Effect of soil penetration resistance on the growth and yield of beans (**Phaseolus vulgaris** L.) 27-R variety[*]

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COMPENDIO

La producción de grano, materia seca de la parte aérea y de raíces de Phaseolus vulgaris L *variedad 27-R, se aumentó cuando la resistencia a la penetración a capacidad de campo en las capas de 0-25 cm o de 12,5 - 25 cm fue aumentada a 6 - 10 bares. Esto se atribuyó a mejor contacto entre las raíces y el suelo. Aumentos adicionales de resistencia a la penetración hasta 21 bares redujeron los rendimientos (en aproximadamente 50%) y el crecimiento de la parte aérea y de raíces. Cuando la resistencia en la capa de 0-12,5 cm se incrementó, el rendimiento y la producción de materia seca de la parte aérea disminuyeron ligeramente. En cambio la producción de raíces seguía la tendencia de los otros tratamientos con la excepción de que la densidad de raíces fue uniforme en la zona 0-25 cm. El experimento se llevó a cabo en macetas de 26 litros de suelo fumigado en un invernadero en el CATIE, Turrialba, Costa Rica. El suelo es un Typic Dystropept fine mixed iso-hyperthermic. Capas de suelo fueron compactadas a la resistencia a la penetración deseada por una prensa hidráulica. Se midió la resistencia contra un pistón circular de 5 mm de diámetro y de acero inoxidable que fue introducido en el suelo hasta 5 mm. Se usó un penetrómetro portátil apto para uso en el campo. Las plantas crecían dentro de los límites de succión de 0,1 a 0,8 bares. Ratas de difusión de oxígeno medidas a 15 cm de profundidad después de un riego mostraron que ningún tratamiento experimentó un suministro limitante de oxígeno aunque medidas de espacio aéreo indicaron condiciones limitantes temporales en algunos tratamientos*

Introduction

MECHANICAL resistance is considered one of the soil physical conditions affecting plant growth, (2, 14) and has been considered a plant growth factor in the soil medium as defined by Tisdale and Nelson (18) having the characteristics of being necessary to determine plant growth in the soil (2, 3).

Bulk density has been used as an index of soil mechanical resistance, but is deficient as such, since it is only one of various contributing factors to mechanical resistance, along with texture, cementation, previous history, organic matter and moisture, to name a few (3, 13).

Veihmeyer and Hendrickson (20) found that different soils had individual values of bulk density that inhibited root penetration of sunflower *(Helianthus annuus)* which ranged from 1.47 to 1.9 g/ml. Taylor and Gardner (15) found a high linear correlation between root penetration of cotton *(Gossypium hirsutum)* and soil resistance to the insertion of a 5 mm diameter circular stainless steel piston for a 5 mm entry. The value was -0.96, while linear correlation between root penetration and bulk density was -0.59, and that between root penetration and soil moisture suction was 0.48. In addition, bulk density is a contributing factor to total soil porosity and thus soil air space, which is considered another soil physical growth factor. Thus

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the use of bulk density as an indiex of mechanical resistance would tend to confound soil aeration effects with mechanical resistance.

Soil resistance to penetration appears to be a good index of mechanical resistance. The soil penetration resistance of the static penetrometer used by Taylor and Gardner (15) correlates well with root penetration, while Taylor and Burnett (16) found that several species studied did not penetrate a fine sandy loam at field capacity when the penetration resistance was between 25 and 30 bars. Measuring soil penetration resistance is a quick, practical field measurement. The limiting values for root penetration measured for a given piston size seems less variable than bulk density values and less dependent on the soil measured. Thus it tends to reflect a crop parameter and has more generality of application. Taylor (17) discusses the effect of soil penetration resistance on seedling emergence, root growth and crop yield.

Phaseolus vulgaris L. is an important crop in the Americas and an important source of protein for many countries in the Caribbean and Latin America. The purpose of this paper is to report on a study made on the effect of soil resistance penetration, on aerial and root growth and production of the red bean, *Phaseolus vulgaris* L., variety 27-R, commonly grown in the tropics. The study was carried out under controlled greenhouse conditions.

