

Characterization of soil aggregate stability using low intensity ultrasonic vibrations

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A b s t r a c t. Ultrasonic dispersion equipment has been developed to investigate soil aggregate stability. An ultrasonic probe was vibrating in water containing soil aggregates. Constant vibration amplitudes of 0.5, 1 and 2 μm were used in ultrasonic soil aggregate stability measurements. Ultrasonic power determined with an energy balance method was 0.7, 2.7 and 8.9 W for the three amplitudes. Vibration amplitudes were close to the cavitation limit of gas saturated deionized water, which was found at 0.5-0.6 μm measuring absorbance with diode array spectrophotometer. Cambisol and Chernozem from a long-term tillage experiment in Lower Austria were investigated. The treatments were conventional, reduced and no tillage. Dissolved organic carbon measured with ultrasonic extraction was higher in Cambisol than in Chernozem. Measuring soil aggregate stability according to DIN norm showed greater stability of Cambisol than of Chernozem, however, can hardly show influences of tillage. Ultrasonic soil aggregate stability showed greater stability of Cambisol. Additionally, the ultrasonic soil aggregate stability method can demonstrate significant influences of soil tillage on aggregate stability *ie* stability decreased from no tillage to reduce tillage and conventional tillage for both soils. Ultrasonic soil aggregate stability measurements correlated with total organic carbon content in aggregates. Total organic carbon content was greater in no tillage than in conventional tillage and larger in Cambisol than in highly degraded Chernozem.

K e y w o r d s: soil aggregate stability, ultrasonic dispersion, cavitation limit, carbon distribution, tillage

INTRODUCTION

Ultrasonic dispersion is a widely used method to disaggregate and disperse soil aggregates. Aggregates and particles of different size may be fractioned and used for further physical or chemical analysis without prior use of chemical agents (Ashman *et al.*, 2009; Zhu *et al.*, 2010). Ultrasonic

waves are emitted into water containing the soil aggregates, and cavitation bubbles are generated. High pressures occur when cavitation bubbles collapse, which promotes disaggregation and dispersion of soil aggregates.

Disaggregation is closely related to the power of the used ultrasonic equipment and to the time the water-soil mixture is subjected to ultrasonic vibrations. The absorbed energy (North, 1976) or absorbed energy per unit volume of fluid (Morra *et al.*, 1991) may be correlated to the process of soil particle disaggregation and dispersion and may serve to quantify the stability of soil particles. Several models for the aggregation of soil assume hierarchical order (Bronick and Lal, 2005; Fristensky and Grismer, 2008). In general these models divide soil particles into micro- and macroaggregates being larger or smaller than 250 μm . The hierarchical nature of soil structure indicates that different aggregation mechanisms operate for different size classes of aggregates; consequently, aggregates of different size classes will have different stability (Amézqueta, 1999).

One main benefit of the ultrasonic method is the ability to quantify several physical parameters of the experiment. The energy used to disaggregate and disperse soil particles, for example, may be used to quantify and compare the results of different ultrasonic stability tests (Fristensky and Grismer, 2008; North, 1976). Nonetheless, problems arise evaluating and comparing ultrasonic dispersion results of different laboratories due to several reasons:

- Different ultrasonic procedures: Probe- and tank-type ultrasonic devices are used. Magnitude of ultrasonic vibration is often quantified using the ultrasonic power. However, power displayed on the instruments may differ

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- from the actual power output depending on equipment, insertion depth and geometry of the ultrasonic probe (Oorts *et al.*, 2005; Schmidt *et al.*, 1999; Zhu *et al.*, 2009a).
- Different soil treatment: Experimental procedures may vary considerably and are often not well defined. Results strongly depend on pretreatment and soil water content (Raine and So, 1994). Treatment time and soil/water ratio influence the effectiveness of the ultrasonic dispersion (Zhu *et al.*, 2010).
 - Different evaluation: Classification of soil particle sizes and presentation of results are not well standardized. The terms macro-, meso- and microaggregates, for example, refer to different particle sizes in the range from 8 mm to 2 μm , and different numbers of classes serve to quantify the frequency of different aggregate fractions (Amézketa, 1999). This makes it necessary to interpret the results within the context of the used methodology (Daraghmech *et al.*, 2009).

