IRRIGATION BY POROUS CAPSULES UNDER HYDROSTATIC PRESSURE*

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INTRODUCTION

The importance of irrigation in crop production is well known. Large increases in food production, necessary for the ever increasing world population may either be obtained by placing more land under irrigated agriculture or by improving water use efficiency of irrigation methods. In arid and semi arid regions of the world, which occupy nearly one third of the total area (Shantz,1956) fields under cultivation during rainy season, usually are fallow during the dry periods due to lack of water. Furthermore, in areas with little stored or well water, normally the cheap methods of irrigation such as flooding or furrow can not be adopted due to scarcity of water and low water use efficiency; at the same time it is beyond the financial capacity of farmer to buy costly irrigation equipment necessary for efficient irrigation. Considering the enormous agricultural potential of these areas when irrigated, the adoption of irrigation methods which use available water more rationally and efficiently is a challenge to agriculturists. In Mexico, Olguin (1975), Garcia (1977) and others have successfully tested under field conditions a non conventional sub surface irrigation method consisting of a serie of gypsum or clay cap

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sules based on principles of suction. However, the method was found by Silva et al,(1978a) to be inadequate on commercial scale in Brazil due to entry of air bubbles into the system and other related problems of maintainence. In order to overcome such difficulties, a study was undertaken with the twicefold objective a) to evaluate technical feasibility of a irrigation method by porous capsules under slight hydrostatic pressure and b) to find an optimum number of corn (Zea mays L. Cultivar Centralmex) plants around the capsule for maximum yields.

MATERIALS AND METHODS

The experiment was conducted at the Bebedouro Experiment Station farm of EMBRAPA, 45 km from Petrolina-Pe from Sept. 1979 to Jan. 1980. Average annual rainfall of the region is about 400 mm, but much of rainfall may not be available to crops due to erratic distribuition and low water holding capacity of the soils. Soils of the experimental farm are oxisols and have been described in detail by Azevedo (1975) and Choudhury & Millar (1979). Some selected physical characteristics are summerised in Table 1.

The porous capsules used in this study were made using Plaster of Paris moulds (Figure 1 A and B) with a mixture ($d = 1.33\ g/cm^3$) of locally found clay minerals principally consisting of shale, calcite and talc. After being dried in shade the capsules were dried in two stages in eletric drier and furnace during 32 hrs at temperatures of 145^0 and 1120^0C, respectively. The capsules at the end of drying process presented dimensions as shown in Figure 1C, mechanical resistance equal to $5\ kg/cm^2$, 20-22% porosity and hydraulic conductivity of 0.0054 ± 0.0007 cm/hr under saturated conditions.

A well levelled and uniform area of 70 x 100 m was selected as the experimental site. After ploughing and harrowing nine furrows 100m long and 0.25m deep were opened following the contour lines 2m apart. In these furrows, irrigation lines consisting of 50 porous capsules (2 m apart), interconnected with tubing (Ø = 1 cm) were installed at 10 cm depth with absolutely no slope. Independently, each line was linked to a small (50 l) water reservoir (r) of a constant water head which in turn was connected to a water tank (R - 250 l) as shown in Figure 2.

The experiment was carried out in a randomized block design with 3 replications consisting of 3 hydrostatic pressure head treatments (T_1 - 0.35m, T_2 - 0.50m and T_3 - 0.70m) and 5 sub treatments of plant population (P_1-1, P_2-4, P_3-7, P_4-10 and P_5-13) around the capsule. Each subtreatment consisted of 10 porous capsules.

The required amounts of nitrogen, phosphorus and potassium were supplied based on the NPK formula 50:60:20 and considering only 1 m^2 area per capsule as the area of root exploration. One third of the N, total P and K were mixed in soil at a depth of 4 cm and in radius of 15 cm around the capsule before sowing. The rest of N was applied in two equal doses, 25 and 45 days after germination. On Sept. 6, 1979 corn was seeded (3 seeds/hole) in 20 cm radius around the capsule and 15 days later thinning was done leaving thus the required number of plants/capsule.

During the experiment, daily release of water from the capsules under each treatment was recorded and the data for rainfall, temperature, relative humidity and pan evaporation from U.S. Weather Bureau Class A Pan were also recorded. On Nov. 28, 83 days after sowing, five plants at random were harvested in each sub treatment for collection of cobs and green matter produced. On Jan. 19, 1980 (135 days after germination) the remaining plants were harvested and grain produced under each sub treatment with constant water content was determined.

In order to determine soil water distribuition patterns, soil samples after 21,42 and 83 days of corn growth were collected from both sides of capsules under P_1, P_3 and P_5 sub treatments at equidistant points of 10, 20, 30 and 40 cm from the vertical axis of porous capsule. Further, in order to ascertain if plants were suffering from water stress during the period of maximun vegetative growth and flowering, tensiometers were installed at 25 cm depth and 2 cm away from the bottom of capsules in P_1, P_3 and P_5 sub treatments and daily water pressure meassurements were taken at fixed time intervals.

RESULTS AND DISCUSSION

Release of water by porous capsules

The mean daily release of water per capsule varied significantly (at 0.01 level) with the hydrostatic pressure to which the porous capsules were submitted (Table 2). A good corn crop would normally need 400 mm of water (Daker, 1970), camparing this value with the amount of water used in the present experiment, the importance of this method of irrigation in water economy is quite evident.

