Sci. Annals, Fac. Phys. & Mathem., Univ. Thessaloniki, **15**, 141, (1975).

# COMPARATIVE INVESTIGATION OF ACTUAL AND POTENTIAL EVAPOTRANSPIRATION

by

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*(Reeeived on 10.12.74 Revised 1.7.75)*

**Abssract**: *Experiments eonducted at the Station of Land Reelamation, in eollaboration with the Meteorological Institute of the University of Thessaloniki, indicate after the first year of the experiment (1973), that the soil moisture regime is the main factor determining the intensity of evapotranspiration under the same elimatological parameters.*

*The maintainance of the amount of soil moisture near the point of «moisture equivalent» (pF = 2.54 or 1/3 atm) involves a much higher water consumption by plants, than the one resulted from a progressive decrease of the amount of moisture, between two successive irrigations, from the moisture equivalent to the «wilting point» (pF = 4.2 or 15 atm).*

*The difference of water consumption for the first case, amounts to 32% for corn (43% during the peak interval), to 22% in corn for green fodder (26% during the peak interval), and 58% in cotton (146% during the peak interval); this fact proves the importancl of the genotype factor of the plant species.*

*An analogous differentiation has been observed in the energy balance; a strong energy flux has been observed towards the system of the first case, and a quite restricted flux towards the system of the second case.*

## INTRODUCTION

According to *Veihmeyer* and *Hendrickson*[17,18,19] the evapotranspiration regime remains stable within a considerable range of the available soil moisture. However, this statement has been disputed by other scientists, who proved, through experiments, that the absorption capacity of plants is gradually reduced by the corresponding gradual decrease of the percentage of soil moisture.

Below we state in brief the views of various research workers:

According to *Penman*[9] the evapotranspiration regime remains stable from the moisture equivalent till the consumption of 20% of the avail-

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able moisture; from that point on, its intensity is considerably reduced, but then a sudden increase is observed when the soil moisture approaches the wilting point.

*Gardner*[3] agrees with Penman, but states a continuous gradual decrease of evapotranspiration till it reaches the wilting point.

Other research workers, like *Thornthwaite*[14,15], *Zinke*[21], *Metz and Douglas*[8], *Knöer*[5], and the *U.S. Army Engineering Waterways Exp. Station in Kicksburg - Mississipi*[16] have found that the evapotranspiration regime, within the range of moisture available, is an exponential form.

The Greek Prof. *L. Liakos*[5], in experiments that he conducted in the U.S.A., found that soil moisture at any given time is related to the initial moisture by the following expression:

$$Qt = Q_o \cdot e^{-kt} \qquad (1)$$

where: $Qt$ = the soil moisture (in mm) at time t (days),
$Q_o$ = the initial moisture (in mm),
$k$ = a constant.

The same scientist has found $k = 0{,}0042$ and $k = 0{,}00925$ for natural pastures under intensive and restricted grazing, respectively.

From expression (1) and other works already mentioned it results that the consumption regime of soil moisture through evaportranspiration is directly related to the moisture available for plants.

From those above mentioned, and other relative works, the distinction between actual and potential evapotranspiration is defined as follows:

a) The actual evapotranspiration (ETe) corresponds to the amount of water consumed by evaporation directly through the soil and transpiration by cultivated plants of normal density and development, with a considerable range in the variation of soil moisture between two consecutive irrigations, within the maximum range between the moisture equivalent and the wilting point.

b) Potential evapotranspiration (ETp) corresponds to the amount of water consumed by evaporation directly through the soil and by transpiration by cultivated plants of optimum density and development, with restricted decrease of moisture, from the moisture equivalent between two consecutive irrigations. According to *Thornthwaite*[14] and *Penman*[10] who introduced this concept, the intensity of evapotranspiration under such conditions, is independent of the «plant» factor, depending solely on the evaporation capacity of the atmosphere.

Under the prevailing conditions of field irrigation in most cultivations, the phenomenon of potential evapotranspiration is restricted to the first few days after each irrigation, meaning that this process refers to the consumption of 20 - 30% of moisture available, while the actual evapotranspiration takes up the whole range of available moisture.

Consequently, only in special cases of irrigation of shallow-rooted vegetables and grass pastures, where water is allowed at small application intervals, can the phenomenon of potential evapotranspiration be accepted. However, the importance of this form of water consumptive use, becomes ever more opportune as the method of trickle-irrigation gets more and more widespread.

By such water applications on land, can be steadily procured, through the proper correlation of agronomic and technical parameters, the optimum which coincides, except for certain cases, with moisture percentage very near the moisture equivalent.

## Experiment and results.

### 1. *Process and application of the research.*

#### 1.1 *Lysimeters employed*

The whole experiment has been planned for the study of more subjects than the one exposed herein. During the first stage, it was effected by two (2) batteries of lysimeters: one by underground water allowance and the other by surface water supply. Figure 1, shows a top-view of the lysimeters used in this research, and Fig. 2 a cross-section of one underground lysimeter, and of a couple of surface water supply lysimeters.

As to the number, form and snrface of the lysimeters, each group consisted of two (2) round lysimeters with diameter d = 2.0m, that is a surface of $3.14m^2$ each, and another two (2) square lysimeters, with sides a = 2.0 m, that is a surface of $4.0m^2$. The sides and bottom of each lysimeter were made of concrete, 10cm thick.

