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# Measurement of Soil Aggregate Stability using Low Intensity Ultrasonic Vibration

*Medición de la estabilidad de agregados de suelo utilizando vibración ultrasónica de baja intensidad*
*Medição da estabilidade dos agregados do solo por vibração ultrasónica de baixa intensidade*

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## ABSTRACT

The objective of this study was to analyse the influence of tillage on soil aggregate stability using the ultrasonic dispersion method with different levels of energy. Experiments are performed with self-developed equipment at low vibration amplitudes of 0.5 µm, 2 µm and 5 µm. Ultrasonic power is 0.7 W, 8.9 W and 22.3 W for the three amplitudes. Samples of aggregates 2 000 - 250 µm of a degraded loamy silt Chernozem, a loamy clay Cambisol and a loamy sand Cambisol from eastern Austria were collected under different tillage regimes: conventional tillage (CT) with mechanical weed control and no tillage (NT) with inter cropping in winter. Measuring Soil Aggregate Stability (SAS) according to DIN norm showed that the stability decreased in the sequence loamy clay Cambisol > loamy sand Cambisol > loamy silt Chernozem. Influences of tillage could be observed with SAS for the last two samples mentioned.
Ultrasonic dispersion tests at vibration amplitude 0.5 µm and 2 µm show higher stability of the Cambisol soils. Significant influences of soil tillage on aggregate stability for the loamy clay Cambisol and the degraded Chernozem were observed after short ultrasonic dispersion times and absorbed energies of 1 - 1.7 J ml$^{-1}$. The measured aggregate stability decreased in the following order: Cambisol NT > Cambisol CT > Chernozem NT > Chernozem CT. Differences in loamy sand Cambisol could not be detected with the ultrasonic method due to a low aggregation level of the macro aggregates. This study highlights the importance of quantifying the energy output of the ultrasonic equipment when analysing changes in soil aggregate stability, for the evaluation of tillage treatments. A more comprehensive analysis of aggregate stability can be obtained when using both, the wet-sieving SAS method and ultrasonic dispersion at low energy levels.

## RESUMEN

*EL objetivo del trabajo fue analizar la influencia del laboreo sobre la estabilidad de los agregados del suelo (soil aggregate stability – SAS) utilizando un método de dispersión ultrasónica con diferentes niveles de energía. Se hicieron ensayos con un equipo de dispersión ultrasónica desarrollado en la Universidad de Ciencias de Recursos Naturales y de la Vida (Viena). Este equipo facilita la aplicación de amplitudes de baja vibración, de 0.5 µm, 2 µm y 5 µm. La potencia ultrasónica determinada por un método de balance de energía es de 0.7 W, 8.9 W y 22.3 W para cada amplitud. Se tomaron muestras de agregados de 2 000 a 250 µm, en tres tipos de suelo del este de Austria: un suelo del tipo Chernozem franco limoso degradado, un Cambisol franco arcilloso y un Cambisol franco arenoso, y sometidos a diferentes tipos de laboreo: laboreo convencional (CT – conventional tillage), laboreo con eliminación mecánica de malas hierbas y sin laboreo (NT – no tillage), con siembra intercalada en invierno. Los resultados de la estabilidad de los agregados del suelo obtenidos según la norma DIN (Deutsches Institut für*

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*Normung) mostraron que la estabilidad disminuía en el siguiente orden: Cambisol franco arcilloso > Cambisol franco arenoso > Chernozem franco limoso. La influencia del tipo de laboreo se observó en el segundo y tercer tipo de los suelos mencionados.*
*La dispersión ultrasónica por amplitudes de baja vibración mostró una estabilidad más alta en suelos del tipo Cambisol. Se observó una influencia significativa del tipo de laboreo sobre la estabilidad de los agregados del suelo (entre 1 y 1.7 J ml$^{-1}$) en el Cambisol franco arcilloso y el Chernozem degradado, resultando una disminución de la estabilidad de los agregados en el orden siguiente: Cambisol NT > Cambisol CT > Chernozem NT > Chernozem CT. No se observaron diferencias en el Cambisol franco arenoso, porque el nivel de agregación de los macroagregados fue demasiado débil.*
*Este trabajo destaca la importancia de cuantificar la energía aplicada por el equipo de ultrasonidos para el análisis de variaciones en la estabilidad de los agregados del suelo con respecto a diferentes tratamientos de laboreo. La combinación de los métodos de análisis de estabilidad de agregados, por tamizado en condiciones de humedad (SAS) y por dispersión ultrasónica a niveles bajos de energía, permite un análisis más preciso de la estabilidad de los agregados del suelo.*

