DETERMINATION OF OVERWINTER PROCESSES INFLUENCE ON BREAKDOWN OF SOIL AGGREGATES

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Abstract: The equation that expresses the influence of factors affecting soil aggregates breakdown, and thus wind erosion, originated from the results of laboratory simulations of soil aggregates breakdown due to low temperatures treatment, field measurements of air temperature and soil moisture, and statistical evaluation of gained outcomes. All the analyses, whether field or laboratory, were realized on three different soils from three different localities of the Bílé Karpaty Mountains foothills – Ostrožská Nová Ves, Blatnice pod Svatým Antonínkem, and Suchá Loz. The statistically significant factors, influencing the soil aggregates breakdown, were determined using multiple regression analysis and stepwise regression. Soil moisture content at time of freezing was the most significant factor affecting soil aggregates breakdown, content of soil particles < 0,01 mm was the least significant one.

Introduction

Wind erosion is a serious problem in many parts of the world and extensive aeolian deposits from past geologic eras give evidence that it is not a recent phenomenon. Area of 19 % of agricultural soils of the Czech Republic is potentially vulnerable to wind erosion (www.sowac-gis.cz). Potential vulnerability to wind erosion relates only to light-textured soils whereas heavy-textured soils are not vulnerable to wind erosion due to the formation of clods and surface crust that resist the blast of wind (Chandler *et al.*, 2005; Langston *et* McKenna Neuman, 2005; Grešová *et* Streďanský, 2011). However, heavy-textured soils can become as erodible as light-textured ones during winter period. This phenomenon occurs in the foothills of the Bílé Karpaty Mountains, east of the Czech Republic

(Podhrázská *et al.*, 2008). Freezing and thawing and freeze-drying of the soil are the main reasons that make resistant heavy-textured soils vulnerable to soil loss by wind. The mentioned overwinter processes are the main contributing factors causing soil aggregates breakdown and subsequent wind erosion also on the Canadian Prairies and northern Great Plains (Bullock *et al.*, 2001). However, the processes proceed here under different climatic conditions than in the Czech Republic due to more highly altitude and thus lower air temperature in the winter period.

The paper deals with the assessment of the most statistically important factors that influence the soil aggregates breakdown in the foothills of the Bílé Karpaty Mountains, and with the quantification of the relationship between the factors using equation.

Materials and methods

The equation that expresses the influence of factors affecting soil aggregates breakdown, and thus wind erosion, originated from the results of laboratory simulations of soil aggregates breakdown due to low temperatures treatment, field measurements of air temperature and soil moisture, and statistical evaluation of gained outcomes.

All the analyses, whether field or laboratory, were realized on three different soils from three different localities of the Bílé Karpaty Mountains foothills – Ostrožská Nová Ves, Blatnice pod Svatým Antonínkem, and Suchá Loz. Some of the general characteristics of the soils used in this study are given in Tab. 1.

Table 1. Pedological characteristics of soils from three experimental areas

Experimental area	Soil type	Soil particles < 0,01 mm (%)	Nonerodible particles > 2 mm (%)	Organic matter (%)	CaCO$_3$ (%)
Ostrožská Nová Ves	chernozem	52,8	54,3	2,3	0,7
Blatnice pod Sv. Antonínkem	chernozem	58,7	58,3	2,9	0,2
Suchá Loz	cambisols	62,7	61,6	3,7	0,2

Own methodology which could simulate the impact of climatic conditions on soil aggregates breakdown was developed. The new methodology was created on the basis of literature survey that deals with simulations of low temperatures impact on soil aggregates breakdown and on the basis of analysis of each individual overwintering method shortcomings.

Laboratory analyses were done with the soil samples according to the methodology that is fully described by Kozlovsky Dufková (2010a) or Kozlovsky Dufková (2010b).

Soil samples from soil surface were air-dried and passed through dry aggregate size distribution (DASD) analysis (Hagen *et al.*, 1987) to determine the amount of non-

erodible fraction (NEF, aggregates > 2 mm in diameter) (Švehlík, 1990). Many studies (e.g. Hinman *et* Bisal, 1968; Staricka *et* Benoit, 1995; Bullock *et al.*, 1999) have shown that soil water content at the time of freezing is an important factor influencing soil disruption. For this reason, water was carefully added to NEF and four soil moisture levels were established – near saturation (Θ_S), field capacity (Θ_{PK}), wilting point (Θ_V), and no water added (dried soil, Θ_0). NEF was consequently exposed to the effect of low temperatures on the laboratory conditions. Effects of freeze/thaw (FT) and freeze/dry (FD) processes were observed. Temperature cutoffs of –2°C for freezing, +2°C for thawing, and –2°C for freeze-drying were used to estimate the number of FT and FD cycles. With regard to the fact that FT and FD processes occur several times during winter, the cycles were repeated several times. DASD analysis was made after every cycle and percentage content of NEF was determined. NEF was repeatedly exposed to low temperatures in FT and FD processes to investigate how many cycles are required for disruption of all NEF.