In the lysimeters with underground water supply, a hydraulic system with an intermediate floater, secured a stable underground level at a depth of 0.70cm from the land surface, and a continuous and free water supply, whose quantity was determined, at any time interval and

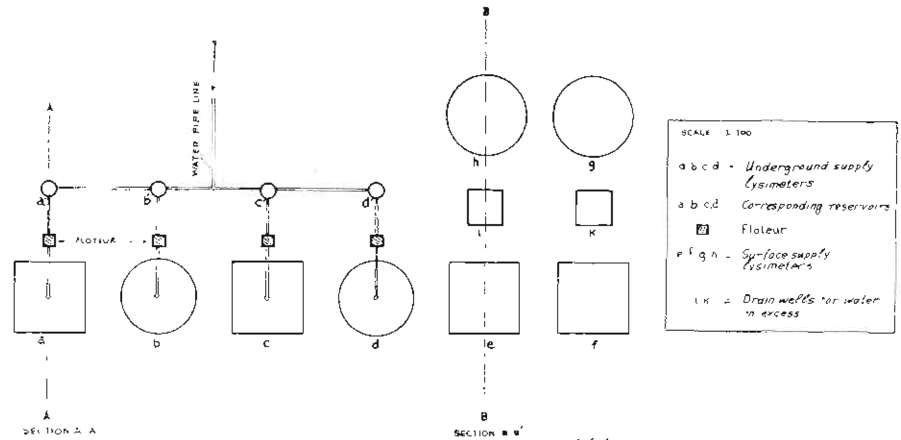
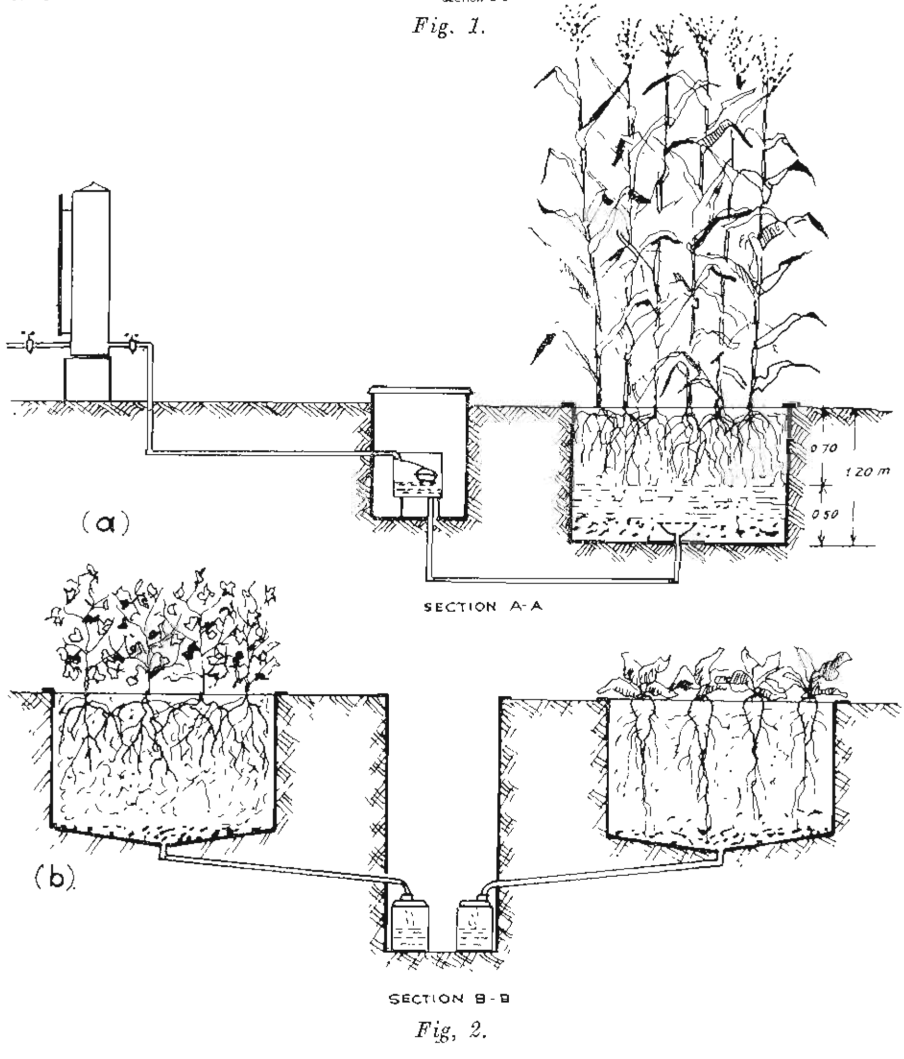

WATER PIPE LINE
FLOTEUR
a b c d
e f g h
i k
SECTION A-A
SECTION B-B'
SCALE 1:100
a b c d - Underground supply Lysimeters
a b c d Corresponding reservoirs
Floteur
e f g h - Surface supply Lysimeters
i k - Drain wells for water in excess

*Fig. 1.*


(a)
0.70
1.20 m
0.50
SECTION A-A
(b)
SECTION B-B

*Fig, 2.*

as a whole, by the rate of evapotranspiration. Thus, every morning the amount of water consumed during the last 24-hours was checked from the readings of the level measuring scale, expressed in the corresponding height (in mm), by the ratio $E_1 : E$, where $E_1$ the surface of the cross-section of the water-reservoir, and E the surface area of the corresponding lysimeter. It is quite clear that, by this system one has an absolutely accurate control of the consumptive use per hour and per day without need of any soil sampling for soil-moisture control.

Through this system, as already proved were provided such hydrological conditions in the surface layer of the ground, where the greatest part of the root system of plants grew, as to maintain the percentage of soil moisture very near to the moisture equivalent and as to secure the basic condition for the phenomenon of potential evapotranspiration.

In the surface water supply lysimeter the allowance of water to cover the deficit of soil moisture, was effected every time after a laboratory test of the actual moisture on soil samples taken with a Veihmeyer sampler, down to a depth of 0.90m and at intervals of 1 ft within the ground. As shown in Fig. 2b, any surplus of water flowed out, through the hydraulic system provided, into small drain wells, and its volume was calculated in order to complete the data of water balance.

