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The effect of temperature change on soil structure stability

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Abstract
The influence of variations of temperature, organic carbon content and land use on soil structure stability was investigated by statistical analysis of field and soil data of two loess covered areas in the German part of the Rhine Basin. Aggregate stability as an indicator of structure stability was determined and related to land use, slope aspect and soil organic carbon content. Because aggregate stability showed no relation with aspect, there is little evidence that soil structure stability is related to temperature. Relations between aggregate stability and soil organic carbon content and between aggregate stability and land use were found to be significant.

1. INTRODUCTION

The occurrence and rate of soil erosion is controlled by a number of causes and factors, viz. ability of precipitation to cause erosion (erosivity), length and steepness of slopes, resistance of the soil to erosion (erodibility), and land use (Wischmeier and Smith, 1978; Dikau, 1986). Climate change may, directly or indirectly, affect some of these causes and factors. This study concentrates on the impact of climate change on soil structure stability, because structure stability controls the rate of soil structure degradation, and it is still in an under-developed research area. Climate affects soil structure stability through its influence on the organic matter status of the soil, which depends on biomass production and decomposition of organic materials by soil (micro)biological activity (Tate, 1987). Soil structure is characterized by the presence of soil aggregates, clusters of soil particles which mutually adhere by chemical and physical binding forces. In surface soils, these forces are mainly controlled by organic matter. Macro-aggregates (>250µm) are mainly stabilized by plant roots and larger fungi (Tisdall and Oades, 1982). Micro-aggregates (20-250µm) are bound together by decomposed organic substances and bacteri. Micro-aggregation in the size class 2-22µm is mainly caused by clay particles, and to a lesser extent by organic materials (Oades, 1993; Tisdall and Oades, 1982). The rate of structure development and structure breakdown is dependent on the dynamics of soil organic matter, which, in turn, is controlled by soil moisture and soil temperature regime (Chaney and Swift, 1984; Tate, 1987; Jenkinson and Ayanaba, 1977). The study of the impact of climate change on soil structure stability is carried out in two areas covered with loess in the catchment of the River Rhine (Dikau, 1986; Clemens and Stahr, 1994; Schalich, 1981).

Objective of research is: to analyze the influence of temperature variation on soil structure stability by establishing relationships between aggregate stability and environmental factors like land use and temperature, and soil properties like soil organic matter content and particle size distribution for loess soils in the German part of the Rhine Basin. Based on a comparative study of aggregate stability in different parts of the Rhine basin with different temperature conditions under the current climate, existing differences in structure stability between areas with different temperature regimes might be an indication of the change in soil structure stability that will possibly occur as a consequence of climate change.

2. STUDY AREA AND METHODS

In the German part of the Rhine basin areas covered with loess were selected to compare the structure stability of the soils and analyze the relationship with environmental factors and soil properties: "the Kraichgau" in the federal state Baden Württemberg in the drainage basin of the river Neckar and the "Jülicher Börde" in the federal state Nordrhein Westfalen, stretching from the drainage area of the Lippe to the west bank of the Rhine into the basin of the Meuse. These areas differ amongst others with respect to climate, relief and mean elevation.
The soil types present in these areas are Braunerden grown with forest, Parabraunerden (agriculture use or forest) and Pararendzina's (agricultural use).
The climate of the Kraichgau is warm and dry (semi-continental). Mean annual precipitation as displayed in table 1 is 806 mm. The precipitation of the period June till August is dominated by high-energy storms. Snow cover and soil frost

may occur from December till March.

Table 1 Climatological data for station Heidelberg

Month	J	F	M	A	M	J	J	A	S	O	N	D	YEAR	
Tmean	1.3	2.4	6.7	10.7	15.0	18.1	19.8	19.0	15.8	10.6	6.1	2.4	10.7	°C
Tmax	3.6	5.3	10.9	15.6	20.4	23.4	25.1	24.4	20.8	14.5	8.5	4.5	14.8	°C
Tmin	-1.4	-0.8	2.6	6.1	9.9	12.9	14.8	14.8	11.6	7.2	3.6	0.0	6.7	°C
Prec	66	52	45	61	73	90	87	90	65	62	60	55	806	mm

Source: Müller (1979)

Temperature data from table 1 are taken from Müller (1979). Mean annual temperature for station Heidelberg is 10.7 °C. The warmest month is July, average temperature 19.8 °C, the coldest month is January, average temperature 1.3 °C. The annual mean minimum temperature is 6.7 °C, the annual mean maximum temperature is 14.8 °C.

