doi: 10.17221/132/2014-SWR

Water Stability of Soil Aggregates in Different Systems of Tillage

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Abstract

Bartlová J., Badalíková B., Pospíšilová L., Pokorný E., Šarapatka B. (2015): Water stability of soil aggregates in different systems of tillage. Soil & Water Res., 10: 147–154.

The influence of various agrotechnical measures on macrostructural changes in topsoil and subsoil was studied in the course of a four-year experiment. Macrostructure was evaluated according to the ability of soil aggregate to resist degradation. Three variants of soil tillage were established: ploughing to a depth of 0.22 m, reduced tillage (subsoiling to 0.35–0.40 m, and shallow disking of soil to a depth of 0.15 m). For observation, three locations were chosen in various production areas of the Czech Republic with differing soil and climatic conditions. In these locations crops were grown under the same crop rotation: rapeseed (*Brassica napus* L.), wheat (*Triticum aestivum* L.), maize (*Zea mays*), wheat (*Triticum aestivum* L.), and barley (*Hordeum vulgare*). After four years of different tillage, a change in the water stability of soil aggregates (WSA) was evident. It was found out that reduced tillage of soil positively influenced both the WSA and the yield of the crops grown. A relationship of positive dependence between WSA, the content of humus substances, and cation exchange capacity of soil was also found. According to the obtained results, for agricultural practice a classification scale of structural quality was proposed on the basis of statistics of one variable (average, its mean error and distribution normality).

Keywords: conventional tillage; shallow disking; soil structure; subsoiling; water-stable aggregates; yield

Soil structure has a significant influence on the ability of soil to support plant growth, the cycle of carbon, nutrients and the absorption, retention and movement of water. Special attention must be given to soil structure in managing ecosystems, where human activity can lead to both short-term and long-term changes affecting the soil function (Kay & Angers 2000). One of the most widespread techniques for evaluating soil structure is the analysis of aggregate size distribution and of water stability of soil aggregates (WSA) (Scott 2000). Determining the momentary state of soil aggregate at individual times does not necessarily suffice to determine the real structural characteristics, as these may change dynamically in time. Soils vary in their level of susceptibility to the external burden of destructive forces. In order to measure this susceptibility, we can make use of assessment of soil aggregate stability (Hillel 1980).

Soil aggregate stability depends on soil type and sort, on the content of organic matter (Tisdall & Oades 1982; Haynes & Swift 1990; Šimanský *et al.* 2013), on the biological activity of the soil (Oades 2005), fertilization (Annabi *et al.* 2007), and also on the form of soil disturbance, frequency of passage of machinery (Safadoust *et al.* 2006), vegetation cover (Gajici *et al.* 2010; Peregrina *et al.* 2010), and soil mass redistribution in the steep parts of slopes (Zádorová *et al.* 2011). In the soil profile, there is also a varying dependence on the existence of various forms of $CaCO_3$, on the presence of ferric oxide, clay, and pH_{KCl} (Kodešová *et al.* 2009).

Formation and stability of soil structure is also considerably influenced by weather dynamics. In the course of individual years, or even within the seasons, the soil aggregates stability varies due to the influence of climatic conditions. The main weather

doi: 10.17221/132/2014-SWR

factors include temperature and precipitation, influencing expansion and shrinkage, freezing and thawing of soil matter (Hlušičková & Lhotský 1994; Abiven *et al.* 2009).

Various authors (Panayiotopulus & Kostopoulou 1989; Caravaca *et al.* 2004) state that natural soils have evidently greater aggregate stability than cultivated soils. The difference in aggregate stability in different forms of soil exploitation is mainly due to the intensity of disturbance of soil and its cultivation. Inappropriate use of soil leads to dissolution of unstable aggregates, and production of finer and more easily transportable particles and microaggregates (Zhang *et al.* 2008). The resistance of an aggregate to water depends on its quality, which is determined by the binding elements of the aggregate, i.e. the organic and mineral colloids and their mutual integration. These characteristics are primarily influenced by the quantity and quality of humus, which especially relates to the microbial activity of soil (Bartlová & Badalíková 2010). Stability of soil aggregate is a frequently used indicator of soil quality, and yet there has not been a standard method of the soil aggregate stability evaluation. Contemporary methods measure only certain parts of soil, or employ methods of wet or dry sieving (Nichols & Toro 2011). Among the most frequently used methods of wet sieving there are several modified methods according to Kemper and Koch (1966).