The aim of this work is to further develop the ultrasonic method for soil science applications.

MATERIAL AND METHOD

Topsoil samples of Cambisol and Chernozem (0–5 cm) were taken from two sites in Lower Austria in fall 2009 (before harvest) that have been under continuous investigation in long-term tillage and erosion experiments. The two sites, Tulln and Pixendorf, situated North-West of Vienna, exhibit experimental fields with altered crop rotation and three different tillage systems:

1. conventional tillage (CT) with mechanical weed control,
2. reduced tillage (RT) with cultivator and cover cropping in winter,
3. no tillage (NT) with inter cropping in winter.

The soil management practices at each site started in the year 1999. The three different tillages were applied to a loamy clay Cambisol and a loamy silt Chernozem (Table 1). The average annual precipitation at both sites is 685 mm with a mean annual temperature of 9.4°C. Tulln has a gradient of 0–2% whereas gradient of Pixendorf site is 5–6%. The experimental set-up varies in allotment length only. The site Pixendorf features an allotment length of 100 m with an allotment width of six metres. In Tulln, the allotment length is 25 m. Samples were air-dried and sieved, and aggregates with diameters between 1 and 2 mm were obtained. Soil aggregate stability was performed in two ways:

Table 1. Characterization of soil samples from Cambisol and Chernozem

Sample	Sand	Silt	Clay	N _{tot}	TOC	CaCO ₃	C/N
	(%)						
Cambisol	11.13	39.87	51.0	0.25	3.33	1.4	13.1
Chernozem	23.61	64.89	11.5	0.14	1.86	14.9	13.5

- soil aggregate stability (SAS) according to DIN-Norm 19683-16,
- ultrasonic soil aggregate stability (USAS) according to Mentler *et al.* (2004), soil aggregates were analyzed after three different sonification procedures: vibration amplitude 0.5 μm for 60 s, vibration amplitude 1 μm for 30 s and vibration amplitude 2 μm for 15 s.

Total organic carbon content (TOC) was measured with a CNS Analysator (Carlo Erba 1500) with flash combustion technique (ÖNORM L-1080-89). For the destruction of carbonates, the samples were pretreated with 15 μl concentrated HCl and subsequently dried.

Extraction of dissolved organic carbon (DOC) from soil samples was conducted with the ultrasonic technique using Bandelin Sonoplus HD 2200 equipment. The ultrasonic probe had a cylindrical shape with a diameter of 12.7 mm in the extraction experiments. Extraction was performed with vibration amplitude 23 μm and an extraction ratio of 1:50 and using high ultrasonic energy (specific energy greater than 312 J ml⁻¹). With HP 8452A Diode Array Spectrophotometer at 254 nm the release of DOC (mg l⁻¹) from the soil samples was determined, according to (Brandstetter *et al.*, 1996).

Commercially available ultrasonic equipment have several shortcomings, that limit their application in soil science: Control parameter is the ultrasonic power, their lowest power setting is rather high and their accuracy is low. In the present study, self-developed ultrasonic soil dispersion equipment is used, which is an adapted ultrasonic material testing system (Mayer, 2006). It is a probe type system, where one end of the cylindrical ultrasonic probe is dipped in water containing the soil aggregates. The probe performs resonance vibrations at ultrasonic frequency (approximately 20 kHz) leading to the emission of pressure waves into the fluid. Vibration amplitude of the cylindrical ultrasonic probe is measured with an induction coil. In a closed-loop electronic circuit, the amplitude is controlled and kept constant with very high accuracy. Vibration amplitude and duration of sonification are selected prior to the dispersion experiment. Compared with commercially available ultrasonic soil dispersion equipment, the self-built system has three main advantages:

- It uses the vibration amplitude rather than the power to control the magnitude of loading in the dispersion experiment. Under well-defined geometrical conditions, the vibration amplitude strongly correlates with the magnitude of the acoustic pressure waves emitted into the fluid, that cause dispersion of soil particles (Kuttruff, 1988; Millner, 1987). Measurement of the vibration amplitude of an ultrasonic probe can be performed accurately with numerous standard measuring methods including induction coils used here, optical methods *eg* with laser vibrometer or indirect methods performing strain measurements (Mayer *et al.*, 2002). In contrast, the actual power of

ultrasonic equipment cannot be measured directly but it is derived from voltage and current signals, the efficiency of the ultrasonic transducer and other electrical and mechanical parameters of the system (Ratoarinoro *et al.*, 1995; Zhu *et al.*, 2009b). This is prone to errors and can lead to large differences between the displayed power and the actual power output (Oorts *et al.*, 2005; Schmidt *et al.*, 1999). Additionally, at low acoustic pressures close to the cavitation limit, the ultrasonic power fluctuates considerably due to the statistically varying water volume subjected to cavitation.