**KEY WORDS**
**Ultrasonic dispersion, soil tillage, soil disaggregation**

**PALABRAS CLAVE**
Dispersión ultrasónica, cultivo del suelo, desagregación del suelo

**PALAVRAS-CHAVE**
Dispersão ultrasónica, cultivo do solo, desagregação do solo

## RESUMO

*Determinou-se a influência da lavoura na estabilidade dos agregados do solo (soil aggregate stability – SAS) com recurso à dispersão ultrasónica. Os ensaios realizados foram executados com um equipamento de dispersão electrónica desenvolvido na nossa Universidade. Este equipamento permite a aplicação amplitudes de baixa intensidade, de 0,5 µm, 2 µm e 5 µm. A potência ultrasónica determinada por um método de balanço de energia foi de 0,7 W, 8,9 W e 22,3 W para cada amplitude ensaiada. Colheram-se amostras de agregados de 2 000 a 250 µm, num solo do tipo Chernozem franco limoso degradado, num Cambisol franco argiloso e num Cambisol franco arenoso a Este da Áustria, submetidos a diferentes tipos de lavoura: lavoura convencional (CT – conventional tillage), lavoura com eliminação mecânica de infestantes e sem lavoura (NT – no tillage), com sementeira intercalada no Inverno. A medição da estabilidade dos agregados do solo de acordo com a norma DIN (Deutsches Institut für Normung) permitiu concluir que a estabilidade diminuiu pela seguinte ordem: Cambisol franco argiloso> Cambisol franco arenoso> Chernozem franco limoso. A influência do tipo de lavoura observou-se para o segundo e terceiro tipo de solos mencionados.*
*A dispersão ultrasónica por amplitudes de baixa vibração apresentou uma estabilidade mais alta para os solos do tipo Cambisol. Observou-se uma influência significativa do tipo de lavoura na estabilidade dos agregados do solo (entre 1 e 1,7 J ml$^{-1}$) no Cambisol franco argiloso e Chernozem degradado. Este facto resultou na diminuição da estabilidade dos agregados pela seguinte ordem: Cambisol NT> Cambisol CT> Chernozem NT> Chernozem CT. Não foram observadas diferenças no Cambisol franco arenoso, porque o nível de agregação dos macroagregados era demasiado fraco.*
*Este trabalho destaca a importância de quantificar a energia aplicada pelo equipamento de ultra sons para a análise das variações da estabilidade dos agregados do solo submetidos a diferentes tipos de lavoura. Pode obter-se uma análise mais rigorosa da estabilidade dos agregados do solo combinando ambos os métodos, crivagem sob condições de humidade (SAS) e dispersão ultrasónica a baixos níveis de energia.*

# 1. Introduction

The breakdown of soil into smaller aggregates and particles can be accomplished using ultrasonic equipment. According to the aggregate hierarchy theory, breakdown occurs when sufficient mechanical stresses are applied to overcome the attractive forces within the aggregates (Raine 1998). Ultrasonic dispersion of aggregated soils is usually conducted using high-intensity ultrasonic instruments (Edwards and Bremner 1967; Field et al. 2006; Zhu et al. 2009b). Acoustic pressure waves are emitted into the soil water solution, which cause cavitation, stressing of soil aggregates and breaking of aggregate bonds. At higher vibration amplitudes, higher pressure waves occur and particle disruption is accelerated (Mentler et al. 2004).