Climatic data of the Jülicher Börde are taken from Müller (1979) as displayed in table 2.

Table 2.2 Climatological data of station Aachen.

Month	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Tmean	1.8	2.2	5.6	8.9	12.9	16.0	17.6	17.2	14.5	10.1	6.0	3.1	9.7
Tmax	4.2	5.1	9.9	13.5	17.8	20.8	22.3	22.2	19.5	14.0	8.6	5.2	13.6
Tmin	-0.9	-0.7	2.0	4.8	8.1	11.4	13.3	13.3	10.9	6.9	3.6	0.7	6.1
Prec	72	59	49	63	67	77	75	82	68	64	67	62	805

Source: Müller (1979)

The mean annual precipitation is 805 mm, with a maximum mean in August of 82 mm, and the driest month is March with 49 mm. The period from June to August is dominated by high-intensity storms, with a monthly maximum total of 82 mm in August. The annual mean temperature is 9.7 °C, the mean temperature of the warmest month (July) is 17.6 °C, the coldest month is January with a monthly mean temperature of 1.8 °C

The effect of climate on soil structure was studied on a meso-scale by comparing loess soils on north- and south-facing slopes with minimum variation of geology and topography. Besides climatologically induced variations, also differences in soil structure between land use types (arable land and forest) and between surface soil and subsoil were investigated.

Soil samples were tested on presence of lime, organic carbon content (Allison, 1935), aggregate stability (Low, 1954; Grieve, 1979; Imeson and Vis, 1984), soil texture and micro-aggregation (Edwards and Bremner, 1967; Imeson and Vis, 1984). Results of the drop test of Low were transformed to the AS-index of aggregate stability (Hollemans and Van Dijk, 1988).
Aggregate stability can be expressed as the reciprocal of AS. With statistical methods of data analysis (cluster analysis, Analysis of Variance, Mann-Whitney U-test; see Davis 1986) differences between groups of samples were evaluated.

3. RESULTS

The statistical analysis of the relations between environmental factors and soil structure stability of loess soils shows that the direct and indirect effects of temperature on

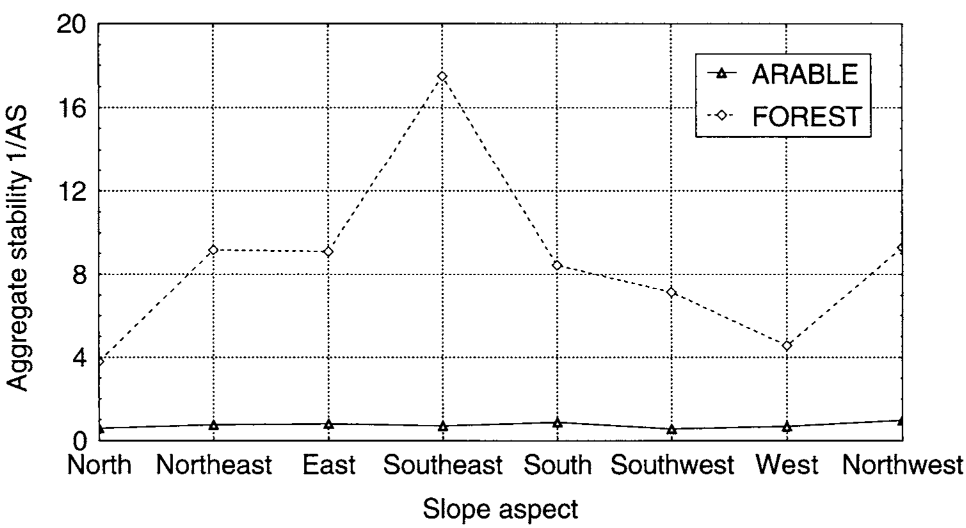

Figure 1 Aggregate stability of agricultural soils and forest soils grouped to aspect

aggregate stability is difficult to recognize in the field. The mean values of aggregate stability of arable surface soils do not vary for slopes having different aspects (figure 1). For forest topsoils the values of aggregate stability vary widely with aspect. The results as displayed in figure 1 suggest that forest soils are stable on south-east facing slopes, and have minimum stability on north facing slopes. There is no clear recognizable pattern of variation of aggregate stability with slope aspect.

