Soil water and aeration and red bean production. I. Mean maximum soil moisture suction*

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COMPENDIO

La producción de grano, materia seca de la parte aérea y el número de vainas por planta, se maximizó cuando el frijol rojo, Phaseolus vulgaris *L., variedad '27-R' cultivado en los trópicos se regó cuando la succión del agua de suelo llegaba a 0,8 bares a 5 cm de profundidad o 06 bares a 15 cm de profundidad. El experimento se llevó a cabo en macetas de 26 litros de suelo fumigado en el invernadero en CATIE, Turrialba, Costa Rica, con un espaciamiento de plantas semejante al usado en el campo Cuando las succiones máximas fueron mayores o menores que el valor óptimo, hubo una reducción en rendimiento Se encontró que la disminución en producción de grano por unidad de cambio de succión en bares, en el lado de succiones menores del óptimo, fue 15 veces mayor que la del lado de succiones mayores del óptimo No se encontraron problemas de plagas ni enfermedades La evapotranspiración potencial se incrementó hasta un valor máximo a la octava semana y luego disminuyó. La evapotranspiración se reducía a medida que aumentaba la succión máxima aplicada.*

Introduction

EXTENSIVE work has shown that soil moisture deficit significantly influences crop growth and yield (19). It was observed that plants behaved similarly in soil with diverse moisture contens Application of the energy concept to soil water (suction or tension) at the wilting percentage showed that a given soil moisture suction of 15 bars was the common denominator between the soils, although their moisture contents varied considerably (16). Total soil moisture suction, the sum of matric suction and osmotic suction, is considered the dominat soil moisture factor which affects plant growth The energetic equivalence of these two terms has been experimentally shown by vapour pressure measurements (17, 18). Wadleigh and Ayres (24) and Wadleigh (25) showed trat in beans and guayule, the effect of matric suction and osmotic suction on growth is equivalent and interchangeable.

Osmotic suction is only important in soils with a high salt content and as a result the total suction in other soils is almost completely represented by the matric suction For non-saline soils the matric suction is the dominant soil water factor which influences plant growth and because of its energy basis, has a greater generality of application for different soils than does soil moisture percentage. This can be seen in the data of Bierhuizen and Vos (3) who obtained a similar relative yield — mean soil suction curve for lettuce, raddish and spinach grown on clay and sandy soils.

Attempts were made to eliminate the arbitrary nature of soil moisture percentage as a soil water index by developing concepts of available water (16) The one most recently used is the water found between the upper limit of field capacity percentage and the lower limit of permanent wilting percentage, the latter having been suggested by Veihmeyer and Hendrickson (23) Common use of this index is to relate yield or growth to the depletion of various fractions of available water in the crop rooting depth, i.e. 25, 50 and 75 per cent prior to irrigation. However, since different soils have different shaped curvi-linear moisture desorption curves between field capacity and permanent wilting point, a given percentage of available water will correspond to a different suction for each soil

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(6, 10) Consequently, results from a given irrigation experiment on a given soil that are expressed in percentage of available water can only be applied on the soil of the experimental site If an energy concept such as soil suction is used (suction has dimensions of energy/unit volume of soil water), then the results obtained from area can be more easily applied to another area

Different functions of soil water suction have been used to study plant growth and yield. Ayers*et al* (1) used the maximum suction at 10 cm soil depth permitted before irrigation as an index to study the effect of different soil suctions (maximum suctions) on the yield of dwarf red kidney beans at different soil salinity levels. Wadleigh and Ayers (24) integrated with respect to time, the total suction corresponding to the average moisture content of the root zone (0-38 cm) of a 10 gallon pot. The value of the average root zone suction with respect to depth, versus time was obtained graphically and from this, time average was obtained, which was called the integrated moisture stress. They obtained a yield response curve with little scatter of the points. Rawitz and Hillel (15) obtained similar results with snapbeans and sunflowers using a similar procedure for a non-saline soil, which means that osmotic suction was ignored and what they called a mean integrated capillary suction index was calculated. Taylor (20) recognizing that the moisture distribution in the root zone is not uniform after some moisture extraction has occurred, desvised a way of integrating the suction with time and a given number of depth intervals in the root zone. However, both forms of obtaining an integrated soil moisture suction require laborious calculations and are thus of limited practical application as a field norm. This opinion has also been expressed by Haise and Hagan (10) and Rawitz and Hillel (15).

