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SOIL COMPACTION: RESPONSES OF SOIL PHYSICAL PROPERTIES AND CROP GROWTH

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A b s t r a c t. Increased levels of soil compaction resulted in higher soil strength, lower air-filled porosity and smaller daily temperature fluctuations. Plants' roots that grown in compacted soil were concentrated in a surface soil layer. Grain yield of spring barley and leaf area index decreased sharply when the degree of compactness exceeded the value of 88 %.

INTRODUCTION

Recent increases in the mechanization of agronomic practices and the use of larger and heavier machines are major factors leading to soil compaction. Throughout an entire growing season, wheel tracks cover up to 250 % (cereals) and 500 % (root crops) of the area of the fields in Poland [1]. This paper describes studies relating the effects of compaction to the physical properties of soils and to crop growth. The studies were undertaken at the Institute of Agrophysics between 1986 and 1991. The detailed description of the experiments and methods was given in previous papers [5-13].

RESULTS AND DISCUSSION

Soil responses

Soil factors which are most closely correlated to compactibility are: texture, water content, structure and the initial compactness level [5]. The relation between soil texture and its susceptibility to compaction is affected by soil moisture status. An increase in moisture content causes a soil to become weaker. This leads to an increase in deformation when stress is applied [9,15]. An example of vertical deformation in a plough layer of a silty loam soil at two soil moisture levels as a function of tractor (4.8 t) passes is shown in Fig. 1.

Soil compaction changes pore and solid volume, and consequently affects many soil properties and processes relevant to plant performance and soil management. With increasing soil compaction, air-filled porosity [5], oxygen diffusion rate [8], and saturated hydraulic conductivity [11] decrease while penetration resistance [5] and crushing strength of soil aggregates [9] increase. Saturated hydraulic conductivity and penetration resistance were most sensitive to soil compaction.

Using a thin section technique, it was shown that the characteristic feature of heavily compacted soil is the formation of horizontally oriented cracks and fissures just below the soil surface [16]. This can markedly reduce water infiltration, air exchange between the soil and atmosphere, and deep root penetration.

The response of most of the properties to soil compaction is closely related to soil water status [5,9,13]. A relation for air-filled porosity and penetration resistance is shown in Fig. 2.

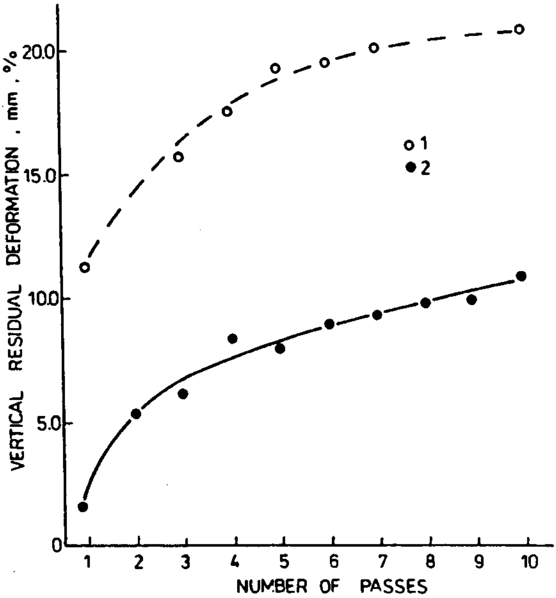

Fig. 1. Vertical deformation in relation to tractor passes and soil moisture status: 1 - moist soil; 2 - dry soil.

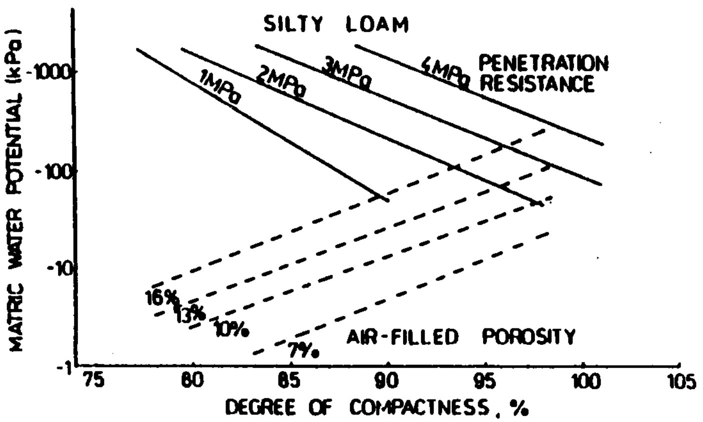

Fig. 2. Different levels of penetration resistance and air-filled porosity of silty loam in relation to the degree of compactness and soil water matric water potential (modified from Lipiec et al. [5]).