There is a strong and significant relationship (R = -0.82) between the index of aggregate stability (AS) and soil organic carbon content. After log-transforming the data to stabilize the variances of both variables (Davis, 1986), the regression equation is:

$$LOG(AS) = 0.099 - 1.138 LOG(\%C) \quad \textbf{(1)}$$

AS decreases with increasing carbon content, which means that aggregates become more stable with increasing carbon content of the soil (figure 3).

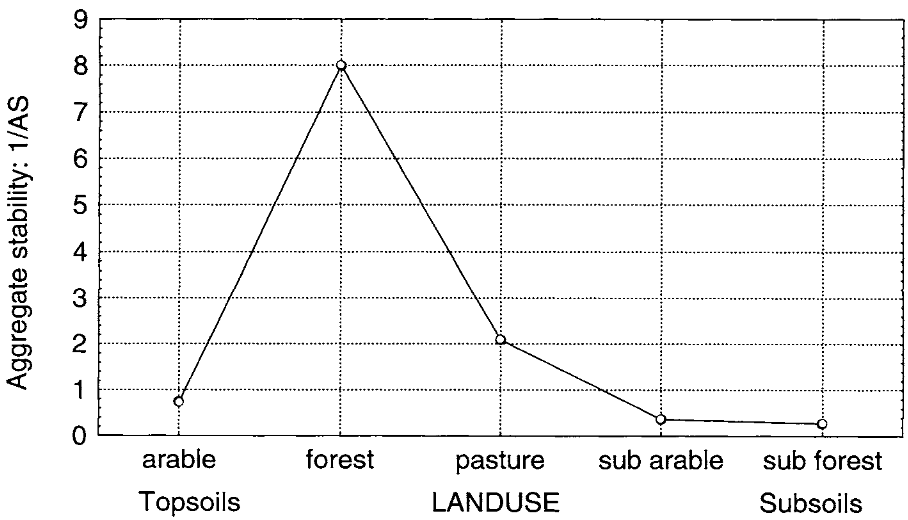

Figure 2 Aggregate stability grouped to land use

From figure 2 the influence on aggregate stability of land use is obvious: forest surface soils are most stable, while arable surface soils have more stable aggregates than subsoils. The aggregate stability of surface soils under pasture is between that of forest and arable soils.

The variation of temperature and soil moisture due to different aspect of valley slopes showed no good correlation with aggregate stability.

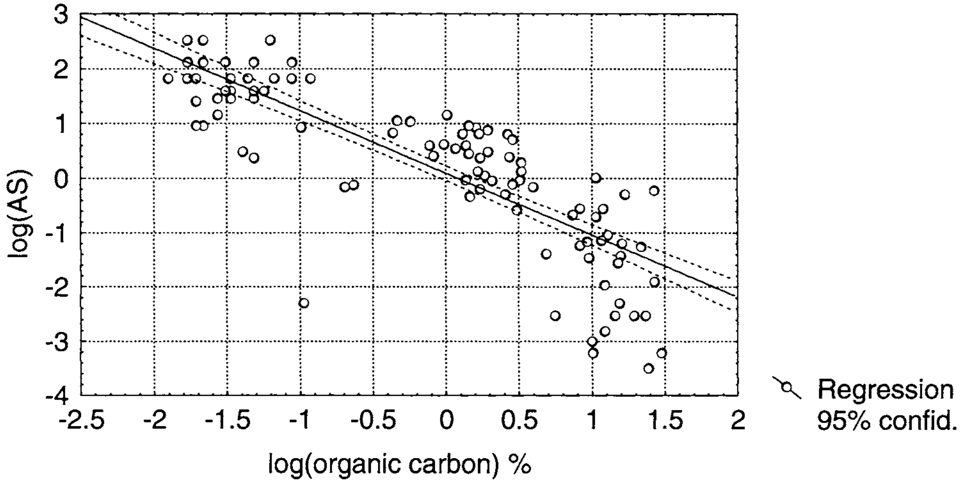

Figure 3 Relation between organic carbon content and aggregate stability index

Table 1 Index of aggregate stability of soils from two sample areas grouped to land use

