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AN ANALYSIS OF SOIL-WATER MOVEMENT IN THE FIELD: II. WATER BALANCE IN A SNAP BEAN CROP

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PIRACICABA-SP
- BRASIL -

F O R E W O R D

In November 1970 the PANEL ON THE USE OF NUCLEAR TECHNIQUES IN SOIL PHYSICS AND IRRIGATION STUDIES recommended that the Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture initiates a coordinated research programme on "The Use of Isotope and Radiation Techniques in Studies of Soil Water Regimes". This programme starded in 1972, involving twelve countries well distributed around the world. Brazil participates in that programme through the Research Agreement nº 1280 between Joint FAO/IAEA Division and Center for Nuclear Techniques in Agriculture. Progress in this research has been reported in annual reports. The present technical report envolves part of the work carried out in Piracicaba, Brazil, during the period October 1973/October 1974.

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UMA ANÁLISE DO MOVIMENTO DE ÁGUA NO CAMPO: II. BALANÇO HIDRICO EM CULTURA DE FEIJÃO

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R E S U M O

Neste trabalho é apresentado um estudo detalhado do movimento de água em uma cultura de feijão. Seu principal objetivo foi o estabelecimento de um balanço hídrico completo, no qual são estimados os fluxos de água no limite inferior do volume de contrôle. A evapotranspiração e a drenagem profunda foram estimadas integrando perfís de umidade de solo obtidos por meio de medidas com sonda de neutrons até a profundidade de 150 cm. A distinção entre as perdas de água por evapotranspiração e por drenagem profunda foi feita medindo-se as direções do gradiente de potencial total da água do solo, utilizando dados de tensiômetro. Os fluxos de água no solo foram também estimados com utilização de dados de condutividade hidráulica medida em condições de campo. Os resultados evidenciam a importância da drenagem profunda em relação a outros componentes do balanço hídrico.

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AN ANALYSIS OF SOIL-WATER MOVEMENT IN THE FIELD: II. WATER BALANCE IN A SNAP BEAN CROP

S U M M A R Y

In this paper a detailed study of soil-water movement in a croped bean field is presented. Its main objective was the establishment of a complete water balance in which soil-water fluxes at the lower boundary of the control volume were estimated. Evapotranspiration and deep drainage were estimated by integrating soil-water content profiles, which were obtained through neutron probe measurements down to a depth of 150 cm. The distinction between water losses caused by evapotranspiration and by deep drainage has been carried out by measuring the directions of the total water potential gradients in the soil profile, using tesniometer data. Soil-water fluxes were also estimated from hydraulic conductivity data obtained in the field. The results show the importance of deep drainage in relation to other components of water balance.

1. INTRODUCTION

This paper presents a detailed study of soil water movement in a bean field. Its main objective is the establishment of a complete water balance in which soil-water fluxes in the lower boundary of the control volume are estimated. These fluxes are in general ignored what corresponds to their inclusion either in the evapotranspiration or storage components of the water balance. Detailed studies of water balances in croped and bare soils *(BLACK et al. 1969, 1970, 1970a, DAVIDSON et al. 1969, LaRUE et al. 1968)* show the difficulties envolved in the estimation of these soil-water fluxes. *GIESEL et al. (1970)* suggested the determination of a zero flux plane in the soil profile for the distinction between water losses by evapotranspiration and by deep drainage. This approach has been used with success by *DAYAN and VACHAUD (1972)* and *STAMMERS et al. (1973)*. In this paper it is also used and discussed under conditions of a very deep water table.

2. THEORY

Let W (cm of water) be the amount of water stored in a soil layer of arbitrary depth at time t calculated according to:

$$W(z) = \int_{z_1}^{z_2} \theta(z)\, dz \qquad (1)$$

z being the vertical position coordinate (cm), considered positive downwards and θ the volumetric soil water content ($cm^3.cm^{-3}$).

