Soil water and aeration and red bean production. II. Effect of soil aeration*

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COMPENDIO

La producción de grano y de materia seca de la parte aérea fue máxima en la variedad 27-R (Phaseolus vulgaris L.) *de frijol rojo cultivado en los trópicos, cuando el promedio del espacio aéreo en la zona radical era mayor de 25%, ó cuando la rata de difusión de oxígeno entre 5-15 cm de profundidad era mayor de 24-28g × 10^{-8} × cm $^{-2}$ × min $^{-1}$. El experimento se llevó a cabo en macetas de 26 litros con suelo fumigado, en un invernadero en el CATIE, Turrialba, Costa Rica, con un espaciamiento de plantas semejante al usado en el campo. No se encontraron problemas de enfermedades ni plagas durante el estudio.*

Introduction

PLANT roots require 0_2 for respiration and the $C0_2$ produced needs to be removed to avoid accumulation to toxic levels. For many plants soil aeration facilitates the entry of 0_2 from the atmosphere into the soil and the exit of $C0_2$ produced, through the process of gaseous diffusion. Percent air space has been found to be a good index of the soil to permit diffusion and thus aeration (1, 11, 14). Oxygen diffusion takes place when a negatively charged platinum electrode is placed in the soil and it acts as a line sink for oxygen flow from the surrounding soil since it is converted to water at the electrode. The steady state flow rate of 0_2 to an electrode of given dimensions has been used as an index of soil aeration (8,9) and has been called the (15) concluded that for the majority of agricultural crops studied, an ir space less than 10-15% is considered limiting for maximum production Stolzy and Letey (12, 13) consider that an ODR less than 20 × 10^{-8} g cm $^{-2}$ min $^{-1}$ is limiting to crop perfomance

Field beans *(Phaseolus vulgaris* L.) have been noted to be sensitive to excessive moisture. Forsythe and Pinchinat (4) have shown that the 27-R variety can lose 90% of its yield by 5 floodings of 12 hours duration done once a week for 5 consecutive weeks, although soil air space was considered good (27%) in between floodings. The importance of determining the soil aeration requirements of 27-R was appreciated.

An experimental variation of soil air space may be achieved by compacting the soil and thus reducing its total porosity. This method has the drawback of also increasing soil resistance to root growth and thus crop response may be a confounded effect of changes in aeration and that of soil resistance. Changing soil air space by varying soil moisture does not have this problem, but there is the possibility of an affect confounded with crop response to moisture itself. Forsythe *et al* (3) suggested that since soil moisture and soil air space are complementary it is convenient to study both factors at the same time

Materials and methods

The procedure explained in Part I (5) was followed here since the experiment was designed to study the effect of soil maximum soil water suction and soil air space in the pots was determined by estimating soil determining the total porosity of the soil. In those moisture of pots without plants by weighings and determinin³ the total porosity of the soil. In those treatments that had a water table inside the pot the average air space of the pot was adjusted using the

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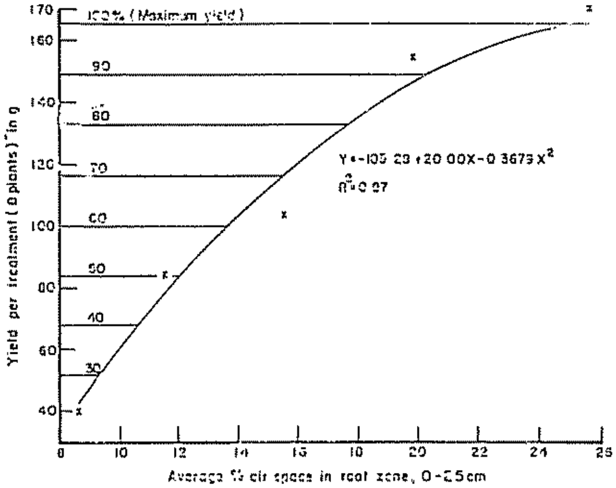

Fig. 1.—*Yield response to average air space, for treatments corresponding to suctions 0 003 - 0 05 bars (x) Averages of experimental data*

