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Changes of nitrogen assimilation and intracellular fluid pH in plants of barley depending on bulk density of compacted soils

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Abstract. The penetration resistance of different arable soils is quite different depending on the Estonian area. We are briefly introducing the results of our research on soil compaction, penetration resistance of different soils in Estonia, uptake of nutrients and changes of intracellular fluid pH of barley depending on soil bulk densities. These data were mainly collected in a research field (58º23´N, 26º44´E) of the Estonian Agricultural University, with different levels of soil compaction (10 levels) on sandy loam Fragi-Stagnic Albeluvisol (WRB) soil in 2001 and 2002. The investigated cultural plant was spring barley (*Hordeum vulgare* L.). In Estonia H. Loogus has studied changes of cellular fluid pH, depending on seedbed, by using microelectrodes directly on plants by quick method. The effect of soil bulk density on cellular fluid pH of barley leaves generally depends of number of passes. The experiment showed also that a higher decrease in nitrogen content started at the same soil bulk density value as the cellular fluid pH quickly increased. If the soil bulk density was increasing up to level 1.52–1.54 Mg m^{-3}, the cellular fluid pH suddenly increased very quickly. Nitrogen assimilation change in plants of barley decreased at the same bulk density values as a remarkable increase of intracellular pH was observed.

Key words: soil compaction, soil bulk density, nutrients, nitrogen assimilation, cellular fluid pH

INTRODUCTION

Numerous sources of literature refer to economic and environmental damages of soil compaction caused by anthropologic factors. With axle loads of tractors greater than 6 Mg, compaction penetrated to depths > 40 cm, where it was very persistent or even permanent (Håkansson and Reeder, 1994; Voorhees et al., 1989). When axle loads of vehicles were increased, the compaction affected deeper soil layers.

A special attention is to be given to the characteristics of machinery used to produce various compaction treatments. Crop responses to soil compaction have to be an important part of any such experiment. Also, the environmental impact of soil compaction, generally negative, has to be considered according to its specificity in different natural areas (Nugis et al., 2001).

Low total porosity and poor aeration at low capillary water retaining capacity of compacted soil inhibited the growth of grain roots. Grain was not capable of forming a decent root system in compacted soil. Thus, it was not possible for grain roots to alleviate the consequences of compaction in subsoil (Kuht & Reintam, 2001).

In this paper we are presenting our results and our viewpoints concerning changes of cellular fluid pH of barley depending of the soil compaction.

MATERIALS AND METHODS

Field experiments with different levels of soil compaction were carried out on the Fragi-Stagnic Albeluvisol (WRB) of the experimental field of the Estonian Agricultural University (EAU) at Eerika, near Tartu, to the West of the town, 58°23´N and 26°44´E. At the same time, we have measured bulk density, soil moisture content and penetration resistance in the same field conditions. The soil characteristics of the umbric horizon of the experimental area are presented in the following: C 1.4%, N 0.11%, K 164 mg kg^{-1}, P 183 mg kg^{-1}, Ca 674 mg kg^{-1}, Mg 101 mg kg^{-1}, pH_{KCl} 6.2, sand (2.0...0.02 mm) 67.9%, silt (0.02...0.002 mm) 22.9% and clay (< 0.002 mm) 9.2%.

By wheels of a heavy tractor (with loader) soil compaction was performed. The traffic was applied uniformly to cover the entire experimental plot: 1 time, 3 times and 6 times, the inflation pressures in the wheels of the tractor were 50 kPa, 100 kPa, and 150 kPa, respectivey (by meth. E. Nugis and J. Kuht).

The samples of the soil and plants were taken twice during the vegetation period: in the sprouting and spearing phase of barley. Plant samples (4 replications) from each variant were taken for measuring cellular fluid pH, and from 4 variants for measuring nutrient content (by E. Reintam and J. Kuht). Soil bulk density was measured by cylinders in layers of 10–40 cm. In the same layers, soil moisture, pH_{KCl}, carbon, nitrogen, phosphorus and potassium content were measured.