The focus of this paper is the stability of the soil macro aggregate fraction in the range of 2 000 - 250 µm, coarse and medium sand included. The physical properties of these aggregates allow for an optimum of gas exchange and water availability. Roots and hyphae stabilize the aggregates, inhibit erosion and are affected by soil utilisation (Tisdall and Oades 1982; Tippkötter 1994). For sustaining agricultural productivity, a good soil structure is needed which in turn depends on the presence of stable soil aggregates (Amézketa 1999).

Several authors (Amelung and Zech 1999; Field and Minasny 1999; Mentler et al. 2004) consider that large aggregates (> 250 µm) disrupt at relatively low absorbed specific energies. Roscoe et al. (2.000) determined a critical energy of 260 - 275 J $ml^{-1}$ which was sufficient to disrupt most of the 2 000 - 100 µm fraction of the investigated Latosols. Carolino De Sá et al. (2002) examined the aggregate stability of Latosols under different land uses applying different levels of ultrasonic energy. High sensitivity and small coefficients of variations were observed when ultrasonic energies between 30 and 90 J $ml^{-1}$ were used, and the best energy level to determine differences in aggregate stability caused by different land uses was 36.3 J $ml^{-1}$.

Traditional techniques (e.g. wet sieving) used in the characterisation of soil aggregate stability typically use only a single stability measurement taken after the application of an arbitrary energy for an arbitrary period of time. The results are highly dependent on the nature of the mechanical energy applied (Raine 1998).

One of the main advantages of the ultrasonic method to determine soil aggregate stability is the possibility to exactly measure the applied energy (North 1976; Raine and So 1993; Schomakers et al. 2011). However, ultrasonic power used in most equipment is too large to differentiate stability, especially of weakly aggregated soils. It has been shown that arable soils require far lower energy inputs than grassland soil to cause fragmentation (Ashman et al. 2009). This paper aims to investigate soil aggregate stability applying very small ultrasonic vibration amplitudes. The process of soil aggregate disruption is studied at low ultrasonic power after sonication with low ultrasonic energies. The used ultrasonic vibration amplitudes are about one decade smaller than those of commercially available ultrasonic equipment employed in soil dispersion experiments. This relatively gentle disruption of aggregates is applied to characterise small differences in aggregate stability that are caused by different tillage of the same soil.

## 2. Material and Methods

### Study site

Topsoil samples (0-10 cm) were taken from three sites in eastern Austria at the end of the growing season in fall 2009 that have been under continuous investigation in long-term tillage and erosion experiments. The soils have been classified according to WRB (IUSS 2007).

i) A loamy clay Cambisol from Tulln in Lower Austria at 48° 18' N and 16° 02' E

ii) A loamy sand Cambisol from Kirchberg (am Walde) in Styria at 48° 16' N and 15° 58' E

iii) A degraded loamy silt Chernozem from Pixendorf in Lower Austria at 48° 16' N and 15° 58' E

The Ap horizon of the Pixendorf Chernozem is severely eroded due to its hillside location and therefore the soil type is addressed as physically degraded.

All sites are experimental fields with altered crop rotation and different tillage systems. Of these, two systems have been chosen to investigate soil aggregate disruption:

a) Conventional tillage (CT, tillage depth 23 cm) with mechanical weed control and

b) No tillage (NT, operation depth 2-7 cm) with inter cropping in winter.

The soil management practices in Lower Austria started in 1999, in Kirchberg in 2007. The mean annual precipitation at the sites in Lower Austria is 685 mm, in Kirchberg 730 mm with mean annual temperatures of 9.4ºC and 9.1ºC, respectively. Tulln has a slope of 0-2 %, Pixendorf 5-6 % and Kirchberg 12-15 %. The investigated soils are characterized in **Table 1**.

### Soil sampling and analysis

Sampling spots were evenly distributed over the whole field and taken representatively. Sample collection followed ISO standards (ISO 10381-2). Samples were taken from 0-10 cm soil depth in order to characterise soil surface macro aggregation. Kasper et al. (2009) found statistically significant differences in organic carbon ($C_{org}$) and total nitrogen ($N_{tot}$) for different tillage treatments especially in this surface layer. Each sample was air-dried, homogenously mixed and sieved to pass a 2 mm sieve.