The release of water with this method of irrigation was not found to be uniform throughout the growing season of corn (Figure 3), the release being a little bit smaller at the beginning and at the end of the growing season which is not difficult to explain keeping in view water requirements of plant. It brings out the fact, that the proposed method does not work solely under hydrostatic pressure, but also autoregulated by the plant water demand like irrigation by suction (Olguin et al, 1976; Santos, 1977) at least during the maximum vegetative growth and water requirement period (four weeks after germination till grain filling). This was found to be more relevant for the treatment with the smallest hydraulic head, where apparently the water demand by plants played a mo re important role than the hydrostatic pressure. However, as is evident from Figure 3, water released under the various treatments was not related to water evaporated from the U.S. Weather Bureau Class A Evaporation Pan. This is in part ex plained because the evaporation took place from free water surface while water for the plants under constant hydrostatic pressure was released at depths deeper than 10 cm, being thus independent of the atmospheric and/or plant demands. Although, subsequent to rains, occurred on Nov. 6 and 12, water release from the porous capsules under all the treatments was found to decrease, it is difficult to conclude whether the observed decrease was due to the effect of the precipitation or to the start of the decrease in water requirements of plants.

Soil water distribuition pattern

The soil moisture profiles after 21, 42 and 83 days of plant growth for corn populations of 1,7 and 13 plants/capsule under different hydrostatic treatments show that the preposedmethod of irrigation is capable of furnishing sufficient available water for the growth of plants (Figure 4 A, Band C). The availa ble water content of soil varied significatly with the treatments, subtreatments and fenologic stage of the plant. As seen in Figu re 4 A, after 83 days , the available water content under a hydrostatic pressure of 0.35m (T_1), plant population of 13 plants/ capsule (P_5) was less than 50% up to 30cm depth, whereas after the same period for treatment T_3 and population one (P_1) it was found to be nearly 100% (Figure 4C). Keeping in view the water necessities of the plant, it may be concluded that population P_5 (13 plants/ capsule) is too high for treatment T_1 and population of one plant/ capsule is rather too low for treatment T_3. Thease findings were further confirmed by plant height measurements through the fenologi cal cycle of corn (Silva, 1980). The plants belonging to T_1P_5 were found to be shortest (160cm) whereas that of T_3P_1 acheived the maximum height (210 cm).

As indicated previously, when the system worked under the lowest hydrostatic pressure, apparently the effect of plant was significant. As is seen in Figure 4A, the water content of the soil profile at three different stages of plant decreased with corn population, but as the hydraulic head of the system increased to 0.50 or 0.75m, the effect of the plant was masked by the effect of the hydraulic head and therefore soil water content under these treatments didnot show any definitive trend to change with plant populations (Figure 4B and C). The matric potential data determined daily by tensiometers installed at 25cm depth during the crop season also brought to light the same facts. Under the same water treatment, at the beginning and end of growing season, subtreatments with higher number of plants presented low potentials, however, during the active growth period (tasseling) this was not true. As seen in Figure 5, after 54 days, subtreatment P_3 (7 plants/capsule) presented lower potentials than P_5 (13 plants/capsule), the same may be due to the comparatively more vegetative growth and evapotranspiration of the former. As would be expected, after rainfall, soil water potential decreased (became less negative), this fact being more relevant for T_1 compared to T_2 and T_3.

Production and Water Use Efficiency

The various treatments of hydrostatic pressure did not show significant effect on either type of production thereby indicating that for proper functioning of the proposed method of irrigation, a hydrostatic pressure of as little as 0.35m is enough. However, for optimum production of either cobs or grain the number of plants around the capsule played a significant role.

Cob production: Althongh, total cob production indicated that yields increased with corn population, but the statistical analysis conducted only on the production of good commercial quality cobs (cobs totally filled) showed that cob production increased with corn density only upto 7 plants/capsule, density after which cob production decreased significantly (at 0.01 level). As it was observed under water distribuition patterns, high density plants did not suffer from water stress (Figs. 4A, B and C) and hence the decrease of good quality cobs under these treatments can not be considered due to lack of water. The elevated number of unfilled and low quality cobs in the high density subtreatments may be attributed to lack of nutrients. This is rather expected because the amounts of fertilizers supplied were based on root exploration area ($1m^2$) and not on the basis of no. of plants/capsule. Hence the possibility of further increase in cob production by applying adequate amounts of fertilizers, in accordance with plant population cannot be ruled out.

<u>Green matter production</u>: In general green matter production increased with plant population, however no significant differences (at 0.01 level) were observed among the subtreatments with more than 1 plant/capsule. Considering 2500 capsules/ha (spacing of 2 x 2m) and a plant density of 7 around each capsule (best density for cob production) the mean green matter produced would be 31.9 tons/ha.

<u>Grain production</u>: As is evident from Table 3 mean grain production increased significantly (at 0.01 level) with plant population upto the subtreatment with 7 plants/capsule. Higher densities did not show any significant increase. Furthermore, grain yields (y) were found to be significantly correlated (at 0.01 level) to population (x) as shown in Figure 6 and a quadratic equation $y = 116.12 + 160.72x - 8.74x^2$ represented nearly 82% of the variation in the obtained yields. As is evident from the figure upto a certain point, corn production increases with the density, decreasing after-words perhaps due to limited space and/or nutrients. According to the curve, maximum yields should be obtained with 9 plants/capsule. In the present study, such optimum (860g) was obtained with only 7. For the Petrolandia-Pe region, under similar conditions of weather, maximum production of 3.100 kg/ha corn has been reported by Queiroz et al (1974). For a normally used popula

tion of 35000 plants /ha such yield corresponds to 88.3g/plant. The maximun grain production obtained in the present study was 123g per plant. Thus it is observed that with the proposed method of irrigation besides the great economy of water, yields obtained are comparable.

