CHANGES IN SOIL AGGREGATE STABILITY INDUCED BY MINERAL NITROGEN FERTILIZER APPLICATION

Martin Brtnický1, Jakub Elbl2, Helena Dvořáčková2, Jindřich Kynický2, Jan Hladký2

1Department of Geology and Pedology, Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic
2Department of Geology and Pedology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Czech Republic, Zemědělská 1, 613 00 Brno, Czech Republic

Abstract


The stability of soil aggregates is one of the most important characteristics of the soil affecting the overall soil quality and its health. In locality Březová nad Svitavou, experiment to reveal the effect of nitrogen dose on the stability of soil aggregates of Rendzina soil was carried out. The aim was to detect changes in soil aggregate stability after 4 and 5 years from the beginning of the experiment. There were tested 7 variants, prepared in triplicate. The results revealed that the stability of soil aggregates decreases with increasing amounts of applied N. Effect of N application was not statistically significant in the fourth but in the fifth year of the experiment. The results also revealed a significant deterioration in the stability of soil aggregates in the fifth year compared to the fourth year of the experiment.

Keywords: nitrogen, soil aggregate stability, quality and health of soil, Rendzina, soil

INTRODUCTION

The stability of soil aggregates is one of the key characteristics of the soil in relation to soil fertility and its overall quality. According to Hillel (1980), we consider the stability of soil aggregates to be the ability of resistance against disintegration force acting on the aggregates. Disintegration caused by water is the most commonly mentioned in respect of the stability of soil aggregates (Hammad et al., 2006, Regelink et al., 2015). The stability of soil aggregates is influenced by the overall condition of the soil, management, and by the natural conditions (Amézketa, 1999; Munkholm et al., 2016). On the other hand, the structure of soil and the aggregate stability influences various soil properties, such as particularly infiltration and water flow in soil (Liebig et al., 2004), the air flow (Du Preez et al., 2011). The stability of soil aggregates is significantly influenced particularly by quality and content of humus, and by biological activity. Increased stability of soil aggregates was detected in soil samples with a high content of organic substances (Epperlein, 2003). Adding organic matter into soil increases the bonding force between aggregates (Huisz et al. 2009). These bonds are not permanent and may lead to their re-rupture. Such destructive force is caused i.e. by disruption of optimal physical condition of the soil, such as compaction, use of fertilizers and decline in organic matter content.

The stability of soil aggregates is directly related to the biological activity of the soil. Generally, the more soil is biologically active, the higher is stability of soil aggregates (Bartlová and Badalíková, 2010; Oades, 1995). In this respect, it is needed to recall that the biological activity of soil and stability of the aggregates vary considerably during the season (Lehrsch and Jolley, 1991).

Fonte et al. (2009) pointed out that nitrogen has significantly destructive effect on the stability of soil aggregates and on the overall structure of the soil.
Prolonged exposure to high doses of nitrogen leads to reduction in the activity of soil organisms and to the collapse of the structure.

The aim of this study was to evaluate the influence of nitrogen fertilization on the stability of soil aggregates.

MATERIALS AND METHODS

Influence of fertilization method on water stability of soil aggregates was tested by field experiment which was conducted in the protection zone of underground drinking water Březová nad Svitavou in 2012. The protection zone is responsible for protection of underground source of drinking water against contamination by pollutants and residues from agriculture (pesticides and fertilizers). The area of our interest is located in the northern part of the Bohemian-Moravian Highlands, 58 km north of city Brno, in eastern part of the Czech Republic, where annual climatic averages (1962–2012) are 588.47 mm of precipitation and 7.9 °C mean of annual air temperature. Detailed information about area of our interest was published by Elbl et al. (2013) and Plošek et al. (2017). The experiment was conducted at 470 m above sea level in the Rendzina soil. Individual variants of experiment were arrayed in blocked design, each one with four replicates (one replicate = 2×10 m plot).

