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CHANGES OF SOIL AGGREGATE STABILITY AS A RESULT OF THE EFFECT OF FREEZE-THAW CYCLES

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Abstract

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The objective of the present research was to assess the changes in soil erodibility during the non-vegetation period as one of the factors affecting the snowmelt erosion. The temperature fluctuation was simulated with the use of a climatic chamber ex situ. The soil surface was for simplicity reasons considered without any plant or snow cover. The paper deals with the rate of soil erodibility determination – the soil erodibility should increase due to the decrease of soil aggregate stability depending on the number of freeze-thaw cycles and initial soil moisture. Soil samples (taken from three sites) were subjected to freeze-thaw cycles under laboratory conditions. Changes in soil agreggate stability were monitored as one of the main soil characteristics which determine the soil erodibility. Two methods were used to determine the soil macroaggregate stability (soil aggregate fraction 1–2 mm): standard single-sieve method of wet sieving (Kemper and Rosenau, 1986), and dry aggregate analysis using a set of flat sieves with a diameter of 1 mm and 0.5 mm. The results of each method are controversial. Intended hypothesis has not been clearly confirmed.

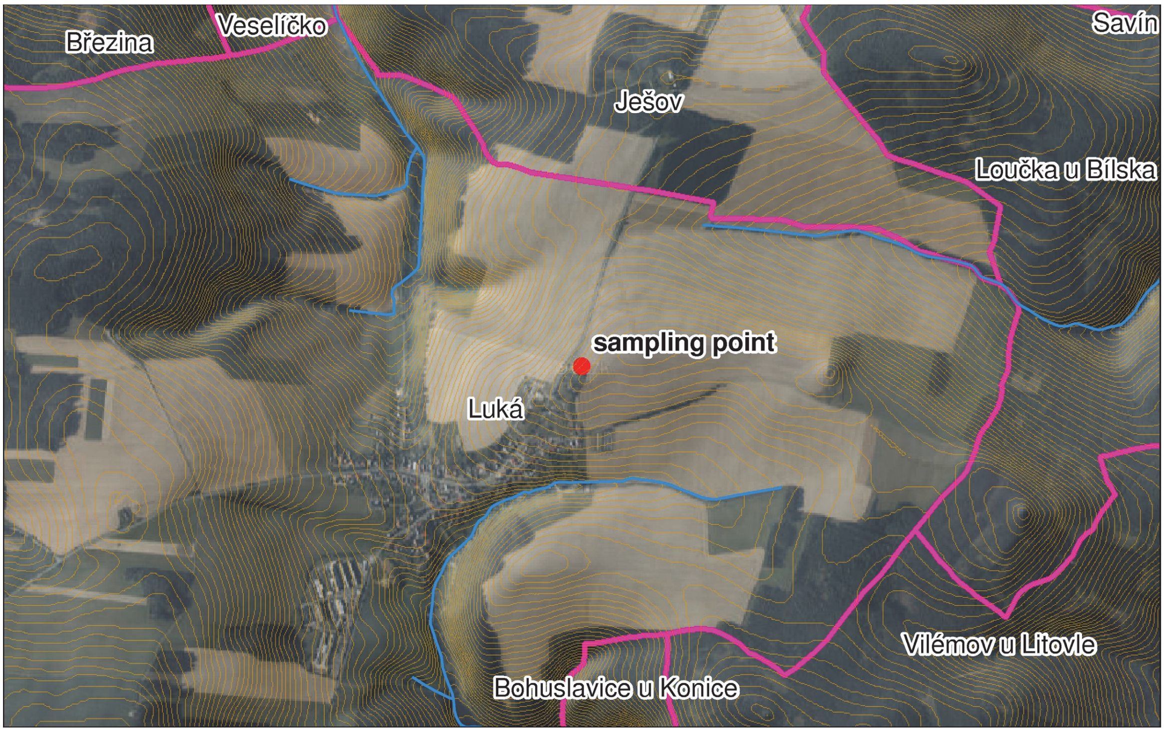
Keywords: cryopedology, snowmelt erosion, erodibility, soil aggregate stability, freeze-thaw cycle