The aim of the study was to determine the influence of various agrotechnical measures on the ability of soil aggregates to resist degradation (i.e. water stability). A classification scale was also established for the quality of soil structure according to WSA.

MATERIAL AND METHODS

Since the year 2007, we have studied the influence of various agrotechnical processes on soil characteristics in three locations within the Czech Republic with various types of production and with varying soil and climatic conditions. Agricultural enterprises in Hrušovany nad Jevišovkou, Unčovice and Lesonice (Figure 1) were selected for the research. Hrušovany nad Jevišovkou is situated at an altitude of 210 m a.s.l., with an annual rainfall of 461 mm, average annual temperature is 9–10°C. The region is warm and dry. The soil here belongs to Luvic Chernozem subtype, clay loamy textured. Unčovice is situated at an altitude of 227 m a.s.l., with an annual rainfall of 536 m and average annual temperature of 8.5°C. The area is warm and moderately humid. The soil subtype is Luvic Chernozem, silt loamy textured. Lesonice lies at an altitude of 510 m a.s.l., with an annual rainfall of 567 mm, average annual temperature is 6.5°C. The region is moderately warm and moderately humid. The soil subtype is Haplic Luvisol, silt loamy textured.

On all the three farms, three systems of soil tillage were applied after growing the same crop. During the monitoring period the same crop rotation (winter rape pre-crop, then winter wheat, maize, winter wheat, spring barley) was applied on all the monitored plots. Soil cultivation in the following variants was chosen:

– conventional – ploughing to a depth of 0.22 m,
– reduced tillage – subsoiling to a depth of 0.35–0.4 m
– reduced tillage – shallow disking to a depth of 0.15 m

For each variant, a plot of land sizing ca. 30 × 100 m was established depending on the type of machinery used. Fertilization and plant protection were relevant to the needs of the individual crops in a given area. In these semi-operational conditions, in individual variations within the crop rotation, WSA, cation exchange capacity, humic acid and crop yield were examined.

Soil samples were always taken in spring (at the beginning of the growing season) and in autumn (at the end of the growing season). In all the cases, soil samples were taken from three places and two depths, i.e. 0–0.3 m (topsoil) and 0.3–0.6 m (subsoil).

The water stability of soil aggregates was determined by wet sieving (Kandeler 1996). This method is based on investigations by Kemper and Koch (1966) and Murer *et al*. (1993). For determination of WSA, air dried aggregates (1–2 mm) are wet sieved in distilled water in a machine providing a mechanical stroke. After wet sieving the mass of stable aggregates is determined. Stable aggregates are destroyed by the addition of $Na_2P_2O_7$ solution, leaving only the sand fraction. Aggregate stability is expressed as the percentage of stable aggregates of the total aggregates after correction of sand content.

Fractional composition of humic substances and content of humic and fulvic acids were determined by the short fractionation method. Cation exchange capacity was determined in an ammonium acetate leachate.

Yield of studied crops was assessed by manual harvesting. The obtained values were calculated for t/ha and standard humidity of 14%. For comparison of the hectare yield of individual crops, a conversion

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to grain units was used. The term grain unit (GU), introduced by Woermann (1944), allows the mutual comparison using a single indicator of the yield of various crops differing in nutrition and energy values.

For statistical evaluation of WSA, an analysis was used with subsequent testing of simple contrast using the Tukey's method. Average values of WSA in topsoil and subsoil, at various forms of soil tillage and times of testing, were expressed in a bar graph with confidence intervals. Crop yield (t/ha) for the studied period was graphically expressed in the same way. Statistical evaluation was carried out using the Statgraphics (Version 7.0) statistical system.

The ratios of the yield of the studied crops, humus substances content, cation exchange capacity, and water stability of variants of tilled soils were evaluated using regression and correlation analysis. After preliminary calculation a linear model was chosen.