The water balance of a control volume of soil in a field ($0 < z < L$), during a period of time t_2-t_1, can be written as:

$$\int_{t_1}^{t_2} (p + i - q_o \pm q_L)dt - \Delta W = 0 \qquad (2)$$

where p and i are the rates ($cm.sec^{-1}$) of water supply at $z = 0$ (precipitation and/or irrigation), q_o the evapotranspiration rate ($cm.sec^{-1}$), q_L the vertical soil-water flux at $z = L$ ($cm.sec^{-1}$) considered positive upwards, and ΔW the net storage during the period t_2-t_1 from $z = 0$ to $z = L$.

Soil-water fluxes, e.g. q_L, are given by Darcy's equation:

$$q(z,t) = -K(\theta) \frac{\partial \psi}{\partial z} \qquad (3)$$

where $K(\theta)$ is the hydraulic conductivity ($cm.sec^{-1}$) and ψ the total soil-water potential head (cm) considered to be the sum of the soil-water pressure head h (cm) and the gravitational head z (cm).

Knowing the total soil-water potential gradient distribution ($\partial\psi/\partial z$) along the profile during the interval of time t_2-t_1, zones

of $\partial\psi/\partial z > 0$ and $\partial\psi/\partial z < 0$ can be established. The transistion between them will be, of course, a zero flux plane where $\partial\psi/\partial z = 0$. Integrating soil-water content profiles along these zones according to equation (1) at times t_1 and t_2 downward (deep drainage) and upward (evapotranspiration) fluxes can be estimated. Another alternative for the determination of these fluxes is the use of equation (3), when hydraulic conductivity data is available.

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3. EXPERIMENTAL SITE AND METHODS

The experiment was conducted between March 15 and May 1, 1974, at the "Escola Superior de Agricultura "Luiz de Queiroz" Experimental Farm, on a very deep profile of an Earthy Red Latosol (Acrohumox, Terra Roxa Estruturada), having a water table several meters below soil surface. Some hydraulic properties of this soil have been reported elsewhere *(REICHARDT et al. 1974)*. The experimental site consisted of a 10x10 m plot on which a snap-bean crop (*Phaseolus vulgaris* L. var. Carioca) was grown. On Figure 3 the development of the crop is shown graphically. Five days before planting the plot was limed with an application of 4 ton/ha of limestone. Fertilization consisted of Urea (100 kgN/ha), Triple Superphosphate (200 kgP_2O_5/ha) and Potassium Chloride (100 kgK_2O/ha).

3.1. Soil-Water content measurements

Soil-water content measurements were done by neutron thermalization technique, using a depth-neutron-moisture probe,which was calibrated at the field site. Four neutron access tubes have been instaled randomly in the center of the plot, down to the depth of 180 cm. Measurements were taken weekly in 30 cm intervals, starting at the depth of 30 cm. Averages of the four measurements were used for the calculations of storages according to equation (1). Gravimetric samples were taken at the surface and at a depth of 5 cm to complete the soil-water content profiles shown in Figure 1.

3.2. Soil-Water potential measurements

Soil-water potential was measured daily at 8.00 am by tensiometers with porous cups at depths of 7.5 - 15 - 30 - 45 - 60 - - 90 - 120 - 150 and 180 cm. Total soil-water potentials were calculated adding the gravitational potential head to the tensiometer readings in cm of water. Some of the total soil-water potential profiles can be seen in Figure 2. Zones of positive and negative

