WHEAT ROOT GROWTH AS AFFECTED BY SOIL STRENGTH[1]

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SUMMARY

Soil compaction is a common problem that affects several soil properties and plant growth. In order to assess the effects of soil strength expressed by its mechanical resistance on roots, a growth chamber experiment was conducted at the Universidade Federal do Rio Grande do Sul, Porto Alegre, in 1994, during 35 days (530 GDD, 0°C base temperature) on a typical Paleudult soil. Treatments, using pots arranged in a completely randomized design, consisted of soil compactions that resulted in resistances of 1.0, 2.0, 3.5 and 5.5 MPa. A combination of soil gravimetric moisture and densities was used in order to minimize possible effects due to lack of water and oxygen supply to the roots under the treatments. As soil resistance increased, roots showed a reduced length, surface and dry matter, but a higher radius. As less soil was explored under high resistances, shoot and root dry matter decreased but the latter suffered the most. This study shows that soil mechanical resistance itself, is an important factor restricting plant growth, with its effects being detected very early in the plant development.

Index terms: wheat, roots, soil compaction, soil resistance.

RESUMO: *CRESCIMENTO DE RAÍZES DE TRIGO AFETADO PELA RESISTÊNCIA MECÂNICA DO SOLO*

A compactação do solo é um problema comum que afeta diversas propriedades físicas do solo e o crescimento das plantas. Este trabalho foi desenvolvido em câmara de crescimento na Universidade Federal do Rio Grande do Sul, em Porto Alegre, em 1994, durante 35 dias (530 GD, 0°C de temperatura base) e objetivou determinar os efeitos da resistência mecânica do solo no crescimento das raízes de trigo. Para tanto, foram utilizados vasos dispostos em

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delineamento completamente casualizado preenchidos com solo Podzólico Vermelho-Escuro álico. Os tratamentos constaram de compactação do solo que resultou em resistências de 1,0; 2,0; 3,5 e 5,5 MPa. A combinação de umidade gravimétrica e densidade do solo foi estabelecida para minimizar os possíveis efeitos de falta de água e oxigênio. Com o aumento da resistência do solo diminuíram o comprimento, a superfície e a matéria seca das raízes, aumentando, porém, seu raio. A menor exploração do solo pelas raízes causou o menor acúmulo de matéria seca na parte aérea e, especialmente, nas raízes. Os efeitos foram percebidos logo no início do desenvolvimento da planta. A resistência do solo, isoladamente, caracterizou-se como um fator de diminuição do crescimento radicular.

Termos de indexação: trigo, raiz, compactação do solo, resistência do solo.

INTRODUCTION

Soil compaction derived from heavy traffic of tractors and other implements can modify some soil properties (Alvarenga et al., 1996) and, subsequently, root growth. Soil compaction can be referred as a mechanical resistance to root penetration, a resultant of soil density and moisture content. Roots can grow through pores and points of less resistance thus avoiding areas of more difficult penetration, but are unable to reduce their diameter to penetrate smaller pores. Soil resistance is commonly measured through the use of a penetrometer (Tormena & Roloff, 1996; Whiteley et al., 1981) because there is usually good correlation between root growth and resistance measured by this method (Taylor, 1974).

Soil compaction may change root growth by altering soil aeration (Hanks & Thorp, 1956; Eavis, 1972). A critical value of 10% of air total soil volume is commonly referred, below which root growth is restricted by lack of oxygen (Vomocil & Flocker, 1961). The effects of compaction are detected on shoot dry weight, leaf area and root dry matter (Goss, 1977; Masle & Passioura,1987). Wheat root length and dry matter are diminished by compaction in the field (Atwell, 1990a). Roots are generally short and thick (Goss, 1977; Wilson et al., 1977) and the diameter increase is due to a higher number and size of the cortex cells (Wilson et al., 1977; Goss & Russel, 1980; Atwell, 1990a). Soil volume exploited by roots can be restricted according to limitation in length caused by soil compaction.