- It is very accurate. Closed-loop control of vibration amplitude and resonance frequency guarantee, that the maximum deviation of pre-selected and actual vibration amplitude is maximum $\pm 1\%$. In contrast, control of ultrasonic power is less accurate and prone to errors. Ultrasonic power may vary during the experiment and is influenced by the process of soil dispersion, for example. Detailed recent study shows that ultrasonic energy can be quantified within 10-20% accuracy only (Zhu *et al.*, 2009b).
- It allows performing experiments at high and very low vibration amplitudes. It is possible, for example to perform experiments below the cavitation limit. Weakly aggregated and degraded soils, for example, can be characterized in this way.

The ultrasonic soil dispersion equipment works at a frequency close to 20 kHz. Cylindrical ultrasonic probe with diameter 30 mm is used. This is larger than diameters of probes used in commercially available equipment, which are typically between 10 and 19 mm (Schmidt *et al.*, 1999). The larger diameter of the ultrasonic probe leads to a better homogeneity of the pressure field. Additionally, emission of acoustic energy increases about linearly with the area of the ultrasonic probe *ie* with the square of the diameter. Using probes with large diameters, certain ultrasonic power can be reached at lower vibration amplitudes and lower acoustic pressures.

Ultrasonic experiments were performed using 80 ml water in a beaker with diameter 44 mm made of PMMA glass. The insertion depth was about 4 mm in all experiments, which means that the distance from the lower end of the ultrasonic probe to the bottom of the beaker was about 50 mm. This length was chosen to avoid resonance of the acoustic waves in the water (half wavelength of sound waves of 20 kHz frequency in water is 37 mm and one wavelength is 74 mm). 4 g soil were inserted in 80 ml deionized water shortly before the dispersion experiment started. The solution was stirred with a magnetic device (2 Hz, cylindrical shape with length 25 mm and thickness 8 mm). Stirring started simultaneously with the ultrasonic vibration and was continued during the experiments to obtain homogeneous soil distribution in the solution.

Power of ultrasonic equipment used for soil science applications can be calibrated with calorimetric methods. North (1976) suggested a procedure, which was later used and adapted by several investigators (Morra *et al.*, 1991;

Oorts *et al.*, 2005; Raine and So, 1994; Roscoe *et al.*, 2000). North uses an energy balance criteria to determine the ultrasonic power *ie* when ultrasonic waves are emitted into water, power delivered by the equipment is balanced by the increase of thermal energies of water and beaker per second plus the loss of heat into the environment per second. The method suggested by North (1976) may be successfully used for commercially available ultrasonic equipment. Power output of such equipment is relatively large, and diameters of ultrasonic probes are relatively small, which causes a relatively small rate of heat loss. In the present investigation however, experiments with very low ultrasonic power close to the cavitation limit are performed. Additionally, the diameter of the ultrasonic probe and its mass are large which leads to large heat capacity and considerable heat transport due to thermal conduction. Due to these reasons, we use the following caloric calibration procedure to determine the power of the ultrasonic equipment. The vibration amplitude of ultrasonic probe end is kept constant during the experiment. The ultrasonic probe is inserted in water (mass of water is m_w and specific heat capacity is c_w), and the increase of water temperature, ΔT during the time period Δt is measured. Changes of thermal energy of water are caused by the ultrasonic vibrations and by the heat exchange with ultrasonic probe, beaker and laboratory air. With the ultrasonic power, P_{US} and the heat exchange per second, $\Delta Q_{Exchange}/\Delta t$, change of thermal energy of water per second, $m_w c_w \Delta T/\Delta t$ is given by Eq. (1):

$$m_w c_w \frac{\Delta T}{\Delta t} = P_{US} + \frac{\Delta Q_{Exchange}}{\Delta t}. \quad (1)$$