Critical penetration resistance and air-filled porosity are 3 MPa [2] and 10 % v/v [3], respectively. Fig. 2 shows that the range of soil water matric potential in which the above factors are not restrictive for plant growth becomes narrower as the degree of compactness increases.

The largest decrease of saturated hydraulic conductivity occurred at the initial increase of bulk density, in absolute values it was smaller in loamy than in sandy soil [11]. The response of unsaturated hydraulic conductivity was different for different soil water status, compaction levels, and soil types.

Hydraulic soil resistance R of loamy sand generally increased with increasing bulk density mainly due to lowered root length density [12]. Under some conditions, water uptake is limited considerably before wilting point (-1 500 kPa) is reached.

Dependence of the crushing strength of soil aggregates on water content and bulk density is related to aggregate size [9]. Generally, the crushing strength decreased with increasing aggregate size [9]. This can be related to the presence of a greater number of cracks in the larger aggregates.

Increased soil bulk density was accompanied by a higher amount of aggregates of >7 mm diameter, and by lower amount of aggregates in the 0.5 to 3 mm range [10].

Daily temperature fluctuations and the noon temperature in the subsurface layer of bare soil were lower in compacted than uncompacted soil [5].

Soil compaction effects on enzymatic activity under increased or excessive moisture content are mainly due to changes in aeration status [17]. When air-filled porosity decreased to 0.15 $m^3 m^{-3}$ and simultaneously ODR decreased to below 40 $\mu g\ m^{-2}\ s^{-1}$ in compacted soil, the dehydrogenase activity curvilinearly increased and catalase activity curvilinearly decreased. Attempts for mathematical modelling of biological activity in differently compacted soil were also undertaken [14].

Crop responses

An increase in the degree of soil compaction resulted in a greater concentration of roots in the surface layer. Fig. 3 gives an example of the effects of soil compaction in the plough layer on root distribution of spring barley. The roots grown in a severely compacted soil were characterized by a higher degree of flattening, tortuous growth, distorted epidermal cells and radially enlarged cortex cells [5].

Simultaneously, higher proportion of fine roots was recorded in compacted soil [8,16]. This can be due to a decrease of the number of large pores. Consequently, the fine roots can penetrate the compact soil easier than the thicker ones.

Changes in the root system and soil conditions affect the uptake of water. In laboratory conditions, with a sufficient supply of water, soil compaction can provide more

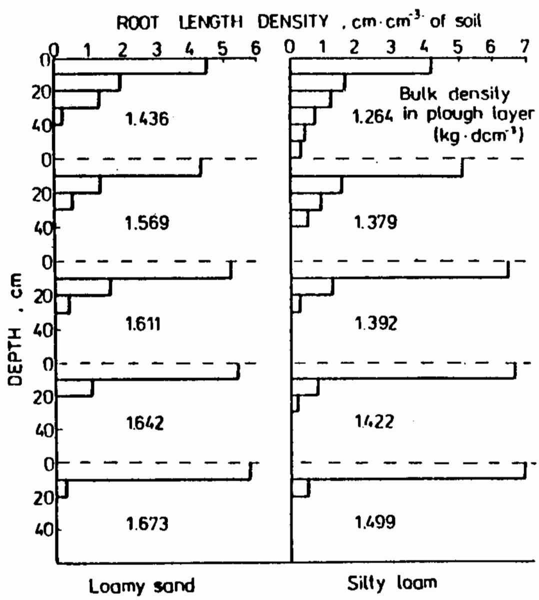

Fig. 3. Root length density distribution of spring barley in the plough layers affected by soil bulk density.

opportunity for a restricted root system to increase water use efficiency [7,8]. This is attributed mainly to higher unsaturated hydraulic conductivity. However, the effect of soil compaction on total water use was not uniform and was related to soil conditions and crop type. Compaction of a silty-clay soil resulted in a higher total water use of maize [7]; compaction of a loess soil in lower water use of barley [8]. Tardieu [18] suggested that the reduction in water use can be due to uneven spatial distribution of roots in compacted soil.