The growth intensity of plants, the cellular fluid pH (on sprouting and stalking of barley) depending on the soil compaction has been tested with other parts of plants (by H. Loogus, microelectrodes EVIKON). The measuring of cellular fluid pH directly in plants, using a microelectrode, is a quick method for explaining soil qualities. By using intracellular pH measurements we can easily detect the most suitable soil condition for plant growing. The weather conditions of the experiment years during the growing period (from May to August) of barley were different. The weather of 2001 was cold and rainy (more than 245 mm rain and average air temperature 14.6°C), and 2002 was a warm and dry (less than 123 mm rain, average air temperature 15.7°C) year. Mathematical methods, namely the analysis of variance (ANOVA) and correlation analysis, were used to process the collected data.

RESULTS AND DISCUSSION

Earlier penetrometric measurements on field trials on the Fragi-Stagnic Albeluvisol soil of EAU showed that double compaction (at an average of 18% water content in the soil) by a heavy tractor (14.9 Mg, 23 - 1/18“6 carrying 3.7 Mg or 37 kN) increased the average penetration resistance of subsoil in a layer of 20–40 cm by 72.5%, four-time compaction by 84%, and six-time compaction by 113%, compared to the non-compacted areas (Kuht et al., 1999). Analyses of the yield and bulk density data indicate that at an inflation pressure of 150 kPa the yield significantly reduced and bulk density increased. Research and field experiments have demonstrated that track-to-track wheel passes by a heavy tractor can cause severe compaction damage to

Sceleti-Calcaric Regosol soils (at Kuusiku, trials by P. Viil and E. Nugis) with an optimum water content (Nugis et al., 2003). If water-permeability of the soil with plant root water suction is equal then it must be taken into consideration that the plant is normally supplied with water. In results of soil compaction, the capillaries must become narrower, which is an obstacle for water streams flowing into the root system, therefore, the plants are suffering under deficit of water on the occasion when the moisture content of the soil is normal. In these conditions it is possible to impediment the flow of nutrient elements into plants. The results of our experiments have shown that plants suffer heavily from a deficit of nutrient elements on compacted soils, depending on the bulk density level of the soil (Kuht & Reintam, 2000; Kuht, 2001; Kuht et al., 2001).

Those calculations of change in cellular fluid pH help solve disputes risen in determing cellular fluid pH, when the seedbed has to be changed. When plant cellular fluid pH is high, growth intensity is low and measures for improving the bulk density of the soil should be used (Loogus, 2001). Results of our experiments revealed a close relation between soil bulk density and intracellular pH ($r = 0.71$) and nutrient assimilation ($r = 0.88$) in all growing phases of barley. In the rainy 2001, there were no significant differences between variants of compaction, or between soil bulk densities. Due to the moist soil (20%), the resistance of the soil to barley roots was low and there was no significant effect on nutrient content in barley dry matter in both growing phases. Still there was observable a decrease in nitrogen content at soil bulk density of more than 1.58 Mg m^{-3} in the sprouting phase (Fig. 1). Though in nutrient assimilation there was no big change, there was observed a remarkable increase of intracellular pH at the same bulk density values. It had almost no effect on the phosphorus content.

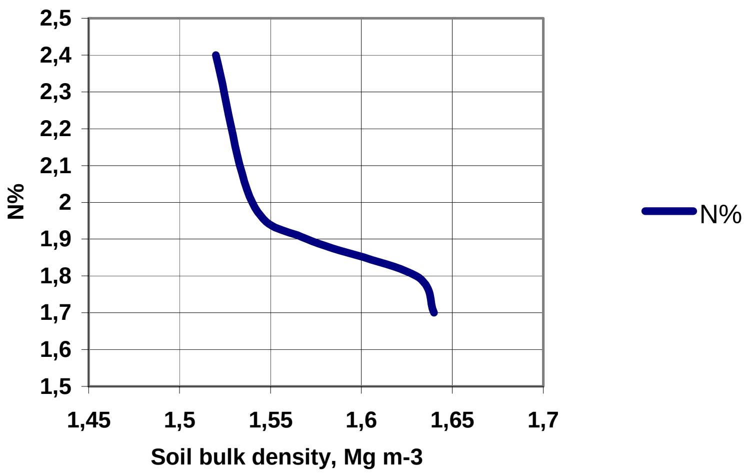

Fig. 1. Effect of soil bulk density on the content of nitrogen in barley shoots in the sprouting phase. $LSD_{0.05}$ for N – 0.19.