## 1.2 *The soil and cultivations on it.*

The basins of the lysimeters were filled-in with earth from the excavation of the exact spots where they were installed. Special care was taken in alternation of layers, to follow exactly that of the surrounding strata. Before filling the lysimeters with earth, their bottoms were covered with a layer of sand and fine pebbles, 15 cm thick.

When the filling-in of the lysimeters with earth was completed, and this earth was duly compressed, samples were taken down to the depth of 0.90 m and at 1 ft intervals of this soil. Results of laboratory analyses and other specifications are given in Table 1. This table includes the data of mechanical analysis, classification of the soil, hydrological constants and our calculations of moisture available per ft of soil (in mm).

From additional determinations, it resulted that the earth was free of any pathogeny, having EC X $10^3 < 2$(in 25°C), ESP<10, PH = 7.5 in pulp, and it contained $CaCO^3$ 2% and active $CaCO^3$ $10^0/_{00}$, while it was hypotonic in nitrogenous and phosphoric components and well supplied in potassium as most soils in the area of Greece.

| Lysimeters | Depth cm | Mechanical Separates Sand 0.05-2.00mm | Silt 0.002-0.05mm | Clay <0.002mm | Types of soil | Hydrological Constants $H_2O$ at 105° C | Wilting point % | Moisture equivalent % | Total porosity % | Apparent Specific gravity | Moisture availiable mm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 - 30 | 56.18 | 26.18 | 17.64 | SL | 1.86 | 7.6 | 19.3 | 37 | 1.50 | 52.65 |
| | 30 - 60 | 66.18 | 20.54 | 13.28 | SL | 1.28 | 6.0 | 15.1 | 31 | 1.49 | 40.68 |
| | 60 - 90 | 55.92 | 29.18 | 14.90 | SL | 2.07 | 6.4 | 18.3 | 33 | 1.45 | 51.77 |
| B | 0 - 30 | 54.18 | 27.54 | 18.28 | SL | 1.90 | 8.4 | 9.9 | 39 | 1.48 | 44.62 |
| | 30 - 60 | 55.18 | 29.54 | 15.28 | SL | 1.55 | 6.9 | 17.3 | 34 | 1.45 | 45.24 |
| | 60 - 90 | 57.92 | 26.18 | 15.90 | SL | 2.19 | 7.5 | 21.1 | 37 | 1.44 | 58.75 |
| C | 0 - 30 | 54.08 | 26.54 | 19.28 | SL | 1.95 | 7.8 | 19.2 | 44 | 1.42 | 48.56 |
| | 30 - 60 | 65.08 | 22.00 | 12.92 | SL | 1.57 | 6.1 | 16.1 | 37 | 1.51 | 45.30 |
| | 60 - 90 | 57.92 | 27.18 | 14.90 | SL | 2.29 | 5.8 | 17.4 | 39 | 1.49 | 51.85 |
| D | 0 - 30 | 46.36 | 30.36 | 23.28 | L | 2.44 | 9.6 | 23.5 | 49 | 1.39 | 57.96 |
| | 30 - 60 | 60.36 | 24.36 | 15.28 | SL | 1.65 | 6.6 | 17.6 | 37 | 1.46 | 48.18 |
| | 60 - 90 | 54.92 | 28.18 | 16.90 | SL | 2.22 | 7.1 | 19.4 | 39 | 1.48 | 54.61 |
| $A_1$ | 0 - 30 | 50.00 | 27.36 | 22.64 | SCL | 2.33 | 9.2 | 17.8 | 44 | 1.33 | 34.32 |
| | 30 - 60 | 54.00 | 28.36 | 17.64 | SL | 1.67 | 7.3 | 17.9 | 37 | 1.44 | 45.79 |
| | 60 - 90 | 55.10 | 30.00 | 14.90 | SL | 2.10 | 6.3 | 17.8 | 40 | 1.43 | 49.34 |
| $B_1$ | 0 - 30 | 46.00 | 30.36 | 23.64 | L | 2.42 | 9.3 | 22.0 | 47 | 1.38 | 52.58 |
| | 30 - 60 | 60.00 | 24.36 | 15.64 | SL | 1.72 | 6.5 | 16.4 | 38 | 1.48 | 43.96 |
| | 60 - 90 | 54.10 | 29.00 | 16.90 | SL | 2.48 | 8.0 | 19.7 | 42 | 1.45 | 50.89 |
| $C_1$ | 0 - 30 | 52.00 | 27.36 | 20.64 | SCL | 2.00 | 8.2 | 19.4 | 42 | 1.30 | 43.68 |
| | 30 - 60 | 56.00 | 24.36 | 19.64 | SL | 2.07 | 8.1 | 18.5 | 41 | 1.50 | 46.80 |
| | 60 - 90 | 55.10 | 28.00 | 16.90 | SL | 2.62 | 7.2 | 18.8 | 40 | 1.49 | 51.85 |
| $D_1$ | 0 - 30 | 59.00 | 24.36 | 16.64 | SL | 1.71 | 6.5 | 17.4 | 37 | 1.43 | 46.76 |
| | 30 - 60 | 56.00 | 24.36 | 19.64 | SL | 1.86 | 7.0 | 17.8 | 39 | 1.48 | 47.70 |
| | 60 - 90 | 58.28 | 28.82 | 12.90 | SL | 2.24 | 7.2 | 20.0 | 42 | 1.46 | 56.06 |

* Calculated by equation $Y = (He - Pa) . da . ds . 10$, where He the moisture equivalent %, Pa the wilting point %, da the apparent specific gravity ($g/cm^3$) and ds depth within the ground in meters.

On these lysimeters were sown on 2.5.73 the following: a) Corn for grain (hybrid 228); b) Corn for green fodder; c) Cotton (variety 4S); d) Alfalfa (variety Medicago Sativa Provan).