Besides these root characteristics, soil strength also affects shoot growth. Shoot dry matter and leaf area are negatively associated with soil resistance (Masle & Passioura, 1987) due to a deficient supply of nutrients (Atwell, 1990a) and/or water. It has also been suggested that carbon allocated to shoots can be limited due to a higher demand from the roots (Masle & Farquhar, 1988). This supports the notion that more carbohydrates are necessary for roots growing in compacted soils. The decreasing overall plant growth affects the roots more severely (Atwell, 1990a). Roots in compacted soils import less carbohydrates than in loosened soil due to a restricted root system (Atwell, 1990b). Nevertheless, the amount of photosynthates necessary to synthesize the same length of roots is much higher in compacted soil (Atwell, 1990b). They would be necessary for the synthesis of osmotic agents (Taylor & Ratliff, 1969) that would help exert an enhanced force to remove soil particles. Although showing a slight increase in osmotically active substances, Atwell (1990b) found that the principal morphological change in root growing in compacted soil was a root radial enlargement.

The objective of this work was to ascertain root growth on different soil resistances, as expressed through different parameters.

MATERIAL AND METHODS

A growth chamber experiment (20/10ºC, 11/13 h, respectively, day and night temperature and photoperiod, and 0.221 cal cm^{-2} min^{-1} radiation) was performed on a typical Paleudult soil. Treatments consisted of four soil compactions leading to the following bulk densities: 1.29; 1.41; 1.56 and 1.67 kg dm^{-3}, with four pots/treatment. Pots were randomly arranged in a growth chamber and rearranged daily. The densities were at a range between that of a typical well-structured soil and that of one with maximum compactation. The original density of undisturbed soil is about 1.5 g cm^{-3}.

Soil analysis showed a pH of 5.5; P (Mehlich) = 12 mg kg^{-1}; K (Mehlich) = 108 mg kg^{-1}; Al (KCl 1 mol L^{-1}) = 0.0 mmole kg^{-1} and O.M. = 1.6 g kg^{-1}. Cylindrical PVC pots (23 x 14.5 cm, height x diameter) received soil previously sieved through a 3 mm sieve. Compaction was performed manually step by step using 1 cm high layer every time. The soil volume necessary for each layer was put in the pot followed by compaction with a cylindrical piece of wood (14.3 cm diameter) until obtaining the desired 1 cm layer. Before compaction, soil was uniformly fertilized with NPK (28.1; 21.8; 16.7 mg kg^{-1} soil) and supplied with N (25 mg kg^{-1}) on days 6, 15, 21 and 27 after emergence. Soil water content was maintained constant for all pots through the experiment on a 25% volumetric base. This was done to provide the same amount of water for each unit of soil volume and to keep the volumetric air above the mimimum necessary for root growth. Soil field capacity (0.21 m^3 m^{-3}) was previously determined by Schuch (1991) for this particular soil using pressure plate extractor. Water was supplied daily through a perfurated plastic tube placed at the center of the pot, running from the surface to the bottom. A 1.5 cm layer of 3 mm styrofoam balls was maintained over the surface to reduce evaporation. Water consumption was minimum because of the short experimental period and the protection against evaporation offered by the styrofoam balls. Thus, the water added may not have affected the soil density.

Seeds (3.5-3.75 mm diameter) from BR-23 wheat cultivar (spring type) were pre-germinated and 12 seedlings (with 5 mm radicle and 3 mm coleoptile length) were placed on each pot (coleoptile tip 1 cm below surface). Two days later only four plants were left. Plant dry matter and root growth were evaluated at 15, 22, 28 and 35 days after seedling transplant by sampling all plants in one pot per treatment. These day periods were selected in order to cover the period of intensive root growth and shoot development, including tillering, which are affected by soil compaction. Root length was evaluated according to Tennant (1975) and root diameter and surface according to Hallmark & Barber (1981). Roots were oven dried (± 65°C) for dry matter calculation. Growing degree days (GDD) were calculated daily using 0ºC as base temperature. At day 35 the soil physical characteristics were evaluated on one pot per treatment using four soil layers: 0-1; 7-8; 14-15; and 20.5-21.5 cm from top to bottom. These four layers were selected to detect the root distribution in the pot utilized. The characteristics evaluated were: soil resistance (pocket penetrometer John Chatillon CATL 714-40 with tip area of 0.196 cm^2), bulk density (Blake, 1965) and macro and micro-porosity (Vomocil, 1965). For volumetric air content calculation it was necessary to determine soil volumetric water content and bulk density.

Analysis of variance was performed and differences evaluated using the Duncan test, 5%. In the case of linear regression, "b" coefficients were compared between treatments using the "t" test.