A classification scale of structural quality was created on the basis of statistics of a single variable (average, its mean error and distribution normality) in MS Excel programme. The scale was divided into 5 intervals, limits are presented in Table 3.

RESULTS AND DISCUSSION

Water stability of soil aggregates. As shown in Figure 1, in Hrušovany nad Jevišovkou, different values of WSA were found according to different methods of tillage, both in topsoil (0–0.30 m) and subsoil (0.30–0.60 m). In contrast to the other two tillage methods, the ploughing variant showed a statistically provable reduction in WSA. The same results were obtained by Hůla *et al.* (2010), who found that, after three years, the ploughing variant showed worsened soil structure in comparison to reduced tillage. Soil tillage based on ploughing can result in faster deterioration of soil structure compared to shallower tillage less disturbing the soil. According to various authors (Daraghmeh *et al.* 2009; Bogužas *et al.* 2010), site adaptable tillage, in comparison to conventional methods, increases the amount of water stable aggregates and improves (soil) structure due to a combination of greater amounts of organic matter, reduced bulk weight of soil, and a greater share of larger aggregates.

The subsoil also showed a statistically provable reduction in WSA in the ploughing variant, if compared to other forms of tillage (Figure 1b). From our results it is evident that in this location the ploughing method negatively affected the stability of soil aggregates. Similar results were obtained by Epperlein (2003) and Kasper *et al.* (2009).

In contrast to Hrušovany, in the Unčovice location the conventional ploughing method proved to be the best both in topsoil and subsoil (Figure 2) but none of the observed differences between monitored tillage variants was statistically provable. Similar results were also obtained by Karlen *et al.* (1994) and Lammerding *et al.* (2011) who did not find significant differences in WSA in subsoiling, conventional, and minimum soil tillage.

The soil at Hrušovany nad Jevišovkou is in quite a good condition in terms of structure, but in its topsoil layer organic residue mineralizes faster (Šarapatka *et al.* 2014). This is probably why a greater difference was evident in various methods of tillage here if compared to the good soil structure in Unčovice.

In the Lesonice location, in the topsoil, a statistically provable reduction in WSA was evident in the ploughing method compared to the other forms of tillage (Figure 3). Similar results – non-ploughing method and reduced tillage improving the stability of soil aggregates – were obtained by Tebrügge

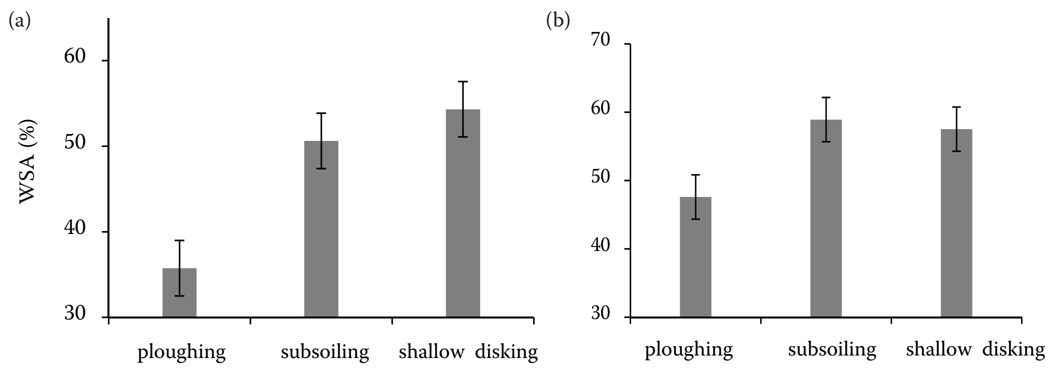

Figure 1. Average levels of water stability of soil aggregates (WSA) in top-soil (a) and in sub-soil (b) processed by different forms of soil tillage – Hrušovany, 2008–2011