The preparation for seeding, fertilization, the amount of grain and all the rest, were done according to the usual peasant mode of cultivation. Owing to the unsatisfactory aspect of the alfalfa, this was re-sown. As a consequence, we deemed expedient to include in this study only comparative data of the three first cultivations.

### 1.3 *Meteorological Data.*

Meteorological data needed for the object of this experiment, were taken from the Sindos Cotton Research Institute ($\varphi = 40^0 40' N$), adjacent to the Station of Land Reclamation.

The directly or indirectly resultant data, referred to,

— Maximum, minimum, and mean air temperature (t),
— Mean relative humidity (H),
— Mean temperature of wet-bulb thermometer (tw),
— Precipitation (h),
— Wind speed ($U_2$),
— Saturation vapour pressure at mean air temperature (ea),
— Dew point temperature (td),
— Saturation vapour pressure at mean dew point (ed),
— Slope of temperature — vapour pressure curve ( (d)ea /(d)t, mm Hg /$^0$F),
— Mean monthly extra terrestrial radiation (Ra),
— Relative duration of bright sunshine (n /N),
— Measured incoming short wave radiation from sun and sky (Rm),
— Net back radiation from the earth (Rb),
— Net radiation or daily heat budget at the surface (Rn)

Mean values of ten-day periods of meteorological data, are shown in Table 2.

### 1.4 *Energy Balance.*

For the expression of the euergy balance we have followed the expressions introduced by *Penman*[11], where the relative terms are expressed in mm $H_2O$ :

$$R_n = R_1 + R_2 + R_3 + R_4 = R_m(1 - r) - Rb \qquad (2)$$

TABLE II

*Meteorological data; Mean daily values of ten-day periods.*

| Period | Air Temperature Min °C | Max °C | Mean °C(1) | Mean °F | Wet-bulb temperature °C(2) | Difference (1)-(2) | Relative humidity % | Rain-fall* mm | Mean Speed Km/h | Wind ($U_2$) Mi/day | ea mm Hg | td °C | ed mm Hg | $\Delta$=ea/t mmHg/°F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | | | | | | | | | | | | | | |
| 1/5–10/5 | 11.5 | 27.8 | 19.7 | 67.5 | 16.9 | 2.6 | 59 | 5.6 | 4.9 | 73 | 17.21 | 15.0 | 12.79 | 0.60 |
| 11/5–20/5 | 10.1 | 23.8 | 17.0 | 62.6 | 14.4 | 2.6 | 61 | 5.6 | 5.6 | 84 | 14.53 | 12.3 | 10.73 | 0.53 |
| 21/5–31/5 | 13.5 | 30.0 | 21.5 | 70.7 | 18.3 | 3.2 | 45 | | 13.0 | 194 | 19.22 | 16.3 | 13.89 | 0.65 |
| 1/6–10/6 | 15.5 | 28.2 | 21.8 | 71.2 | 18.0 | 3.8 | 59 | 4.7 | 10.5 | 157 | 19.58 | 15.5 | 13.20 | 0.68 |
| 11/6–20/6 | 14.6 | 27.5 | 21.0 | 69.8 | 16.7 | 4.3 | 52 | 0.9 | 17.6 | 263 | 18.65 | 13.6 | 11.68 | 0.64 |
| 21/6–30/6 | 15.7 | 30.6 | 23.1 | 78.6 | 19.0 | 4.1 | 47 | | 11.6 | 173 | 21.19 | 16.5 | 14.07 | 0.75 |
| 1/7–10/7 | 18.1 | 32.9 | 25.5 | 77.9 | 20.7 | 4.8 | 50 | 3.3 | 12.8 | 191 | 24.46 | 18.0 | 15.47 | 0.80 |
| 11/7–20/7 | 19.2 | 34.2 | 26.7 | 80.1 | 22.0 | 4.7 | 57 | 13.4 | 8.8 | 132 | 26.26 | 19.5 | 17.00 | 0.84 |
| 21/7–31/7 | 18.7 | 31.5 | 25.1 | 77.2 | 20.1 | 5.0 | 59 | | 14.1 | 211 | 23.89 | 17.1 | 14.62 | 0.79 |
| 1/8–10/8 | 17.4 | 31.3 | 24.4 | 75.9 | 19.7 | 4.7 | 52 | | 10.2 | 152 | 22.91 | 16.9 | 14.43 | 0.77 |
| 11/8–20/8 | 17.4 | 31.3 | 24.3 | 75.7 | 18.9 | 5.4 | 52 | | 13.4 | 200 | 22.78 | 15.4 | 13.12 | 0.76 |
| 21/8–31/8 | 17.8 | 30.0 | 23.9 | 75.0 | 20.4 | 3.5 | 66 | | 7.9 | 118 | 22.24 | 18.4 | 15.86 | 0.75 |

* Such depth of rainfall is the accumuluted one of each corresponding ten-day period.