If the average of the moisture content of the root zone just before irrigation (minimum moisture content index) is converted to soil water suction by using a soil moisture desorption curve we obtain a depth average of suction in the root zone just before irrigation. This suction is the maximum suction experienced during an irrigation cycle. The minimum suction would be that existing in the root zone inmediately after an irrigation. The field capacity suction is commonly used to estimate this value. The time (event) average of these maximum capillary suctions has been called the mean maximum capillary suction index by Rawitz and Hillel (15) and has been used by various researchers. Using this method for potatoes, Rawitz and Hillel found there was good agreement between yield curves obtained in the growth chamber and those obtained in the field, for the same soil. The mean maximum capillary suction is a sensitive indicator of soil moisture status and can be applied practically as a field norm for irrigation.

It is more convenient if the suctions can be measured directly in the field with tensiometers or other suitable instruments. The depth of maximum root activity is considered suitable for the placement of these instruments (10). In this study the mean maximum capillary suction are measured at 5 cm and 15 cm depths for a red bean variety ('27-R') of *Phaseolus vulgaris* which is grown in the tropics.

Studies have shown that the evaporative demand of the environment modifies the suction-yield curve, specially at the higher suction (3). Taylor (20, 21) cites ranges of optimum mean maximum capillar suctions according to the evaporative demand. Guides for levels of evaporative demands may be taken from the study of Denmead and Shaw (4) where the calculated Class A pan evaporation equivalent to a high demand is between 7.9 and 9.4 mm/day for a medium demand 3.8 - 5.2 mm/day and a low demand 1.35-2.5 mm/day.

Materials and methods

Approximately 25 litres of soil were placed in pots 30 cm high, 20 cm wide (internally) and 50 cm long, made of tin-coated iron sheets painted firstly with asphalt paint and then green paint. The soil is the "Margot" series, a Typic Dystropept, fine mixed isohyperthermic. The top 20 cm of the soil profile was sampled, air dried, passed through a 5 mm sieve, and fumigated with methyl bromide for 24 hours. the soil had a bulk density of 0.91 g/ml when packed in the pot; particle density 2.49 g/ml, a clay loam texture under the USDA system with 32% clay, 40% silt and 28% sand. Resistance to a 5 mm diameter piston immersed 5 mm in the soil varied from 1,1 bars for the 0,003 bar suction treatment to 9 bars for the 12.8 bar suction treatment. The soil had a pH in water (1:1) of 4.5; organic matter 6.0%; total N 0.36%; CN ratio 9.7; available phosphorus (Bray-Kurtz) 1.6 ppm; cation exchange capacity 40 me/100 g (oven dried soil); calcium 8.0 me/100 g; potassium 0.6 me/100 g; magnesium 2,5 me/100 g, and electric conductivity of a saturated extract 0.4 mmho/cm.

Soil was placed in the pots to a height of 25 cm and was fertilized to eliminate risks of nutrient deficiency following doses per hectare suggested by Martini (13). The amount of fertilizer applied to a pot of 2 plants was calculated considering that the plant population per hectare was 200,000. The pots were randomly distributed on 3 tables 1 m high and on each table they formed two rows with 2 plants per pot 10 cm x 50 cm used in the field. Week-old red bean '27-R' seedlings were used in the planting.