**Table 1:** Site conditions at the experimental fields (sample depth 0 - 300 mm)

| | Sand (%) | Silt (%) | Clay (%) | $N_{tot}$ (%) | $C_{org}$ (%) | $CaCO_3$ (%) | SOM (%) | C/N |
|---|---|---|---|---|---|---|---|---|
| Tulln Cambisol | 11.13 | 39.87 | 51.00 | 0.25 | 3.33 | 1.40 | 5.74 | 13.10 |
| Kirchberg Cambisol | 52.78 | 33.22 | 14.00 | 0.11 | 1.73 | <0.50 | 2.98 | 13.30 |
| Pixendorf Chernozem | 23.61 | 64.89 | 11.50 | 0.14 | 1.86 | 14.90 | 3.21 | 13.50 |

Data represent mean values of six measurements during the growing season of 2009 (May to September). Differences between tillage systems were not significant (n=5). SOM: Soil Organic Matter.

All textural analyses were made with the pipette method using $Na_4P_2O_7$ for dispersion and $H_2O_2$ to destroy organic matter (ISO 11277). Carbon and nitrogen were measured using dry combustion with a Carlo Erba NA 1500 (ISO 10694; ISO 13878). SOM was calculated: Corg x 1.724, the assumed average C-concentration of the organic matter of 58 % (Scheffer and Schachtschabel 2010). Determination of calcium carbonate was in accordance with the Scheibler volumetric method (ISO 10693).

### Soil aggregate stability (SAS)

Soil aggregate stability (%) of the investigated soils was calculated using the wet sieving method described in DIN-Norm 19683-16. The method is modified after Kemper and Rosenau (1986) and the SAS samples were analysed with three repetitions from each plot and tillage treatment (n = 18). Four g of air-dried soil aggregates of diameter of 2 000 - 1 000 µm (EW) were dipped on a sieving machine equipped with sieves of 250 µm mesh. The percentage of water stable aggregates (% SAS) (Eq. 1) was calculated with the obtained parameters:

$$\% \, SAS = \frac{m_K - m_A}{EW - m_A} \cdot 100 \qquad (1)$$

with $m_K$, the weight of the stable aggregates in the fraction > 250 µm after dipping and $m_A$, the mass of sand after chemical dispersion of the remaining aggregates.

### Ultrasonic dispersion

Ultrasonic dispersion experiments were performed with a self-developed ultrasonic dispersion equipment 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 with a diameter of 30 mm performs resonance vibrations at ultrasonic frequency (approximately 20 kHz) leading to the emission of pressure waves into the soil water solution.

Vibration amplitude of the cylindrical ultrasonic probe is measured with an induction coil. In a closed-loop electronic circuit, the amplitude, rather than the power, is controlled and kept constant with very high accuracy.

Vibration amplitude and duration of sonication are selected prior to the dispersion experiment. The same ultrasonic probe was used in all experiments.

During the ultrasonic experiments, the soil-water suspension was placed in a Plexiglas beaker with a diameter of 44 mm. The insertion depth of the ultrasonic probe 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 is ¾ of the wavelength of acoustic waves in water at the used ultrasonic frequency of 20 kHz. Therefore no resonance may be attended in the soil water solution, which would cause undefined increases of acoustic pressure.

Dispersion experiments were performed with 4 g samples of air-dried aggregates (2 000 - 1 000 µm) in 80 ml de-ionised water. The soil was inserted shortly before the ultrasonic treatment and the solution was stirred with a magnetic device (2 Hz, cylindrical shape with length 25 mm and thickness 8 mm) to obtain homogeneous soil distribution. Stirring started simultaneously with the ultrasonic vibration and was continued during the experiments. The soil samples were analysed with five repetitions from each plot and tillage variant (n = 30).