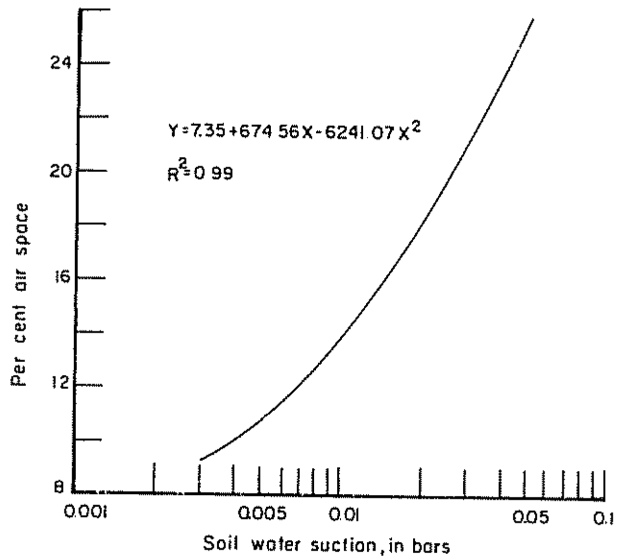

Fig. 3.—*Air space in drained soil above water table in relation to soil suction at 5 cm depth for range 0-0 05 bars suction.*

predetermined air space of the flooded soil to form a weighted mean for the air space of the upper drained volume (7) The 0.003 bar treatment had a water table 17 cm high, that of 0.006 bars 13 75 cm, and 0.0125 bars 7 5 cm

The ODR was measured by platinum microelectrodes of the type TW W 146556K 600V from Dick's Machine Shop, Lansing, Michigan. Measurements were made at 5 and 15 cm depths within the root zone, in all pots every 3 days Metal wires 30 cm long with one end filed were painted with asphalt paint, and inserted to the appropriate depths in the soil and removed at measuring time to allow the insertion and extraction of the microelectrodes without damaging them The procedure according to Letey and Stolzy (10) was followed.

Results and discussion

Figure 1 separates the effect of air space from the confounded effect of excess water on yield that is observed in Fig. 3 in Part I (5). Response was significant to the 1% level A levelling of the yield curve in response to a change in air space was obtained and the value corresponding to maximum yield is approximately 25 per cent. This is higher than the range of 10-15 per cent required for most crops studied, and indicates that the 27-R bean is more demanding than many crops for good aeration. Figure 2 shows the response of dry mater production to increasing air space, which is similar to the grain yield response. Maximum production was obtained at approximately 20 per cent space. Dasberg and Bakker (2) obtained a linear correlation of 0.82 between dry matter production of the Dubble Witte bean variety and increasing air space up to 20 per cent, the upper limit of their experimental range.

Figure 3 shows the experimental relation obtained from 4 repetitions of the soil water suction at 5 cm depth and the average air space of the drained soil