TABLE III

*Energy balance data; Mean daily values of ten-day periods. (Latitude 40° 40')*

| Period | $R_a$ Cal/cm² | $R_a$ mm $H_2O$ | Sunshine hours (n) | Maximum duration of bright sunshine hours (N) | Relative Sunshine (n/N) | $R_m$ Cal/cm² | $R_m$ mm $H_2O$ | $\sigma T_a^4$ mm $H_2O$ | $0.56\text{-}0.092\sqrt{ed}$ | $0.10+0.90n/N$ | $R_b$ mm $H_2O$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | | | | | | | | | | | |
| 1/5–10/5 | 967 | 16.40 | 9.98 | 14.46 | 0.690 | 541 | 9.17 | 14.72 | 0.23 | 0.721 | 2.46 |
| 11/5–20/5 | 967 | 16.40 | 7.37 | 14.46 | 0.510 | 435 | 7.38 | 14.21 | 0.26 | 0.559 | 2.06 |
| 21/6–31/5 | 967 | 16.40 | 10.99 | 14.46 | 0.760 | 606 | 10.27 | 15.12 | 0.22 | 0.784 | 2.62 |
| 1/6–10/6 | 1025 | 17.38 | 8.85 | 15.05 | 0.588 | 504 | 8.54 | 15.18 | 0.23 | 0.629 | 2.21 |
| 11/6–20/6 | 1025 | 17.38 | 9.56 | 15.05 | 0.635 | 533 | 9.03 | 15.01 | 0.25 | 0.672 | 2.53 |
| 21/6–30/6 | 1025 | 17.38 | 9.45 | 15.05 | 1.628 | 552 | 9.35 | 15.46 | 0.22 | 0.665 | 2.26 |
| 1/7–10/7 | 1001 | 16.98 | 9.98 | 14.76 | 0.676 | 570 | 9.66 | 15.96 | 0.20 | 0.708 | 2.27 |
| 11/7–20/7 | 1001 | 16.98 | 10.14 | 14.76 | 0.687 | 577 | 9.78 | 16.22 | 0.18 | 0.718 | 2.10 |
| 21/7–31/7 | 1001 | 16.98 | 10.67 | 14.76 | 0.724 | 576 | 9.77 | 15.89 | 0.21 | 0.752 | 2.51 |
| 1/8–10/8 | 900 | 15.25 | 9.91 | 13.77 | 0.720 | 522 | 8.85 | 15.73 | 0.21 | 0.748 | 2.48 |
| 11/8–20/8 | 900 | 15.25 | 10.67 | 13.77 | 0.775 | 534 | 9.05 | 15.71 | 0.23 | 0.798 | 2.89 |
| 21/8–31/8 | 900 | 15.25 | 10.12 | 13.77 | 0.735 | 511 | 8.67 | 15.62 | 0.19 | 0.762 | 2.26 |

TABLE IV

Mean daily values of ten-day periods of the Net Radiation $R_n$

| Period | $R_m$ Cal/cm² | $R_m$ mm $H_2O$ | (1–r)* | $R_b$ Cal/cm² | $R_b$ mm $H_2O$ | $R_n = R_m(1-r) - R_b$ Cal/cm² | $R_n = R_m(1-r) - R_b$ mm $H_2O$ |
|---|---|---|---|---|---|---|---|
| 1973 | | | | | | | |
| 1/5–10/5 | 541 | 9.17 | 0.78 | 145.2 | 2.46 | 267.7 | 4.69 |
| 11/5–20/5 | 435 | 7.38 | 0.78 | 121.5 | 2.06 | 217.7 | 3.69 |
| 21/5–31/5 | 606 | 10.27 | 0.78 | 154.6 | 2.62 | 318.0 | 5.39 |
| 1/6–10/6 | 504 | 8.54 | 0.78 | 130.4 | 2.21 | 262.6 | 4.45 |
| 11/6–20/6 | 533 | 9.03 | 0.78 | 149.3 | 2.53 | 266.1 | 4.51 |
| 21/6–30/6 | 552 | 9.35 | 0.78 | 133.3 | 2.26 | 296.8 | 5.03 |
| 3/7–10/7 | 570 | 9.66 | 0.78 | 133.9 | 2.27 | 310.3 | 5.26 |
| 11/7–20/7 | 577 | 9.78 | 0.78 | 123.9 | 2.10 | 326.3 | 5.53 |
| 21/7–31/7 | 576 | 9.77 | 0.78 | 148.1 | 2.51 | 302.1 | 5.12 |
| 1/8–10/8 | 522 | 8.85 | 0.78 | 146.3 | 2.48 | 260.8 | 4.42 |
| 11/8–20/8 | 534 | 9.05 | 0.78 | 170.5 | 2.89 | 246.6 | 4.17 |
| 21/8–31/8 | 511 | 8.67 | 0.78 | 133.9 | 2.27 | 264.9 | 4.49 |

* r = 0.22 for plant covered area

$$b = \frac{R_2}{R_4} = \frac{t_s - t_a}{es - ed} . a . p \quad (3)$$

$$Rb = \sigma T_a^4 (0,56 - 0,092 \sqrt{ed}) (0,10 + 0,90n/N) \quad (4)$$

Where: $R_n$ = The energy available on the earth's surface.
$R_1$ = The heat flux into ground or vegetation or in the opposite direction.
$R_2$ = The sensible heat transfer from air to surface or in the opposite direction.
$R_3$ = The heat converted to chemical energy in the process of photosynthesis considered negligible (1—2% of the amount of energy).
$R_4$ = The heat used in converting liquid to vapour (spent for evapotranspiration).
$R_m$ = The measured incoming solar radiation.
r = The reflection coefficient (taken as 0,22 for plant covered area, and 0,05 for free water surface).
$R_b$ = The net back radiation of long wave from the earth's surface.
h = The value of the «Bowen ratio».
$t_s$ = The mean temperature of the water surface (°C).
$t_a$ = Mean air temperature. (°C)
es = Saturation vapour pressure at ts temperature (mm Hg).
ed = Saturation vapour pressure at mean dew point (mm Hg).
a = The psychrometer constant = 0,000662.
p = Atmospheric pressure ≈ 760 mm Hg, when a . p = 0,5 .
σ = The Stefan - Boltzman constant = $2,01 \times 10^{-9}$ mm day.
$T_a$ = Mean air temperature (°K).
n/N = Relative duration of bright sunshine.

The energy balance data are shown in Tables 3 and 4.