Materials and methods

Pots and soil

Approximately 25 litres of soil were placed in pots 30 cm high, 20 cm wide (internally) and 50 cm along, made of iron sheets 1.5 mm thick to give high pressure strength, which were painted first with asphalt paint and then green paint. The top of the pots were bent outwards to form lips thus giving them added strength. The soil is the "Margot" series, a Typic Dystropept, fine mixed iso-hyperthermic. The top 10 cm of the soil profile was sampled, fumigated for 24 hours with methyl bromide, passed through a 5 mm sieve and mixed in preparation for various compaction treatments. The soil in the field at the time of sampling had the following average properties: bulk density 0.88 g/ml; particle density 2.46 g/ml; volumetric moisture 43 per cent; total porosity 64.1 per cent, air space 21.1 per cent, upper plastic limit 97 per cent (gravimetric), sticky point 81.5 per cent, lower plastic limit 68.3 per cent, field capacity (1/3 bar percentage disturbed soil) 52 per cent, and a clay loam texture under the USDA system with 32.2 per cent clay, 43 per cent silt and 24.7 per cent sand. The soil had a pH in water (1.1) of 5.3; organic matter 6.4 per cent, total N 0.36 per cent, CN ratio 10.5, available phosphorus (Bray -1) 2.1 ppm, cation exchange capacity 41 me/100 g (oven-dried soil), calcium 4.6 me/100 g, magnesium 1.6 me/100 g, potassium 0.7 me/100 g, sodium 0.4 me/100 g and manganese 0.08 me/100 g.

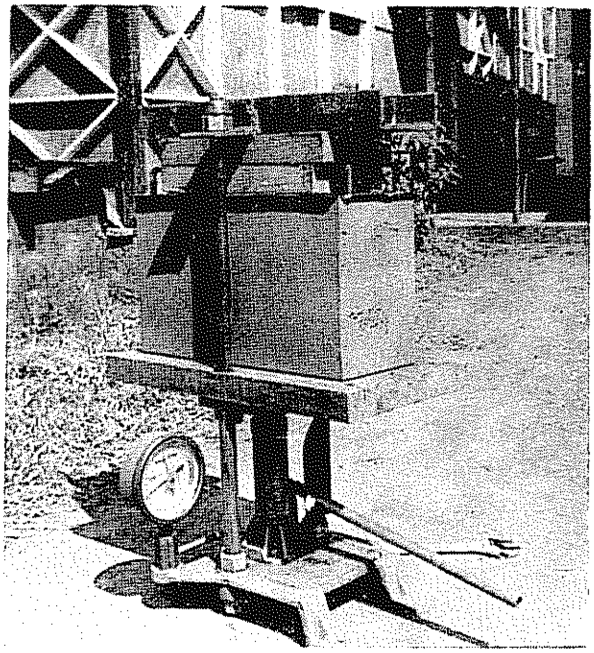

Fig. 1.—*Hydraulic press used to compact the soil in the pot shown.*

Compaction treatments

Soil was placed in the pot in 4 layers, which could be uniformly compacted by a hydraulic press to a height of 6.25 cm each, to form a total height of 25 cm. The two upper layers (12.5 cm thick) or two lower layers (12.5 cm thick) received the same treatment, and this resulted in upper (0-12.5 cm) and lower (12.5-25 cm) compaction layers. Soil was compacted to give various values of penetration resistance in bars when at field capacity (52 per cent moisture). The treatments were: T1, control or no compaction in upper and lower layers or 0/0; T2, upper layer 2 bars, lower layer no compaction or 2/0; T3, 3.6/0; T4, 6.5/0; T5, 11.7/0; T6, 21/0; T7, 0/2; T8, 0/3.6; T9, 0/6.5; T10, 0/11.7; T11, 0/21; T12, 2/2; T13, 3.6/3.6; T14, 6.5/6.5; T15, 11.7/11.7; and T16, 21/21. The experiment therefore consisted of 16 treatments with 4 repititions and had a random block design. The treatments correspond to varying degrees of compaction for three possible field conditions: the surface layer compacted and the subsoil loose, the surface layer loose and the subsoil compacted, and both the surface layer and subsoil compacted (6).

