# BARLEY PLANTS STRESS DEPENDING ON SOIL DEGRADATION DUE TO SOIL COMPACTION

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***ABSTRACT. Barley plants stress depending on soil degradation due to soil compaction.*** *A field experiment carried out on the experimental area of Estonian University of Life Science on Stagnic Luvisol soil. For soil compaction the hard tractor (total load 4.44 Mg) has been used. The induce compaction was done by wheel traffic applied uniformly to cover the entire of the full experimental plots: 1 time, 3 times and 6 times. The measuring with the microelectrode the cellular fluid pH directly from plants is a quick method for explaining soil qualities. By using intracellular pH measurements we can detect easily the most suitable soil condition for plant growing. For the chemical analysis of plants the Kjeldhal method was used to determine the nitrogen content in plants of barley. In our experiments the intracellular pH indicated very well the critical level of soil bulk density for barley growth, which was 1.52–1.60 Mg $m^{-3}$ in sandy loam soil depending on number of compaction. For soil bulk density in plough layer 1.52 Mg $m^3$ (the cellular fluid pH had increased with higher soil density, particularly steeply on space of soil bulk density 1.52–1.58 Mg $m^{-3}$). The drastic decrease of nitrogen content started at the same soil bulk density values, where the cellular fluid pH suddenly increased. The level of the degree of intracellular fluid pH ($C_{pH}$) is the most favorable which corresponds to the conditions $C_{pH}$ = 0.01, and on the contrary if $C_{pH}$ = 1.00 then degree of $C_{pH}$ is maximum worst level.*

***Ke words.*** *Soil bulk density, barley, cellular fluid pH, degree of cellular fluid pH, soil degradation, plant stress*

## Introduction

Crop responses to soil compaction have to be an important part of any such experiment. 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. The bulk density of soil is an important factor in physical-chemical qualities. Soil tillage may cause compression of soil bringing about changes in bulk density sowing place and optimal physical parameters of its soil have been studied and he has found the calculation methods that make the seedbed more profitable for finding out whether the soil is appropriate for growth of plants (Nugis, 1988). Some of the substances took into the soil affect pH first. It has been found that during vegetation period under unfavorable conditions (degree of frost, excess moisture) the plants may increase their cellular fluid pH as a reaction to unfavorable conditions (Loogus, 2001). In our investigations we detected the criteria of some growth conditions since from the intracellular fluid pH (CFpH) will exceed the optimal value for plants and the most important growth parameters of barley will suddenly decrease.

## Materials and methods

A field experiment carried out on the experimental area at Eerika, near Tartu (58°23´N and 26°44´E) of Estonian University of Life Science on Stagnic Luvisol (WRB) soils.

For artificial soil compaction the hard tractor has been used. A wheeled vehicle loaded with 2.02 Mg on the first axle and – 2.42 Mg on the rearward axle (total load is 4.44 Mg). The induce compaction was done by wheel traffic applied uniformly to cover the entire of the full experimental plots: 1 time, 3 times and 6 times. The samples of soil and plants were taken 2 times during vegetation period: in sprouting and spearing phase of barley. Plant samples (4 replications) from each variant were taken for measuring cellular fluid pH. The growth intensity of plants, the cellular fluid pH (on sprouting and on earing of barley) depending on the soil compaction with another part of plant has been tested (by microelectrodes). The measuring with the microelectrode the cellular fluid pH directly from plants is a quick method for explaining soil qualities. By using intracellular pH measurements we can detect easily the most suitable soil condition for plant growing. For the chemical analysis of plants the Kjeldhal method was used to determine the content of nitrogen.

Soil bulk density was measured with cylinders in 10 cm layers up to 40 cm. At the same layers were measured soil moisture and $pH_{KCl}$.

## Results and discussion

As our data (Kuht et al., 2003) and data of other authors (Kurkidijan, Guern, 1989; Roos *et al.*, 1998; Fabien *et al.*, 1999) showed, the intracellular pH increased in soil stress conditions.

If water-permeability of the soil with plant roots water suction is equal then its take into consideration that the plant is normal water supplying. In results of soil compaction the capillaries are to make narrower which obstacle of the water stream into the root system, therefore, the plants are suffering under the deficit of water during such occasion when the moisture content of soil is normally. Concerning that will be able to start impediments of plants nutrient elements. The result of our experiments has shown that the plants felts highly deficit of nutrient elements at compacted soils, depending of soil bulk density level (Kuht *et al.*, 2001).

