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Contribution to irrigation from shallow water table under field conditions

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ABSTRACT

The mathematical model SWBACROS was applied to estimate the contribution of a shallow groundwater to the water needs of a maize crop. The model was applied with the top and boundary conditions defined by the observed irrigation/rainfall events and the observed water table depth. The simulated water contents of the top zone were very close to the observed values. Furthermore the model was applied with an assumed free drainage bottom boundary condition. The difference of the computed water content profiles under the presence and absence of the water table gave a very good estimate of the capillary rise. It was found that under the specific field conditions about 3.6 mm/day of the water in the root zone originated from the shallow water table, which amounts to about 18% of the water, which was transpired by the maize crop.

1. Introduction

World population today is about 6.5 billion and it is estimated that it will be increased to 9.1 billion by the year 2050 (UN, 2004). Irrigation supplies approximately 40% of the world foodstuffs on less than 18% of the arable land and has a significant future role in meeting the projected world food demand (Ayars et al., 2006). It is estimated that irrigation consumes more than 80% of the good quality water. This makes it the greatest user of water, very far from its other competitors, namely urban, industrial and environmental use. It is more than certain that competition among agricultural, urban, industrial and environmental needs will be even more intense in the near future. Any effort towards improving irrigation efficiency is worthwhile because it can lead to saving large quantities of good quality water.

Shallow ground water table exists in many areas of the world. This shallow ground water can be used by plants either by using drainage water for irrigation or through in situ use. Saline drainage ground water has been studied extensively as a supplemental source of irrigation water (Rhoades et al., 1989; Ayars et al., 1993, 2006). In situ use of ground water by crops is a more complicated matter than irrigating with drainage ground water. It depends on several factors such as depth to the water table, hydraulic properties of the soil, stage of the crop growth, ground water quality etc. Quantification of the water taken by the roots from the shallow water table is of great significance and has been a topic of extensive research in the last few decades.

Wallender et al. (1979) found that 60% of the evapotranspiration (ET) of a cotton crop was extracted from a 6 dS m^{-1} shallow water table.

Ayars and Schoneman (1986) found that capillary rise of water of ECe = 10 dS m^{-1} from a water table of 1.7–2.1 m deep contributed to up to 37% of evapotranspiration (ET) of a cotton crop.

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Prathapar and Qureshi (1998) observed that under shallow water table conditions irrigation can be reduced by up to 80% without affecting crop yield and increasing soil salinization.

Soppe and Ayars (2003) by using weighing lysimeters maintained a saline (14 dS m^{-1}) water table at 1.5 m depth and found that ground water contributed up to 40% of daily water used by safflower crop. On a seasonal basis 25% of the total crop water use originated from the ground water. The largest contribution occurred at the end of the growing season when roots were fully developed. The applied irrigation in the presence of a water table was 46% less than irrigation applied to the crop without a water table.

Kahlown et al. (2005) investigated the effect of shallow water tables on crop water requirements by using 18 large size drainage type concrete lysimeters. They found that when a water table was kept at a depth of 0.5 m, wheat met its entire water requirement from the ground water. Sunflower required only 20% of its total need from irrigation. However maize and sorghum were found to be waterlogging sensitive crops whose yield were reduced with higher water table.

Most of the previous research is conducted by using weighing and drainage lysimeters. The method is very accurate but has serious limitations because of the cost of construction, operation and maintenance of the lysimeters. A common characteristic of most of this research is that it is focused on the existing conditions of the experiment and the conclusions are difficult to be extended to other situations.

Thessaloniki plain, Greece, covers an area of about 100 000 hectares. The plain is cultivated with cotton (34%), maize (12%), rice (17%), sugarbeets (6%), alfalfa (3%), orchards (20%) and some other crops in smaller extent. Bad irrigation management, non functional drainage systems and also seepage from the rice fields, which are covered with water for long periods of time, result in high water table during summer in many parts of the plain. Salts accumulated in the root zone during summer are leached by rainfall in winter time when the deepening of the water table (because of the absence of rice fields) permits it.

In some areas of the plain the depth to the water table during the cultivation period can be as low as 40–50 cm from the ground surface. Capillary rise is very large and contributes to crop water requirements significantly. Even though farmers reduce irrigation by taking advantage of this shallow water table, contribution of this to transpiration has never been quantified. It is obvious that if it is managed correctly, groundwater can contribute significantly to crop water needs and therefore reduce applied irrigation.

The objective of this paper is to estimate ground water contribution to transpiration. Towards this goal, the mathematical model SWBACROS (Babajimopoulos et al., 1995) is used.

2. Materials and methods

2.1. The mathematical model

The mathematical model is based on the equation which describes the unsaturated, transient, water flow in a heterogeneous soil under the presence of a crop:

$$C(\theta)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[K(\theta)\left(\frac{\partial h}{\partial z} - 1\right)\right] - S(h) \quad (1)$$

where, $C(\theta) = \partial\theta/\partial h$ is the specific moisture capacity function (1/L), h is the pressure head (L) which is negative in unsaturated soil, $K(\theta)$ is the unsaturated hydraulic conductivity (L/T), θ is the volumetric soil water content (L^3/L^3), z is the vertical dimension directed positive downwards (L), t is the time (T) and S is the root water uptake (1/T). Eq. (1) is solved by the Douglas–Jones predictor–corrector method (Douglas and Jones, 1963; Babajimopoulos, 1991, 2000).

A detailed description of the model is given by Babajimopoulos et al. (1995). It is referred here that the unsaturated hydraulic conductivity and the specific moisture capacity functions are computed as in Van Genuchten (1978, 1980). The sink term is computed as in Belmans et al. (1983) by:

$$S(h) = \alpha(h)S_{max} \quad (2)$$

where, $\alpha(h)$ is a dimensionless prescribed function of pressure head and S_{max} is the maximal possible water extraction by roots defined as in Feddes et al. (1978) by:

$$S_{max} = \frac{E}{R_d} \quad (3)$$

where, E is the potential transpiration and R_d is the root depth.

Fig. 1 is a graphical representation of Eq. (2) with the x axis representing absolute values of the pressure head. Water uptake is maximal between $|h_1|$ and $|h_2|$ and varies linearly between 0 and $|h_1|$ and between $|h_2|$ and $|h_3|$. Actual transpiration is computed by integration of Eq. (2) over the root zone depth.

The potential transpiration rate, E, is computed by:

$$E = ETP - EV \quad (4)$$

where, ETP is the potential evapotranspiration rate computed by the modified Penman method (Doorenbos and Pruitt, 1984) and EV is the potential evaporation rate from soil surface computed as in Al–Khafaf et al. (1978) by:

$$EV = ETP\exp(-0.623LAI) \quad (5)$$

where, LAI is the Leaf Area Index function.

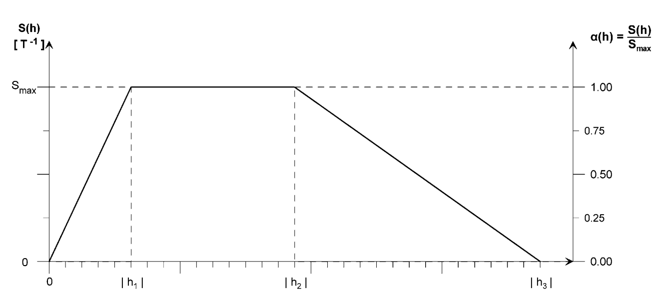

Fig. 1 – General shape of the sink term S (Feddes et al., 1978).