EVALUATION OF DRAINAGE IN BUDGET METHOD BASED IRRIGATION SCHEDULING
EVALUATION DU DRAINAGE AU PILOTAGE DE L'IRRIGATION PAR LA METHODE DU BILAN HYDRIQUE

Kouman S. Koumanov
Institute of Fruit Growing, 12 Ostromila, Plovdiv 4004, Bulgaria
E-mail: ksoumanov@hotmail.com

Abstract
Subject of analysis is the drainage *G* below root zone when, due to a rainfall or overirrigation of magnitude *N*, soil water storage *W* has been increased above the field capacity W_{fc} up to saturation W_s. It is widely accepted that: $G = N - (W_{fc} - W_n)$, where W_n is the water storage just before the rainfall (irrigation). However, in most soils water drainage is rather slow than instantaneous and is unavoidably accompanied by root water uptake and evaporation. Hence, water amount available for evapotranspiration should always exceed the difference $(W_{fc} - W_n)$ with some portion of the volume $(W_s - W_{fc})$ which was ignored in currently used methodology for irrigation scheduling.

If the effective water storage upper limit is W_2^n ($W_{fc} < W_2^n < W_s$) and the water storage just before the overwetting event is W_1^n, than the effective part of rainfall (irrigation) will be $N_o = W_2^n - W_1^n$ and respectively $G = N - N_o$. In present solution the curve of soil water storage $W(t)$ is substituted, by time-intervals (usually decades), with linear functions $F_i(t)$, $(i=1, 2, \ldots I)$, and the values of W_1^n and W_2^n are obtained after extrapolation of the functions $F_i(t)$ from the adjacent time-intervals $(i-1)$ and $(i+1)$ to the date of overwetting t_n in the (i)-interval. Other non-overwetting rainfalls and water applications, occurring in the considered time-intervals, are also included in the equations derived. Criterion for overwetting is formulated in terms of the solution and some specific cases are considered, too.

Key words: irrigation scheduling, budget method, drainage below root zone.

Present state of the problem

The drainage below root zone is an element from the negative part of water budget equation, widely used in both research experiments with irrigation and on-farm irrigation scheduling. Subject of present article is not the drainage at all but the leakage after accidental overwetting of root zone, resulting from rainfalls or improper irrigation management. The direct measurement of such a leakage is possible but complications of technical, methodological and financial character make it very difficult. In general, the change in soil water storage depends on numerous factors as: the soil moisture in the moment of water supply, the magnitude of water supply, the soil characteristics, the depth of root zone, the root water uptake, the crop, etc. In field conditions it is practically impossible to estimate all factors affecting this complex process. That is why, the amount of water drained below the root zone is usually evaluated using series of simplifications (Kostiakov, 1956; Krafti, 1964; Davidov, 1965). A common assumption is that water storage in root zone can increase only to the value of field capacity and the entire water amount, entering the soil afterwards, drains downward (Grant et al., 1986; Irrigation – Guid Pratique, 1990). In other words, if after a rainfall (irrigation) of magnitude *N* the soil water storage *W* has been increased above that at field capacity W_{fc}, than the drainage *G* is given by the expression: $G = N - (W_{fc} - W_n)$, where W_n is the water storage just before the rainfall (irrigation). However, a careful analysis showed that such an approach could bear significant errors (Koumanov, 1995). In most soils water drainage is rather slow than instantaneous (Hamblin, 1985) and both root water uptake and evaporation unavoidably accompany it. Hence, if W_s denotes the soil water storage at saturation, water amount available for evapotranspiration will always exceed the difference $(W_{fc} - W_n)$ with some portion of the volume $(W_s - W_{fc})$ which is ignored in currently used methodology for irrigation scheduling. Obviously, this ignored water amount should be reciprocal to soil hydraulic conductivity and proportional to the depth of root zone.

The more reliable solution

As in the previous approaches, present solution is based on the water budget equation written for each of time-intervals (usually decades) the vegetation period has been divided in:

$$G = m + N - ET + \left(W_i - W_{i+1}\right) \tag{1}$$

where G denotes the drainage, m – the applied irrigation water, N – the rainfall, W_i and W_{i+1} – the soil water storage in root zone respectively at the beginning and at the end of the time-interval. For simplicity, the other terms of water budget equation are ignored or assumed nil.

If the root zone is overwetted in result of a rainfall of magnitude N, than the drainage will be:

$$G = N - N_0, \tag{2}$$

where N_0 denotes that portion of the rainfall, which is used for evapotranspiration, i.e. the effective rainfall.