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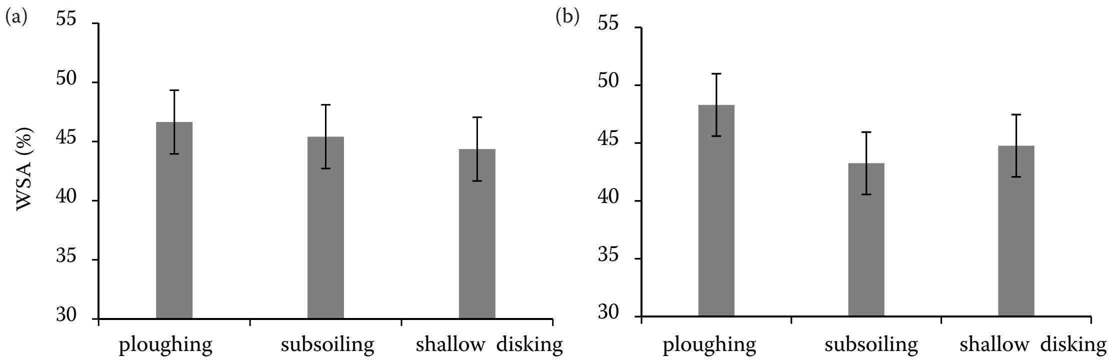

Figure 2. Average levels of water stability of soil aggregates (WSA) in top-soil (a) and sub-soil (b) processed by different forms of soil tillage – Unčovice, 2008–2011

and Düring (1999). In subsoil, the highest values were those on the subsoiled site, the lowest values appeared in shallow disked soil. The difference between these values was statistically provable. This was probably due to the subsoiling that reached down to the subsoil layer, thus aerating the stagnic horizon, which promoted biological activity and resulted in increased stability of aggregates. Our results confirm the findings of various authors (Kandeler & Murer 1993; Scott 2000; Six *et al.* 2004; Oades 2005) that intermediate products of decay of microorganisms and their excretions have a positive influence on water stability of soil structure. Among the monitored sites, the soil in the Lesonice location is in the worst structural condition, therefore suitable agrotechnical intervention is needed as this could significantly improve the soil structure.

Evaluation of structural quality in terms of WSA. After a four-year period of monitoring the three locations, a classification scale of structural quality was created from all data on percentage of WSA (Table 1). The most frequently obtained values of water stability ranged from 30 to 60%. Table 2 presents the statistical evaluation.

Yield of crops grown. The evaluation showed that reduced tillage increased the main crop yield in comparison to the ploughing variant in all monitored locations. In Hrušovany a provable difference was found in 2008 winter wheat grown on a shallow disked plot in comparison to the other variants, in 2009 maize grown on a subsoiled plot in comparison to the other variants, and in 2011 spring barley grown on a ploughed plot in comparison to the other variants (Figure 4a).

Table 1. Classification scale of structural quality based on percentage of water stability of soil aggregates (WSA)

WSA (%)	Quality of structure
< 18	very low
18.1–34.0	low
34.1–50.0	medium
50.1–66.0	high
> 66.1	very high

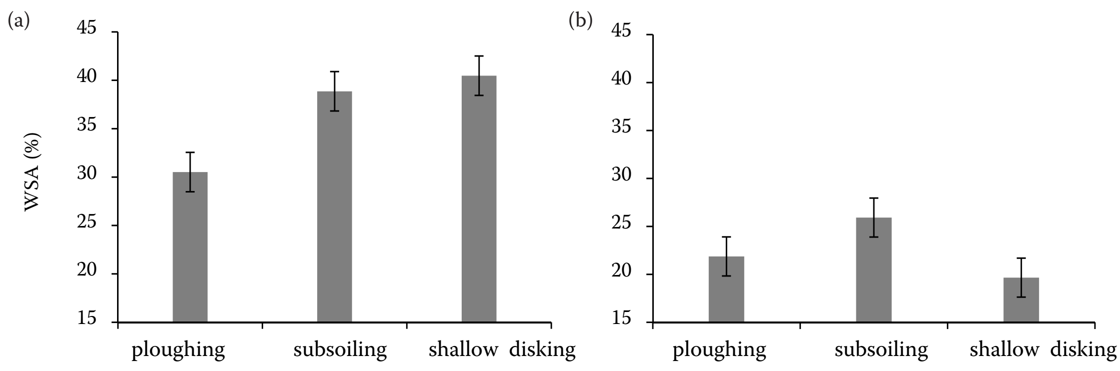

Figure 3. Average levels of water stability of soil aggregates (WSA) in top-soil (a) and sub-soil (b) processed by different forms of soil tillage – Lesonice, 2008–2011