Water use efficiency: Water use efficiency was defined as the ratio of corn yield per capsule to volume of water released per capsule. Water use efficiencies for hydrostatic pressure treatments of 0.35, 0.50 and 0.70m were respectively 2.0, 1.9 and 1.7 kg/m^3, values quite high especially considering that in the present study just 50 kg N/ha were applied. It has been reported by Devender Reddy et al (1980) that water use efficiency of corn under semi arid conditions increases with N level upto 180 kg N/ha. Hence there is ample scope for increasing the observed efficiency. When the values of water use efficiency obtained in the present study are compared with those cited in literature for other methods of irrigation, efficiency of porous capsule is found to be only inferior to irrigation by suction (Table 4) which was tried in Brazil and found to be inadequate under field conditions (Silva et al, 1978a).

Considering the advantages of the irrigation by porous capsule method, such as water economy, water use efficiency, simple operation and its adoptibility on small scale, it may be concluded that the method is quite adequate for arid and semi arid conditions.

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S U M M A R Y

A field experiment was contucted at an Experiment Station of EMBRAPA in Pernambuco, Brazil with the objectives to evaluate the technical feasibility of irrigation by porous capsule under hydrostatic presure and to determine the effect of plant population on corn production. The experiment tested hydrostatic pressures of 0.35, 0.50 and 0.70m and corn populations of 1, 4, 7, 10 and 13 plants/capsule with three replicates in a randomized block design. Each replicate consisted of 10 capsules installed at 0.25m deep along the contour lines with absolutely no slope.

The hydrostatic pressure significantly influenced water release from the capsule. Total water consumption varied from 7.96 to 10 cm/ha thereby indicating the extent of water saving.

The hydrostatic pressure did not affect production significantly but the differences due to plant population were significant at 0.01 level. A second degree quadratic equation described satisfactorily the yield curve and estimated that 9 plants/capsule would give the best grain production.

In the present study 7 plants/capsule gave the highest production with a water use efficiency of 2.0 kg/m^3, which compared to conventional methods of irrigation is rather high.

R E S U M E

Une experience "in field" etait fait a la "EMBRAPA", en Pernambuco, BRÉSIL; pour evaluer les possibilités techniques d'irrigation au moyen de capsule poreuses sous une pression hydrostatique et determiner l'effet de population des plantes relativament à la prodution de maïs. L' experience était faite dans les conditions suivantes:

- pression hydrostatique: 0,35; 0,50 et 0,70;
- population de maïs: 1,4,7,10 et 13 plantes/capsule;
- L' essai comprend trois repetitions.

Toutes les repetition étaint formées de 10 capsules installées à 0,25m de profondeur le long des lignes de contour avec déclinaeson nulle.

La pression hydrostatique avait une grande influence sur l'ecoulement de l'eau de la capsule. La consommation total de l'eau variait de 7,96 à 10cm/ha, ce qui montre une grande economie d'eau. La pression hydristastique n'affectait pas la production, mais les differénces concernant la population des plantes etaient significantes (0,01 niveau). Une equation (deuxieme degre) permet d'estimer de maniere satisfaisante la production. Aussi, cette equation estime que 9 plantes/capsule donneraient les meilleurs resultats.

Dans cette étude, 7 plantes/capsule ont donné la plus grande production avec um rendement d'utilisation de l'eau egal a 2,0kg/m^3, comparant avec les methodes conventionnells d'irrigation, ce rendement est elevé.

ZUSAMMENFASSUNG

Es wurde ein Aussenexperiment in der EMBRAPA - Pernambuco. (landwirtschaftliches Unternehmen von Brasilien - in Pernambuco) auf dem Experimental-Feld dieser Firma mit dem Ziel der Begutachtung der technischen Durchfuehrbarkeit der Bewaesserungsmethode durch poroese Kaesten unter hydrostatischem Druck durchgefuehrt und um die Wirksamkeit bezueglich der Anzahl der Pflanzen auf die Maisproduktion zu bestimmen. In diesem Experiment wurden hydrostatische Drucke von 0,35; 0,50 und 0,70 m und eine Anzahl von 1, 4, 7, 10und 14 Pflanzen pro Kasten in kasuellen Reihen mit 3 Wiederholungen getestet. Jede Wiederholung bestand in 10 Kaesten mit 0,25 m Tiefe mit gleicher Nivelierung and ohne Gefaelle.

Der hydrostatische Druck beeinflusste wesentlich (Niveau: 0,01) den Abgang des Wassers. Der Wasserverbrauch variierte zwischen 7,96 bis 10 cm/ha, was eine grosse Wassererersparnis bedeutet.

Die Wirksamkeit des hydrostatischen Druckes bezueglich der Produktion wurde nicht untersucht, jedoch der Unterschied zwischen der Anzahl der Pflanzen war auffallend: Niveau 0,01. Eine quadratische Aequation zeigt klar die Produktionskurve und es wurde eine maximale Produktion von 9 Pflanzen/Kasten festgestellt.

In diesem Studium wurde eine Maximalproduktion von 7 Pflanzen/Kasten mit einer Effizienz von 2,0 kg/m^3 Wasserverbrauch erzielt, was als sehr hoch im Vergleich zu den gebraeuchlichen Bewaesserrungsmethoden angesehen werden muss.

Table 1 : Some physical properties of the soil of the experimental site[a].

Property	Depth interval (cm)			
	0-15	15-30	30-45	45-60
Sand (%)	84	85	78	73
Silt (%)	8	7	10	8
Clay (%)	8	8	12	19
Textural Class	Loamy Sand	Loamy Sand	Sandy Loam	Sandy Loam
Particle density (g/cm^3)	1.64	1.66	1.60	1.62
"Field Capacity" (%)	10.62	11.73	10.40	11.84
15 bar (%)	2,96	2,75	4,02	5.82

[a]Data reported by Azevedo (1975)

TABLE 2: Mean daily release of water by porus capsules under different treatments during Sept. 7 to Nov. 18,1979.