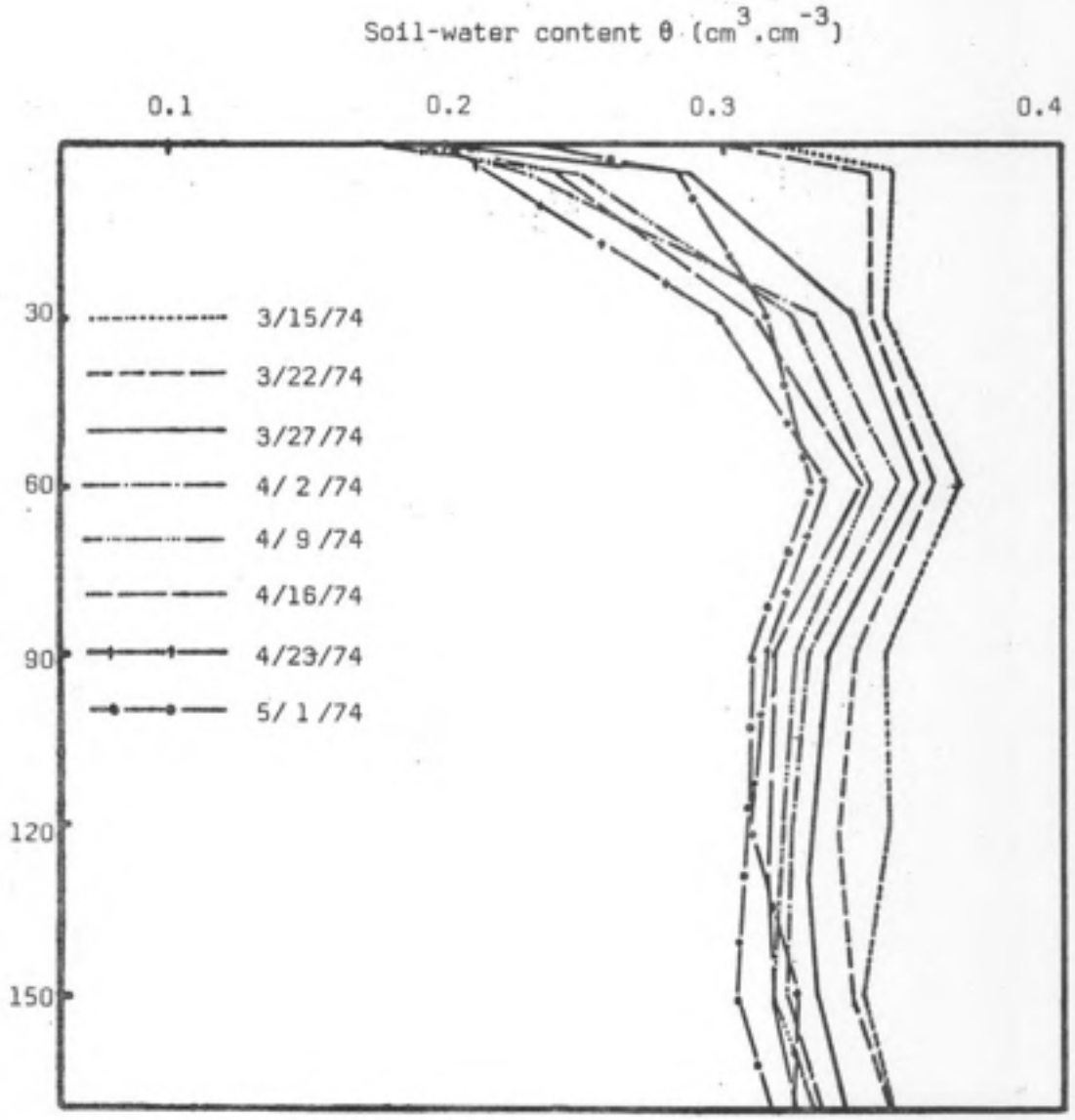

Figure 1 - Soil-water content profiles obtained through neutron probe measurements.