The 6.25 cm thick compacted layers in the lower 12.5 - 25 cm compaction zone were formed by applying approximately 15 cm layers of loose soil between 35 - 38% moisture and applying uniform compaction pressures of varying values and durations. A hydraulic press of the Fred S. Carver Co. was modified as shown in Figure 1 to apply this pressure directly on the soil in the pots through wooden blocks. A pressure of 4

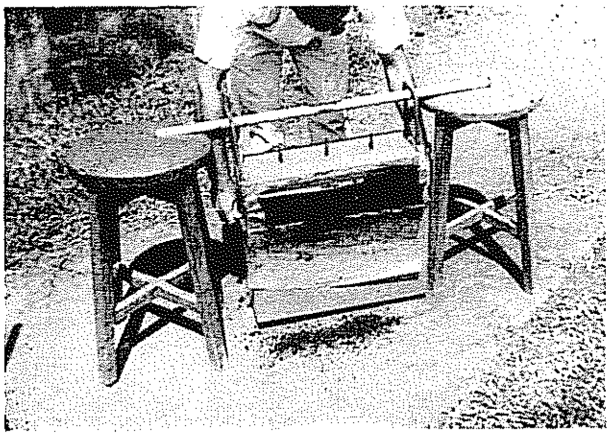

Fig 2.—Removal of soil compacted on the platform inside the pot

psi (0.27 bars) applied on the soil for 10 minutes produced a penetration resistance of 2 bars at field capacity, a pressure of 8 psi (0.55 bars) for 15 minutes produced a penetration resistance of 3.6 bars, a pressure of 10 psi (0.69 bars) for 30 minutes a penetration resistance of 6.5 bars, a pressure of 45 psi (3.1 bars) for 30 minutes a penetration resistance of 11.7 bars and a pressure of 130 psi (8.96 bars) for 30 minutes a penetration resistance of 21 bars. It was difficult to compact the soil at 52 per cent moisture (field capacity), since the expulsion of free water occurred and the required penetration resistance could not be obtained after hours of pressing.

The soil had to be compacted at lower moisture contents of 35 - 38 per cent and then brought to 52 per cent moisture for penetration resistance measurements. A John Chatillon push-pull gauge Cat. Nº 719-40 MRPFR was used as a static penetrometer. Maximum thrust readings were taken when its 5 mm diameter stainless steel piston penetrated 5 mm into the soil.

In the treatments with the upper 0-12.5 cm zone compacted, it was necessary to compact the soil in the base of a pot and then transfer it and place it above uncompacted soil. A special removable platform was constructed for this as shown in Figure 2. The soil was lifted from the platform with the polyethylene sheet.

Risks of nutrients deficiency were eliminated by applying fertilizer as suggested by Martini (11). The amount of fertilizer applied to a pot of 2 plants was calculated considering that the plant population per hectare was 200,000 Two-day-old pregerminated seeds were put in holes that were drilled 2 cm in diameter and 4.5 cm deep. This corresponded to positions 5 and 6 explained later on. They were then covered with loose soil. The pots were grouped in 4 repititions and were randomized on 4 tables each 3 m long x 1.1 m wide x 1.0 m high.