Heat flow between water and environment due to convection or thermal conduction is driven by a temperature gradient. Heat flow from water to beaker, ultrasonic probe or laboratory air is proportional to the respective temperature difference. At the beginning of ultrasonic power measurements, all mechanical components of the system including ultrasonic probe and beaker are at ambient temperature. Water with temperature below ambient temperature is used at the beginning of the experiment. $\Delta Q_{Exchange}/\Delta t$ is greater zero and increase of thermal energy of water per unit time is the sum of ultrasonic power and heat flow into the water. Water temperature is measured and increases during sonification. When water temperature is above ambient temperature, $\Delta Q_{Exchange}/\Delta t$ becomes less than zero. When the temperature of water and environment coincide, $\Delta Q_{Exchange}/\Delta t$ becomes zero and the ultrasonic power is directly correlated to the increase of water temperature.

Spectroscopic experiments were conducted using a HP 8452A Diode Array Spectrophotometer. The tip of the ultrasonic probe is inserted into a beaker containing gas saturated de-ionized water. The beaker is mounted in the optical path of the photometer with the light source on one side and the diode array detector on the other.

A wavelength range from 300 to 800 nm was chosen with a bandwidth of 2 nm and an integration time of one second. The ultrasonic probe vibrates at different previously selected vibration amplitudes, and the absorption coefficient is measured. Cavitation leads to bubbles in the water that cause scatter and reflection and thus attenuation of the transmitted light. Therefore, the absorption coefficient abruptly increases when cavitation occurs, which serves to detect the occurrence of cavitation. The experiments were repeated five times with constant temperature 22°C in the absorption cell.

SPSS Version 8 (Bühl and Zöfel, 1999) was used to calculate means and standard deviations of all data and one-way ANOVA followed by the Duncan Test ($p < 0.05$) to compare means.

RESULTS AND DISCUSSION

Ultrasonic power is measured at different vibration amplitudes of the ultrasonic probe. Temperature increase of water is measured and the absorbed thermal energy per second is calculated. Figure 1 shows the results of measurements for vibration amplitudes 1, 2, and 3 μm. Each measurement is repeated four times. The abscissa shows the water temperature. Ultrasonic probe and beaker have ambient temperature of 20°C, whereas water temperature is below ambient at the beginning of the experiments. Therefore, heat flows into the water from ultrasonic probe, beaker and laboratory air at the beginning. With increasing water temperature heat flow decreases and vanishes, when water temperature is 20°C. At higher temperature, heat flows from water to beaker, ultrasonic probe and laboratory air. Absorbed energy per second when water temperature is 20°C is the ultrasonic power.

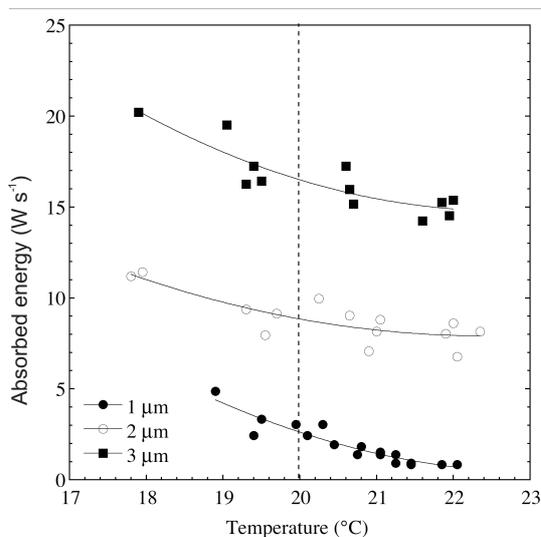


Fig. 1. Increase of thermal energy of water per second for vibration amplitudes of 1 μm (closed circles), 2 μm (open circles), and 3 μm (closed squares).

Ultrasonic power at vibration amplitude 1 μm determined in this way is by mean 2.7 W. At vibration amplitude 2 μm, the mean ultrasonic power is 8.9 W. Mean power at 3 μm is 16.5 W, and at vibration amplitude 0.5 μm mean power is 0.7 W (not shown in Fig. 1). Data scatter is relatively large, which is caused by the statistical occurrence and magnitude of cavitation close to the cavitation limit. Consequently, the absorbed energy varies in the different experiments.