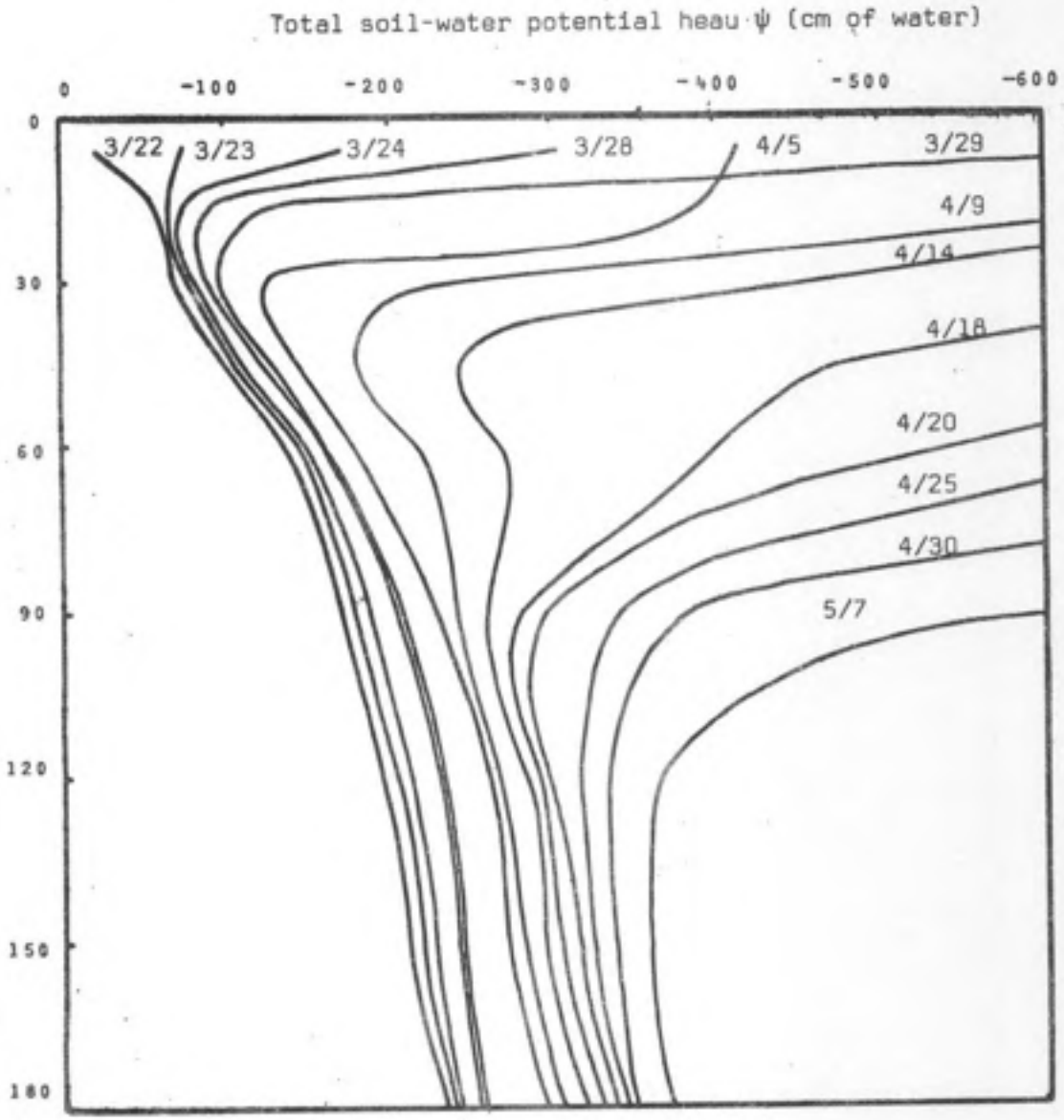

Figure 2 - Total soil-water potential distributions in a Snap Bean Crop.