Dial gauge tensionmeters were placed in each pot approximately in the centre of the soil surface 5 - 7 cm from the plants and 15 cm deep (measured from the base of the tensionmeter porous cup). The pots were irrigated when the tensionmeter reading was 0.8 bars, this value being close to the optimum maximum suction value of 0.6 bars found by Forsythe and Legarda (4). Rain water was added to the pots until the tensionmeter reading was 0.1 bars thus ensuring that no free water was formed at the base since the soil moisture remained under tension. The oxygen diffussion rate (ODR) was measured by platinum micro-electrodes from Dick's Machine Shop, Lansing, Michigan Measurements were made near the centre of the soil surface 5 - 7 cm from the plants and 15 cm deep. Metal wires with a thickness similar to the micro-electrodes, 15 cm long with one end filed to a point, were painted with asphalt paint, and inserted to a 15 cm depth in the soil and removed at measuring time to allow the insertion and extraction of the micro-electrodes without damaging them. Readings were taken every 2 weeks starting 2 weeks after planting and the procedure according to Letey and Stolzy (10) was followed.

Upon reaping the experiment the soil was irrigated to 0.1 bar and compartmentalized into 4 horizontal layers, I, II, III and IV of 6.25 cm thickness and 10 vertical columns 10 x 10 cm and 25 cm deep which defined 10 positions for each horizontal layer. Position 1 started in the upper lefthand corner, position 2 the lower left - hand corner and positions 3 to 10 followed a similar sequence ending with position 9 in the upper right-hand corner and 10 in the lower right-hand corner. The rectangular soil blocks formed by the intersection of the columns and layers were sampling units for root density, and for each layer, 4 of these blocks were sampled for bulk density, soil resistance and soil moisture. Bulk density and moisture samples were obtained by constant volume cylinders introduced into the soil blocks.

Each soil block was placed in a container and broken down under a stream of water and as a result the roots were washed loose and floated in the water. The suspended soil and floating roots were passed through 2 mm and 1 mm sieves several times until no more roots were extracted. The roots were dried on blotting paper, placed in a 70°C oven until constant weight.

Yields in terms of seed weight (13 per cent) number of pods per plant, number of seeds per pod and weight per seed were determined. Aerial dry matter was also determined.

Results and discussion

The crop cycles lasted for 77 days from the 11th of September to the 27th of November, 1974. During the cycle the average greenhouse maximum daily temperature was 30.7°C, minimum 18.3°C and average 24.5°C, and the average maximum relative humidity was 98.1 per cent, minimum 49.9 per cent and the average 73.8 per cent.

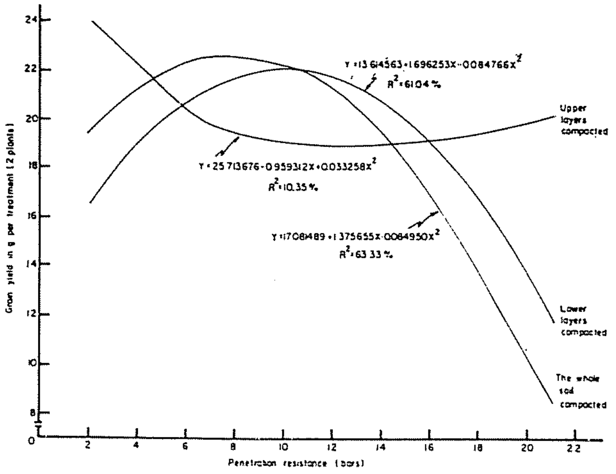

Fig. 3.—*Grain yield response to soil penetration resistance when only upper layers (0-12.5 cm) are compacted, when only lower layers (12.5 - 25 cm) are compacted, and when the whole soil is compacted. Soil water suction 0.1 to 0.8 bars.*

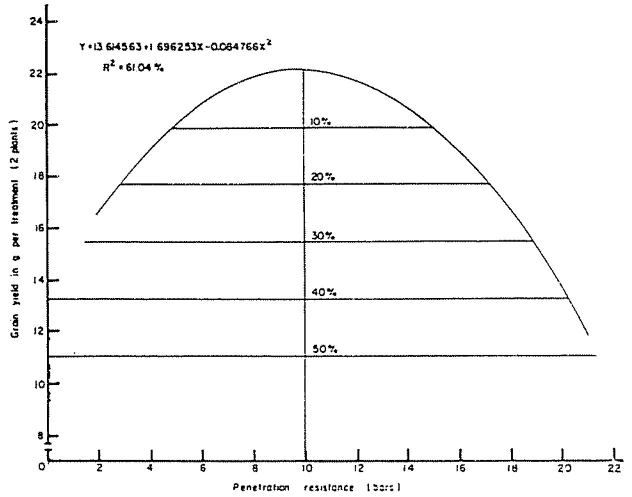

Fig. 5.—*Grain yield response to soil penetration resistance, expressed as relative yield, when the whole soil is compacted. Soil water suction 0.1 to 0.8 bars.*