Absorbance determined with HP 8452A Diode Array Spectrophotometer are shown for light with wavelengths between approximately 340 and 550 nm in Fig. 2. Wavelengths are indicated on the abscissa and absorption coefficients on the ordinate. If cavitation occurs, absorbance increases significantly compared to no cavitation. Cavitation bubbles in the light path of the spectrophotometer cause scattering and reflections, which increases absorbance. Increase of absorption coefficient is visible within the whole range of investigated wavelengths from 300 to 800 nm.

Experiments with different vibration amplitudes of the ultrasonic probe in the range between 0.3 and 0.8 μm are performed to determine the cavitation limit. Figure 3 shows the absorption coefficient for different vibration amplitudes of the ultrasonic probe. Between 0.5 and 0.6 μm there is sharp increase in absorbance. Thus minimum vibration amplitude necessary to cause cavitation in gas saturated deionized water is 0.5-0.6 μm.

Few experimental investigations on the cavitation limit in water can be found in the literature. For frequency 15 kHz, the minimum acoustic pressure amplitudes necessary to cause cavitation in tap water are found in the range from 0.5 to 2 bar (Esche, 1952). With the vibration frequency, f , the vibration amplitude, u , the mass density, ρ , and the sound velocity, c , the acoustic pressure, p_a , can be calculated using Eq. (2) (Kuttruff, 1988; Millner, 1987):

$$p_a = 2\mu f u \rho c. \tag{2}$$

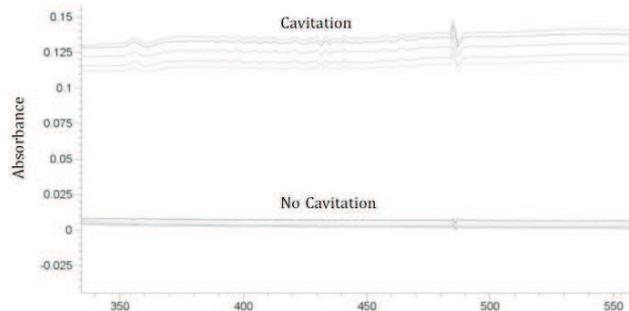


Fig. 2. Absorption coefficients determined with HP 8452A Diode Array Spectrophotometer for wavelengths between 340 and 550 nm without cavitation (lower lines) and with cavitation (upper lines).

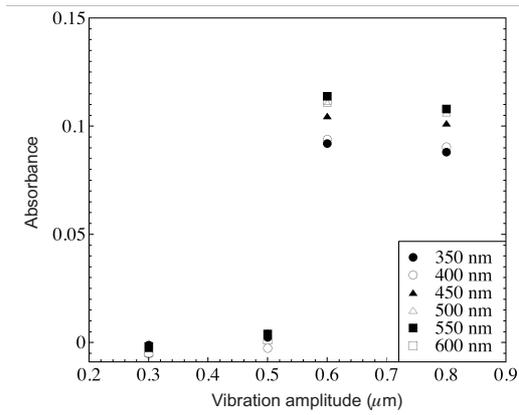


Fig. 3. Absorption of light with different wavelengths in water subjected to ultrasonic vibrations with amplitudes between 0.3 and 0.8 μm .

Considering the mass density of water (998 kg m^{-3} at 20°C) and the sound velocity in water (1483 m s^{-1} at 20°C), the acoustic pressure amplitudes are 0.9 bar for vibration amplitude $0.5 \mu\text{m}$ and 1.1 bar for $0.6 \mu\text{m}$. This means that the minimum acoustic pressure necessary to cause cavitation in gas saturated deionized water at 20 kHz frequency is about atmospheric pressure.

Additional experiments have been performed with deionized and degassed water. Cavitation limit under these conditions is at higher vibration amplitudes in the range between 1 and $1.5 \mu\text{m}$, which corresponds to acoustic pressures between 1.9 and 2.8 bar. This supports studies reported in the literature, that degassing of water raises the cavitation limit (Raine and So, 1994). In the present investigation, ultrasonic soil disaggregation experiments are performed using vibration amplitudes of 0.5, 1, and $2 \mu\text{m}$, which is close to or slightly above the cavitation limit.