## 2. *Results achieved.*

### 2.1 *Comparison between actual (ETe) and potential (ETp) evapotranspiration.*

As already mentioned, while potential evapotranspiration was checked every day, actual evapotranspiration was checked at certain intervals according to the actual needs of consumptive use. In order to

TABLE V

*Comparison between values of actual and potential evapotranspiration.*

| | Corn (grain) | | | Corn (green fodder) | | | Cotton | | |
|---|---|---|---|---|---|---|---|---|---|
| | ETe (mm) | ETp (mm) | $\frac{ETp}{ETe}$ | ETe (mm) | ETp (mm) | $\frac{ETp}{ETe}$ | ETe (mm) | ETp (mm) | $\frac{ETp}{ETe}$ |
| May | 75 | 98 | 1.31 | 90 | 115 | 1.28 | 65 | 86 | 1.32 |
| June | 132 | 148 | 1.12 | 187 | 209 | 1.12 | 100 | 126 | 1.26 |
| July | 183 | 262 | 1.43 | 282 | 357 | 1.26 | 145 | 182 | 1.25 |
| August | 102 | 143 | 1.40 | — | — | — | 109 | 268 | 2.46 |
| Total | 492 | 651 | 1.32 | 559 | 681 | 1.22 | 419 | 662 | 1.58 |

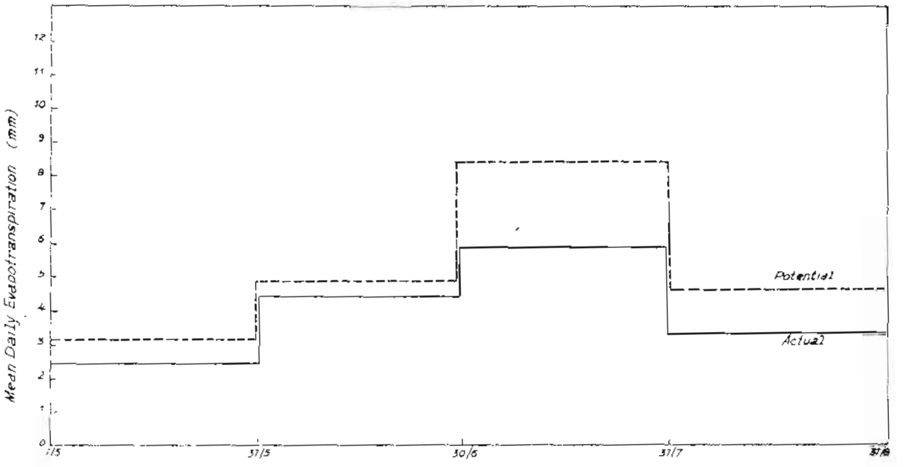


Fig 3 Curves of Actual and Potential Evapotranspiration Refering to the Cultivation of Corn for grain

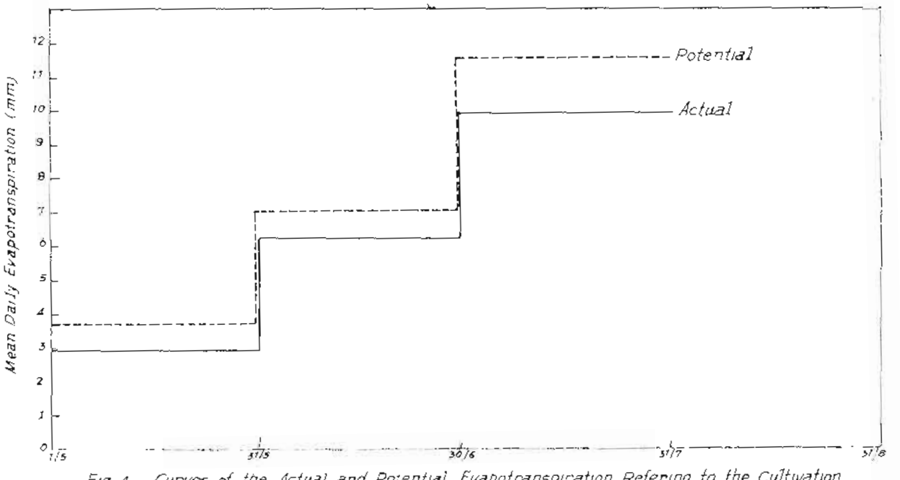


Fig 4 Curves of the Actual and Potential Evapotranspiration Refering to the Cultivation of Corn for green fodder.

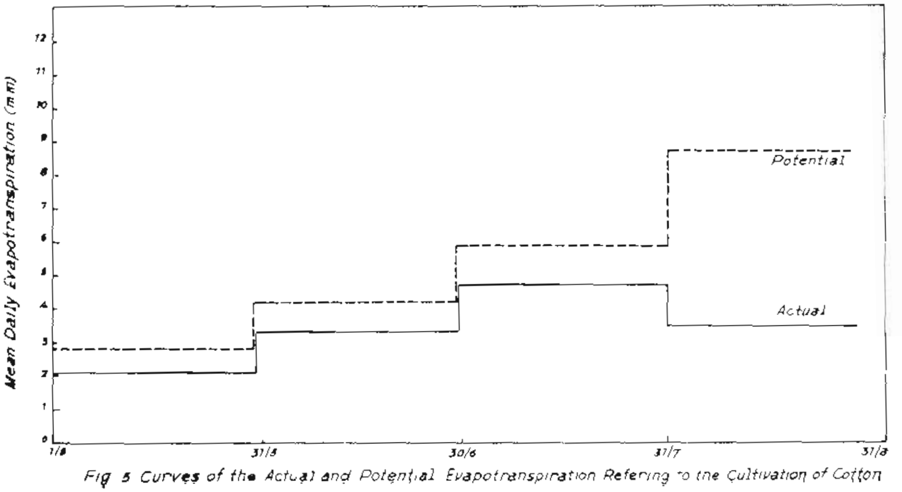


Fig 5 Curves of the Actual and Potential Evapotranspiration Refering to the Cultivation of Cotton

realise comparisons, we effected a periodical addition of daily values of potential evapotranspiration. Thus resulted the comparative data of Table 5, which are graphically presented in Figs. 3,4, and 5; in these graphs, each section of the curve of consumptive use, represents the daily mean of the corresponding period.