Figure 3 shows the yield response to mechanical resistance when the upper layers, I and II (0-12.5 cm). are compacted, when the lower layers III and IV (12.5 - 25 cm) are compacted, and when all layers (0-25 cm) are compacted. Analysis of variance indicated that resistance significantly influenced yield at the 5 per cent level for all treatments. The effect of resistance when only the upper layers are compacted is slight. The Duncan test showed that T2 and T3 were not significantly different from each other but gave significantly (5% level) higher yields than T4, T5 and T6, which were significantly similar to each other. This surprisingly slight depressing effect can be attributed to the fact that the roots were able to go through the compacted upper layers, perhaps through cracks, and upon reaching the lower uncompacted layers they were abel to develop adequately. A similar type of root behaviour has been observed in the field by Cooper (1) and Trouse (19). Figure 7 shows root weight development in the upper and lower layers for this case.

Figure 3 shows that when only the lower layers are compacted, yield increases until resistance is 10 bars and then it decreases. In the case when all layers are compacted, yield increases up to 8.09 bars and then decreases. The zone of these curves which corresponds to increasing yield with increasing resistance has been observed by other workers (5, 7, 8, 12) and this is attributed to better contact between the roots and the soil which facilitates more efficient absorption of nutrients and water. A similar relationship is seen on root development in Figure 7, except for curve 3. The reducing effect of increasing penetration resistance on yields is also expressed in terms of relative yield in Figures 4 and 5.

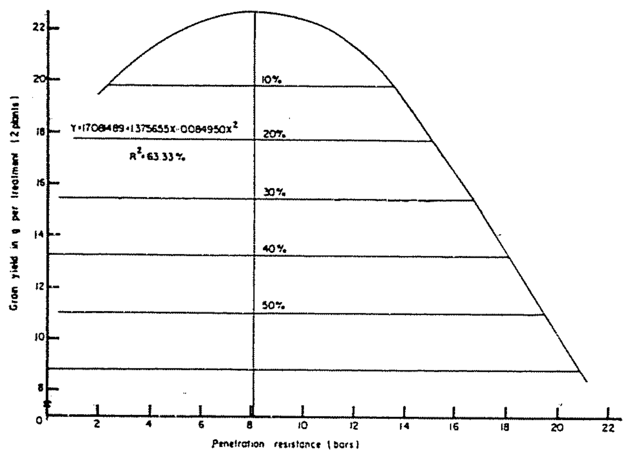

Fig. 4.—*Grain yield response to soil penetration resistance, expressed as relative yield, when only lower layers (12.5 - 25 cm) are compacted. Soil water suction 0.1 to 0.8 bars.*

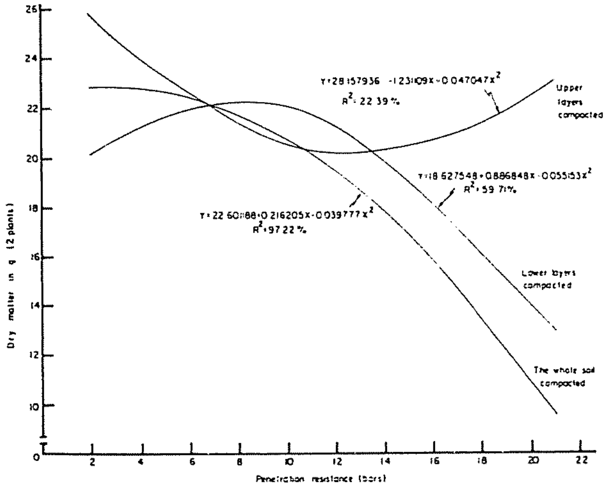

Fig. 6.—*Aerial dry matter response to soil penetration resistance when only upper layers (0-12.5 cm) are compacted, when only lower layers (12.5-25 cm) are compacted, and when the whole soil is compacted. Soil water suction 0.1 to 0.8 bars.*