Figure 4 shows mean values and standard deviation (five repetitions) of SAS measurements according to DIN-Norm 19683-16. Samples of Cambisol show overall higher stability than samples of Chernozem due to the higher content of organic carbon and clay. Differences in SAS between the three tillage systems proofed to be not significant for Cambisol. Soil aggregates of Chernozem lost more than 50% of their stability through CT in comparison to RT and NT. Differences of Chernozem in SAS between RT and NT proofed to be not significant. The hillside location increases the loss of clay and organic matter and reduces soil aggregate stability.

Figure 5 shows the results of ultrasonic soil aggregate stability measurements after sonification with three different vibration amplitudes and sonification times. Vibration amplitude $0.5 \mu\text{m}$ for 60 s (Fig. 5a): with the ultrasonic power of 0.7 W the absorbed ultrasonic energy in 80 ml water and 4 g soil is 42 J and the specific absorbed ultrasonic energy is 0.5 J g^{-1} . Figure 5a shows that the implementation of different tillage practices had a wide influence on the water stable aggregate fractions, characterized by USAS

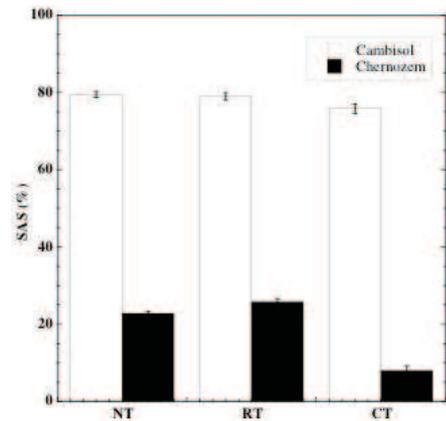


Fig. 4. Soil aggregate stability (SAS, %) of two soils (Cambisol and Chernozem) and three tillage systems (CT, RT, and NT).

with vibration amplitude $0.5 \mu\text{m}$. The largest decrease in aggregate stability can be observed in Chernozem (clay content 11%). Ten years of CT resulted in the loss of nearly 80% aggregate stability (USAS). In the same time period Cambisol (clay content 49%) was more resistant to conventional tillage systems and shows a reduction in USAS of only 20%. Vibration amplitude $1 \mu\text{m}$ for 30 s (Fig. 5b): with the ultrasonic power of 2.7 W the absorbed ultrasonic energy is 81 J and the specific absorbed ultrasonic energy is about 1 J g^{-1} . Figure 5b shows a significant difference in USAS between CT and the conservation oriented tillage practices for Cambisol. Treatments NT and RT of Cambisol show no significant differences. Tillage systems of Chernozem, on the other hand, cannot be distinguished. Vibration amplitude $2 \mu\text{m}$ for 15 s (Fig. 5c): with the ultrasonic power of 8.9 W the absorbed ultrasonic energy is 134 J and the specific absorbed ultrasonic energy is about 1.6 J g^{-1} . Figure 5c shows that the vibration amplitude $2 \mu\text{m}$ delivers useful results for both soil types. Differences in USAS between NT and CT are significant for Cambisol and Chernozem. Cambisol lost nearly 60% of its stability, Chernozem more than 80%.

All USAS measurements after different sonification amplitudes and times show that Cambisol is more stable than Chernozem (Fig. 5a-c), which coincides with the results of the SAS method. In contrast to the SAS method, however, the USAS method using vibration amplitudes close to the cavitation limit can additionally detect differences in soil aggregate stability after different tillage. For both investigated sites, soils show a higher aggregate stability, if no tillage is practiced. RT decreases aggregate stability characterized by USAS and CT shows the lowest aggregate stability.