Graphs in Figs. 3,4, and 5 indicate that during the first stage of the cultivation, differences between these two kinds of consumptive use appear rather small, while afterwards they become quite clear, having as follows:

a) In the cultivation of corn for grain, from the time of inflorescence till the full formation of the spadix, persisting at a smaller rate till the harvesting of the crop.

b) In the cultivation of corn for green fodder, they begin a little before the inflorescence and last till the harvest of the crop. The largest differences are observed during the last stage of the cultivation.

c) In the cultivation of cotton, differences begin from the time of inflorescence and continue till the boll-opening. The largest differences were observed from the appearance of the bolls till their full development.

## 2.2 *Crop yield and corresponding values of tranformation coefficient.*

The transformation coefficient, introduced and widely applied by the Italian School, consists the fundameutal element and criterion, governing the irrigation budget. This, as is known, expresses the ratio of crop yield to the corresponding duty of water. Data of each particular yield and their corresponding values of transformation coefficient are shown in Table 6, where A, B and C are the lysimeters with underground water supply corresponding to ETp (potential evapotranspiration) and $A_1$, $B_1$, $C_1$ those with surface water supply corresponding to ETe.

From the column containing the transformation coefficient values, it arises that while for corn for grain and cotton these values are higher in the case of actual evapotranspiration, in the case of corn for green fodder we observe a reverse superiority.

## 2.3 *The differentiation of the energy balance.*

In order to render clearer the differentiation of the energy balance between the two processes of water consumption, this refers to the period

TABLE VI

*Crop - yield and corresponding values of transformation coefficient.*

| Lysimeters | Cultivation | Area $m^2$ | No of plants | No of spadices or bolls | Duration of vegetation cycle in days | Yield in Kgs | Yield Kgs/stremma (1) | ET $m^3$/stremma (2) | Transformation coefficient (1):(2) |
|---|---|---|---|---|---|---|---|---|---|
| A | Corn for grain | 4.00 | 24 | 56 | 125 | 3.824 | 956 | 651 | 1.468 |
| $A_1$ | » » » | 4.00 | 30 | 54 | 122 | 2.816 | 704 | 492 | 1.532 |
| B | Corn for green fodder | 3.14 | — | — | 88 | 42.000 | 13,356** | 681 | 19.612 |
| $B_1$ | » » » » | 3.14 | — | — | 88 | 32.000 | 10,364** | 559 | 18.540 |
| C | Cotton | 4.00 | 42 | 636 | 125* | 2.130 | 532 | 662 | 0.803 |
| $C_1$ | » | 4.00 | 44 | 340 | 125* | 1.500 | 375 | 419 | 0.895 |

* From the sowing till the first harvest crop.
** Green crop.

of the higher water requirement, that is the month of July. In Table 7 are included the corresponding data.

TABLE VII

*Data of differentiation of the energy balance between the two processes of the evepotranspiration - Month of July with highest water requirements.*

| Regime of consumptive use and cultivations | $R_n$ (mm) | $R_4$ (mm) | $R_1+R_2$ (mm) |
|---|---|---|---|
| Corn for grain | | | |
| Potential | 164 | 262 | — 98 |
| Actual | 164 | 183 | — 19 |
| Corn for green fodder | | | |
| Potential | 164 | 357 | —193 |
| Actual | 164 | 282 | —118 |
| Cotton | | | |
| Potential | 164 | 182 | — 18 |
| Actual | 164 | 145 | + 19 |

The data of Table 7 indicate that, in the case of the potential evapotranspiration there has been a quite intensive «flux» of energy towards the system, while this flux was very reduced towards the system of actual evapotranspiration, being negligible in the case of cotton.

## DISCUSSION

The difference in the water consumption regime arises clearly and undoubtedly from the corresponding different regime of soil moisture.

However, a thorough study of graphs in Fig. 3, 4, and 5, in correlation with that of the elements, that shape the regime of evaporative capacity of the atmosphere, leads to the conclusion that the theory of *Makkink and Hernst*[7] is confirmed, i.e. with a small evaporative capacity the two forms of water consumption coincide, regardless of the pF values in the soil. On the contrary, with a high evaporative capacity of the atmosphere, the ETe (actual evapotranspiration) appears smaller than the ETp (potential evapotranspiration), the rate of their difference depending from the difference of the corresponding pF values of soil moisture.

A similar explanation of results, confirms the theory of *Visser*[20], who having studied the water-consumption in correlation with the movement of water within the ground, and the whole soil moisture regime, formed the view that the fluctuation of the evaporative capacity of the atmosphere is for a certain cultivation the regulating factor, which determines at a given time the percentage of ready moisture available in the soil.

The fact that this scientist has found as marginal value of this amount, corresponding to $pF = 1.5$, that is smaller than the corresponding to the «moisture equivalent» ($pF = 2.54$), is not surprising; on the contrary it consists a contestation, from a practical viewpoint, of the traditional assumption of the hydrological constants of soil. We should mention here, that from our laboratory analysis of soil samples taken from lysimeters of potential evapotranspiration, has been found a $pF \approx 3.0$ value for the surface layer, but in some cases a $pF = 2.5 \approx 2.2$ below the 30cm depth.

The initial view of Thornthwaite and Penman who introduced the concept of the potential evapotranspiration, and which has been adopted afterwards by almost all those who proposed methods for calculating evapotranspiration, that this process is independent of the kind of plant or vegetation, as long as proper conditions are provided, is indisputably overthrown by our own results. Graphs in Fig. 3, 4 and 5, clearly indicate the need for introducing cultivation factors in the case of ETe as well as in ETp.

Our continuing research, aims among other things to the control of the point of accuracy of methods proposed and also to the modification of the cultivation factors, or the introduction of new ones.

## Conclusions

The results obtained and observations made during the experiment, lead to the following conclusions:

1. The difference between actual (ETe) and potential (ETp) evapotranspiration is clearly defined and is attributed to the different range of the available soil moisture for plants.