Field measurements of air temperature and soil moisture were realized. The air temperature in 2 m above the ground was measured by Hobo sensor (Onset Computer Corporation), the ground air temperature at the soil surface was measured by Dallas DS18B20 sensor (Maxim/Dallas Semiconductor Products, Maxim Integrated Products).

VIRRIB sensor (Amet) was measured soil surface moisture at 0,5 m below the ground.

The task of the temperature measurements was to record the number of FT/FD cycles in the field conditions during the winter period from November 2009 to April 2010 and from November 2010 to April 2011.

Results from laboratory simulations and field measurements were statistically evaluated to check whether the suggested methodology of soil aggregates breakdown in the laboratory conditions simulates the field FT/FD processes exactly. Statistical analyses were made using Minitab 15.1. (Minitab Inc.), Unistat 5.1 (Unistat Ltd.), and MS Office Excel programmes.

Results and discussion

Comparison of the field and laboratory simulated FT/FD processes was realized on the basis of comparison of erodible fraction cumulative increases (EF; aggregates < 2 mm in diameter) that came after particular FT/FD cycles (Fig. 1). The reason of using cumulative increases of EF was the unequal content of NEF in the analysed samples at the beginning of the field and simulated FT/FD process. The cumulative increases show the gradual increasing in the amount of disintegrated soil aggregates from the first to the last cycle of field and simulated FT/FD processes.
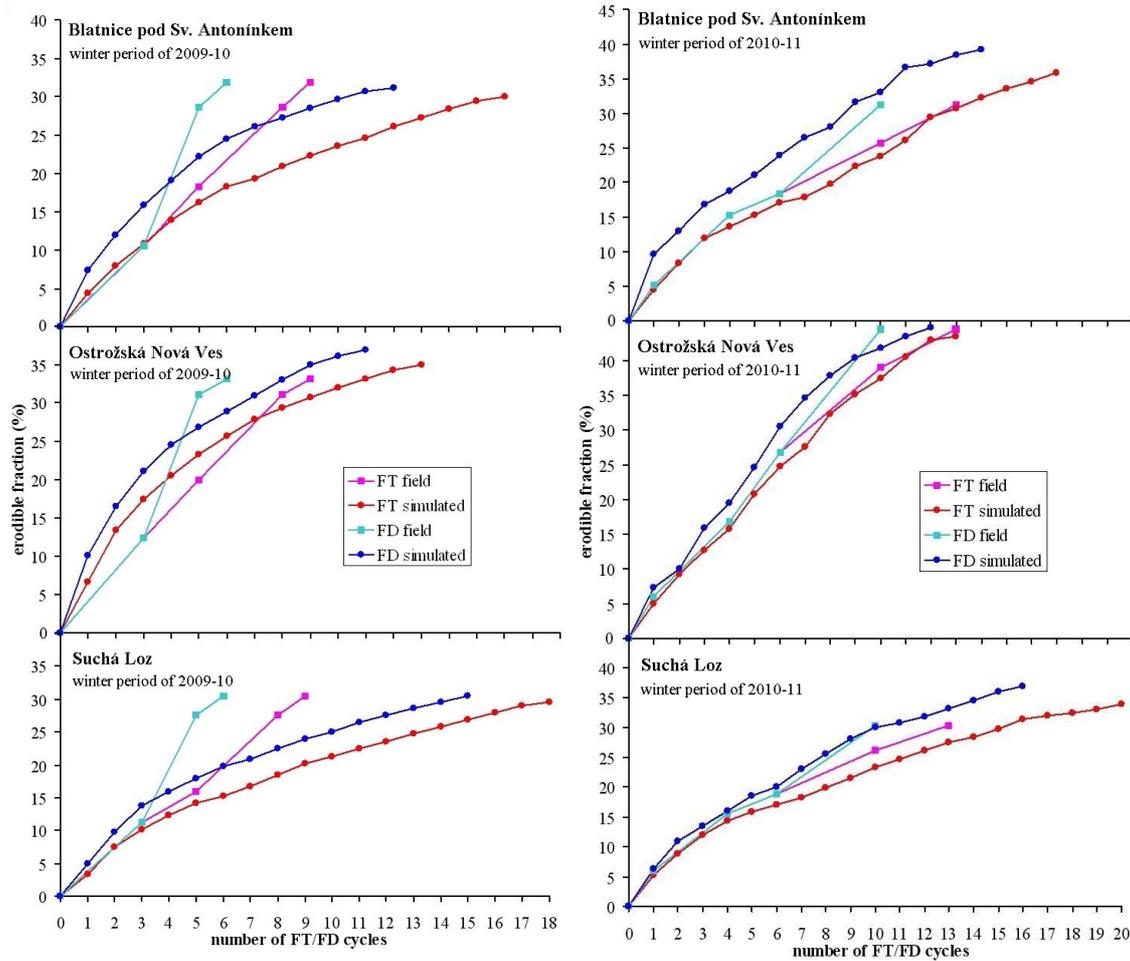
Figure 1. Effect of number of FT/FD cycles on cumulative increases of erodible fraction