Ultrasonic dispersion was used to study the process of soil aggregate disruption after different applied specific energies. The soil macro aggregate fraction 2 000 - 250 µm was investigated to describe aggregate breakdown curves for each soil type and tillage variant after the application of ultrasonic agitation at 0.5 µm, 2 µm and 5 µm for different time periods (15 s, 30 s, 45 s, 60 s, 120 s, 240 s and 480 s). Ultrasonic power determined with an energy balance described in Schomakers et al. 2011 is 0.7 W, 8.9 W and 22.3 W, respectively. Particle size analysis at different absorbed ultrasonic energies per millilitre served to monitor the progress of disaggregation in the ultrasonic field. The dispersion experiments were stopped after certain sonication times and the mass fractions were correlated to the absorbed ultrasonic energy per millilitre.

### Soil mass fractionation

Mass fractions in the ultrasonic experiments were determined by wet sieving after the various ultrasonic treatments. Immediately after the sonication, the soil-water suspension samples were placed in the sieving tower (Fritsch Analysette 3 Pro) with vibration amplitude set at 0.1 µm and frequency at 50 Hz. A standardized sieve of aperture 250 µm was used. Sieving lasted one minute with 700 ml water. The remaining soil fraction 2 000 - 250 µm was transferred from the sieve to a porcelain cup with distilled water, placed in an oven and dried at 105 °C for 24 h. The final mass fraction was determined with an accuracy of 0.01 g.

### Statistical evaluation

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.

## 3. Results and Discussion

### Soil aggregate stability (SAS) according to DIN-Norm 19683-16

The results of the Soil Aggregate Stability (SAS) measurements according to DIN-Norm 19683-16 are presented in **Figure 1**. The most stable soil is Tulln NT with 76 % stable aggregates. Differences in SAS between the tillage systems of Tulln are not significant. The overall higher stability of these two samples is due to the higher content of organic carbon and clay. Kirchberg NT has 42 % stable aggregates followed by Kirchberg CT (33 %) and Pixendorf NT (23 %). The least stable sample according to this method is Pixendorf CT, with 8 % stable aggregates. Pixendorf is a severely degraded Chernozem. The hillside location increases the loss of clay and organic matter. Through erosion of the topsoil, calcium carbonate accumulates on the surface and forms crusts (Scheffer and Schachtschabel 2010). Root growth is aggravated, and aggregate stability lowers. In addition, it has been shown that the soil structure deteriorates through tillage (Holland 2004; Lal et al. 2007). As roots and hyphae are decomposed and not replaced by intensive tillage, the organic matter content lowers and the stability of aggregates > 250 µm decreases (Tisdall and Oades 1982).

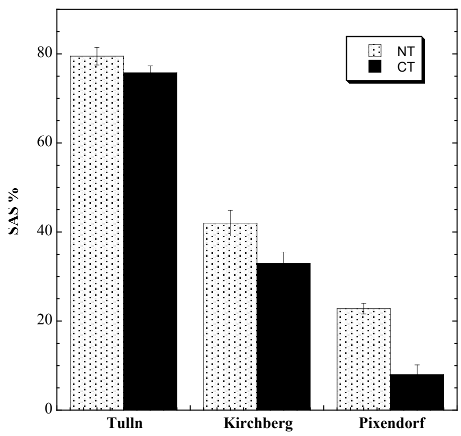


**Figure 1.** Soil aggregate stability (SAS) of the three investigated soils and tillage treatments (NT: no tillage; CT: conventional tillage) according to DIN-norm 19683-16. Error bars represent the standard deviation (n=3).

### Influence of absorbed specific energy on dispersion

Mass fractions of soil particles at different absorbed ultrasonic energies per millilitre and vibration amplitude of 0.5 µm are shown in **Figures 2a-c**. All investigated soils show an overall decrease of the 2 000 - 250 µm aggregate fraction with increasing absorbed specific energy. At 0.5 µm, Tulln is the most stable soil, followed by Kirchberg, and the least stable soil is Pixendorf. This coincides with the SAS method (**Figure 1**). The sand-size fractions of Tulln (**Figure 2a)** steadily decrease with prolonged ultrasonic treatment. Initially the NT treatment (58 %) is significantly more stable than the CT treatment (38 %) but the difference progressively decreases and at absorbed specific energy of 1 J ml$^{-1}$, i.e. after 2 min of sonication, the difference is not significant.