These variant were prepared:
1. N0 – without fertilization, sole crop winter wheat
2. N25 – 25% of recommended dose of N for winter wheat (35 kg N/ha)
3. N50 – 50% of recommended dose of N for winter wheat (69 kg N/ha)
4. N50 + C – 50% of recommended dose of N for winter wheat and recommended dose of lignohumate (69 kg N/ha + 250 l C/ha)
5. N50 + K – 50% of recommended dose of N for winter wheat and recommended dose of compost (69 kg N/ha + 50,000 kg K/ha)
6. N100 – 100% of recommended dose of N for winter wheat
7. N100 + C – 100% of recommended dose of N for winter wheat recommended dose of lignohumate (138 kg N/ha + 250 l C/ha)

The following fertilizers were used for establishment of experiment: (a) organic waste compost – K; (b) mineral fertilizer DAM 390; (c) organic-mineral fertilizer Lignohumate – C. Recommended dose in Czech Republic of K is 5 kg/m² (50,000 kg/ha) per 5 years according ČSN EN 46 5735, consequently this dose were used and represents 100% dose of K. The certified compost Black Dragon from aerobic composting plant CKB Brno. And recommended total dose of nitrogen for winter wheat, which is grown in protection zone of drinking water is 170 kg N/ha according Government Regulation no. 262/2012 Coll. The presented experiment was established in protection zone of drinking water, therefore 138 kg N/ha was chosen as 100% dose of nitrogen per one year. Nitrogen was applied by mineral fertilizer DAM 390 (combination of ammonium, nitrate and amidic form of nitrogen) three times per year. Furthermore one variant were fertilized by special kind of organic-mineral fertilizer Lignohumate, which can be described as product of chemical transformation of lignosulfonate. Lignohumate (C) is solid fertilizer which after dissolution forming a solution of humic salts (humic and fulvic acids in the ratio 1:1) and potassium. The dose of 250 l C/ha was applied once a year. All used fertilized have been registered for using in agriculture according Fertilizers Law.

Samples were taken from the surface layer and transferred immediately to the laboratory and air-dried. After sieving the sample through a set of screens in order to separate the fraction with aggregate size of 1–2 mm, 4 g sample of this fraction was placed in a sieve of washing apparatus and washed in distilled water for 5 minutes. The sample was dried at 105 °C to constant weight, and placed into a solution of sodium pyrophosphate. The sample was re-dried at 105 °C to constant weight and content of stable soil aggregates was calculated in accordance with DIN 19683-16.

I: Descriptive statistics for 2015.

<table>
<thead>
<tr>
<th></th>
<th>N0</th>
<th>N25</th>
<th>N50</th>
<th>N100</th>
<th>N50+K</th>
<th>N50+C</th>
<th>N100+C</th>
</tr>
</thead>
<tbody>
<tr>
<td>N valid</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Mean</td>
<td>40.83</td>
<td>41.29</td>
<td>39.57</td>
<td>38.53</td>
<td>40.21</td>
<td>40.64</td>
<td>38.20</td>
</tr>
<tr>
<td>Median</td>
<td>42.87</td>
<td>41.84</td>
<td>39.94</td>
<td>38.58</td>
<td>40.54</td>
<td>40.50</td>
<td>37.88</td>
</tr>
<tr>
<td>Min</td>
<td>33.67</td>
<td>37.70</td>
<td>37.03</td>
<td>34.21</td>
<td>36.50</td>
<td>39.16</td>
<td>34.63</td>
</tr>
<tr>
<td>Max</td>
<td>44.22</td>
<td>43.54</td>
<td>41.46</td>
<td>42.33</td>
<td>41.55</td>
<td>41.60</td>
<td>42.03</td>
</tr>
<tr>
<td>Variance</td>
<td>19.83</td>
<td>3.45</td>
<td>1.86</td>
<td>9.03</td>
<td>2.67</td>
<td>0.60</td>
<td>2.52</td>
</tr>
<tr>
<td>SD</td>
<td>4.45</td>
<td>1.86</td>
<td>1.37</td>
<td>3.00</td>
<td>1.63</td>
<td>0.77</td>
<td>2.52</td>
</tr>
<tr>
<td>RSD</td>
<td>10.91</td>
<td>4.50</td>
<td>3.45</td>
<td>7.80</td>
<td>4.07</td>
<td>1.90</td>
<td>6.60</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

The subject of our interest was to determine the effect of fertilization on aggregate stability of arable soil in area of our interest which was determined in 2015 and 2016.