Treatment ΔH	Mean Daily *	Release of Water/capsule Total	Total Water Applied**
	l		mm
T_1(0.35m)	4.30a	318.23	79.56
T_2(0.50m)	4.83b	357.40	89.35
T_3(0.70m)	5.40c	399.41	99.96

* Means followed by the same letter do not differ significantly at the 0,01 level

** Estimated multiplying total water released by the Nº of capsules/ha. In the present study 2500.

Table 3: Mean number of cobs, green matter and grain production of corn (*Zea mays L.*) for different treatments and subtreatments.

Hydrostatic pressure Treatment ($m\ H_2O$)	Population subtreatment (plants/capsule)*				
	1	4	7	10	13
			Number of Cobs**		
0.35	8.6	28.3	31.3	23.6	21.3
0.50	9.6	22.6	30.3	23.6	26.6
0.70	9.6	25.0	25.3	22.6	20.0
		Green Mater Production in kg			
0.35	7.0	11.8	11.8	14.0	13.8
0.50	7.3	10.2	12.5	13.6	15.8
0.70	5.8	11.0	14.0	14.0	18.3
		Grain Production in g			
0.35	288.8	592.4	837.7	790.0	661.7
0.50	258.9	804.8	829.8	732.9	807.9
0.70	219.7	541.7	915.7	904.7	876.7

*Mean of 3 replications, each one with 5 plants

** Good commercial quality

TABLE 4: Water use efficiency of different methods of irriga tion for corn (*Zea mays* L.) production.

Method of irrigation and Reference	Water Use Efficiency Kg/m^3
Closed Furrow (Silva & Magalhães, 1978)	0.7
Open Furrow (Lira & Torres, 1977)	1.0
Sprinkling (Silver et al. 1978b)	0.9
Trickle Irrigation (Olguin et al 1976)	1.4
Porous capsule - under Suction (Olguin et al. 1976)	2,7
Porous capsule - under Pressure (Δ H = 0,35m)	2,0

LEGEND OF FIGURES

Figure 1. Characteristics of gypsum moulds used for construction of porous capsule.

Figure 2. Longitudinal layout of the studied irrigation system.

Figure 3. Rate of daily release of water for the porous capsules when subjected to hydrostatic pressures of 0.35, 0.50 and 0.70m as compared to evaporation and precipitation during the fenologic cycle of corn (Zea mays L.).

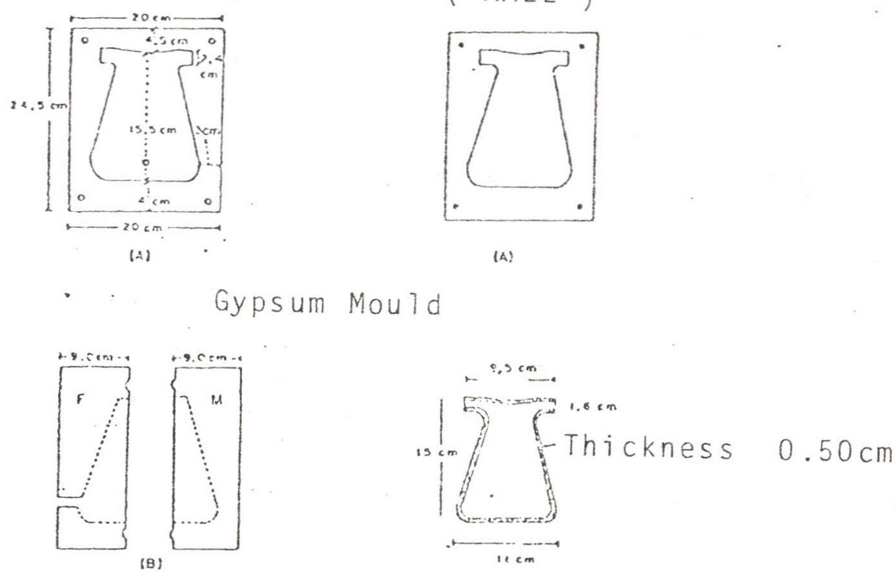
Figure 4. Water distribuition patterns under different hydrostatic pressures and corn population after 21, 42 and 83 days of growth.

Figure 5. Daily matric potentials of soil under different plant populations and hydrostatic pressure of 0.35m during a part of the fenologic cycle of corn.

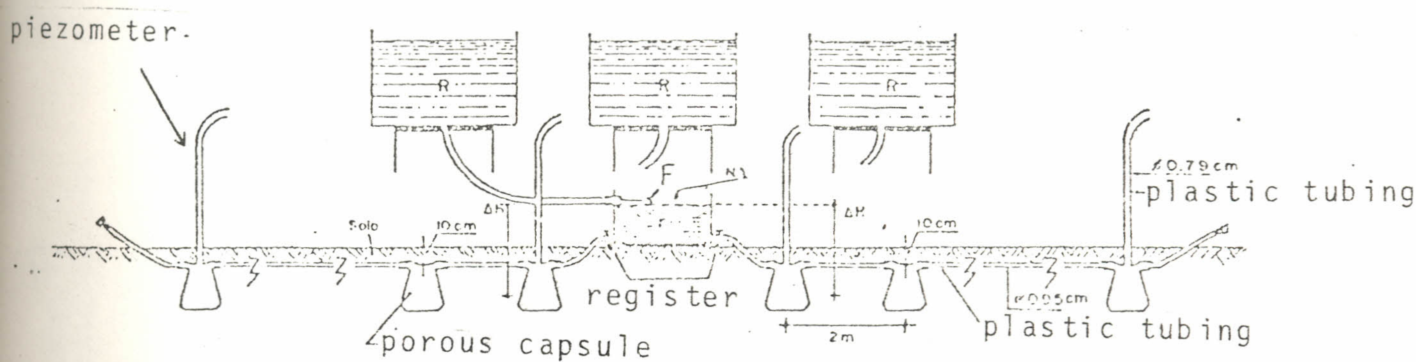
Figure 6. Correlation between corn yield and plant population.