The pots had treatments of the following maximum suction measured at 5 cm depth: 0.10, 0.20, 0.40, 0.80, 160, 3.20, 6.40 and 12.80 bars. When the pots reached the maximum suction they were irrigated until the suction fell to 0.050 bars. They were also treatments at lower suctions to provide limiting conditions of aeration in order to study this effect concurrently with the maximum suction effect. Suction of 0.003, 0.006, 0.0125, 0.025 and 0.05 bars were applied through asbetos wetting pads (Figure 1) connected by hydrostatic lines to containers with free water. By regulating the height of the containers it was possible to maintain these constant suctions within ± 2.5 cm of water (± 0.0025 bars). Water manometers which made

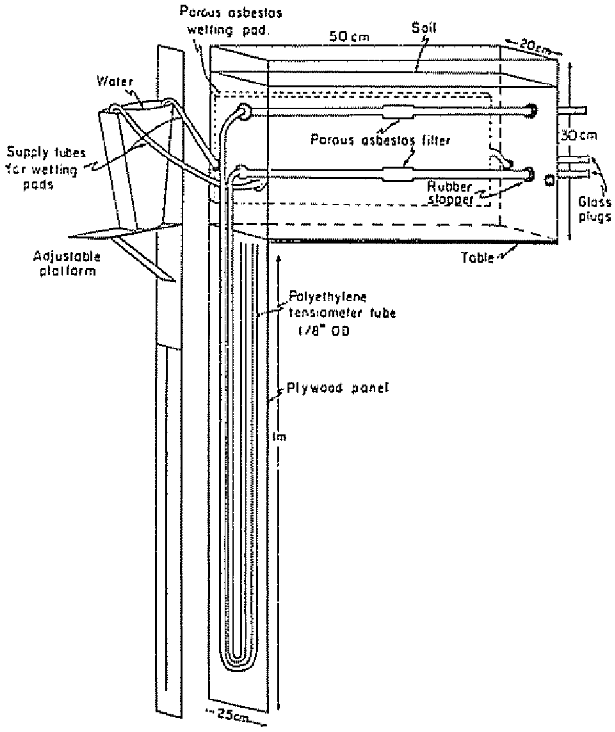

Fig. 1 —*Pot and variable water table system used for treatments of 0 003 - 0 060 bars.*

contact with the soil through porous asbestos filters were used as tensiometers (Figures 1 and 2). The air space corresponding to the different low suctions were determined by estimating soil moisture of pots without plants by weighing, and determining the total porosity of the soil. Values of 4 repetitions were used

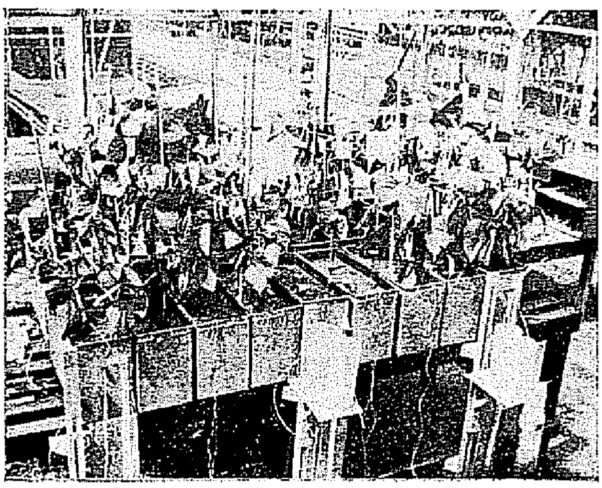

Fig 2.—*Pots planted with beans, showing tensiometer, nylon block and thermometer installations*

The experiments had a randam block design with 13 treatments and 4 repetitions Moisture suctions were measured at 5 and 15 cm depths. Suctions up to 0 050 bars were measured with water manometer tensiometers, suctions between 0 10 and 0.80 bars with dial gauge tensiometers, and suction between 1.60 and 12.80 bars with nylon blocks individually calibrated in pressure-plate equipment

The daily maximum and minimum of the temperature and relative humidity of the greenhouse were measured, and this and other weather data were used to calculate USWB Class A pan evaporation using the formulas of García-López (8) Papadakis (14) and Van Bavel (22) with modifications by Legarda and Forsythe (11), who found that the formulas adapted well to a tropical area, such as Turrialba, Costa Rica. An average of the estimations of the three formulas was used.