INTRODUCTION

Erosion is a complex process involving disruption of the soil surface, and transport and sedimentation of loose soil particles by water, wind, ice and other factors (Janeček *et al.*, 2012). Although water erosion is now more and more discussed, snowmelt erosion is rarely mentioned in the Czech Republic (CZ). As a result of the snowmelt, a surface runoff occurs with devastating consequences. Even a small amount of the surface runoff is dangerous due to the specific soil conditions during cold periods and lack of vegetation cover. Snowmelt erosion plays a significant role in some specific areas. Locations with heavy snow cover with the risk of sudden melting are the most endangered (Pokladníková and Šťastná, 2006). The ignorance of the issue under Czech conditions limits, however, its solution. Representatives of the Nordic countries, where the problem occurs in the largest extent, have the deepest knowledge of this type of erosion. According to Toman and Podhrázská (2002), the issue of snowmelt determination is relatively underdeveloped in the Czech Republic due to the difficulty of determining the factors influencing the intensity of erosion. One of these factors is the soil erodibility, which is mainly determined by the soil shear strength and by the soil aggregate stability. Repeated freezing and thawing of the soil profile in winter period result in an increased erodibility. Both soil characteristics are during winter adversely affected due to the cryopedological processes. The opinions on the effect of freezing on the stability of soil aggregates are contradictory. Øygarden (2000), Oztas and Fayetorbay (2003), Kværnø and Øygarden (2006) and others agree that frost effects the soil aggregates destructively, and it thus weakens the soil structure. As well as the shear strength, the soil aggregate stability is inversely related to the water content in soil (Øygarden, 2000). Soil water is squeezed out of soil aggregates and creates small ice crystals around them; these destruct partially during their creation the soil aggregates. Many high-quality soil particles are therefore broken with the arrival of melting (Malenová and Toman, 2005).