I PART
(FEMALE)

II PART
(MALE)



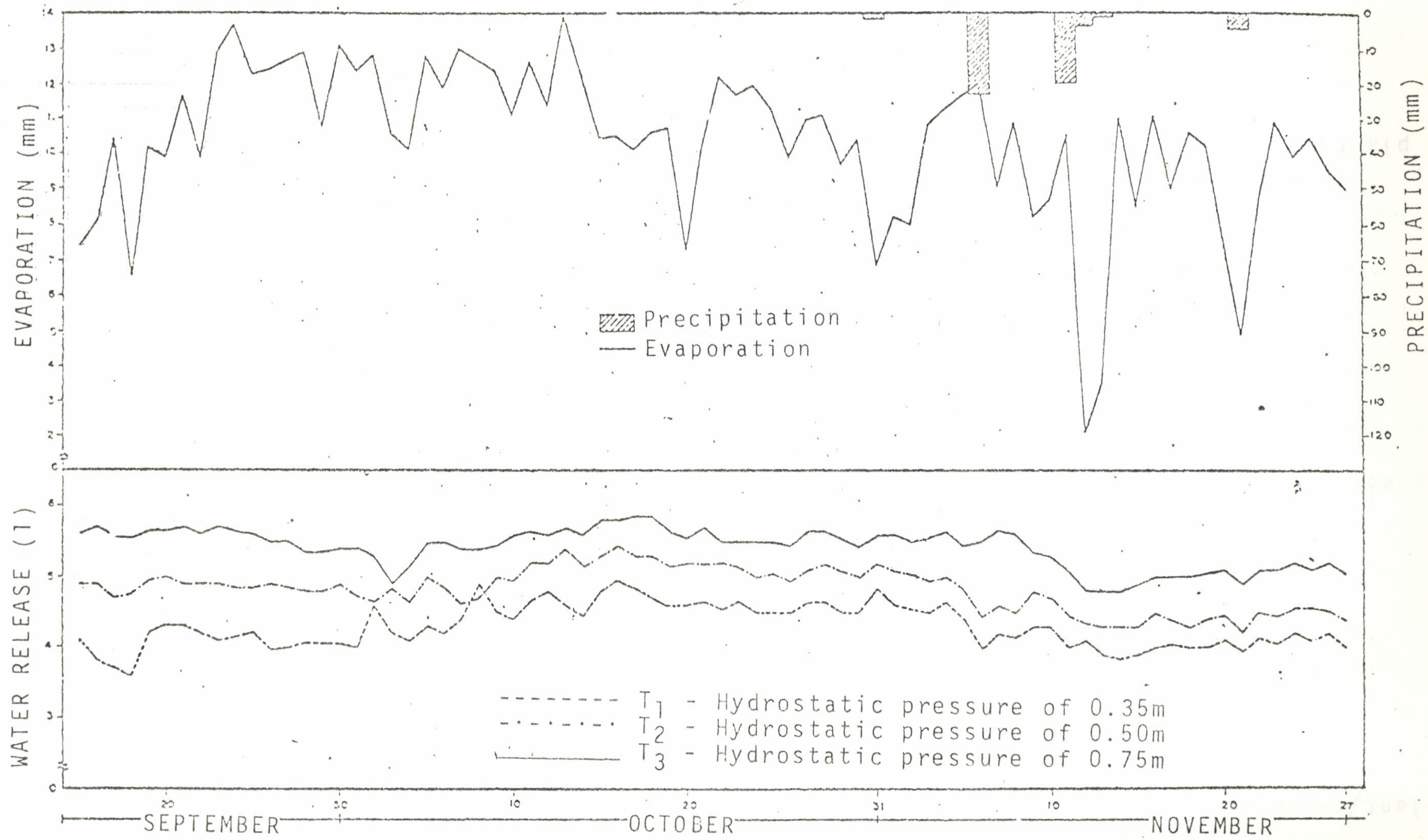
Gypsum Mould



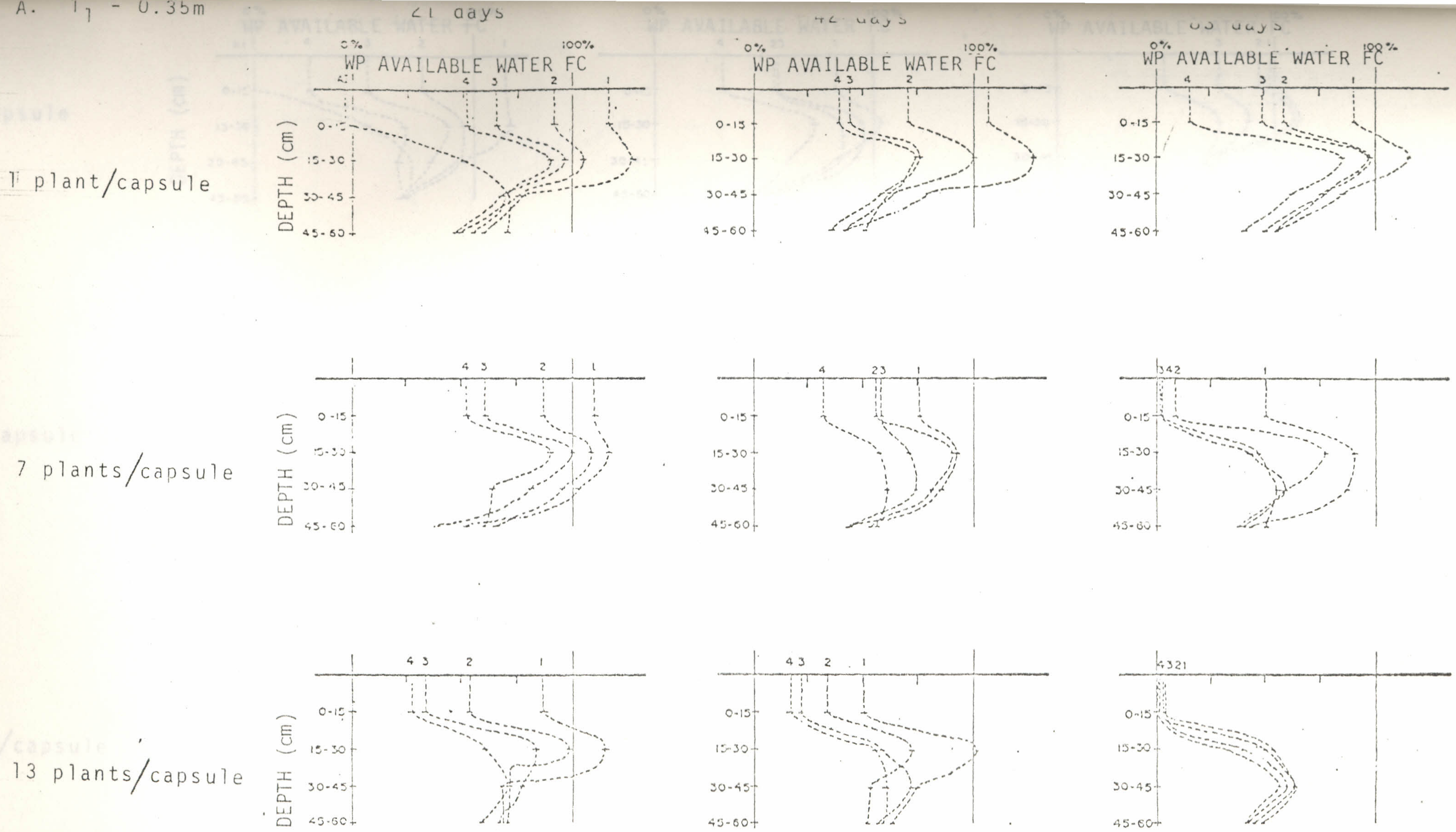
r - Water reservoir with constant head (50 l)

R - Water tank (250 l)

F - Floater



EVAPORATION (mm)
PRECIPITATION (mm)
Precipitation
Evaporation
WATER RELEASE (1)
T1 - Hydrostatic pressure of 0.35m
T2 - Hydrostatic pressure of 0.50m
T3 - Hydrostatic pressure of 0.75m
SEPTEMBER
OCTOBER
NOVEMBER