Graphical comparison of field and simulated FT/FD processes is based on the subjective assessment. Objective comparison was made by the statistical analyses in Unistat and Minitab programmes using of:

– Pearson correlation coefficient that expresses dependence between EF cumulative increases of field and simulated FT/FD processes; the Pearson correlation coefficient R measures the extent to which two continuous variables are related (Minařík, 2007), R = 0,9130–0,9935 for this study; the P-value tells if the correlation coefficient is significantly different from 0, P = 0,001–0,053 for this study,

– two-sample t-test and confidence interval for field vs. simulated FT/FD processes; these procedures are used to make inferences about the difference between two population means (Friesl, 2004); example of results for Blatnice pod Sv. Antonínkem study area (winter period of 2009–10) are given in Fig. 2 as an individual value plot and a box plot.
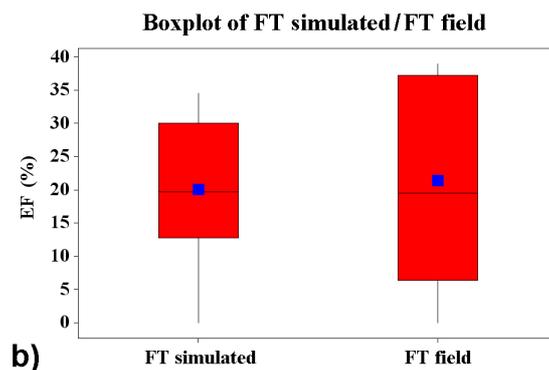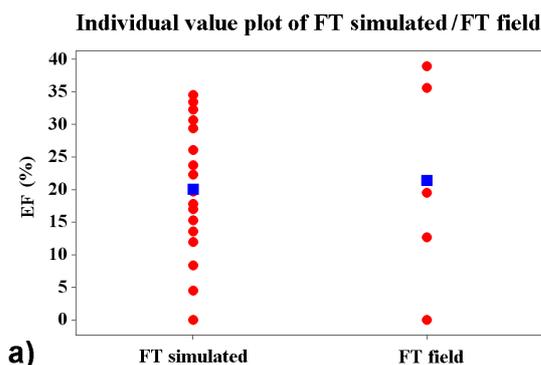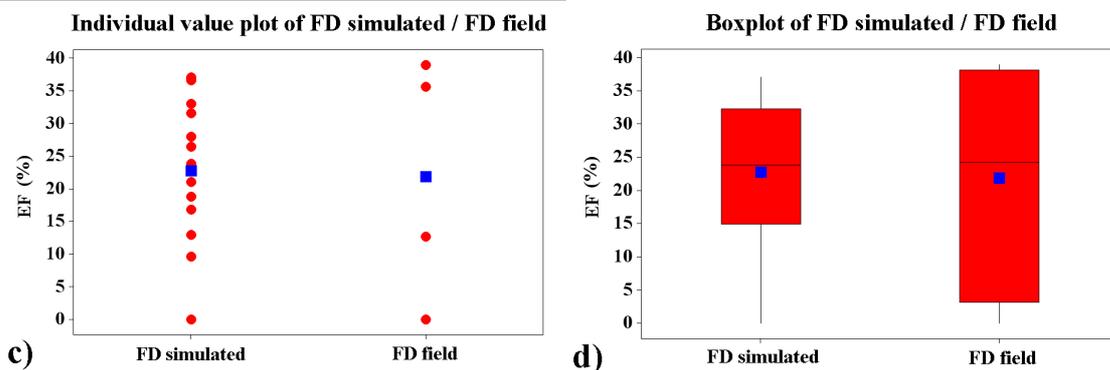
Figure 2. Individual value plots and box plots for erodible fraction cumulative increases of FT (a, b) and FD (c, d) simulated and field processes for the soil from the study area of Blatnice pod Sv. Antonínkem, winter period of 2009–10