The present approach for evaluating of drainage G is illustrated graphically on *Figure 1* where the soil water storage in root zone W is plotted versus the time t. The period analyzed is divided into time-intervals, numbered consecutively. The number of each interval *(i)* is ascribed also to the point (the moment) marking its outset, as well as to the value of soil water storage at that point. The solution is valid under the following assumptions:

- the depth of root zone is constant;
- after a rainfall or overirrigation the value of soil water storage exceeds that at field capacity W_{fc}; if the water amount entered root zone is large enough, the soil water storage can reach its maximal value W_s, which that at soil saturation;
- the entire water amount entered root zone after the soil saturation is directly transmitted and drained downward, below the root zone;
- the process of drainage is accompanied by evapotranspiration, i.e. the effectively used portion of rainfall always exceeds the difference $(W_{fc} - W_n)$ where W_n is the water storage just before the rainfall.
- in time-intervals the curve of water storage change $W(t)$ is substituted respectively by the functions $F_i(t)$, $(i=1, 2, \ldots I)$ whose equations can be written. They can be either linear or of higher degree.

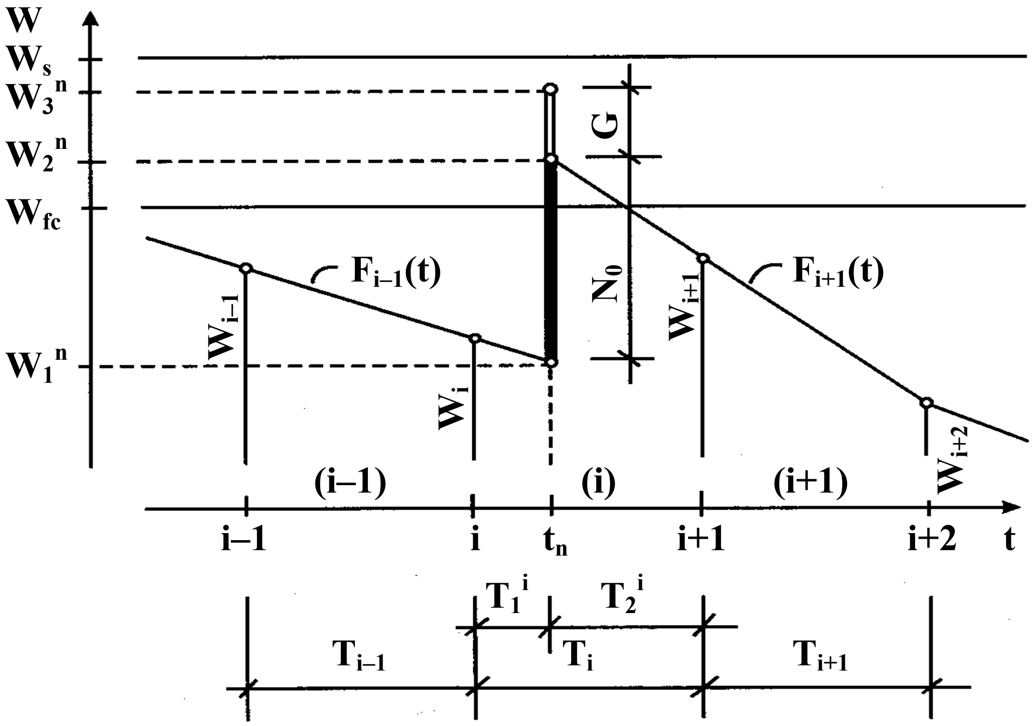

Fig. 1

Based on the assumptions made, the drainage below root zone can be evaluated after extrapolation of the substituting functions F_i *(t)* from the adjacent intervals *(i–1)* and *(i+1)* towards the date of overwetting rainfall in the interval of consideration *(i)*. The advantage of such an approach is that the equations of these functions can be easily written for the adjacent intervals where, in general, the root zone is not overwetted. Simple and widely used case is the linear approximation of the water storage curve where the function F_i *(t)* for an arbitrary time-interval *(i)* is:

$$F_i = \frac{W_{i+1} - W_i}{T_i} t + W_i, \tag{3}$$

In this equation t denotes the time elapsed from the interval outset and T_i – the interval length. Let the date of overwetting rainfall divides the time interval *(i)* into two subintervals *(i_1)* and *(i_2)*, $T_i = T_1^i + T_2^i$. The value of soil water storage just before the rainfall can be estimated by extrapolation of the approximating line F_{i-1} *(t)* from the interval *(i–1)* throughout the entire subinterval *(i_1)* to the moment t_n. The expression for W_1^n is obtained from equation *(3)* written for the interval *(i–1)*, $t = T_{i-1} + T_1^i$:

$$W_1^n = \frac{W_i - W_{i-1}}{T_{i-1}}.\left(T_{i-1} + T_1^i\right) + W_{i-1} \tag{4}$$