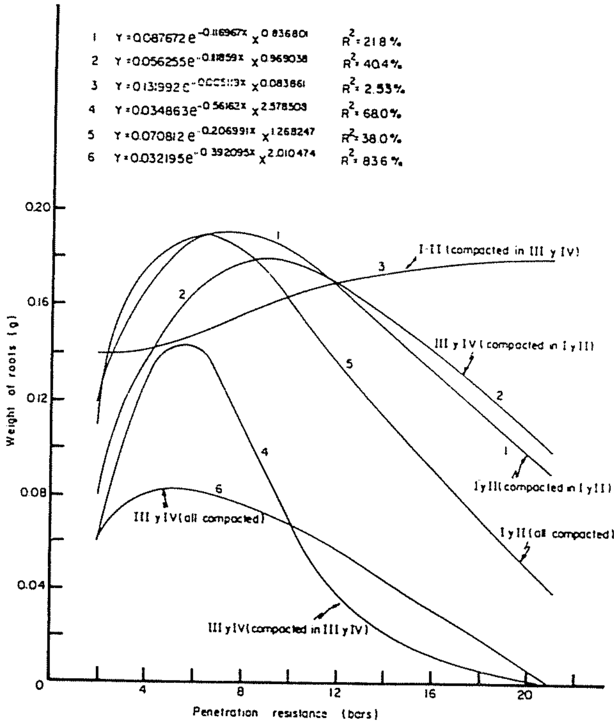

Fig. 7.—*Root weight in the upper layers (0-12.5 cm), the lower layers (12.5-25 cm) and the whole profile in response to soil penetration resistance in the upper layers, lower layers and the whole profile. Soil water suction 0.1 to 0.8 bars.*

Figure 6 shows the relationship between aerial dry matter production and resistance and it is noted that the curves are similar to the grain yield curves. The weight of an individual seed whose average was 0.6 g, was not affected by the treatments.

Figure 7 shows the relationship between root development and resistance for the upper and lower layers. As mentioned earlier, the curves are similar to those in Figure 3. Generally, root density in the upper layers is higher than in the lower but in the case when the upper layers are compacted, there seems to be little difference in the densities. Root densities in the vertical columns 5 and 6 were greatest and these were also the columns where the seeds were planted. The remaining columns were significantly lower in root density but not different from each other.

The value of R^2 for a linear association between resistance and bulk density was 91 per cent and yield-bulk density curves were similar to yield-resistance curves, and for the soil studied, the bulk density for the highest resistance treatment was only 1.2 g/ml. Minimum values for oxygen diffusion rate (ODR) at 15 cm depth for the various treatments were never below 27.6 g x 10^{-8} x cm^{-1} x min^{-1}, and these corresponded to readings taken after an irrigation. The limiting value for many crops is considered 20 g x 10^{-8} x cm^{-1} x min^{-1}. Legarda and Forsythe (9) found 26 g x 10^{-8} x cm^{-1} x min^{-1} to be limiting for 27-R so that limiting values of ODR were not experienced.

At the end of the experiment the soil was irrigated and the air space was determined. Averages for 4 samples in each layer were determined and these were considered to estimate the minimum air space during the growing cycle.