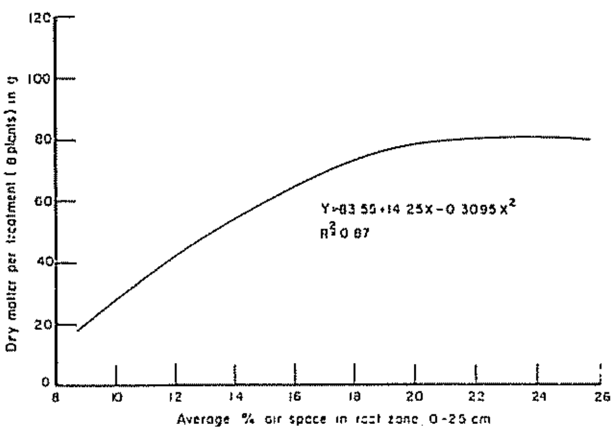

Fig 2.—*Dry matter production response to air space.*

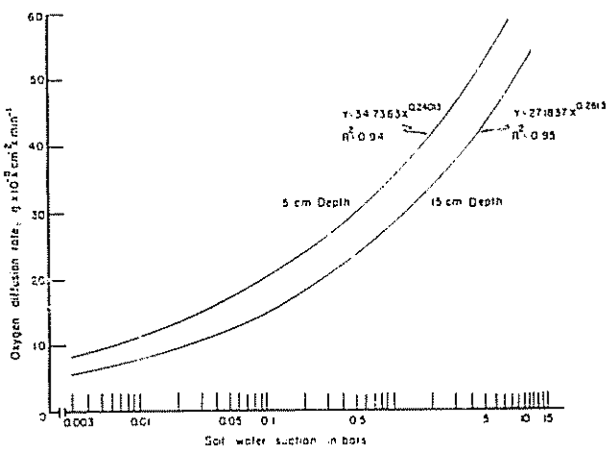

Fig 4.—*Relation between soil suction at 5 cm depth and oxygen diffusion rate at 5 and 15 cm depth.*

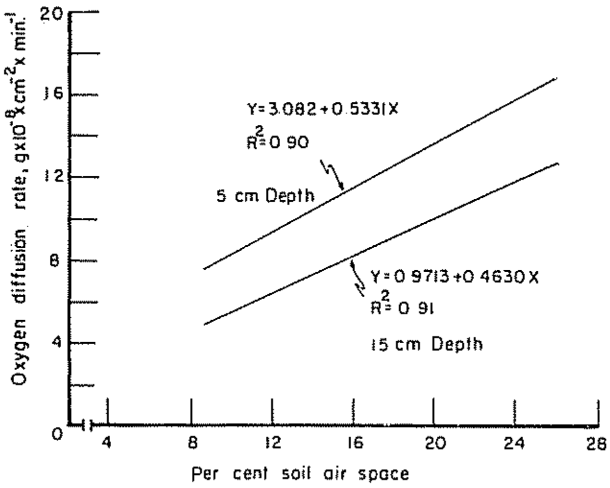

Fig. 5.—*Relation between oxygen diffusion rate at 5 and 15 cm depth and the average air space.*

above the water table The response was significant at the 1% level. The soil at zero bars suction (below the water table) had an average of 6.2% air space with a standard deviation of 0.64%.

Figure 4 shows the relationship between soil maximum suction at 5 cm depth and ODR at 5 and 15 cm depth. The ODR at 5 cm depth is higher than that of 15 cm depth, probably due to the fact that the soil has a lower moisture content a 5 cm and thus a greater air space ODR increased with increasing maximum suction up to 12 bars. Stolzy and Letey (13) and Gavande (6) found a peak in the ODR response with subsequently dropped as the soil dried. This has been attributed to poor moisture electrode contact. Presumably in our case there was good contact. Since the suctions values between 0.003 and 0.05 bars were constant it was possible to correlate the average soil air space for these values and the ODR, which is shown in Figure 5. Again ODR at 5 cm is higher than that of 15 cm, and this is again probably due to a

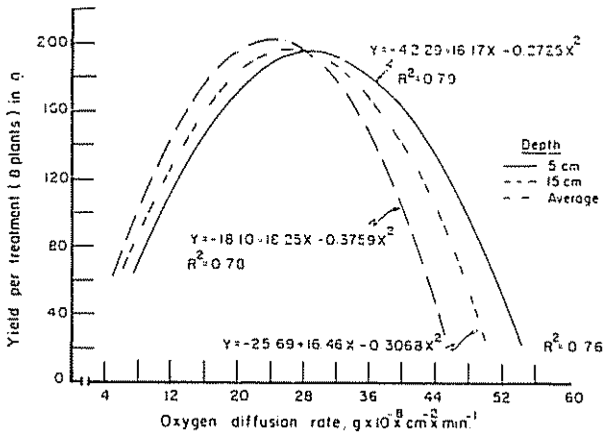

Fig. 7.—*Relation between yield and oxygen diffusion rate.*

lower moisture content and thus a greater air space at 5 cm. The high linear correlation between ODR and air space suggests a close relationship between the aeration indices, although soil depth will influence the interpretation.