2015

Tab. I indicates descriptive statistics with ANOVA for the soil aggregate stability in 2015. The highest average soil aggregate stability in 2015 was found to be 41.29% in the variant N25. The stability was decreasing as follows: N0 (mean 40.83%), N50 + C (mean 40.64%), N50 + K (mean 40.21%), N50 (mean 39.57%), N100 (mean 38.53%) and N100 + C (mean 38.20%).

Increasing the dose of N had a negative impact on the stability of soil aggregates. To confirm the evidence supporting the allegation, the post-hoc Tukey’s HSD test was carried out. The test did not prove statistically significant (P < 0.05) effect of the fertilization method on the stability of soil aggregates. Therefore, the effect of fertilization on soil aggregate stability in 2015 cannot be confirmed. On the other hand, the Fig. 1 apparently shows that different methods of fertilization could potentially affect the decline in soil aggregate stability. I.e., adding lignohumate into compost reduced the decrease in the stability of soil aggregates (N50 + K; N50 + C), in comparison with the variants fertilized only with mineral fertilizer. The same phenomenon was observed in the study of Udom et al. (2015). However, variant N100 + C did not reveal improvement of the stability of soil aggregates. An et al. (2010) states it is probably due to already considerably high dose of mineral N (Fonte et al., 2009).

2016

In 2016, samples were taken to determine the effect of the fertilization method on soil aggregates stability. The descriptive statistics of sampling in 2016 supplemented with an analysis of variance (ANOVA) is given in Tab. II. As it can be seen from Tab. II, the highest aggregate stability of the soil was measured in variants N0 (mean 45.15%), and stability of soil aggregates was decreasing in the following order: N50 + C (mean 38.16%), N25 (mean 37.76%), N50 + K (mean 36.06%), N30 (mean 35.96%) N100 + C (mean 35.60%) and N100 (mean 33.02%). Similarly as in 2015, 2016 detected a higher step improvement was detected. Moreover, the statistically significant difference (P < 0.05) was found between particular years of the experiment. It can be assumed longer monitoring would have confirmed conclusions of other studies (Zhang et al., 2015). However, variant N100 + C did not reveal significant effect of one exception of the variant N0 where step improvement was detected. Conversely, the addition of C and K had a demonstrable impact on reducing the negative impact of the application of mineral N on the stability of soil aggregates.

As seen in the Fig. 1 and Tab. III, it is evident the soil aggregate stability was deteriorated in 2016, with one exception of the variant N0 where step improvement was detected. Increasing dose of N significantly decreased the stability of soil aggregates in the following order N0 > N50 > N100. Conversely, the addition of C and K had a demonstrable impact on reducing the negative impact of the application of mineral N on the stability of soil aggregates. The measured values were subsequently subjected to further statistical research. Potential differences between the variants were analyzed using post-hoc Tukey’s test and differences within individual variants in 2015 and 2016 using t-test. Found differences among the variants and years are shown in Tab. III. The following Tab. IV shows accurate comparison results of 2015 and 2016. Based on these values, it can be stated that the stability of soil aggregates demonstrably decreased in all fertilized variants in 2015 and 2016, while the stability of soil aggregates was increased in the variant without added fertilizer (N0). These results indicate a negative effect of the application of compost or organic-mineral substances. The results are consistent with the work of Wang et al. (2013); Zhang et al. (2016b); Bronick and Lal (2005).

Soine et al. (2016) warn that the destruction of soil structure exhibiting a reduced stability of aggregates leads to significant reduction of soil functions, such as changing soil moisture conditions and deterioration of soil infiltration capacity. Due to the collapse of soil structure, soil pores are destroyed. This prevents from the infiltration of surface water that flows into watercourse then. This entails the risk of runoff of fertilizer and other substances applied into the soil. The substances cannot be retained in the soil. In practise, it leads to unnecessary overuse of fertilizers and chemicals.
II: Descriptive statistics for 2016.