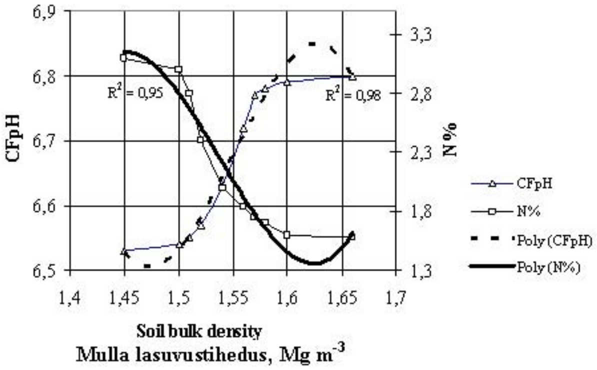


**Figure 1.** Relationships between cellular fluid pH and nitrogen content of barley depending on soil bulk density (according to Kuht *et al.*, 2003), $LSD_{0,05}$ for CFpH= 0.03 and for N= 0.19 (average of two years)

***Joonis 1.*** *Odrataimede lämmstikusisalduse ja rakumahla pH vahelised seosed sõltuvalt mulla lasuvustihedusest*

In our experiments the intracellular pH indicated very well the critical level of soil bulk density for barley growth, which was 1.52–1.60 Mg $m^{-3}$ in 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 low. In the next year in 2002 the growing season was dry, and dry soil (in average 7%) was more resistant to the root grow. In very dry vegetation period conditions in 2002 the best possible cellular fluid pH level was about 1.52 Mg $m^3$. This connections (Figure 1) for us is very important which were shown that if the soil bulk density increasing up to level 1.52–1.54 Mg $m^{-3}$ then the cellular fluid pH suddenly increasing very quick. The data of experiment showed also that the higher decrease of nitrogen content started at the same soil bulk density value, as the cellular fluid pH increased. We thought that probably the plant feeling the dangerous situation and he could start to mobilize of reaction to protection.

As showed our data and also data of other publications (Bacon *et al.*, 1998) the elongation rates of plants correlated with the increase intracellular fluid pH. As can see in Figure 2 the critical point to grow of barley shoots was observed by CFpH 6.57 after them the lengths of shoots decrease.

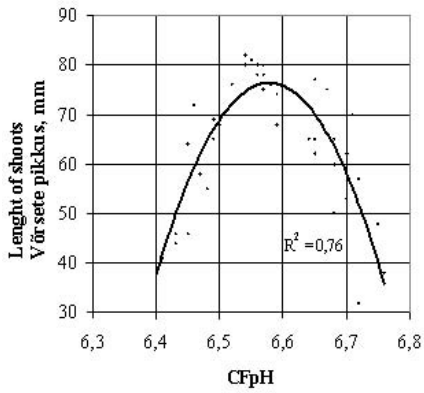


**Figure 2.** Relationships between shoots length and intracellular fluid pH (CFpH) in earing phase of barley, *n* =40 (average of 2002 and 2003).

***Joonis 2.*** *Võrsete pikkuse ja rakumahla pH (CFpH) vaheline seos odra loomisfaasis, n=40 (2002. ja 2003.a. keskmisena).*

According research data of Bacon et al. (1998) the elongation rates of barley decreased in soil stress situation – with decreasing soil water content, where as the pH of cell fluid increased from 5.9 to 6.9 as the soil dried. The plant hormone abscisic acid (ABA) is the major player in mediating the adaptation of the plant to stress. According studies of Zhang et al. (2002) the optimum pH for the abscisic acid-binding is about 6.5. Analysis showed that the ABA concentration was greatly increased at 6 d after emergence when seedlings were grown in compacted soil and root and shoot growth and leaf conductance of barley were all reduced when plants were grown in compacted soil with a bulk density of 1.7 Mg $m^{-3}$ (relative to uncompacted control plants 1.1 Mg $m^{-3}$; Mulholland *et al.*, 1996). In addition, as plants growing on compacted soils frequently experience the coupled effects of impeded root growth and anaerobic rooting conditions (Roberts *et al.*, 2002).