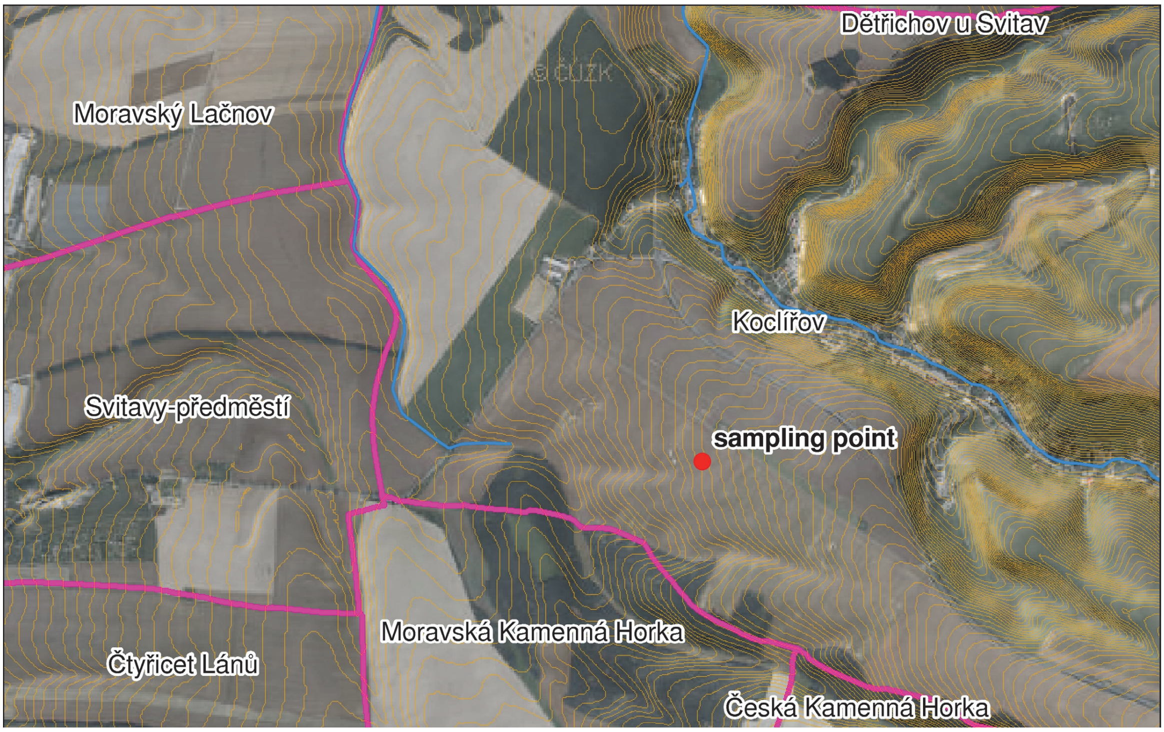
MATERIALS AND METHODS

Soil samples for the examination in ex situ were taken at three sites: Luká (altitude 512 m.a.s.l.) (Fig. 1), Bystřice nad Pernštejnem (altitude 564 m.a.s.l.) (Fig. 2) and Koclířov (altitude 525 m.a.s.l.) (Fig. 3). The first sampling was carried out after the melting



1: *Soil sampling in the cadastral area Luká 23 April 2013 and 31 July 2013*

2: *Soil sampling in the cadastral area Bystřice upon Pernštejn 26 April 2013 and 31 July 2013*



3: *Soil sampling in the cadastral area Koclířov 26 April 2013 and 31 July 2013*

of snowpack at the end of April 2013, and summer sampling at the end of July 2013, before harvesting. The winter oilseed rape, which is the only sparse coverage of the soil surface during the winter period, was sown at all sites.

The spring sampling was rather late due to the long duration of snow cover. Sampling depth was chosen as small as possible. Only the topsoil without vegetation cover to a depth of 2.5 cm was taken.

Soil Properties (Texture)

All three sites had medium-weight loamy soils.

Luká

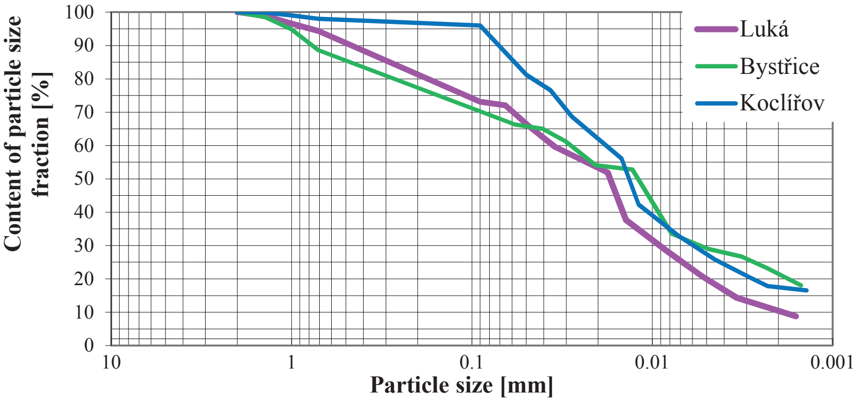
Main soil unit (MSU) 26: Modal cambisol, eubasic and mesobasic on the shale, mostly medium soils, medium skeletal, with favorable moisture conditions.

Bystřice nad Pernštejnem

MSU 29: Modal cambisol, eubasic to mesobasic, gleyed soils including weakly gleyed varieties, on the gneisses, mica schists, phyllites or granites, medium soils to lighter medium, without skeleton to medium skeletal, with prevailing good moisture conditions.