It was already mentioned that the water storage just after the rainfall termination W_3^n exceeds that at field capacity W_{fc} (Figure 1). Part of the surplus *(W_3^n - W_{fc})* is drained downwards while the remaining portion is used for evaporation and transpiration. The upper limit W_2^n of the effective water storage can be obtained from the equation *(3)* written for the interval *(i+1)*, $t = -T_2^i$:

$$W_2^n = \frac{W_{i+1} - W_{i+2}}{T_{i+1}} T_2^i + W_{i+1}. \tag{5}$$

Than the effectively used portion of the rainfall will be:

$$N_0 = W_2^n - W_1^n. \tag{6}$$

The equations remain simple even if rainfalls or irrigation water applications (other than that of consideration, *N*) occur in the time-intervals *(i–1)*, *(i)* and *(i+1)*, on condition that the water storage has not been increased over the W_{fc} value. Than the equations (4) and (5) will look as follows:

$$W_1^n = \frac{W_i - W_{i-1} - M_{i-1}}{T_{i-1}} \left(T_{i-1} + T_1^i\right) + W_{i-1} + M_{i-1} + M_1^i, \tag{7}$$

$$W_2^n = \frac{W_{i+1} - W_{i+2} + M_{i+1}}{T_{i+1}} T_2^i + W_{i+1} - M_2, \tag{8}$$

where M_{i-1} and M_{i+1} denote the sums of water amounts additionally entered root zone in the form of rainfalls and irrigation applications during the intervals *(i–1)* and *(i+1)* respectively; M_1^i and M_2^i have the same meaning but for the subintervals *(i_1)* and *(i_2)* of the interval *(i)*. The considered rainfall *N* does not participate in these sums.

The criterion for overwetting in an arbitrary time-interval *(i)* is formulated as follows:

$$M_i > \left(W_{fc} - W_i\right)\frac{T_i}{T_1^i} + \left(W_i - W_{i+1}\right), \tag{9}$$

where M_i is the sum of all rainfalls and irrigation application occurred in time limits of the interval.

It is possible that a rainfall results in overwetting registered by equation *(9)* and in the same time the value of W_2^n, obtained from equation *(5)*, is lower than that of W_{fc}. Formally this fact means that the process of drainage continues after the water storage in root zone has been decreased to values lower than W_{fc}. Although this case is not impossible, it is not in compliance with the assumptions made and, hence, it would be more correct to accept that if $W_2^n < W_{fc}$ than $W_2^n = W_{fc}$. The effectively used portion of the rainfall, according to equation *(6)*, than will be:

$$N_0 = W_{fc} - W_1^n. \tag{10}$$

Conclusions

Some portion of the water amount currently considered as drainage is used effectively for evaporation and transpiration. This portion is reciprocal to soil hydraulic conductivity and proportional to the depth of root zone.

The drainage below root zone can be evaluated by extrapolation of the water-storage-curve substituting functions from the adjacent time-intervals towards the date of overwetting in the interval of consideration. This approach is characterized with simplicity, increased reliability and satisfying exactness.

References:

Davidov, D. (1965):
Varhu izcisliavaneto na izpolzuvaemia valej pri polskite opiti. (in Bulgarian) Rastenievadni Nauki 2(11), 21-23.

Grant, J., Goldhamer, D. and Gagnon, M. (1986):
The water budget method. Irrigation scheduling for southern San Joaquin Valley deciduous orchards. Leaflet 21419, Cooperative Extension, University of California, 12pp.

Hamblin, A.P. (1985):
The influence of soil structure on water movement, crop root growth, and water uptake. Advances in Agronomy 38, 95-158.

Irrigation – Guid Pratique (1990):
Rieul, L. (ed.), CEMAGREF et CEP – France Agricole, 319pp.

Kostiakov, A.N. (1956):
Osnovi na melioraciite. (in Bulgarian) 459pp.

Koumanov, K. (1995):
On the methods for evaluating the used part of the rainfall under field experiments. Plant Science 32(7-8), 159-161.

Krafti, G. (1964):
Opredeliane na sumarnoto vodopotreblenie po balansovia metod i vrazkata mu s izpariaemostta. (in Bulgarian) Rastenievadni Nauki 1(3), 147-158.