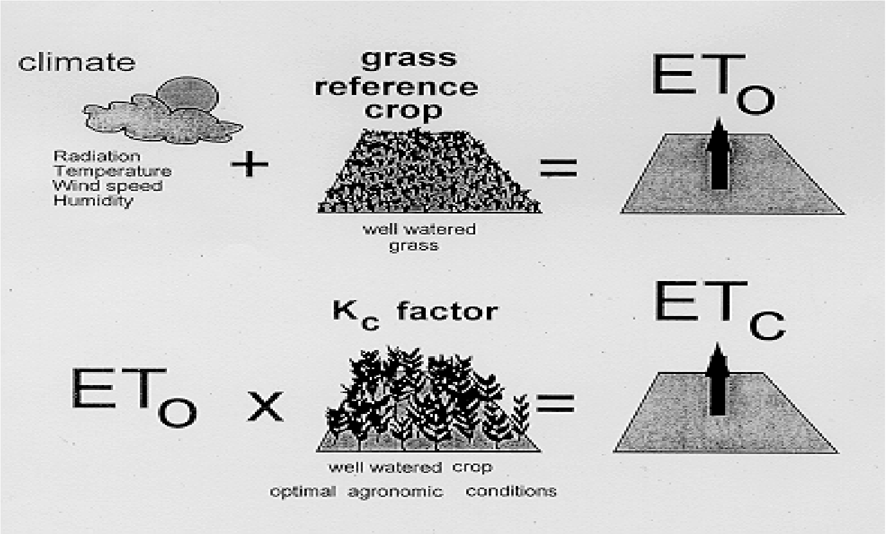

Figure 1. Calculating crop evapotranspiration (ET_c)

Table 2. Crop coefficient (K_c) for various growth stages of selected vegetable crops.

Crop	Initial	Development	Mid season	Late	At harvest
Cabbage	0.4[1] - 0.5[2]	0.7 - 0.8	0.95 - 1.1	0.9 - 1.0	0.8 - 0.95
Carrots	0.4 - 0.6	0.6 - 0.75	1.0 - 1.15	0.8 - 0.9	0.7 - 0.80
Cucumber	0.4 - 0.5	0.7 - 0.8	0.95 - 1.05	0.8 - 0.9	0.65 - 0.75
Lettuce	0.3 - 0.5	0.6 - 0.7	0.95 - 1.1	0.9 - 1.0	0.8 - 0.95
Onions dry	0.4 - 0.6	0.7 - 0.8	0.95 - 1.1	0.85 - 0.9	0.75 - 0.85
Onions green	0.4 - 0.6	0.6 - 0.75	0.95 - 1.05	0.95 - 1.05	0.95 - 1.05
Pepper	0.3 - 0.4	0.6 - 0.75	0.95 - 1.1	0.85 - 1.0	0.8 - 0.9
Tomato	0.4 - 0.5	0.7 - 0.8	1.05 - 1.25	0.8 - 0.95	0.6 - 0.65
Watermelon	0.4 - 0.5	0.7 - 0.8	0.95 - 1.05	0.8 - 0.9	0.65 - 0.75

[1] The first crop reading is for high humidity and low wind conditions.

[2] The second reading is for low humidity and strong wind conditions.

Source: Doorenbos and Kassam (1979).

2. Soil:

Total and readily available water

Ideally, a soil should hold enough water to facilitate plant growth, and have the capability to drain away any excess. It is important to understand the way in which water behaves in the soil if irrigation efficiency is to be maximised.

Soils differ in their ability to store water, depending on their texture. Sandy soils hold the least because they have large pore spaces between the sand particles. Clay soils have much smaller pore spaces, giving them a greater water holding capacity. Most soil profiles are a mixture of the various texture classes, and the total water storage capacity depends on the cumulative storage capacities of the various layers within the profile.

Aggregate stability is another important factor, which indicates the ability of the soil to withstand structural breakdown during wetting.

Total available water (TAW), readily available water (RAW) and depletion fraction (p) are critical to planning an appropriate irrigation schedule. To maintain soil moisture at optimum levels, it is important to understand that not all of the total available water (Table 3) is used before the next irrigation is applied.

Table 3. Available soil water in mm/ m soil depth for different soil textures

	Total available water in mm per metre of soil depth	
Texture class	**Range**	**Average**
Sand	30 - 65	49
Sandy Loam	90 - 123	106
Loam	155 - 172	164
Light Clay Loam	172 - 180	172
Clay Loam	155 - 172	164
Heavy Clay Loam	137 -155	147

For example, if the RAW for clay loam soil is set to be 80 mm of water (50% of total available), irrigation would be needed as soon as that amount is used. Note that the amount of water to be applied will depend on the depth of the crop's root system (Table 1).

3. Climate data:

Climate data includes: Temperature, relative humidity, sunshine hours and wind speed.