Koclířov

HPJ 25: Modal leached cambisol, eubasic to mesobasic, exceptionally also pelic cambisol on marl and hard marlite, medium flysh, Permian Carboniferous, medium to medium skeletal, soils with good water capacity.



4: *Topsoil texture*

Determination of Soil Aggregate Stability by Wet Sieving

Initial soil moisture content and aggregate stability were determined immediately after sampling. Fraction of 1–2 mm has been separated with the use of a set of classic flat screens after air-drying of the sample (for 24 hours). Drying of aggregates before analysis should be done at room-temperature or the temperature representative of field conditions. Oven-drying increases stability in otherwise unstable aggregates (Nimmo and Perkins, 2002). Scaling weight 4 g of thus prepared samples was subjected to a standard single-sieve method of wet sieving (Kemper and Rosenau, 1986). The samples were sieved in distilled water for 3 minutes with a frequency of 35 cycles/min and the vertical amplitude 1.3 cm, through a sieve with the mesh diameter 0.25 mm. The residue on the sieve was dried at 105 °C (for 6 hours), weighed and then dispersed and sieved 5 minutes in a solution of sodium polyphosphate, so that all the clay particles were washed out and only sand particles remained on the sieves. When the aggregates did not break apart even after 5 minutes of sieving in solution, they were helped mechanically. The residue on the sieve (particle size of only about 0.25 mm) was dried and weighed.

Effort to prove the aggregate stability dependence on soil water content during the freezing led to the testing of two sets of samples – air-dried samples (24 h) and samples with initial water content. Sets of samples from each site were placed in closed plastic boxes and subjected to a several freeze-thaw cycles. Each sample was prepared in a triplicate. There was an effort to reproduce natural conditions when choosing the characteristics of a freeze-thaw cycle. Duration of one cycle was set at 24 hours. Samples were subjected to the temperature of –5 °C for 12 hours and to the temperature of +5 °C for another 12 hours. Changes in aggregate stability were determined after 4, 5, 6, 7 and 24-hour cycles. Samples were dried, the 1–2 mm fraction was separated and the aggregate analysis using the wet sieving was carried out after several cycles. The result was the percentage of waterstable soil aggregates (Kandeler *et al.*, 1996):

$$SAS = 100 \times \frac{M_2 - M_3}{W - (M_3 - M_1)}, \quad (1)$$

SAS.....soil aggregate stability [%],
M_1.......weight of dish [g],
M_2.......weight of dish, waterstable aggregates and sand [g],
M_3.......weight of dish and sand [g],
W........sample weight [g].

Aggregate Analysis by Dry Multi-sieve Method

Due to unsatisfactory results arising from the first method chosen, the research was supplemented by an aggregate analysis using a set of standard flat sieves. The most consistent method (Chepil, 1962 in Kemper and Rosenau, 1986) using rotary sieves has been replaced by the use of flat sieves with a sufficiently small weighed portion. Soil aggregates, fraction 1–2 mm, were separated from the air-dried samples. 50 g weighed portions were subjected to the same number of frost cycles as in the case of wet sieving (0, 4, 5, 6, 7 and 24-hour cycles). Subsequently, the aggregates were sieved through a sieve with mesh diameter 1 and 0.5 mm for 5 minutes with horizontal amplitude 0.1 mm (López *et al.*, 2007 in Kozlovsky Dufková, 2010). Thr percentage loss of stable macro-aggregates was determined by weighing residues on sieves. The residue on a 1 mm-sieve was re-exposed to other freeze-thaw cycles. The aggregate analysis by dry sieving is, unlike the wet sieving, a non-destructive method. The Soil sample of an initial weight 50 g is thus repeatedly sieved after a certain amount of freeze-thaw cycles. During the wet sieving analysis, the soil sample is destroyed, and a duplicate is therefore necessary for each analysis. The result was the percentage of dry-stable soil aggregates SAS *:

$$SAS^* = 100 \times \frac{SA}{SA + NA}, \quad (2)$$

SAS*...soil aggregate stability [%],
SA.......weight of stable aggregates [g],
NA......weight of unstable aggregates [g].