The distribution of total organic carbon (TOC) in water stables aggregates of Cambisol is shown in Fig. 6a. A relatively large content of TOC is visible in NT aggregates. TOC content is significantly larger in NT than in RT or CT aggregates for aggregates greater than $250 \mu\text{m}$. Figure 6b shows TOC in water stables aggregates of Chernozem from Pixendorf. TOC is higher in all NT aggregate fractions

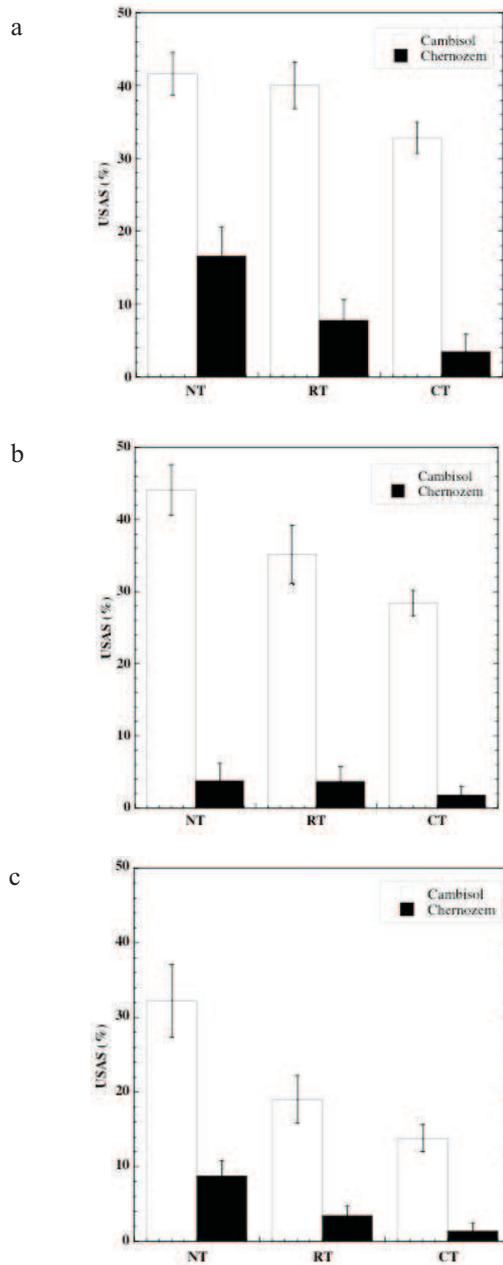


Fig. 5. Ultrasonic soil aggregate stability (USAS, %) of Cambisol and Chernozem for three tillage systems (CT, RT and NT); USAS after sonification with amplitude: a – $0.5 \mu\text{m}$ for 60 s, b – $1 \mu\text{m}$ for 30 s, c – $2 \mu\text{m}$ for 15 s.

compared to CT aggregate fractions. TOC in NT and CT mesoaggregates ($>630 \mu\text{m}$) differs significantly, whereas differences in RT and CT fractions are not significant. Comparing all aggregate fractions, highest TOC content is measured in the NT fractions of Cambisol (up to 8%). TOC in aggregates greater than $250 \mu\text{m}$ from Cambisol with CT and RT is lower compared with the same aggregate classes of Chernozem.

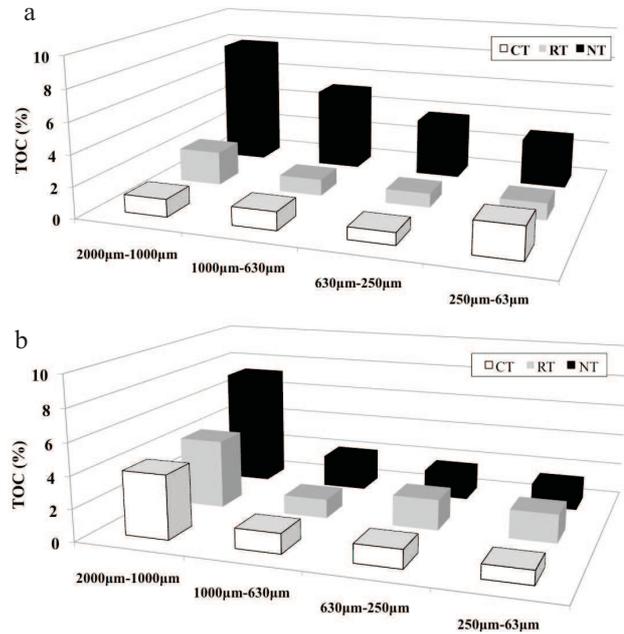


Fig. 6. Distribution of total organic carbon (TOC, %) in water stable aggregates for: a – Cambisol and b – Chernozem.