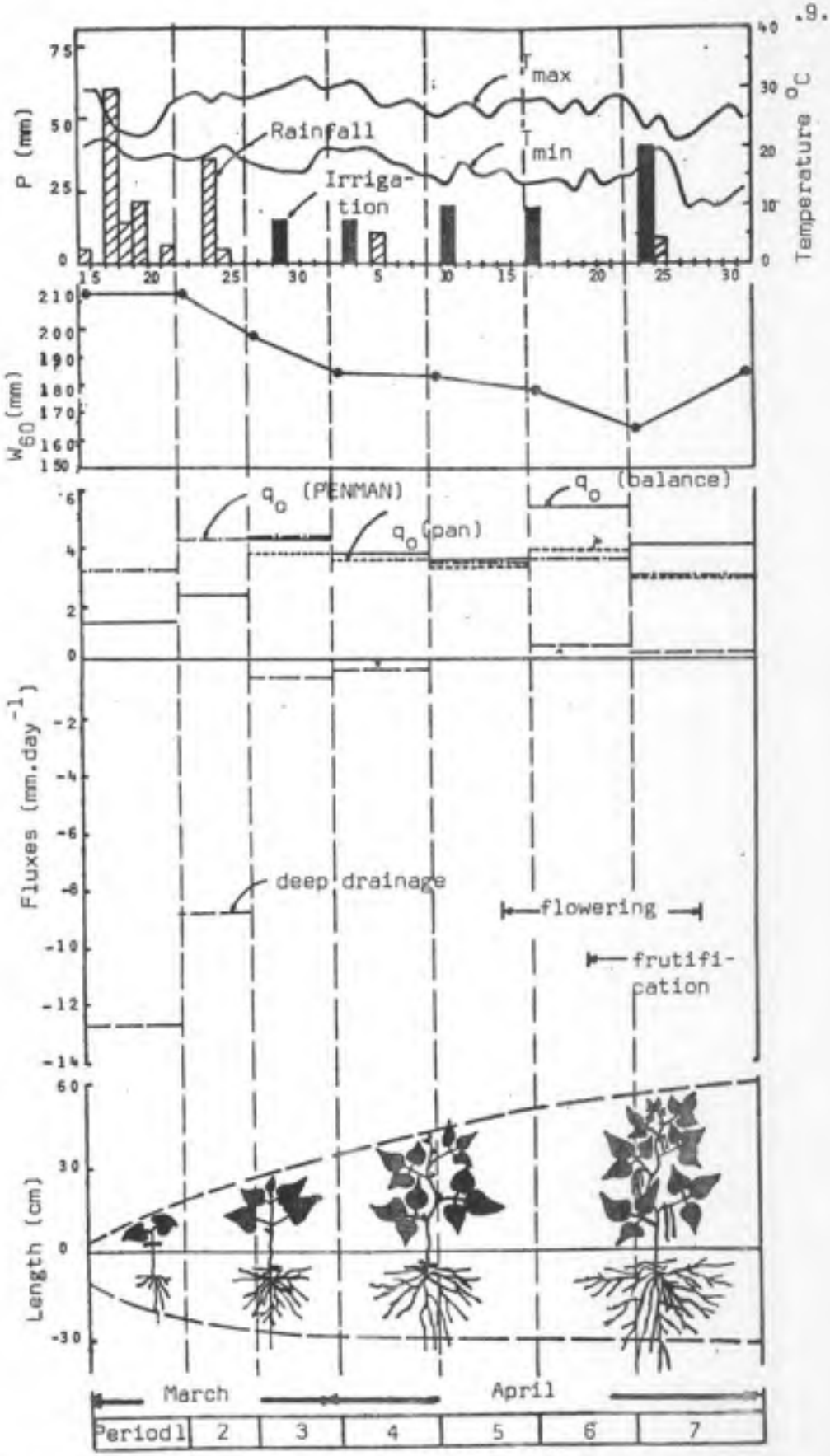

Figure 3 - Rainfall, irrigation, temperature, storage, fluxes and crop development from March 15 to May 1.

total soil-water potential gradient, as discribed in theory, can there clearly be seen.

3.3. Meteorological data

During the experimental period the following meteorological observations have been performed:

a. rainfall;
b. air temperature;
c. relative humidity;
d. sunshine hours;
e. wind speed at 2 m from soil surface, and
f. class A pan evaporation.