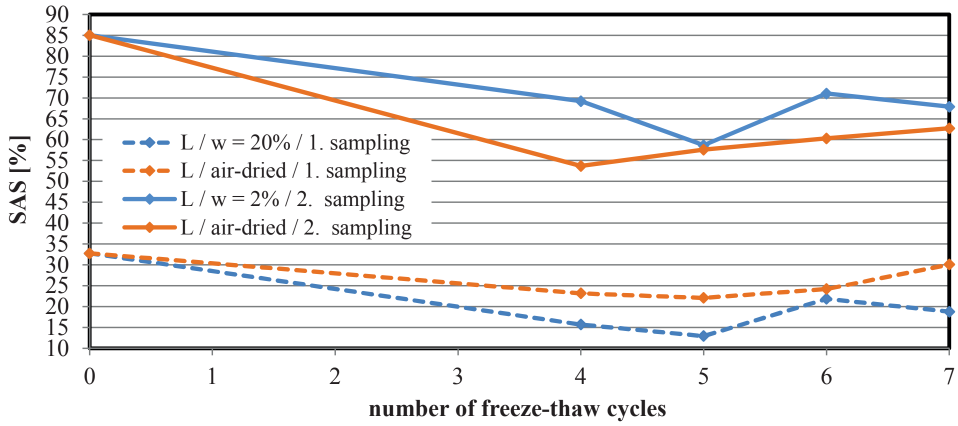
RESULTS

The sampling areas were situated on medium-weight loamy cambisols. The resulting values of proportional content of water-stable macro-aggregates (determined by wet sieving) are presented in the following graphs.

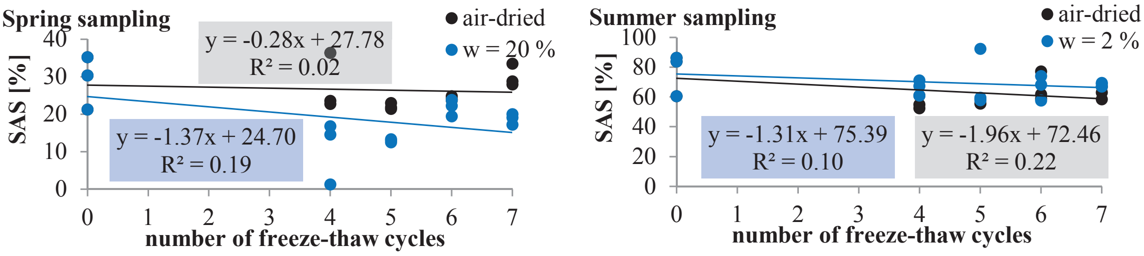
Simple linear regression analysis did not give significant correlations. There is a clear difference between values of SAS in spring and summer soil samples. The increase of aggregate stability during the vegetation period is well-known fact. Nevertheless, the correlation coefficient for SAS and number of FT cycles varied only from –0.14 to –0.47 in case of Luká sampling site.

The trend in the case of samples from Bystřice locality is rather opposite. SAS increased with few FT cycles and then started to decrease, as Mostaghimi (1988) describes it. The correlation coefficient for SAS and number of FT cycles varied from – 0.08 to 0.77.