	Jülicher Börde	Kraichgau
land use	AS	AS
Arable	1.56	1.61
Forest	0.43	0.29
Pasture	0.57	0.61
subsoil arable	4.58	5.41
subsoil forest	6.60	6.61
all samples	2.75	2.91

The aggregate stability of soils of two different areas is listed in table 1. The difference of means of aggregate stability calculated for 5 groups of land use was not significantly different for areas under different climate. The mean of aggregate stability for all groups indicated that soils in the Kraichgau area (with warmer and drier climate) are somewhat less stable than in the Jülicher Börde, but this difference was not significant on the α=0.05 level.
However, as the tests give an indication of the present state, there still can be a difference between the *development* of aggregate stability, due to differences in climate.

The present study of the effect of temperature variations on aggregate stability of loess soils shows that temperature does not have a significant influence on the structure stability of soils. Soil structure stability is strongly correlated with the soil organic carbon content, which is determined by the land use. According to the study of Veeneklaas et al (1994), climate change may have a profound effect on land use, thereby implicitly influencing soil properties as well.

4. REFERENCES

- Allison, L.E. (1935):
  Organic carbon by reduction of chromic acid. Soil Sci. 40: pp.311-320
- Chaney, K. and R.S. Swift (1984):
  The influence of organic matter on aggregate stability in some British soils. Journal of Soil Science, 35, pp.223-230
- Clemens, G. and K. Stahr (1994):
  Present and past soil erosion rates in catchments of the Kraichgau area (SW-Germany). In: Catena 22 (1994) pp.153-168
- Davis, J.C. (1986):
  Statistics and data analysis in geology. 2nd edition. John Wiley & Sons, New York Chichester
- Dikau, R. (1986):
  Experimentelle Untersuchungen zu Oberflächenabfluss and Bodenabtrag von Messparzellen und landwirtschaftlichen Nutzflächen. Heidelberger Geographischen Arbeiten Heft 81. Heidelberg, Germany
- Edwards, A.P. and J.M. Bremner (1967):
  Dispersion of soil particles by sonic vibration. J. Soil Sc.18:47-63
- Grieve, I.C. (1979):

Soil aggregate stability tests for the geomorphologist. Technical Bulletin 25. British Geomorphological Research Group
- Hollemans, W. and P. van Dijk (1988):
Faktoren van invloed op infiltratie en bodemerosie. Regionale vergelijking tussen drie gebieden in zuid-limburg. Fysisch Geografisch & bodemkundig laboratorium, Universiteit van Amsterdam (In Dutch)
- Imeson, A.C. and M. Vis (1984):
Assessing soil aggregate stability by water-drop impact and ultrasonic dispersion. Geoderma, 34: 85-100
- Jenkinson, D.S. and A. Ayanaba (1977):
Decomposition of Carbon-14 Labeled plant material under tropical conditions. Soil Sci. Soc. Am. J., Vol 41, pp912-915
- Low, A.J. (1954):
The study of soil structure in the field and in the laboratory. Journal of Soil Science, 5, pp57-74
- Müller, M.J. (1979):
Handbuch ausgewahlter Klimastationen der Erde. Forschungsstelle Bodenerosion der Universität Trier Mertesdorf (Ruwertal)
- Oades, J.M. (1993):
The role of biology in the formation, stabilization and degradation of soil structure. Geoderma 56, pp 377-400
- Schalich, J. (1981):
Boden- und Landschaftsgeschichte in der westlichen Niederrheinischen Bucht. In: Fortschr. Geol. Rheinld. u. Westf. 29, pp 505-518
- Tate III, R.L. (1987): Soil organic Matter. Biological and ecological effects. J. Wiley & sons
- Tisdall, J.M. and J.M. Oades (1982):
Organic matter and water-stable aggregates in soils. Journal of soil science 33 pp 141-163
- Veeneklaas, F.R., L.M. van den Berg, D. Slothouwer and G.F.P. IJkelenstam (1994):
Rhine Basin study: Land use projections based on biophysical and socio-economic analyses. Volume 4, Land use: past, present and future. Report 85.4, Winand Staring Centre (SC-DLO), Wageningen, the Netherlands
- Wischmeier, W.H. and D.D. Smith (1978):
Predicting rainfall erosion losses - a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No. 537