Results and discussion

The crop cycle lasted 81 days starting from germination which started on the 5th of January, 1972. During the cycle the average greenhouse maximum daily temperature was 30 4°C, minimum 18.6°C and average 24.5°C, and the average maximum relative humidity was 95.7%, minimum 47 6%, and the average 78 8%. The average soil temperature at 5 cm was 22 9°C, whereas that at 15 cm was 22 0°C. The average of the Class "A" pan evaporation calculated from the three formulas previously mentioned serves as an index of the evaporative demand of the environment. During the experiment the estimated pan evaporation varied between 3 45 - 6 48 mm/day, which may be characterized as a medium demand.

Table 1 shows the estimated pan evaporation (E) for different periods together with relations between potential evapotranspiration (PET) and evapotranspiration (ET), such as values of *f* evaluated as (PET/E) and R evaluated as (ET/PET) during crop growth for different maximum suctions. The value of PET used to estimate *f* was the volume of water consumed divided by the horizontal sectional area of the pot The high values of *f* which usually do not surpass 1 2, are probably due to advective effects and the possibility that plant foliage shaded an area larger than the surface of the pots. However, it is observed that there is an increase of *f* with a developing canopy up to the 8th week and its subsequent decrease possibly due to leaf maturity and leaf fall. The diminishing value of R with increasing maximum suction (decreasing soil moisture) follows the pattern of soil drying for moderate evaporative demand and shallow rooting of 25 cm (7)

Figure 3 shows the effects of the maximum suction at 5 and 15 cm depth on grain yield, adjusted to 14 per cent moisture. Yield changes with respect to the 5 cm suction were significant at the 1% level. Maximum yield was obtained when maximum suction was between 0 7 and 0 8 bars at 5 cm depth, and between

Table 1.—The F factor, PET/E, and the R factor, ET/PET, during bean growth for different maximum suctions.

Date Nº of weeks, days and months		E mm	0.003 Factor f	Suction in bars											
				0.006	0.0125	0.025	0.050	0.10	0.20	0.40	0.80	1.60	3.20	6.40	12.80
				Factor R*											
1	5 - 8 Jan.	13.8	0.80	0.82	0.73	0.64	0.82	0.64	0.55	0.55	0.36	0.36	0.45	0.45	0.36
2	9 - 15 Jan.	27.7	0.87	0.83	0.71	0.71	0.63	0.63	0.38	0.38	0.29	0.33	0.33	0.38	0.29
3	16 - 22 Jan.	45.4	0.68	0.94	0.84	0.87	1.00	0.74	0.45	0.45	0.32	0.26	0.26	0.29	0.23
4	23 - 29 Jan.	39.2	1.10	0.91	0.79	0.84	0.86	0.79	0.40	0.53	0.37	0.23	0.19	0.21	0.16
5	30 Jan. - Feb.	38.6	1.37	0.91	0.85	0.77	0.85	0.85	0.60	0.64	0.47	0.45	0.23	0.17	0.13
6	6 - 12 Feb.	41.8	1.48	0.90	0.84	0.82	0.90	0.81	0.74	0.65	0.53	0.52	0.44	0.23	0.15
7	13 - 19 Feb.	43.7	1.69	0.93	0.88	0.82	0.81	0.76	0.69	0.64	0.61	0.49	0.47	0.30	0.19
8	20 - 26 Feb.	31.8	2.64	0.95	0.88	0.76	0.76	0.71	0.67	0.62	0.60	0.45	0.48	0.43	0.23
9	27 Feb. - 5 Mar.	37.1	1.99	0.95	0.93	0.84	0.78	0.74	0.64	0.58	0.54	0.54	0.51	0.42	0.39
10	5 - 11 Mar.	39.8	1.71	0.94	0.88	0.78	0.71	0.63	0.66	0.57	0.51	0.50	0.47	0.28	0.26
11	12 - 18 Mar.	38.6	1.48	0.91	0.79	0.67	0.60	0.63	0.53	0.47	0.39	0.37	0.33	0.23	0.21

* R = 1 for treatment of 0.003 bars.