The sum of water lost from the soil surface by **evaporation** and from the crop via **transpiration** is referred to as **evapotranspiration**, and is abbreviated as **ET**. Water losses through ET are influenced by weather conditions such as temperature, wind, solar radiation and relative humidity, and are estimated using these factors.

Using the moisture accounting method

The moisture accounting method is illustrated by the following example (Table 4), in which a tomato crop is grown in clay soil at Tatura. As soon as the accumulated deficit exceeds 40 mm, a further irrigation is supplied.

To use the moisture balance sheet, complete the following steps.

- Decide which crop will be grown (eg. tomatoes).
- Estimate or measure root depth by digging a hole next to the crop, or alternatively use Table 1.
- Find out the soil type and determine total available water (see Table 3).
- Decide on an appropriate depletion fraction (p) roughly 0.3-0.5 for vegetable crops.
- Calculate readily available water = depletion fraction (p) × total available water.
- Calculate net irrigation application depth (mm) = root depth × readily available water.
- Record reference evapotranspiration (ET_o) from climate data or calculate it from pan evaporation.
- Multiply ET_o in mm/day (column A) by the appropriate crop coefficient (K_c) value (column B) to obtain crop water needs.
- Record daily rainfall and estimate effective rainfall (mm) (column D & E).
- Add up column H for all water deficits since the last irrigation and subtract effective rainfall. (After an irrigation event the soil is saturated and crop water use is assumed to be zero).

Table 4. Moisture balance sheet for scheduling irrigation in a lettuce crop

Crop: Tomatoes Effective root depth (D_{rz})= 0.55 metre (Table1),
Soil type: Clay $p = 0.4$ (Table1), TAW = 180 mm/m (Table8), RAW = 0.4 × 180 = 72 mm
Month: January Net irrigation depth = $D_{rz} \times$ RAW = 0.55 × 72 = 39.6 (rounded to 40 mm) (see step 6)

	A	**B**	**C = A × B**	**D**	**E = D - 5mm**	**F**	**H = (E+F) - C**
Day	**ET_o (mm/day)**	**Crop coefficient (K_c)**	**Crop water use (ET_c) (mm/day)**	**Rainfall (mm)**	**Effective rain (mm)[1]**	**Irrigation application d_{net} (mm)**	**Cumulative soil water deficit (mm)**
1	7.6	0.85	6.5	0	0	0	-6.5
2	8.6	0.85	7.3	3.8	0	0	-13.8
3	8.6	0.85	7.3	0.4	0	0	-21.1
4	8.8	0.85	7.5	0	0	0	-28.6
5	7.1	0.85	6.0	0	0	0	-34.6
6	9.1	0.85	7.7	0	0	40	Irrigation
7	6.4	0.85	5.4	0	0	0	0.00
8	3.4	0.85	2.9	0	0	0	-2.9
9	6.2	0.85	5.3	6	1	0	-8.2
10	6.3	0.85	5.4	3.2	0	0	-13.6
11	4.3	0.85	3.7	4.6	0	0	-17.3
12	7.7	0.85	6.5	1.4	0	0	-23.8
13	8.7	0.85	7.4	17.8	12.8	0	-11.0
14	7.2	0.85	6.1	0	0	0	-17.1
15	7.0	0.85	6.0	0	0	0	-23.1
16	8.4	0.85	7.1	0	0	0	-30.2

[1] To calculate effective rainfall, during spring, summer and autumn periods, subtract 5 mm from each of the daily rainfall totals. Assume rainfalls of 5 mm or less to be non-significant (zero). In winter, all the rainfall is assumed to be effective.

Crop water needs

The amount of water required to supplement crop water needs depends on the water requirements of the crop, local climate and soil conditions. Crop water needs can be estimated using weather data (evapotranspiration based method). This method allows growers or irrigation designers to estimate how much water will be required during the cropping season, and how best to deliver it to meet the crop's peak demand. This method is most effective when used in conjunction with other scheduling techniques.

Further Reading

Papers

Allen R.G., Pereira L.S., Raes D. and Smith M. (1998). Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage paper No. 56. Rome.

Doorenbos J. and Kassam A.H. (1979). Yield response to water. FAO Irrigation and Drainage paper No.33, p.25, Rome, Italy.

Doorenbos J. and Peruitt W.O. (1992). Crop water requirements. FAO Irrigation and Drainage paper No.24, (Rev.), Rome, Italy.

Manuals and Guidelines

Best management practice manuals and irrigation guidelines for vegetable crops*:

1. Best Management Guidelines for Irrigation of Processing Tomatoes, Melons, Carrots and Onions.
2. Irrigation scheduling for vegetable crops - growers guide.
3. *Agriculture Note*: Irrigation scheduling for vegetable crops.

* Available from the authors.

The previous version of this note was published in October 2001.