Four years of field experiments with five wheel-compaction treatments showed the usefullness of Hakansson's degree of compactness for comparison of compaction between soil types [4,5]. Rooting depth, leaf area index and grain yields of spring barley sharply decreased when the degree of compactness in the plough layer of a silty loam and a loamy sand exceeded value of about 88 % [5]. The results implied that excessive soil penetration resistance of compacted soil is the main factor limiting root growth of spring barley. Response of grain yields to soil compaction is shown in Fig. 4.

The negative effect of excessive soil compaction was greater in years with unfavourable sowing-shooting weather conditions (low rainfall, high sunshine duration and high air temperature) [4].

CONCLUSIONS

1. The main factors which affect soil compactibility are: texture, water content, structure and initial compactness level.

2. An increase in soil compaction resulted in higher penetration resistance, higher aggregate crushing strength, lower air-filled porosity, lower oxygen diffusion rate, lower saturated hydraulic conductivity and smaller daily temperature fluctuations. The response of these properties is dependent on soil water status.

3. Increasing soil compaction caused a greater accumulation of roots in the topsoil. The roots grown in severely compacted soil were thicker and flattened and were characterized by tortuous growth, distorted epidermal cells and radially enlarged cortex cells.

4. Leaf area index and grain yields of spring barley sharply decreased when the degree of compactness exceeded about 88 %.

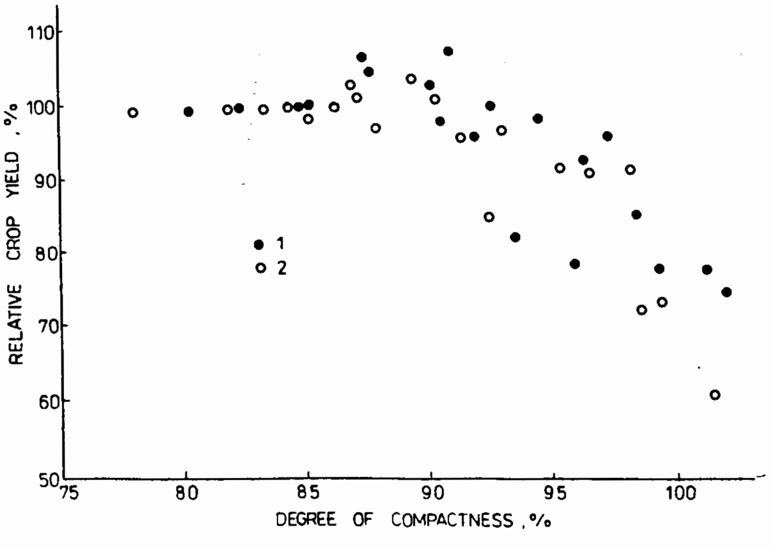

Fig. 4. Relative crop yield (100 = control plots) of spring barley in relation to the degree of compactness: 1- loamy sand; 2 - silty loam.

This response to soil compaction was greater in years with smaller rainfalls in the sowing-shooting period.

5. Usefullness of the degree of compactness for characterizing the compaction of a tilled soil layer was demonstrated for soil physical conditions as they relate to crop production.

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ZAGĘSZCZENIE GLEBY: REAKCJA WŁAŚCIWOŚCI FIZYCZNYCH GLEBY I WZROST ROŚLIN

Wraz ze wzrostem stopnia zagęszczenia gleby wzrasta opór mechaniczny i wytrzymałość agregatów na zgniatanie, zmniejsza się porowatość powietrzna, wydatek dyfuzji tlenu oraz wahania temperatury. Korzenie rosnące w glebie zagęszczonej koncentrowały się głównie w wierzchniej warstwie gleby. Wskaźnik powierzchni liści oraz plon ziarna jęczmienia jarego zmniejszały się istotnie wraz ze wzrostem stopnia zagęszczenia gleby powyżej 88 %.