0.5 and 0.6 bars at 15 cm depth. The fall in yield on the side of increasing maximum suctions is attributed to water deficit while the yield drop on the side of decreasing maximum suction is considered to be a combination of deficient aeration and low maximum suctions.

Part II (12) of this series of papers will discuss the influence of aeration on yields. It is sufficient to note here that a non-limiting value of air-space of 25 per cent was reached in the experiment before maximum suction rose to 0.05 bars and thus in the section

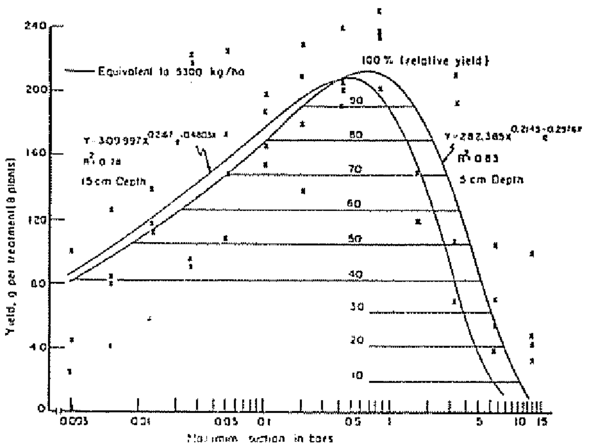

Fig. 3.—*Relation between yield and maximum suction at 5 and 15 cm depths for the treatment 0.003 - 12.60 bars (x) Experimental data for 5 cm depth*

of the yield curve of Figure 2 between 0.05 bars and 0.8 bars, yield is considered to be lowered by the low suction values themselves. The rate of yield drop with respect to change of maximum suction between 0.80 and 0.003 bars of is approximately 15 times the rate of drop between 0.80 and 12.8 bars, and this indicates a moisture excess depresses the bean yields much more than a moisture deficient.

In this experiment, the values of maximum suction for optimum yield of 0.8 bars at 5 cm depth and 0.6 bars at 15 cm depth, approximate that obtained by Bernardo *et al.* (2) with variety 'Vi 1013', which was 0.5 bars at 10 cm depth. Other maximum suction values cited for maximum production of beans are 1.0 bar for the variety 'Canario 101' (9) and between 0.75 - 2.0 bars (5, 21). Field beans are commonly thought to be a crop that is favoured by dry conditions. While the yield response curves in Figure 3 show that 27-R will give a crop at high maximum suctions, the yield is much lower than that obtained at the optimum maximum suction, which corresponds to a relatively moist soil.

Figure 4 shows that dry matter production response to maximum suctions at 5 cm are similar to grain yield response in Figure 3. Response was also significant at the 1 per cent level. The linear degree of determination between yield and dry matter production is $R^2 = 85.7\%$, which indicates close association between yields and vegetative growth, whereas R^2 for yield and number of pods per plant is 87.6% indicating close association of the latter two parameters. An average maximum of 14.75 pods per plant was

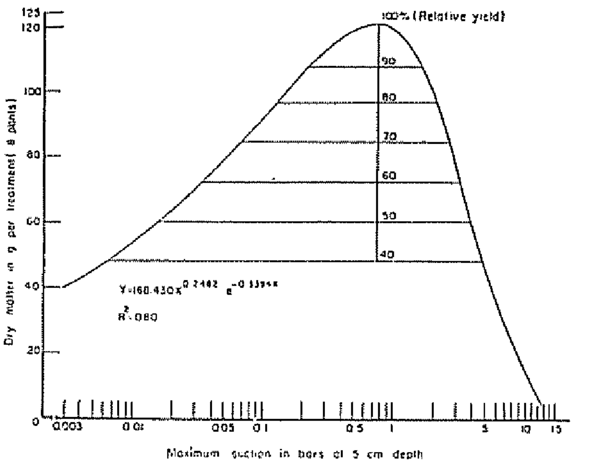

Fig 4.—*Relation between aerial dry matter production and maximum suction at 5 cm depth*

obtained for the 0.8 bar suction and a minimum of 2.75 pods plant for the 0.003 bar treatment.