Figure 6 shows that ODR increases with time for 5 and 15 cm depths. The response is significant at the 1% level. This is probably due to a more uniform drying of the pots by the more developed plant roots when the 5 cm tensiometer indicated the need for irrigation as was shown by Fig. 4 in Part I (5). The values of ODR are estimated for all suctions and are thus low and cannot in themselves be interpreted. The importance of the graph is to show the trend with time.

Figure 7 shows that maximum grain yields were obtained at a maximum ODR between 24-28 y $\times$ 10^{-8} $\times$ cm $^{-2}$ $\times$ min $^{-1}$, which is higher than the value of 20 $\times$ 10^{-8} $\times$ cm $^{-2}$ $\times$ min $^{-1}$ considered to be limiting by Stolzy and Letey (13). The drop in yield past the peak is attributed to limiting moisture conditions. Figure 8 shows a similar type curve for aerial

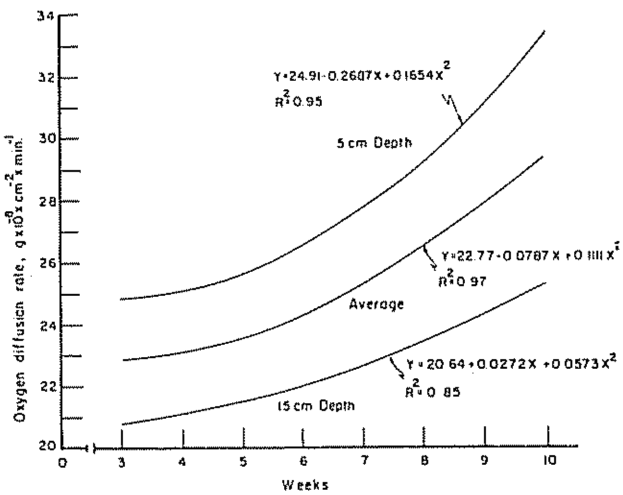

Fig. 6.—*Relation between time in weeks and oxygen diffusion rate. Readings started with 3 week-old plants.*

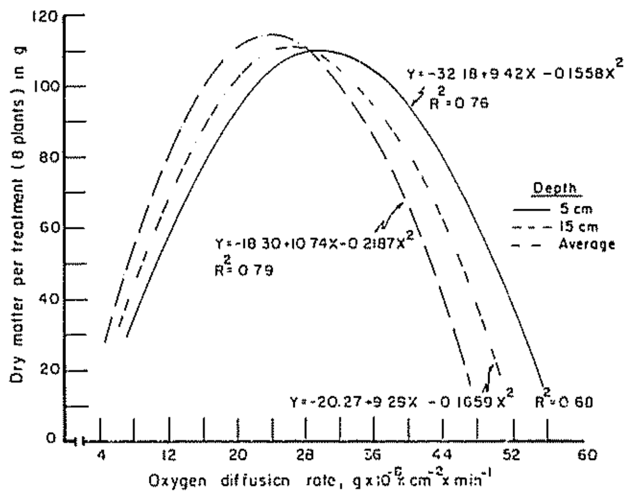

Fig. 8.—*Relation between aerial dry matter production and oxygen diffusion rate.*

dry matter production. No diseases nor pests were observed, and soil resistance to a 5 mm penetration of a piston 5 mm in diameter varied from 1.1 bars at 0.003 suction to 9 bars at 12.8 bars suction, values which are considered non-limiting to root growth.

Conclusion

Both the values of limiting air space and ODR suggest that 27-R is more demanding for good aeration than the average crop and Part-I shows that a moist soil is also needed for optimum yields. Thus the 27-R variety of *Phaseolus vulgaris* L. needs a relatively moist soil which provides good aeration at the same time to obtain optimum yields.

Summary

Grain and aerial dry mater production were found to be maximum in the 27-R variety of *Phaseolus vulgaris* L., a red bean grown in the tropics, when average soil air space in the root zone was greater than 25% or when oxygen diffusion rate between 5-15 cm soil depth was greater than 24-28g $\times$ 10^{-8} $\times$ cm^{-2} $\times$ min^{-1}. 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. No disease nor pest problems were encountered during the study.

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