Use of nutrient elements by plants depends on cellular fluid pH. Some of the substances taken into the soil affect soil pH first, and such pH level has been found in the soil layers (Hoffmann et al., 1999). The results of many authors (Bowler & Fluhr, 2000; Shelp et al., 1999; Kinnersley, 2000) showed that alkalinisation of plant cells may be induced by an increase in intracellular calcium in stress conditions.

As our data and data of other authors (Kurkdjian & Guern, 1989; Roos et al., 1998; Fabien et al., 1999) showed, the intracellular pH increased in stress conditions. It is important to study the effect of bulk density of soil on soil pH and cellular fluid pH of plants.

The preliminary data of field trials, carried out in 2001 and 2003 at the Estonian Agricultural University, showed that cellular fluid pH had increased at higher soil density, particularly rapidly on sites of soil bulk density of 1.52–1.54 (Fig. 2).

In our experiments the intracellular pH indicated very well the critical level of soil bulk density for barley growth, which was 1.52–1.6 Mg m^{-3} in the sandy loam soil depending on soil moisture conditions (at this first point nutrient acquisition and total yield of barley will decrease). In the rainy year of 2001, there were no significant differences between compaction variants, and differences between soil bulk densities were also low. In the next year of 2002, the growing season was dry, and dry soil (in average 7%) was more resistant to the root grow. Fig. 2 also indicates that in the very dry vegetation period conditions in 2002 the best possible cellular fluid pH level was about 1.52 Mg m^3. Mengel and Kirkby (1987) observed that in a dry year, due to a thicker soil, the uptake of elements moving into the plant with water, such as nitrogen, calcium and magnesium, might increase. In a moist soil there are more nitrates than in a dry soil.

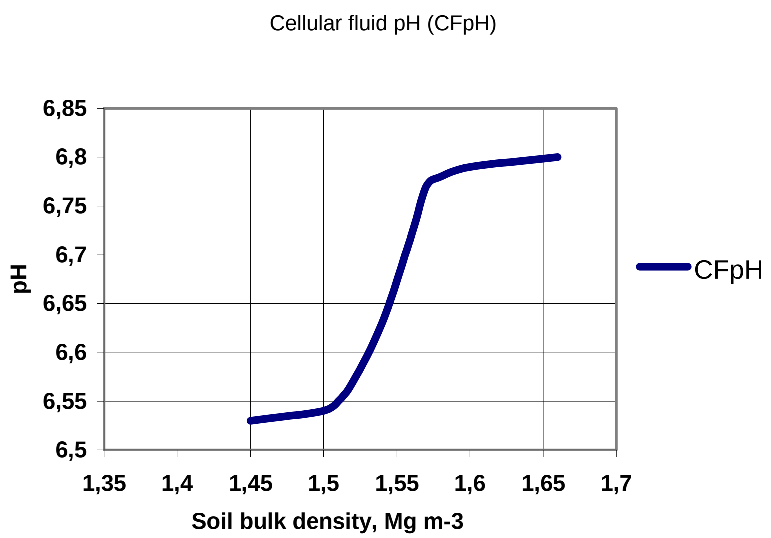

Fig. 2. Effect of soil bulk density on average cellular fluid pH in barley leaves in sprouting (in average 2001 and 2002). $LSD_{0,05}$ for CFpH = 0.03.

These connections (Fig. 2) are very important to us as they show that if the soil bulk density is increasing up to a level of 1.52–1.54 Mg m^{-3}, then the cellular fluid pH is suddenly increasing very quickly. The data of the experiment also showed that a higher decrease in nutrient content started at the same soil bulk density value as the cellular fluid pH increased. We thought that probably the plant can feel the dangerous situation and could start mobilising from reaction to protection.

In plant breeding, determination of cellular fluid pH helps discover more productive field crops more quickly (Loogus, 1995, 1998).

CONCLUSIONS

The results of the experiments and measurements have shown that:

- Plants experience a heavy deficit of nutrient elements on compacted soils, depending on the soil bulk density level.
- Cellular fluid pH increased at higher soil density, particularly rapidly on sites of soil bulk density of 1.54–1.58 Mg m^{-3} in a wet soil and 1.52–1.58 Mg m^{-3} in a dry soil, and a bigger decrease in nutrient content started at the same soil bulk density value as the cellular fluid pH quickly increased.
- Nitrogen assimilation change in plants of barley decreases at the same bulk density values as a remarkable increase of intracellular pH was observed.

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