These data were used for the establishment of the water balance and to calculate potential evapotranspiration according to *PENMAN (1948)*. Part of the meteorological data is presented in Figure 3.

3.4. Soil Solution Sampling

Extraction of soil solution for the measurement of ion concentration has been performed according to *REEVE and DOERING (1965)*. Samples were obtained applying a negative pressure of 600 milibars to porous cups located at depths of 30 - 60 - 100 and 140 cm from soil surface. Soil-water samples were analysed in the laboratory for ion concentration (Cl^-, NO_3^-, Ca^{++}, K^+ and pH).

4. RESULTS OBTAINED

The experimental period of 48 days was divided in 7 periods which are shown in Figure 3. These periods were used for water balance calculations. Table I shows the results considering L = 60 cm since, on the average, 90% of plant roots where distributed over the first 30 cm (Figure 3). Weekly plants were extracted carefuly to examine root and shoot development.

Period 1 was rainy, the whole soil profile being under drainage according to tensiometer readings. During this period the evapotranspiration rate q_o was considered equal to the class A pan evaporation rate corrected with a factor 0.78. The average depth of the zero flux plane was considere equal to zero. Runnoff was estimated as 10% of rainfall rates greater than 50 mm.day^{-1}.

In Period 2 the same approach was taken to estimate q_o during rainy days. During sunshine days q_o was estimated integrating soil water content profiles above the zero flux plane which was, on the average, 7 cm below soil surface.

Period 3 was dry in which storage decreased although one irrigation was applied. Therefore the computation of q_o included the integration of water content profiles above the average zero flux plane (25 cm) and the irrigation.

The approach applied in Period 3 for the estimation of q_o also was used in Periods 4 and 5. In Period 4, since ΔW was positive above the average zero flux plane (36 cm), evapotranspiration was considered equal to rainfall and irrigation imputs discounting the positive storage.

In Period 6 and 7 the average zero flux plane (122 cm) lies below the lower boundary L of the control volume and q_z was a positive input to the control volume. The computation of q_o included the

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TABLE I - WATER BALANCE FOR L = 60

Dates	Period	(cm average depth of zero flux plane	P rain (mm)	I irrigation (mm)	R runnoff (mm)	Q_o evapotranspiration (mm)	Q_z deep drainage (mm)	ΔW storage (mm)
3/15 - 3/22	1	0	104.6	0	-6.1	- 9.8	- 89.9	- 1.2
3/22 - 3/27	2	7	40.3	0	0	- 11.4	- 44.2	-15.3
3/27 - 4/2	3	25	0	15.0	0	- 25.0	- 3.5	-13.5
4/2 - 4/9	4	36	11.8	15.0	0	- 25.8	- 2.2	- 1.2
4/9 - 4/16	5	55	0	20.0	0	- 24.4	- 0.1	- 4.5
4/16 - 4/23	6	122	0	20.0	0	- 37.1	+ 3.7	-13.4
4/23 - 5/1	7	122	9.0	40.0	0	- 32.2	+ 2.4	+19.2
		TOTAL	165.7	110.0	-6.1	-165.7	-138.8	-29.9

P, I, Q_o and Q_z are integrated values of p, i, q_o and q_z over the respective periods of time.

integration from the average zero flux plane up to the soil surface and the irrigation, as it has been done in Period 3.

In all periods q_L was considered unknown in the water balance and calculated according to equation (2).

Figure 3 shows also evapotranspiration data obtained through the water balance (from Table I), class A pan evaporation corrected by a factor of 0.78 and Penman's potential evapotranspiration *(PENMAN, 1948)*.

Table II shows ion concentration data collected during the experimental period.

The yield of the plot was 1 600 kg/ha.