We have observed that for mostly better conditions of soil the optimum cellular fluid pH (CFpH) barley leaves are equal 5.77 (like something that control, i.e. without compaction) and for mostly worst soil conditions due to excessive compaction the CFpH are equal 6.99. Concerning that we have determined the degree of CFpH. Thus the degree of intracellular fluid pH (CpH) is calculated by the formula:

$$C_{pH} = \frac{F_i - F_o}{F_w - F_o} \text{, where} \qquad (1)$$

$F_o$, $F_i$ and $F_w$ are the values of parameters characterising an intracellular fluid pH (CFpH) in sprouting time of the plant: in optimum, in intermediate, in the worst, respectively.

At the same time we should be noted that for engineers above principles could be used also for calculation directly of soil vulnerability to compaction if the optimum level of agro technical bearing capability is 100 kPa, intermediate level is 140 kPa and worst level is 200 kPa (for sandy loam and loamy sand soils of Estonia).

According formula 2 the results of the theoretical research work are shown in Table 1.

**Table 1.** Degree of intracellular fluid pH ($C_{pH}$) and depending on times of compaction and on the different levels of nitrogen fertilizer
***Tabel 1.*** *Rakumahla pH koefitsient ($C_{pH}$) olenevalt tallamiskordadest ja lämmastikuannusest*

| Number of passes *Ülesõitude arv* | Degree of intracellular fluid pH on different levels of nitrogen *Rakumahla pH koefitsient erinevatel lämmastikutasemetel* ($C_{pH}$) | | | |
|---|---|---|---|---|
| | 0 | $N_{40}$ | $N_{80}$ | $N_{120}$ |
| Non-compacted (control) *Tallamata (kontroll)* | 0,36 | 0,31 | 0,32 | 0,29 |
| Compacted 3 times *Tallatud 3 korda* | 0,15 | 0,30 | 0,28 | 0,30 |
| Compacted 6 times *Tallatud 6 korda* | 0,24 | 0,14 | 0,51 | 0,43 |

As is shown in the Table 1, this method is rather sensitive and allows to drawing plausible conclusions on negative effects of soil compaction. The level of the degree of intracellular fluid pH ($C_{pH}$) is the most favourable which corresponds to the conditions $C_{pH}$ = 0.01, and on the contrary if $C_{pH}$ = 1.00 then degree of $C_{pH}$ is maximum worst level.

At this Table 1 is shown that the effect of the degree of intracellular fluid pH ($C_{pH}$) is significantly increased (Figure 3), when traffic is applied of 6 passes at field. It may be assumed that in the several level of nitrogen fertilizer these positive effect disappeared depending time of passes by the vehicle.

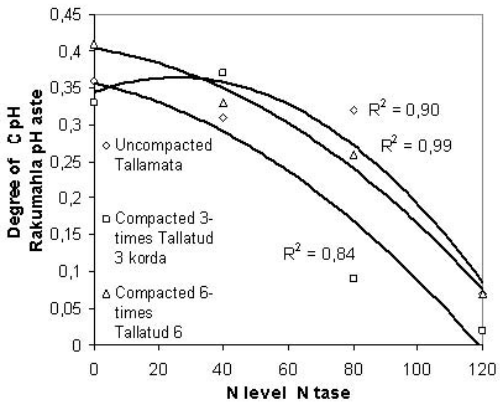


**Figure 3.** Relationship between degree of intracellular fluid pH ($C_{pH}$) and number of passes – 0; 3 and 6 time depending of the levels of nitrogen (N) fertilizer
***Joonis 3.*** *Rakumahla pH koefitsient ($C_{pH}$; aste) sõltuvalt lämmastikuannustest erinevatel tallamiskordadel –0; 3 ja 6 korda.*

As is shown in the Figure 3 that if we have the N= 0 then the degree of intracellular fluid pH is actually the same like something that 3 time passes by wheel of tractor. If we have the same level of the nitrogen fertilizer then the 6 times passes is influenced rather stronger. If the same level of the nitrogen fertilizer is increased then negative effect of soil compaction is decreased and the degree of intracellular fluid pH is more favorable in comparison with more less of the level of nitrogen fertilizer.