Individual value plot is useful to look at side-by-side plots of the data in order to compare the groups. Individual value plots illustrate the dispersion (each dot represents a value observed in a sample) and means (the blue symbols on each plot represents the mean of the sample). A box plot can tell a lot about the distribution of the data. The box represents the middle 50 % of the differences, the line through the box represents the median difference, lines extending from the box represent the upper and lower 25 % of the differences (excluding outliers) (Hendl, 2004).

Statistical analyses show that the field and simulated FT/FD processes of soil aggregates breakdown do not significantly differ from 95 %. It means that the suggested methodology of FT/FD processes in the laboratory conditions really simulates the field FT/FD processes.

Statistically significant factors that influence the soil aggregates breakdown were determined using multiple regression analysis (by Minitab program) and stepwise regression (by Unistat program). Regression analysis investigates and models the relationship between a response (dependent variable) and predictors (independent variables). The result of regression analysis is a regression model/equation. Stepwise regression removes and adds variables to the regression model for the purpose of identifying a useful subset of the predictors (Hendl, 2004).

Stepwise regression analysis was made using final content of NEF after several FT/FD cycles in the winter period as the dependent variable. The independent variables included initial content of NEF before FT/FD processes effect, number of cycles of FT/FD processes in the winter period, soil moisture content at time of freezing, content of soil particles < 0,01 mm, content of organic matter, and content of CaCO$_3$. Multicollinearity was detected for the variables content of organic matter and CaCO$_3$ during creating of correlation matrix (these two variables were highly correlated with other variables in the matrix), thus these variables were excluded from the regression model by Minitab and Unistat programmes. The resulting relationship is given by equation (1). Correlation coefficient for the relationship is 0,8940 and P-value = 0,000.

$$NEF_{end} = -14,09 + 0,49 NEF_{start} - 0,43V - 1,02FT - 1,34FD + 0,62M \quad ,(1)$$

where NEF_{end} = final content of non-erodible fraction after several FT/FD cycles in the winter period (%), NEF_{start} = initial content of non-erodible fraction before FT/FD processes effects (%), FT = number of freeze-thawing cycles in the winter period, FD = number of freeze-drying cycles in the winter period, V = soil moisture content at time of freezing (%), M = content of soil particles < 0,01 mm (%).

According to the cluster analysis and dendrogram (by Minitab program, Fig. 3), the factor that affects the soil aggregates breakdown at most in the winter period is a variable "soil moisture content at time of freezing". Variable "content of soil particles < 0,01 mm" influences the soil aggregates breakdown at least.
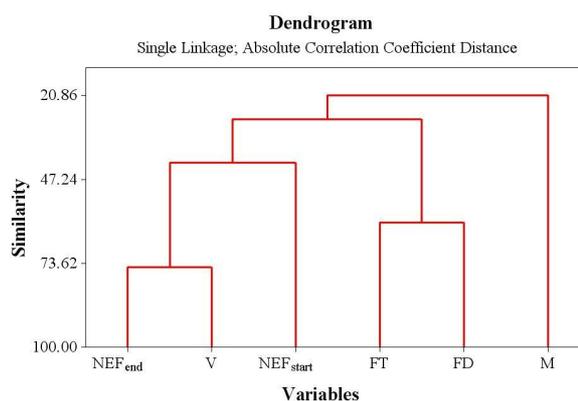

Figure 3. Dendrogram displaying the groups formed by clustering of variables and their similarity levels

Conclusion

The relationship (1) is able to determine the amount of NEF after several FT/FD cycles in the winter period, when soil moisture content at time of freezing and content of soil particles < 0,01 mm are known. The equation is not able to

specify actual amount of eroded soil, however is able to tell if the heavy-textured soil is vulnerable to loss by wind after winter period on the basis of prediction for the erosion threshold of 40 % NEF. Bisal *et* Ferguson (1968) reported that soils with < 40% NEF were prone to wind erosion and they called this value as an erosion threshold.

Acknowledgement

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