RESULTS AND DISCUSSION

The interaction among the physical properties of soil generally result on a plant response difficult to be interpreted (Eavis, 1972). For this reason, to detect the effects of soil mechanical resistance, other soil properties such as bulk density and moisture content were controlled so that they played a minor role on root growth limitation.

Macroporosity (Table 1) ranged between 0.176 and 0.357 m^3 m^{-3}, still on levels accepted for root growth (Alvarenga et al., 1996). Microporosity was not altered and total porosity was diminished, showing that only macroporosity is affected by soil compaction (Dias JR & Pierce, 1996). Plant water availability is important in soil compaction experiments because of the interaction with the factor under study (Gregory et al., 1978). To avoid that, volumetric water content (Table 1) was maintained close to field capacity (previously determined), even in the higher soil bulk density. Volumetric water content was similar through all the treatments. Volumetric air content (Table 1) was always higher than 10% critical value, considered as limiting to root growth (Hanks & Thorp, 1956; Eavis, 1972).

Soil mechanical resistance to root penetration increased as a result of the interaction between the diminishing gravimetric water content and the increasing soil bulk density. The magnitude of soil strengths (Table 1) were 1.0, 2.0, 3.5, and 5.5 MPa from the lower to the higher soil densities. This was the main factor influencing root growth since aeration and water content were probably non-limiting as previously exposed.

Table 1. Soil physical characteristics under compaction treatments

Bulk density	Soil strength	Volumetric water	Gravimetric water	Volumetric air	Micro-porosity	Macro-porosity	Total porosity
kg dm^{-3}	MPa	m^3 m^{-3}	kg kg^{-1}	m^3 m^{-3}			
1.29	1.0	0.261 a[(1)]	0.202 a	0.252 a	0.178 a	0.357 a	0.535 a
1.41	2.0	0.254 a	0.180 b	0.214 b	0.175 a	0.311 b	0.486 b
1.56	3.5	0.262 a	0.168 c	0.149 c	0.186 a	0.248 c	0.434 c
1.67	5.5	0.255 a	0.153 d	0.115 d	0.197 a	0.176 d	0.373 d

[(1)] Means followed by same letter within a column are not significantly different at the 0.05 level according to Duncan test.

The results provide an insight into plant behaviour under different soil resistances. As early as 16 days after emergence, both shoot and roots were affected by the treatments imposed. At 1.0 and 2.0 MPa, root dry matter, surface, and length behaved similarly with time (Figures 1a, 1b and 2a). A slight decrease in root dry matter, surface and length was found at 2.0 MPa resistance (Figures 1a, 1b and 2a). Root radius was also similar(Figure 2b), indicating that root restriction was similar for both resistances. Wheat plants can probably tolerate soil resistance at this range with no special growth restriction. A quite different reaction was found with soil resistances of 3.5 and 5.5 MPa. There was a strong limitation of root growth detected by its dry matter, length and surface (Figures 1a, 1b and 2a). The root radius, which seems to be a good indicator of this kind of stress, increased with the increase in the resistance (Figure 2b). This response was the same at all sampling times and is due to an increase in the size and number of cortex cells as shown by Wilson et al. (1977), Goss & Russell (1980), and Atwell (1990a).

The decrease in root length (Alvarenga et al., 1996) and surface with high soil resistance led the plants to occupy a smaller soil volume which was expressed by a low root mass density (Figure 3a) and root length density (Figure 3b). Thus, roots were less effective in exploring the soil, decreasing water and nutrient interception and absorption as well as diminishing their supply to shoot, important factors associated with reduced plant growth in compacted soils (Gregory et al., 1978).