Both, the CT and NT fractions of Pixendorf (**Figure 2b**) and Kirchberg (**Figure 2c**) are disaggregated gradually but the CT fractions are less stable than the NT fractions throughout the treatment. The higher stability of the NT aggregates is probably caused by the higher content of organic matter, which enables the soil surface aggregates to withstand rapid wetting and mechanical forces. Differences between the tillage systems are more pronounced for Pixendorf especially up to 1 J ml$^{-1}$, the difference is significant.

Hence, the stability of both soils, Tulln and Pixendorf can be well characterized at low vibration amplitude of 0.5 µm up to a sonication time of 60 seconds. CT and NT fractions of Kirchberg, on the other hand, cannot be significantly distinguished at this vibration amplitude.

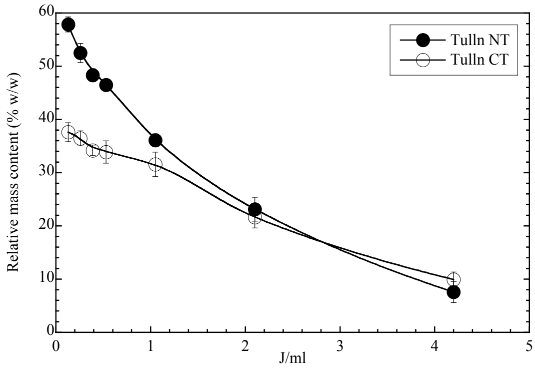


**Figure 2a**

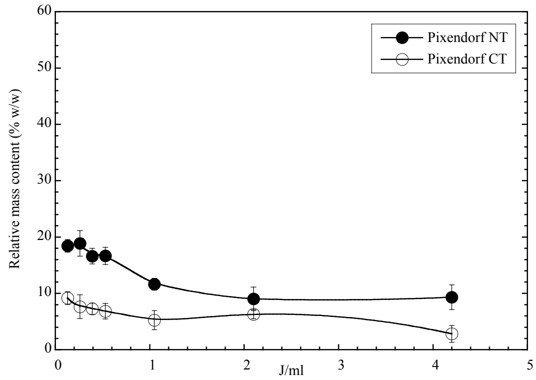


**Figure 2b**

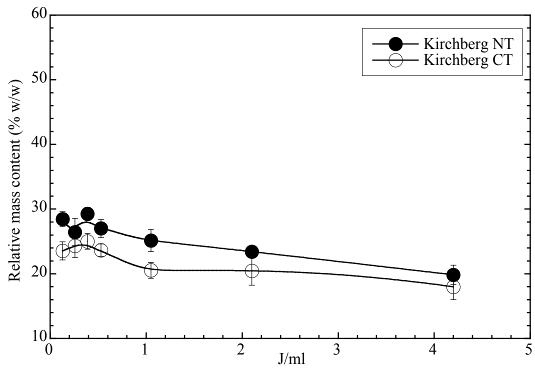


**Figure 2c**

**Figures 2a-c**. Relative mass content of coarse and medium sand-size fractions (2 000 - 250 µm) at different absorbed specific energies and vibration amplitude 0.5 µm. Data of Tulln (2a), Pixendorf (2b) and Kirchberg (2c) are shown for no tillage, NT (closed circles) and conventional tillage, CT (open circles). Error bars represent the standard deviation (n=5).

**Figures 3a-c** show the influence of a vibration amplitude of 2 µm on the dispersion of the three soils. The rapid decrease of Tulln sand-size fractions > 250 µm (**Figure 3a**) can be observed and abates at about 6.7 J $ml^{-1}$, i.e. after 1 min of sonication at 2 µm. The most significant difference between the tillage variants can be observed at 5 J $ml^{-1}$. It is not possible to discriminate between NT and CT thereafter and up to the investigated energy of 134 J $ml^{-1}$ (data not shown).