Figure 5 shows the relationship between maximum suction at 5 cm depth and maximum suction at 15 cm depth for various stages of growth for maximum suctions at 5 cm of 0.1 bar and greater. The data indicates that maximum suction at 5 cm is always greater than the corresponding value at 15 cm and this should be expected due to greater root concentration and evaporation in the surface layers. However, the regressions of 5 to 9 weeks do not reflect this until maximum suctions at 5 cm are greater than 0.3 bars. The change in the regression curves with the age of the plants indicates that after 5 weeks, root development at 15 cm depth is such that there is notably more active moisture extraction than before since the suction values are closer to the 5 cm ones, and this increases gradually with the age of the plant. The wetter range of the 3 and 4 week regression lines reflects the fact that the less developed plants were unable to dry the soil as much as plants of 5 weeks and older. The good correlation between 5 cm and 15 cm maximum suctions indicates that 15 cm maximum suction values can be used just as effectively as those at 5 cm to control soil moisture in the root zone. The same conclusion may be drawn from Figure 3. This would have the advantage of being able to comfortably use the tensiometer to measure soil moisture since the values of maximum suction for optimum growth of 0.5 - 0.6 bars is well within tensiometer range. However, there is the disadvantage that special calibration would be needed for the first 4 weeks of growth.

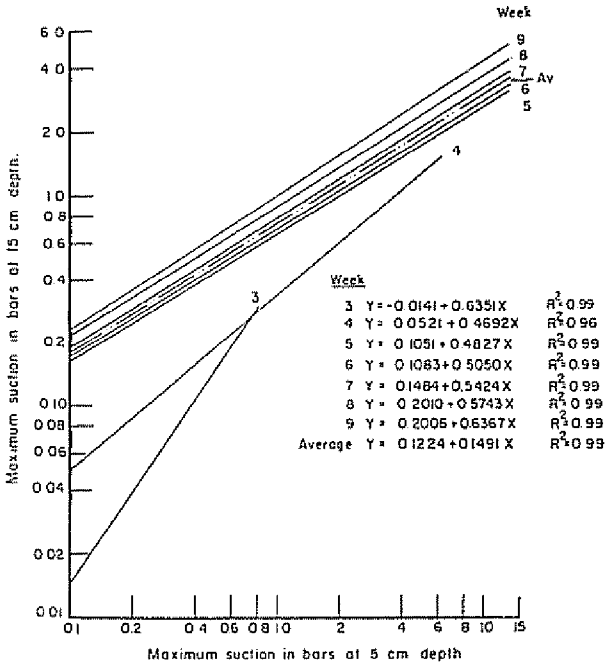

Fig 5.—*Relation between maximum suction at 5 cm and maximum suction at 15 cm depth as a function of growing time in weeks.*

No diseases nor pests were observed during the crop cycle, so it may be concluded that the effects observed were directly due to the treatments.

Summary

Grain and aerial dry matter production and the number of pods per plant were found to be maximum in the '27-R' cultivar of *Phaseolus vulgaris* L., a red bean grown in the tropics, when the maximum soil moisture suction was 0.8 bars at 5 cm depth or 0.6 bars at 15 cm depth. The experiment was carried out in 26 liter pots of fumigated soil in a greenhouse at CATIE, Turrialba, Costa Rica, with plant spacing similar to field conditions. When the maximum suctions were greater or lesser than the optimum yield value, there was a reduction in yield. It was found that grain production loss per unit bar of suction change when the cyclic maximum suctions were less than the optimum value, were 15 times greater than the rate of production loss when the values were greater than the optimum. No disease nor pest problems were encountered during the study.

Potential evapotranspiration increased to a maximum at the eight week and subsequently decreased. Evapotranspiration decreased with increasing maximum suction.

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