Plants could manage root and shoot growth up to 2.0 MPa without severe growth impairment. Roots were slightly more sensitive in the 2.0 MPa resistance, as showed by a decrease in root/shoot ratio (Figure 4a). At 3.5 Mpa, a strong reduction in top growth was found, the effect being more severe at 5.5 MPa (Figure 4b). To partially compensate for a reduced shoot growth under high soil strength, plants increase CO_2 assimilation rate and water use efficiency (Masle & Farquhar, 1988), despite a reduction in leaf area (Goss, 1977; Masle & Passioura, 1987). Also a greater investment of photosynthates

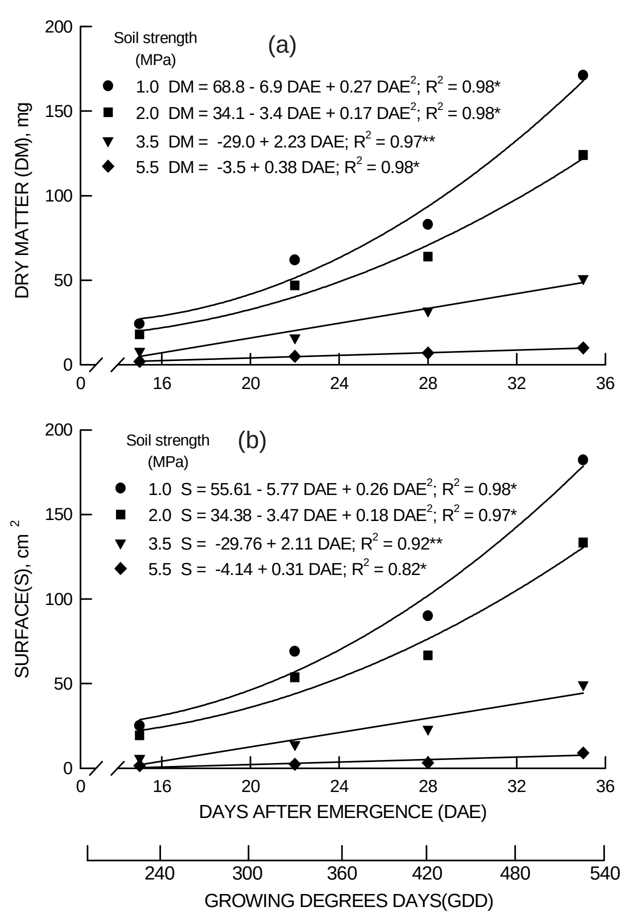

Figure 1. Wheat root dry matter (a) and surface (b) under different soil strengths.

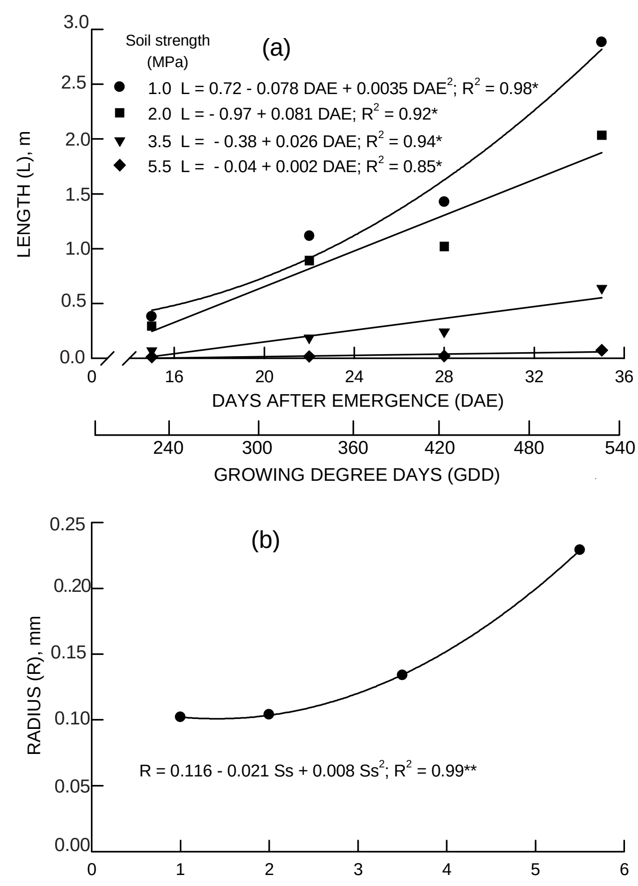

Figure 2. Wheat root length (a) and radius (b) under different soil strengths.