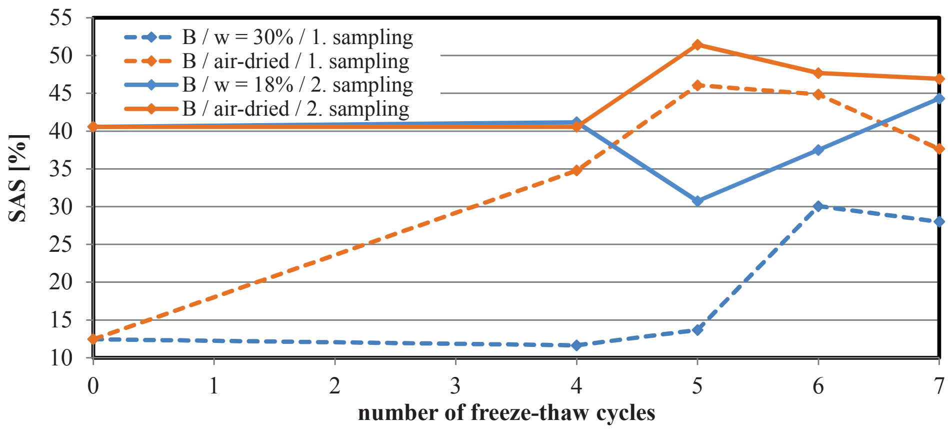
The most significant correlations were given by the experiment with samples from Koclířov. But on the other side, SAS of moist sample were unexpectedly higher than SAS of air-dried sample (similar to Luká – summer samples). For samples with low water content (Koclířov-spring sampling: w = 10%, Luká – summer sampling: w = 2%), this could be caused by a big fluctuation of SAS values and inaccuracies that lead to this phenomenon.



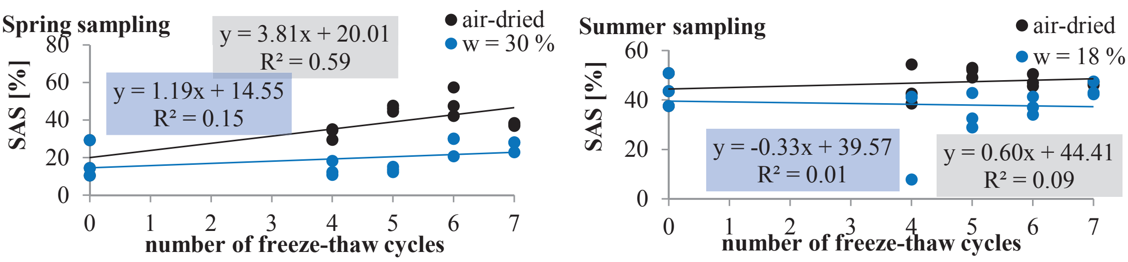
5: *The mean content of water-stable macro-aggregates (Luká)*



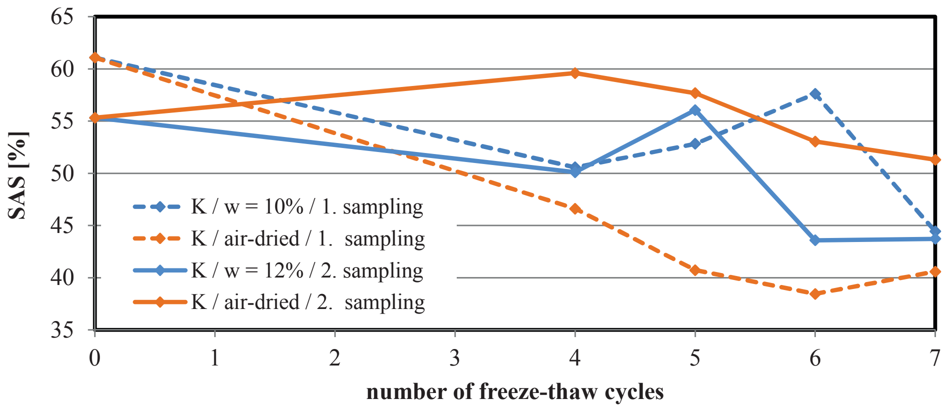
6: *Plot of soil aggregate stability and number of freeze-thaw (FT) cycles (Luká)*