2. This difference becomes considerable when the evaporation capacity of the atmosphere is also high. In this case the amount available soil moisture should be very high, a fact that overthrows the theory of Veihmeyer-Hendrickson and confirms that of Makkink, Hernst and Visser.

3. The particular differences between ETe and ETp have been found to be considerably higher in the case of tilled cultivations of corn for grain and of cotton as compared with those of corn for green fodder, that is cultivation covering the entire ground.

4. The genotype factor seems to be of particular importance in both processes of evapotranspiration. This is apparent from Graphs in Figs. 3, 4 and 5. As a consequences, the introduction of cultivation factors, in every sort of method proposed, becomes incontestable.

5. Examination of each diagram of water consumption, leads to the conclusion that its curves appear as normal in cultivations of corn for grain and corn for green fodder as well. However, in the case of cotton we observe a considerable water consumption during the interval between 15/8 to 14/9, while the corresponding climatological conditions do not account for such an evapotranspiration regime. This genotype particularity may be due to the fact that cotton is a plant with biennial vegetation cycle.

6. Observations of the hourly regime of evapotranspiration (which are meant to be the object of a more specialized processing in context with climatological data), effected on lysimeters of potential evapotranspiration, proved that a percentage of water consumption of 8 - 15% is noted at intervals from 20:00 hours till 08:00 a.m. of the following day, meaning that a notable evapotranspiration occurs during the night hours. This percentage appears higher than the results of worldwide experiments.

7. Values of transformation coefficient appear higher in the case of ETe, with the exception of the corn for green fodder cultivation.

8. The differentiation of solar energy balance in the two processes of water consumption has been very characteristic. In the case of ETp an intense «flux» of enery towards the system has been found; higher in the case of corn for green fodder and corn for grain cultivations, and considerably reduced in that of cotton.

In the case of ETe, the energy flux being markedly smaller, it has however been appreciable in the corn for green fodder cultivation.

This means that the plant factor plays an important role in the formation of energy balance.

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## ΠΕΡΙΛΗΨΙΣ

# ΠΕΙΡΑΜΑΤΙΚΗ ΔΙΕΡΕΥΝΗΣΙΣ ΤΗΣ ΠΡΑΓΜΑΤΙΚΗΣ ΚΑΙ ΔΥΝΑΜΙΚΗΣ ΕΞΑΤΜΙΣΟΔΙΑΠΝΟΗΣ

Ὑπὸ

ΚΩΝΣΤΑΝΤΙΝΟΥ ΑΘ. ΚΩΝΣΤΑΝΤΙΝΙΔΟΥ καὶ ΓΕΩΡΓΙΟΥ ΛΙΒΑΔΑ

*(Ἐκ τοῦ Ἐργαστηρίου Μετεωρολογίας Πανεπιστημίου Θεσ/νίκης)*

Ὁ διεξαγόμενος εἰς τὸν Σταθμὸν Ἐγγείων Βελτιώσεων πειραματισμός, ἐν συνεργασίᾳ μετὰ τοῦ Μετεωρολογικοῦ Ἰνστιτούτου τοῦ Πανεπιστημίου Θεσσαλονίκης, παρέσχε κατὰ τὸ πρῶτον ἔτος πειραματισμοῦ (1973) ὡς ἀποτέλεσμα ὅτι, ὑπὸ τὴν ἰδίαν συνισταμένην τῆς ἐπιδράσεως τῶν κλιματολογικῶν παραγόντων, ἡ ἐν τῷ ἐδάφει δίαιτα τῆς ὑγρασίας εἶναι ὁ ρυθμιστικὸς παράγων, ὁ καθορίζων τὴν ἔντασιν τῆς ἐξατμισοδιαπνοῆς.

Ἡ διατήρησις τοῦ ποσοστοῦ τῆς ἐδαφικῆς ὑγρασίας πλησίον τοῦ ἰσοδυνάμου τῆς ὑγρασίας» (pF = 2.54 ἢ 1/3 atm), συνεπάγεται λίαν ὑψηλοτέραν ὑπὸ τῶν φυτῶν ὑδατοκατανάλωσιν, ἐν συγκρίσει πρὸς ἐκείνην, ἥτις διαπιστοῦται μὲ προοδευτικὴν μείωσιν τοῦ ποσοστοῦ ὑγρασίας μεταξὺ δύο διαδοχικῶν ἀρδεύσεων, ἀπὸ τοῦ ἰσοδυνάμου τῆς ὑγρασίας πρὸς τὸ «σημεῖον μαράνσεως» (pF = 4.2 ἢ 15 atm).

Ἡ ὑπὲρ τῆς πρώτης περιπτώσεως διαφορὰ ὑδροκαταναλώσεως, ἀνῆλθεν εἰς 32% διὰ τὸν ἀραβόσιτον (43% κατὰ τὴν περίοδον τῆς αἰχμῆς), εἰς 22% διὰ τὸν ἀραβόσιτον διὰ χλωρὰν νομὴν (26% κατὰ τὴν αἰχμὴν) καὶ εἰς 58% διὰ τὸν βάμβακα (146% κατὰ τὴν αἰχμήν), πρᾶγμα ὅπερ ἀποδεικνύει τὴν ἰσχὺν τοῦ γενοτυπικοῦ παράγοντος τοῦ εἴδους τοῦ φυτοῦ. Ἀντίστοιχος διαφοροποίησις παρετηρήθη καὶ εἰς τὸ «ἰσοζύγιον ἐνεργείας», διαπιστωθείσης μιᾶς ἀφθόνου «ροῆς» ἐνεργείας πρὸς τὸ σύστημα τῆς πρώτης περιπτώσεως, λίαν περιωρισμένης δὲ τοιαύτης πρὸς τὸ σύστημα τῆς δευτέρας περιπτώσεως.