<table>
<thead>
<tr>
<th></th>
<th>N0</th>
<th>N25</th>
<th>N50</th>
<th>N100</th>
<th>N50 + K</th>
<th>N50 + C</th>
<th>N100 + C</th>
</tr>
</thead>
<tbody>
<tr>
<td>N valid</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Mean</td>
<td>45.15</td>
<td>37.76</td>
<td>35.96</td>
<td>33.02</td>
<td>36.06</td>
<td>38.16</td>
<td>35.60</td>
</tr>
<tr>
<td>Median</td>
<td>44.75</td>
<td>37.63</td>
<td>35.92</td>
<td>33.18</td>
<td>36.09</td>
<td>38.32</td>
<td>35.70</td>
</tr>
<tr>
<td>Min</td>
<td>43.44</td>
<td>36.99</td>
<td>35.32</td>
<td>32.13</td>
<td>35.16</td>
<td>37.37</td>
<td>34.59</td>
</tr>
<tr>
<td>Max</td>
<td>48.31</td>
<td>38.69</td>
<td>36.62</td>
<td>33.55</td>
<td>36.86</td>
<td>39.16</td>
<td>36.12</td>
</tr>
<tr>
<td>Variance</td>
<td>2.36</td>
<td>0.44</td>
<td>0.33</td>
<td>0.25</td>
<td>0.63</td>
<td>0.44</td>
<td>0.27</td>
</tr>
<tr>
<td>SD</td>
<td>1.54</td>
<td>0.66</td>
<td>0.58</td>
<td>0.50</td>
<td>0.79</td>
<td>0.66</td>
<td>0.52</td>
</tr>
<tr>
<td>RSD</td>
<td>3.40</td>
<td>1.75</td>
<td>1.60</td>
<td>1.51</td>
<td>2.20</td>
<td>1.73</td>
<td>1.46</td>
</tr>
</tbody>
</table>


III: Statistical analyses of potential differences in aggregate stability of soil among individual variants.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N0</td>
<td>A</td>
<td>B</td>
<td>*</td>
</tr>
<tr>
<td>N25</td>
<td>A</td>
<td>C,F</td>
<td>*</td>
</tr>
<tr>
<td>N50</td>
<td>A</td>
<td>D</td>
<td>*</td>
</tr>
<tr>
<td>N100</td>
<td>A</td>
<td>E</td>
<td>*</td>
</tr>
<tr>
<td>N50 + K</td>
<td>A</td>
<td>A,D</td>
<td>*</td>
</tr>
<tr>
<td>N50 + C</td>
<td>A</td>
<td>F</td>
<td>*</td>
</tr>
<tr>
<td>N100 + C</td>
<td>A</td>
<td>A,D</td>
<td>*</td>
</tr>
</tbody>
</table>

Different letters indicate significant differences between individual variants in 2015 and 2016 at the level P < 0.05 (ANOVA; post-hoc Tukey's HSD test). Symbol * indicates significant differences in soil aggregate stability within one variants between 2015 and 2016 at the level P < 0.05 (t-test). The results of t-test are listed in Tab. IV.
### CONCLUSION

Based on the obtained results, we can conclude that nitrogen has a destructive influence on the stability of soil aggregates. The highest stability of soil aggregates was measured in the N0 variant. Increasing doses of nitrogen degrade the stability of soil aggregates. This is probably due to the suppressing soil biological activity after the addition of nitrogen. The exception is the N50 + C variant where slight increase in soil aggregate stability was observed, probably due to the addition of carbon. The findings of this study are consistent with other studies. Furthermore, it can be assumed that the same fertilization would deepen the negative effect described there, thus deteriorate soil aggregate stability.

Acknowledgment

This work was supported by the National Agency for Agricultural research (NAZV), project: The possibilities for retention of reactive nitrogen from agriculture in the most vulnerable infiltration area of water resources, registration no. OJ 122007.

### REFERENCES


Contact information
Ing. Martin Brtnický: martin.brtnicky@seznam.cz
Ing. Jakub Elbl: jakub.elbl@mendelu.cz
Ing. Helena Dvořáčková: helena.dvorackova@mendelu.cz
doc. Mgr. Jindřich Kynický, Ph.D.: jindrak@email.cz
Ing. Jan Hladký, Ph.D.: pudoznalec@gmail.com