## Conclusions

According of this study and earlier our studies, the main criteria's since that the main condition of growth of barley decrease suddenly by soil stress situation is as fallows:

1. For soil bulk density in plough layer 1.52 Mg $m^3$ (the cellular fluid pH had increased with higher soil density, particularly steeply on space of soil bulk density 1.52–1.58 Mg $m^{-3}$).
2. For intracellular fluid pH (CFpH) – 6.57 (since that criteria the shoots length of barley will suddenly decrease)
3. The higher decrease of nitrogen content started at the same soil bulk density value, as the cellular fluid pH suddenly increased.
4. Without of nitrogen fertilizer the influence of soil compaction is rather negative.
5. The level of the degree of intracellular fluid pH ($C_{pH}$) is the most favourable which corresponds to the conditions $C_{pH}$ = 0.01, and on the contrary if $C_{pH}$ = 1.00 then degree of $C_{pH}$ is maximum worst level.

## Acknowledgement

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## Odrataimede stress sõltuvalt mulla omaduste halvenemisest tallamise tagajärjel

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Käesoleva uurimuse vajadus tulenes põllukultuuride negatiivsest reageerimisest mulla ülemäärasele tihenemisele. Taimed ei ole suutelised tallamisega liigselt tihendatud mullas oma juurekava vajalikul tasemel välja arendama. Sellele lisaks takistavad tiheda mulla halvenenud füüsikalised omadused ka vee ja toitainete juurdepääsu taimedele. Kõik see kutsub esile muutusi taimede füsioloogilistes protsessides, mille tulemusel pidurdub ka maapealsete osade kasv, väheneb nende stressitaluvus ja saak.

Vastavad katsed korraldati Eesti Maaülikooli Põllumajanduse- ja keskkonnainstituudi katsealal näivleetunud mullal. Mulla erinevad tihedusfoonid rajati raske traktoriga (4,44 Mg) laustallamise teel kolme- ja kuuekordse jälg-jälje kõrval ülesõitudega põllust. Kontrollvariandiks oli laustallamisega tihendamata ala. Katsealale külvati oder. Odrapõllu väetamisel kasutati nelja lämmastiku taset – $N_0$, $N_{40}$, $N_{80}$ ja $N_{120}$. Taimsed proovid võeti odra loomise perioodil, millest määrati mikroelektroodidega ka odrataimede erinevate osade rakumahla pH väärtus. Samadest proovivõtu kohtadest võeti ka mitmetest kihtidest mullaproovid tähtsamate füüsikaliste omaduste (lasuvustihedus, poorsus) määramiseks.

Nagu näitavad arvukad uurimisandmed, viivad mulla omaduste halvenemised taimede rakumahla pH tõusule. Selle põhjuseks on enamasti puudused taimede veega varustamisel. Rakumahla pH väärtus on oluline abtsiishappe (ABA) moodustumisel taimedes, mille kogusest omakorda oleneb taimede vastupanuvõime ebasoodsatele oludele (stressitaluvus). Koos algse rakumahla pH väärtuse suurenemisega kaasneb ühtlasi aga taimedes moodustuva ABA hulga vähenemine.

Katsed odraga andsid meie uurimustes järgmised tulemused ja kriteeriumid:

1. Rakumahla pH suurenes mulla lasuvustiheduse suurenedes, kusjuures järsk pH väärtuse tõus ilmnes lasuvustiheduse vahemikus1,52–1,58 Mg $m^{-3}$.
2. Rakumahla pH väärtuse 6,57 juures algab odrakõrte pikkuste järsk lühenemine.
3. Odrataimede lämmastikusisalduse tunduv vähenemine ilmnes samade mulla lasuvustiheduse väärtuste juures, kus toimus ka rakumahla pH väärtuste järsk tõus.
4. Järeldus, et odrataimede rakumahla pH koefitsiendi ($C_{pH}$) väärtuse juures 0,01 juures on taimede kasvutingimused kõige soodsamad, väärtuse 1,00 juures aga kõige halvemad.
5. Kõige enam avaldus mulla tallamise negatiivne mõju odrataimedele lämmastikuta foonil.

Seega põhjustas mulla ülemäärane tallamine odra taimede normaalseks kasvuks vajalike füsioloogiliste protsesside pidurdumise, mis oli tingitud rakumahla pH järsust tõusust.