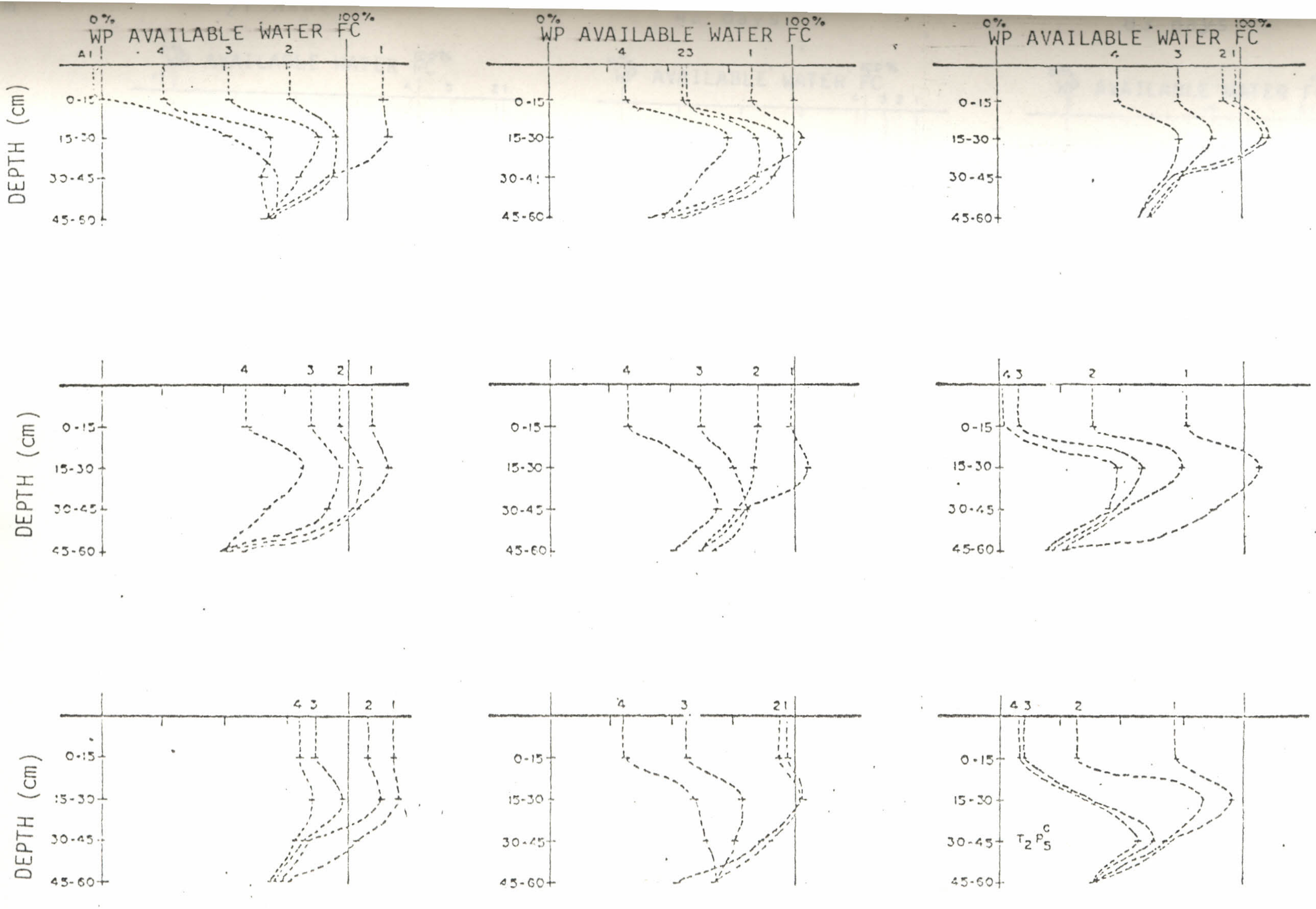


WP - Wilting point
FC - Field Capacity
AI - Soil water content before irrigation
1,2,3,4 - 10, 20, 30 and 40 cm distance from vertical axis, respectively

t/capsule

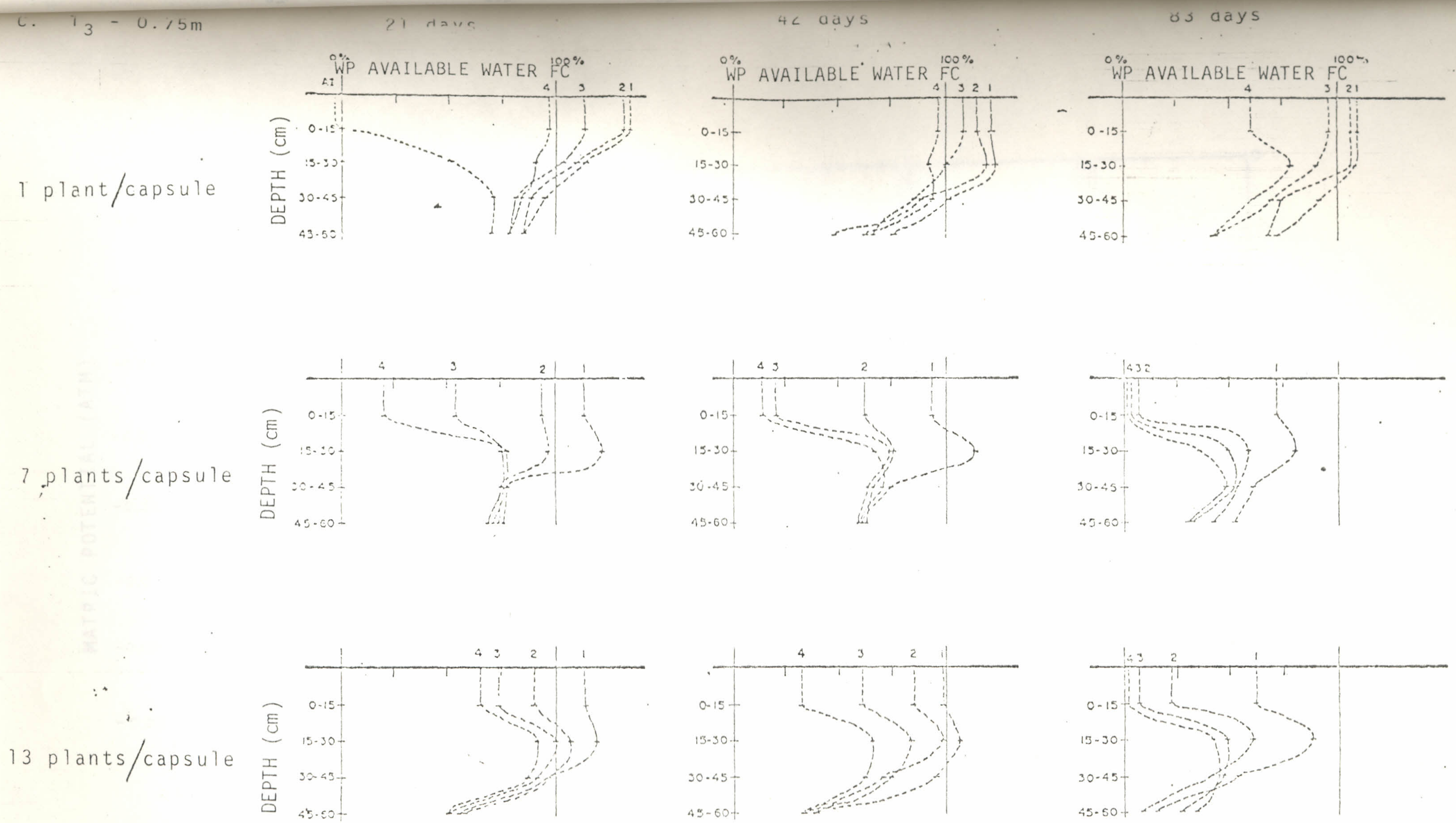
ts/capsule

ants/capsule



WP - Wilting point
FC - Field Capacity
AI - Soil water content before irrigation
1,2,3,4 - 10, 20, 30, and 40 cm distance from vertical axis, respectively