TABLE II - Ion Concentration of Soil solution as a function of depth and time

Ion	deph (cm)	3/22	3/9	4/9	4/20
Cl^- *	30	2.0	4.6	1.2	-
	60	6.0	1.4	9.1	1.3
	100	1.5	1.0	1.9	0.7
	140	1.6	1.4	0.9	0.6
NO_3^- *	30	11.0	3.3	4.8	-
	60	43.0	6.0	1.4	1.1
	100	0.8	99.0	1.9	1.1
	140	1.1	82.0	0.9	0.7
Ca^{++} *	30	22.0	2.8	5.7	-
	60	14.0	2.7	1.8	2.8
	100	4.2	1.5	1.2	2.8
	140	2.7	1.4	1.1	3.6
K^+ **	30	36.0	21.5	-	-
	60	22.5	27.0	27.2	66.0
	100	19.0	14.0	21.5	28.2
	140	28.0	14.0	14.5	73.0
pH	30	6.3	8.3	-	-
	60	7.3	7.5	7.5	-
	100	7.6	7.6	7.5	7.2
	140	7.4	7.2	7.6	-

* - Cl^-, NO_3^- and Ca^{++} data are given in moles per liter x 10^4

** - K^+ data is given in micrograms per milliliter

5. DISCUSSION

The use of the zero flux plane method *(GIESEL et al. 1970)* for the determination of the evapotranspiration component of the water balance was successful in this experiment, although some limitations have to be discussed. The time interval (t_2-t_1) over which the balance was made has to be variable depending on the particular weather conditions present. Periods of heavy rain have to be separated from dry periods because of difficulties in establishing the depth of the zero flux plane, especially average values. During the dry periods in which small irrigations were applied difficulties also arise because more than one zero flux plane might be present in the profile. In these cases irrigation was added to the evapotranspiration component and only the deepest zero flux plane was considered.

As an alternative for the estimation of Q_z, calculations were made using Darcy's equation (3) and hydraulic conductivity data obtained by *REICHARDT and LIBARDI (1974)* for the same field site. Values obtained for Q_z in the seven Periods are, respectively, -20.2; -6.6; -4.2; -1.2; -0.5; +1.8 and + 1.2 mm. For Periods 1 and 2 these Q_z values are lower than those using the zero flux plane method (Table I). .The high values of Q_z obtained through the zero flux plane technique seem to be of the right order of magnitude since in the water balance they yield reasonable values for Q_o. The reason for the lower values of Q_z obtained through Darcy's equation should be due to the use of an average value of θ in the $K(\theta)$ relation. *REICHARDT and LIBARDI (1974)* presented drainage data for this soil which showed high fluxes close to saturation and a very rapid decrease with time. This fact may also have contributed to an underestimation of hydraulic conductivity (K) values by these authors. Another source of error lies in the determination of the total potential gradient $\partial x/\partial z$ when the upper soil layers become dryer.

In the other periods Q_z was of the some order of magnitude when calculated by the two methods. In these periods, however, Q_z is negligible as compared to the other components of the water balance.

This study shows that deep drainage fluxes q can be an important component of the water balance. Using soil solution ion concentration data presented in Table II together with these fluxes q_z an estimation of salt leaching can be made. In periods 1 and 2 the water losses by deep drainage were, respectively, 84 and 62% of the total water losses (evapotranspiration, runoff, decrease in storage and deep drainage). Over the whole period of the 48 days these losses ammounted to 40%.

Paralell to this experiment two other bean crops were grown, one covering the soil surface with a straw mulch to prevent evaporation and an other unirrigated. The yields of these crops were 520 and 490 kg/ha, respectively. These low yields with respect to the irrigated plot show the importance of supplementary irrigation in dry years like 1974. The high N fertilization however stimulated the vegetative growth of the irrigated crop so that its yield was still low when compared to maximum yields obtained in field experiments

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6. CONCLUSION

The distinction between deep drainage and evapotranspiration fluxes in a snap bean crop was possible through the establishmenent of a zero flux plane within the soil profile. This technique shows advantages over the flux estimation using Darcy's equation.

Deep drainage, which has been ignored by several authors working on similar conditions, cannot be neglected in water balance studies in tropical soils.

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