Air space below 5.3 per cent was found in T6 layers I and II, T11 layers III and IV, and T16 all layers. All other treatments had over 18 per cent air space. For values between 24-36.3 per cent, we may include T1 layers I, III and IV; T2 all layers; T3 layers III and IV; T4 all layers; T5 layers III and IV; T6 layers III and IV; T7 layers II, III and IV; T8 layers III and IV; T9 all layers; T10 layers I and II; T11 layers I and II; T12 layers I, II and IV; and T13 layers I and II. Legarda and Forsythe (9) found that values of air space less than approximately 25 per cent were limiting to the 27-R bean variety. We may thus consider that treatments with air space greater than 24 per cent as non-limiting, between 18-24 per cent as slightly limiting (depressing yields by 20 per cent) and less than 5.3 per cent strongly depressing. Since these values are temporary minimum values after irrigation, it is hard to say to what degree they have influenced yields, especially since the minimum values of ODR were non-limiting.

Summary

Grain, aerial dry matter production, and root production of the 27-R variety of *Phaseolus vulgaris* L. increased when penetration resistance at field capacity in the 0-25 cm layers or the 12.5 - 25 cm layers was increased to 6-10 bars and this was attributed to better contact between the roots and the soil. Further increase in penetration resistance up to 21 bars reduced yields (by approximately 50%) and aerial and root growth. Increased resistance in the 0-12.5 cm layer only slightly reduced yield and aerial dry matter production, ho- reduced yield and aerial dry matter production; ho- the other treatments except that root density was similar throughout the 0-25 cm soil depth. The experiment was carried out in 26 liter pots containing a fumigated Typic Dystropept fine mixed iso-hypertermic soil in a greenhouse at CATIE, Turrialba, Costa Rica. Soil layers were compacted to the desired penetration resistance by a hydraulic press. Resistance to a 5 mm diameter circular stainless steel piston pushed 5 mm into the soil was measured with a portable penetrometer suitable for field use. The plants were grown within the soil moisture suction range of 0.1 and 0.8 bars. Oxygen diffusion rates maesured at a 15 cm depth after irrigation indicated that none of the treatments experienced limiting oxygen supply although air space measurements indicated temporary limiting condictions in some treatments.

Literature cited

1. COOPER, A.W. Effects of tillage on Soil Compaction. *In* Compaction of agricultural soils, pp 315-364. Saint Joseph, Mich., American Society of Agricultural Engineers, Monograph. 1971. 471 p.
2. FORSYTHE, W. M. Las propiedades físicas, los factores físicos de crecimiento y la productividad del suelo. Fitotecnia Latinoamericana 4: 165-176. 1967.
3. FORSYTHE, W.M. Aportes de la Física del suelo a la producción agrícola. *In* IV. Congreso Nacional de la Sociedad Venezolana de la Ciencia del Suelo, Maturín, Agosto 22-27, 1976. Memoria pp 68-84. 1977.
4. FORSYTHE, W.M. and LEGARDA, L. Soil water and aeration and red bean production. I. Mean maximum moisture suction. Turrialba 28:81-86. 1978.
5. HEAT, O.V. A study in soil cultivation. The effects of varying soil consolidation on growth and development of rain-growth cotton, Journal of Agricultural Science 27: 511-540. 1937.
6. HUERTAS, A.A. Efecto de la resistencia mecánica del suelo sobre la producción del frijol (*Phaseolus vulgaris* L.) variedad 27-R. Tesis Mag. Sc. IICA-CTEI. Turrialba, Costa Rica. 1975. 322 p.
7. HYDER, D and SUEVA, F. Seed and plant-soil relations as affected by seed bed firmness on a sandy loam rangeland soil. Soil Science Society of America Proceedings 20: 416-419. 1956.
8. KEEN, B.A. and CASHEN, C.H. Studies in soil cultivation. IV. The physical effect of sheep fold on the soil. Journal of Agricultural Science 22: 126-134. 1932.
9. LEGARDA, L. and FORSYTHE, W.M. Soil water and aeration and red bean production. II. Effect of soil aeration. Turrialba 28:175-178. 1978.
10. LETEY, J. and STOLZY, L.H. Measurement of oxygen diffusion rates with the platinum micro-electrode. I. Theory and equipment. Hilgardia 35: 545-554. 1964.
11. MARTINI, J.A. Caracterización del estado nutricional de los principales "Latosoles" de Costa Rica, mediante la técnica del elemento faltante en el invernadero. Turrialba 19: 394-408. 1969.
12. PARKER, J.J. and TAYLOR, H.M. Soil strength and seedling emergence relations. I. Soil type, moisture, tension, temperature, and planting depth effects. Agronomy Journal 57: 289-291. 1965.
13. PEARSON, R.W. Soil environment and root development. *In* Plant Environment and Efficient Water Use. Madison, Wis., American Society of Agronomy. 1966. 295 p.
14. SHAW, B.T. Ed. Soil physical conditions and plant growth. Agronomy (series) Vol. 2. New York, Academic Press, 1952. 491 p.
15. TAYLOR, H.M. and GARDNER, H.R. Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. Soil Science 96: 153-156. 1963.
16. TAYLOR, H.M. and BURNETT, E. Influence of soil strength on the root growth habits of plants. Soil Science 98: 174-180. 1964.
17. TAYLOR, H.M. Effects of soil strength on seedling emergence, root growth and crop yield. *In* Compaction of Agricultural Soils. pp. 292-305. Saint Joseph, Mich., American Society of Agricultural Engineers Monograph. 1971. 471 p.
18. TISDALE, S. and NELSON, W. Soil fertily and fertilizers. 3rd ed. New York, MacMillan, 1975. 694 p.
19. TROUSE, A.C. Soil conditions as they affect plant establishment, root development, and yield. *In* Compaction of Agricultural Soils. pp. 241-253. Saint Joseph, Mich., American Society of Agricultural Engineers Monograph. 1971. 471 p.
20. VEIHMEYER, F.J. and HENDRICKSON, A.H. Soil density and root penetration. Soil Science 65: 487-493. 1948.