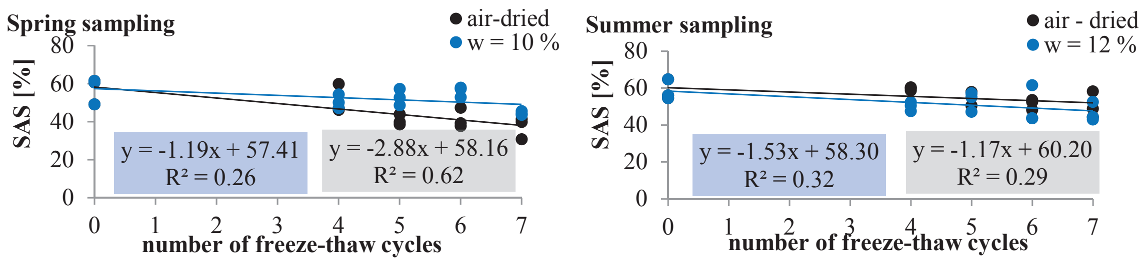
7: *The mean content of water-stable macro-aggregates (Bystřice)*



8: *Plot of soil aggregate stability and number of freeze-thaw (FT) cycles (Bystřice)*

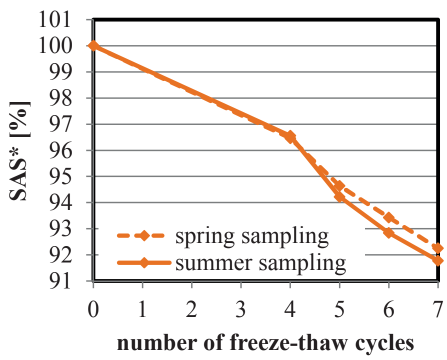


9: *The mean content of water-stable macro-aggregates (Koclířov)*

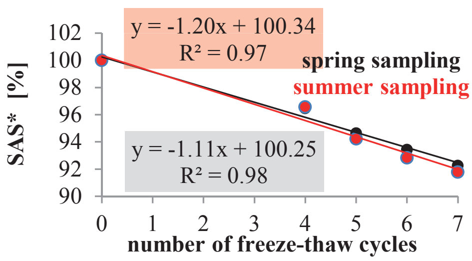


10: *Plot of soil aggregate stability and number of FT cycles (Koclířov)*

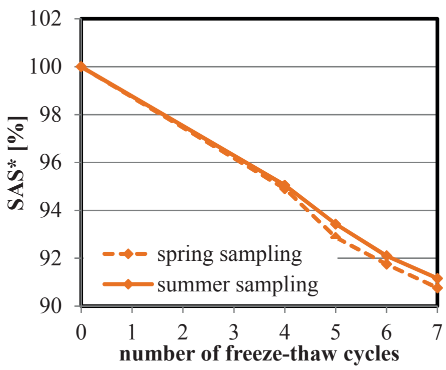
Percentage of water-stable macro-aggregates fraction 1–2 mm determined by dry sieving is presented in the following graphs.



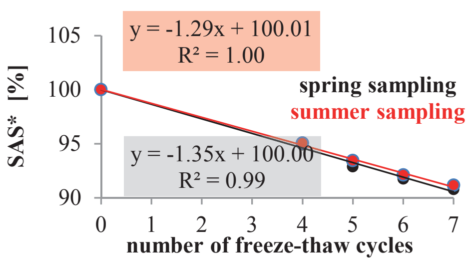
11: *Percentage of stable macro-aggregates (Luká)*



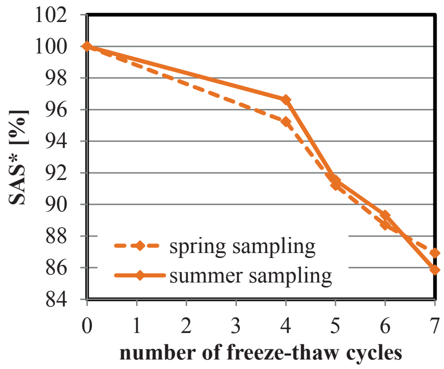
12: *Plot of dry soil aggregate stability and number of FT cycles (Luká)*