Disaggregation is more rapid and affects more stabile aggregates at higher vibration amplitude of 2 µm compared to 0.5 µm. The accelerated particle disruption at higher vibration amplitudes is a consequence of higher acoustic pressure emitted into the soil water solution. After 1 min of sonication at 2 µm, the fractions of Tulln disperse almost completely to the measured final sand content (> 250 µm) of about 5 % at very high-absorbed energies (134 J $ml^{-1}$, not shown).

**Figure 3b** shows a significant difference between Pixendorf CT (4.8 %) and NT (13.0 %) at 1.7 J $ml^{-1}$, only. With an ultrasonic power of 8.9 W it is therefore not possible to differentiate between the tillage variants for the degraded Chernozem with an increase of energy. This is consistent with findings of similar experiments. With an ultrasonic energy output of 8.92 J $ml^{-1}$, Kasper et al. (2009) found no significant differences in soil aggregate stability between conventional, reduced and minimal tillage of the investigated sandy loam Chernozem.

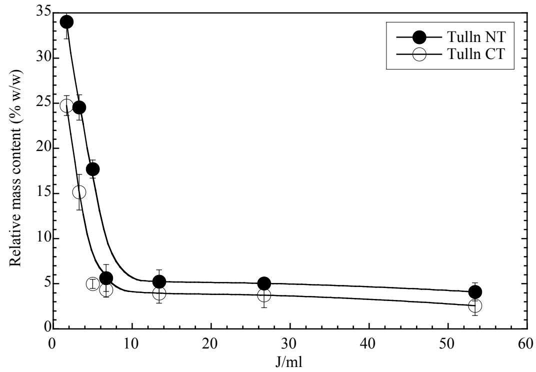


**Figure 3a**

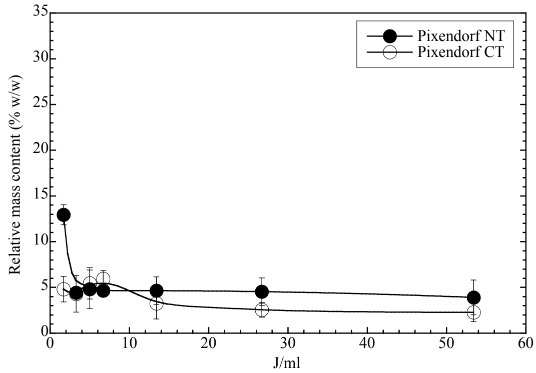


**Figure 3b**

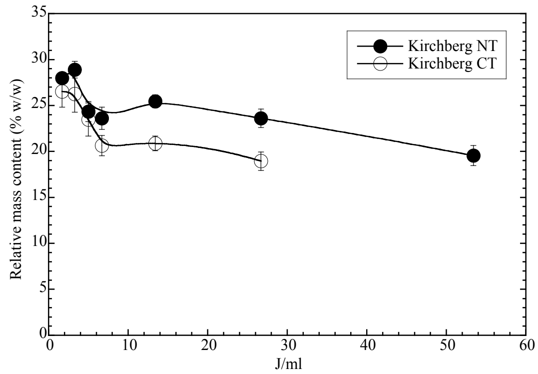


**Figure 3c**

**Figures 3a-c.** Relative mass content of coarse and medium sand-size fraction (2 000 - 250 µm) at different absorbed specific energies and vibration amplitude 2 µm. Data of Tulln (3a), Pixendorf (3b) and Kirchberg (3c) are shown for no tillage, NT (closed circles) and conventional tillage, CT (open circles). Error bars represent the standard deviation (n=5).

The increase of applied energy and the change in mass distribution within the fractions were correlated and adjusted according to the regression equation in the statistical analysis. Adapting linear regression for Tulln and Pixendorf, the aggregate size fraction 2 000 - 250 µm of Pixendorf NT correlates significantly negatively ($r = -0.886$; $p < 0.01$; $n = 16$) by increasing the applied energy. This coincides with the same aggregate fraction from Tulln NT ($r = -0.996$; $p < 0.01$; $n = 16$).