The DOC release from aggregates of different tillage systems at Tulln and Pixendorf using the ultrasonic extraction method is shown in Fig. 7. Tulln displays a significantly higher release of easily water-soluble organic substances. The DOC release for Chernozem displays differences among the management systems. For both soil types, the release of DOC in NT soils is higher than in CT soils.

The impact of common and conservation-oriented tillage systems on physical and chemical properties of soil can be observed in long-term tillage experiments. Soil management influences the stability of aggregates and noticeably the carbon storage and distribution within the fractions (Kasper *et al.*, 2009; Sohi *et al.*, 2010). The maintenance of a ‘good’ soil structure is critical for agricultural sustainability, and depends on the stability of the aggregates (Amézketa, 1999).

Both aggregate stability measurements, USAS and SAS, show a significant difference between the stability of Cambisol from Tulln and the Chernozem from Pixendorf. In addition, the USAS method using low vibration amplitudes close to the cavitation limit shows that tillage accelerates the disaggregation process for both soil types.

Agricultural management affects the stability of macroaggregates while microaggregates are independent of it (Amézketa, 1999; Fuller *et al.*, 1995). Cambisol contains more water stable macroaggregates, which show prolonged resistance towards disruption compared to the Chernozem from Pixendorf. A change in aggregate stability occurs for both soils comparing conservation oriented to conventional tillage systems, which is best demonstrated in ultrasonic experiments with vibration amplitude above the cavitation limit.

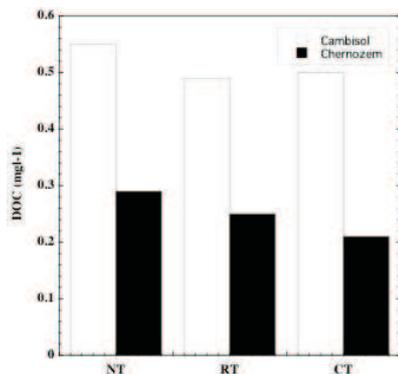


Fig. 7. Release of dissolved organic carbon (DOC, mg l⁻¹) of Cambisol and Chernozem using ultrasonic extraction technique.

Analysis of the soil show that the energy of draft forces of tillage tools during cultivation separates macroaggregates and increases the disaggregation process. The reduction of soil aggregate stability goes along with a decrease in the amount of organic carbon and nitrogen (Kasper *et al.*, 2009; Sohi *et al.*, 2010). Tillage does not only reduce soil organic matter but influences the distribution of organic carbon in the aggregate fractions, which determines the surface-orientated processes *eg* carbon release and in particular water soluble carbon (DOC). The solubility depends on the surface of the aggregates, carbon content and molecular composition.

It is shown, that the chosen vibration amplitudes, sonification times and setup of experiments (ultrasonic probe, soil water ratio, *etc.*) is appropriate to monitor slight differences in soil aggregate stability. Key experimental parameters, like sonification time and vibration amplitude, can be adapted using the ultrasonic method whereas sieving methods are known to provide only relative estimates of the investigated parameters (Bieganowski *et al.*, 2010; Daraghme *et al.*, 2009).

CONCLUSIONS

1. Ultrasonic soil aggregate stability (USAS) measurements using vibration amplitudes close to the cavitation limit can be successfully used to characterize low and highly aggregated soils. USAS can also demonstrate influences of tillage on soil aggregate stability, which can hardly be found using the conventional Soil aggregate stability (SAS) sieving method. Results of USAS measurements correlate with total organic carbon (TOC) content in aggregates.

2. Several parameters of the ultrasonic dispersion experiment need to be standardized to obtain reproducible results. It is suggested to use the vibration amplitude of the ultrasonic probe to control the experiment. Details of the experimental procedure, including determination of ultrasonic power, time of sonification, mass of water and soil aggregates, diameter of the ultrasonic probe, insertion depth *etc.* are suggested in the present work.

3. Ultrasonic dispersion equipment may be further used to quantify available carbon pools. Extraction of dissolved organic carbon (DOC) from aggregates is performed applying high ultrasonic energy to the soil water mixture.

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