Notas y Comentarios

Tortuga que digiere el pasto

La tortuga tiene talentos alimenticios hasta ahora no reconocidos. Según un reciente estudio la tortuga verde (*Chelonia mydas*), la especie antes abundante en el Caribe, puede digerir celulosa lo mismo que las ovejas, vacas y algunos otros mamíferos. Esta es la primera vez que esta cualidad ha sido observada en un reptil (*Comparative Biochemistry and Physiology*, vol 63 A, p 127).

La celulosa, conocida también como "fibra dietética", constituye el armazón de la pared celular en el tejido vegetal. Ningún animal posee las enzimas para digerirla pero algunas bacterias lo hacen con facilidad. Por consiguiente, algunos animales han desarrollado relaciones simbióticas con estas bacterias. La vaca, con su enorme tanque de fermentación, el rumen, es el ejemplo más conocido.

Todos los reptiles se creía que pasaban toda la celulosa ingerida, sin ningún cambio, a las heces. Pero la tortuga verde parece ser una excepción. Sus heces muestran claramente que algo, en alguna parte del interior del intestino está atacando a la celulosa. Karen Bjorndal, del Departamento de Zoología de la Universidad de Florida, acaba de armar todas las piezas del enigma.

Encontró que el lugar de la digestión de la celulosa era el "ciego", una expansión grande del intestino, llena de fluído, situada entre el intestino delgado y el grueso (no exactamente el mismo que el ciego de los mamíferos, pero similar en su función). La tortuga verde digiere hasta el 90 por ciento de la celulosa y, al igual que en la vaca, los productos de esta rotura bacteriana fueron los ácidos grasos volátiles (acetato, butirato y propionato).

Comparado con otro animal que digiere en el ciego, el dugong (*Dugong dugong*), la eficiencia de la tortuga está casi a la altura de los estándares mamíferos. Si usa ácidos grasos volátiles de la misma manera que otros animales, entonces algo como el 15 a 20 por ciento de las necesidades de energía de la tortuga pueden ser suplidos por estos convenientes microbios. Pero, cuáles son estos microbios, y como arriban al ciego de las tortugas recién nacidas, es algo que todavía no se conoce.