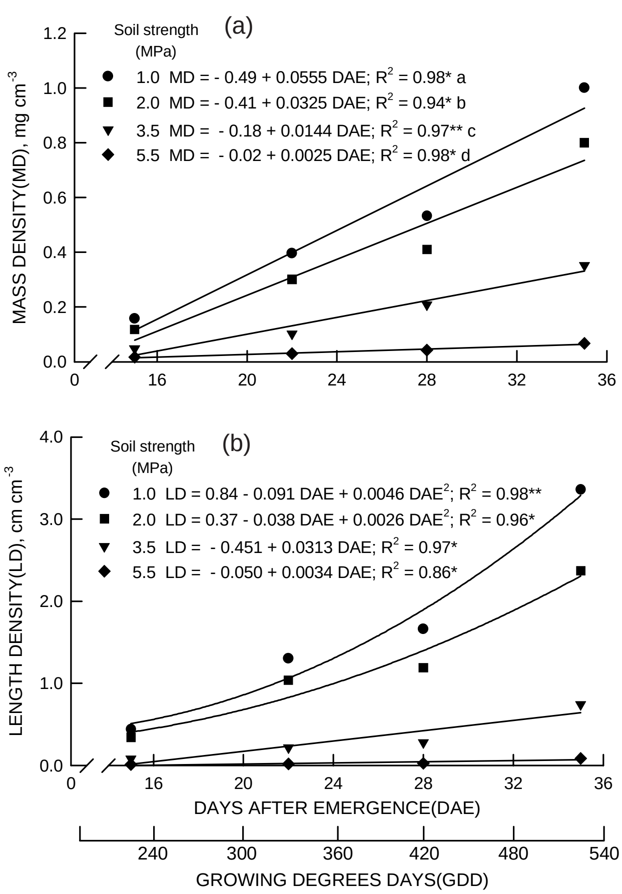

Figure 3. Wheat root mass (a) and length (b) densities under different soil strengths.

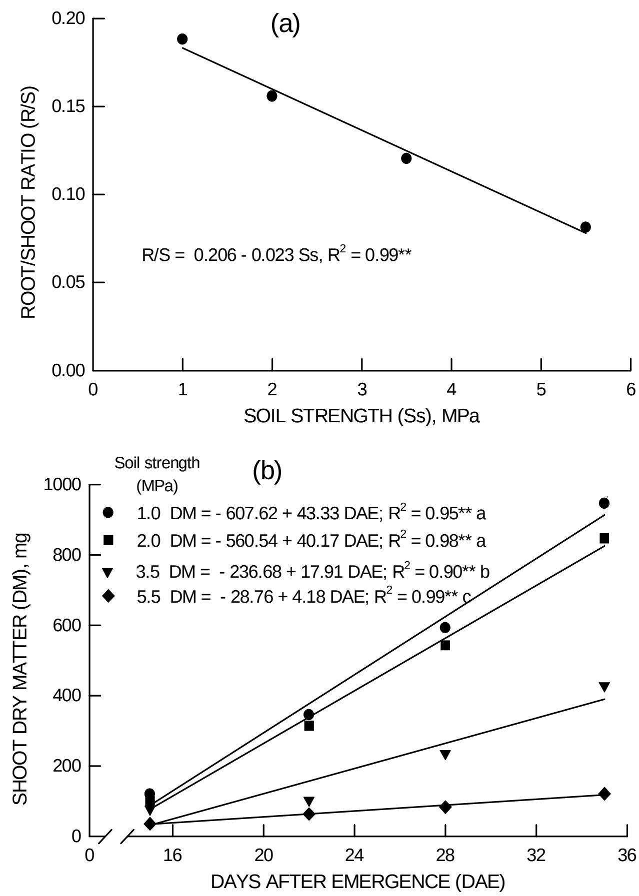

Figure 4. Wheat root/shoot ratio (a) and shoot dry matter (b)under different soil strengths.

is made in roots (Masle & Farquhar, 1988). Hence, Atwell (1990b) suggested that root growth restriction is not caused by a lack of carbohydrate supply but due to root's capacity to maintain sufficient turgor pressure to remove soil particles.

CONCLUSIONS

1. The root characteristics analyzed were highly sensible to changes in resistance. A strong reduction in length and surface led the plants to explore soil volume less efficiently.

2. Both root and shoot dry matter were affected by the stress imposed, the former being more severely restricted. Plants could manage fairly well at resistances up to 2.0 MPa. At 3.5 MPa and higher, growth limitation was severe.

3. The effects of soil strength appear at the beginning of plant life and extended throughout the experimental period. The earliness of the response can be visualized by the onset of responses on root and shoot growth.

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