The 2 000 - 250 µm fraction of the Kirchberg samples (**Figure 3c**) progressively decreases with prolonged ultrasonic treatment. More aggregates of 2 000 - 250 µm, which cannot be dispersed using 2 µm ultrasonic treatment are present in this soil than in Tulln and Pixendorf. This can be explained by the overall high sand content in the Kirchberg samples (**Table 1**). Mass contents at high ultrasonic energy (134 J $ml^{-1}$) disperse to about 17 % (data not shown). Again, it is not possible to significantly differentiate between the tillage variants nor to see a substantial decline of the sand fraction 2 000 - 250 µm at low vibration amplitude of 2 µm. Dispersion of Kirchberg sand fractions indicates that the aggregation level is low. Moreover the tillage experiment started in 2007, only. Differences in aggregate stability between the tillage variants might be less pronounced within the investigated triennium.

Dispersion experiments at 5 µm, in the range of 16.7 J $ml^{-1}$ to 134 J $ml^{-1}$ (not shown) do not allow for a differentiation between soil aggregate stability nor tillage variant. The mass fractions 2 000 - 250 µm decrease rapidly indicating that the aggregates are too weakly bonded to withstand acoustic pressure amplitudes at ultrasonic power of 22.3 W.

It is shown that the dynamic of soil dispersion depends on the absorbed ultrasonic energy and the amplitude. Influences of vibration amplitudes on soil dispersion and aggregate stability assessment have already been studied (Mayer et al. 2002; Mentler et al. 2004; Zhu et al. 2009a). Fristensky and Grismer (2008) observed declining aggregate stability with an increase in aggregate size and the relatively rapid disruption of the 2 000 - 1 000 µm aggregates with the applied energies between 0 and 5 800 J $g^{-1}$.

The present results demonstrate the influence of low vibration amplitude on the dispersion of the macro aggregate fraction 2 000 - 250 µm of two soil types under agricultural use. While the Chernozem and the loamy clay Cambisol can both be clearly characterized at energy levels up to 1 J $ml^{-1}$ (at 0.5 µm) and up to 1.7 J $ml^{-1}$ (at 2 µm), tillage systems for the loamy sand Cambisol cannot be distinguished.

# 4. Conclusions

Ultrasonic dispersion experiments at low vibration amplitudes can show differences in aggregate stability of soils under different tillage systems (conventional tillage and no tillage). Further analysis of the soil fraction 2 000 - 250 µm reveals different dispersion behaviour between the investigated soils with an increase in applied energy. Compared to 2 µm, 0.5 µm has a low impact on soil aggregates. Forces exerted on aggregates and particles at 5 µm were too large to allow for any differentiation between the soils or tillage treatments.

Commercial equipment typically works at much higher vibration amplitudes, acoustic pressures and ultrasonic power (Roscoe et al. 2000; Zhu et al. 2009b) than that used in the present study. This limits a comprehensive characterisation of soil aggregation, where gentle stressing of less stable aggregates is preferable. Ashman et al. (2009) investigated soil stabilisation by biological processes and compared slaking, shaking and ultrasound procedures for step-wise aggregate fragmentation. The applied ultrasonic power of 100 W was not suited for biological studies since it aggressively disturbed the microbial community. In future, experiments at low vibration amplitude could be an alternative fractionation method in biological studies but more research is required.

This study, however, supports the conclusion of others (Holland 2004; Lal et al. 2007; Kasper et al. 2009) that conventional soil cultivation decreases aggregate stability. With experiments at 0.5 µm it is possible to demonstrate influences of tillage on soil aggregate stability of relatively stable arable soils as well as of unstable soils. The results suggest similar ranking of the soils concerning their stability compared to the wet-sieving method (SAS), and indicate that both, the wet-sieving method and the dispersion at low vibration amplitude are important for evaluating changes in soil structure parameters.

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