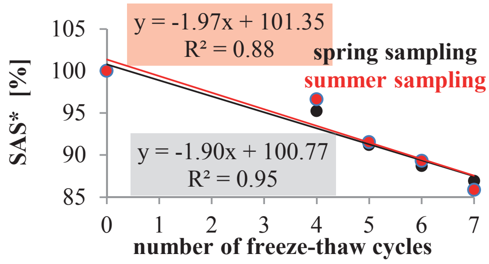
13: *Percentage of stable macro-aggregates (Bystřice)*



14: *Plot of dry soil aggregate stability and number of FT cycles (Bystřice)*



15: *Percentage of stable macro-aggregates (Koclířov)*



16: *Plot of dry soil aggregate stability and number of FT cycles (Koclířov)*

DISCUSSION

Although the hypothesis of decreasing the aggregate stability during an increased number of freeze-thaw cycles was not confirmed by the wet sieving method, there is an evident dependence of aggregate stability on soil moisture (Fig. 5) and on the sampling time (Fig. 6). The amount of water-stable aggregates variably decreased or unexpectedly increased with the increasing number of freeze-thaw cycles (Fig. 5, Fig. 7, Fig. 9). According to Lehrsch (1997), the aggregate stability increased with a few freeze-thaw cycles, but additional FT cycles have little effect. Freeze – drying also reported to an increased aggregate stability (Oygarden, 2000). Mostaghimi (1988) found that the rate of freezing had no effect on aggregate stability. Small fluctuation of values may indicate inaccuracies in measurements and very small changes of SAS due to the freeze-thaw cycles. The dependence of SAS on the time of sampling can be seen especially at the samples from the localities Luká and Bystřice (Fig. 13, Fig. 15). Soil samples taken in summer show a significantly higher SAS, unlike the samples taken during the spring thaw. It is obvious that SAS decreases during the winter and then increases during the vegetation period. Based on the measured results it can be assumed that the simulated conditions were not appropriately chosen. Although the results of the dry sieving method are represented by the same parameter (SAS) as in the case of the wet sieving method, methods cannot be compared. The dry sieving was chosen only as a supplementary method and proves the continuous trend of the decreasing amount of stable macro-aggregates SAS* due to the increasing number of freeze-thaw cycles.

CONCLUSION

The paper deals with the assessment of the impact of cryopedological effects on soil erodibility as one of the causative factors of snowmelt erosion. The soil aggregate stability is one of the main soil characteristics which determine the rate of erodibility. SAS changes depending on the temperature and humidity changes were monitored ex situ. 24-hour freeze-thaw cycles (−5 °C for 12 hours and 5 °C for next 12 hours) were simulated in a climatic chamber. The percentage of stable soil aggregates was determined after the sampling, and subsequently after running 4, 5, 6 and 7 freeze-thaw cycles. The dependence of SAS (Soil Aggregate Stability) on cryopedological phenomena is a controversial topic in foreign literature. Although many authors agree that aggregate stability decreases due to the repeated freezing and thawing of the soil, this hypothesis has not been proven. The results indicate a clear increase in SAS during the growing season. However, SAS did not change significantly as a result of cryopedological phenomena simulated in laboratory conditions. The results of multi-sieve aggregate analysis point to a steady decreasing trend of SAS (water-stable aggregates) due to the increasing number of freeze-thaw cycles. Nor the SAS* (air-stable aggregates) has decreases significantly. With regard to time-consuming changes of soil characteristics, it can be assumed that the duration of freeze-thaw cycles has not been appropriately chosen. There is a possibility of a further research in the cryopedological phenomena, but it is probably desirable to consider some changes in methodology (into account comes change of cycle duration, number of cycles or the temperatures).

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