c. T_3 - 0.75m



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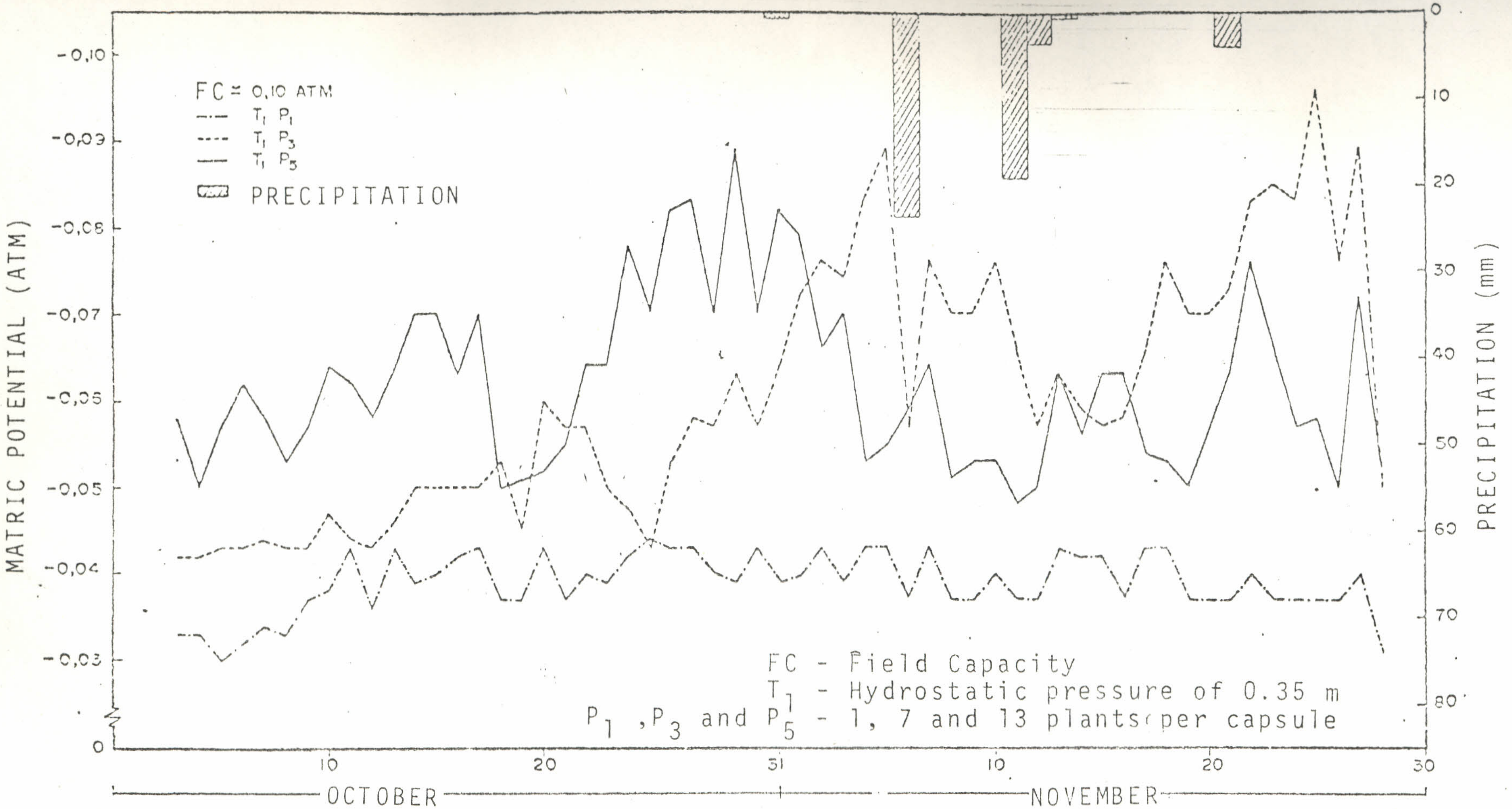
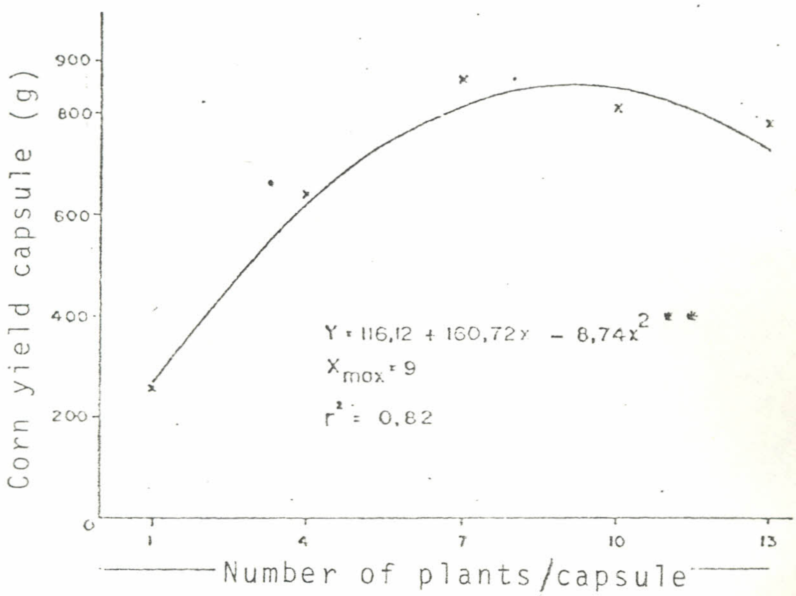


FC ≃ 0,10 ATM
T1 P1
T1 P3
T1 P5
PRECIPITATION
MATRIC POTENTIAL (ATM)
-0,10
-0,09
-0,08
-0,07
-0,06
-0,05
-0,04
-0,03
0
PRECIPITATION (mm)
0
10
20
30
40
50
60
70
80
10
20
31
10
20
30
OCTOBER
NOVEMBER
FC - Field Capacity
T1 - Hydrostatic pressure of 0.35 m
P1 ,P3 and P5 - 1, 7 and 13 plants per capsule



Corn yield capsule (g)
900
800
600
400
200
0
1
4
7
10
13
Number of plants/capsule
Y = 116,12 + 160,72x - 8,74x2 **
Xmax = 9
r2 = 0,82