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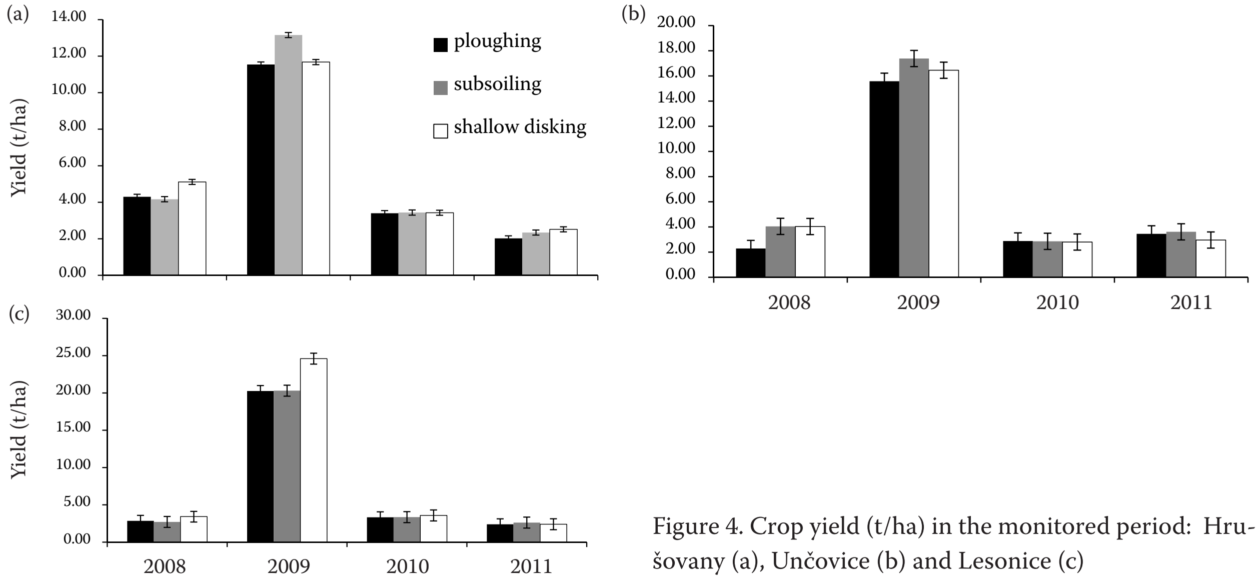

Figure 4. Crop yield (t/ha) in the monitored period: Hrušovany (a), Unčovice (b) and Lesonice (c)

In Unčovice a provable difference was only found in 2009 maize grown with shallow disking in comparison to the other variants (Figure 4b). In Lesonice a provable difference was found in 2008 winter wheat grown on a ploughed plot in comparison to reduced tillage and in 2009 maize grown on a subsoiled plot in comparison to the ploughed variant (Figure 4c). Our results confirm the statements of various authors (Romaneckas *et al.* 2001; Jin *et al.* 2007; Katai 2009; Alleto *et al.* 2011) who found higher yield on subsoiled and shallow disked soil in comparison to traditional ploughing.

Relationship between water stability of soil aggregates and yield of crops grown. The relationship of dependence between WSA (%) and yield converted to grain units (q) on ploughed, subsoiled and disked plots is shown in Figure 5. In the shallow disked soil the dependence was statistically provable: the yield of monitored crops increased with increasing water stability. In ploughed and subsoiled variants no provable dependence between water stability of soil aggregates and yield was found.

Simultaneously with our monitoring, an economic evaluation of monitored forms of tillage in individual locations was carried out within the project (Badalíková *et al.* 2011). It was found that, compared to ploughing, the subsoiling variant brought by 15% higher profit and the profit from the disking method was by 30% higher. The shallow disking variant (to a depth of 0.15 m) was the most economically favourable in all locations.

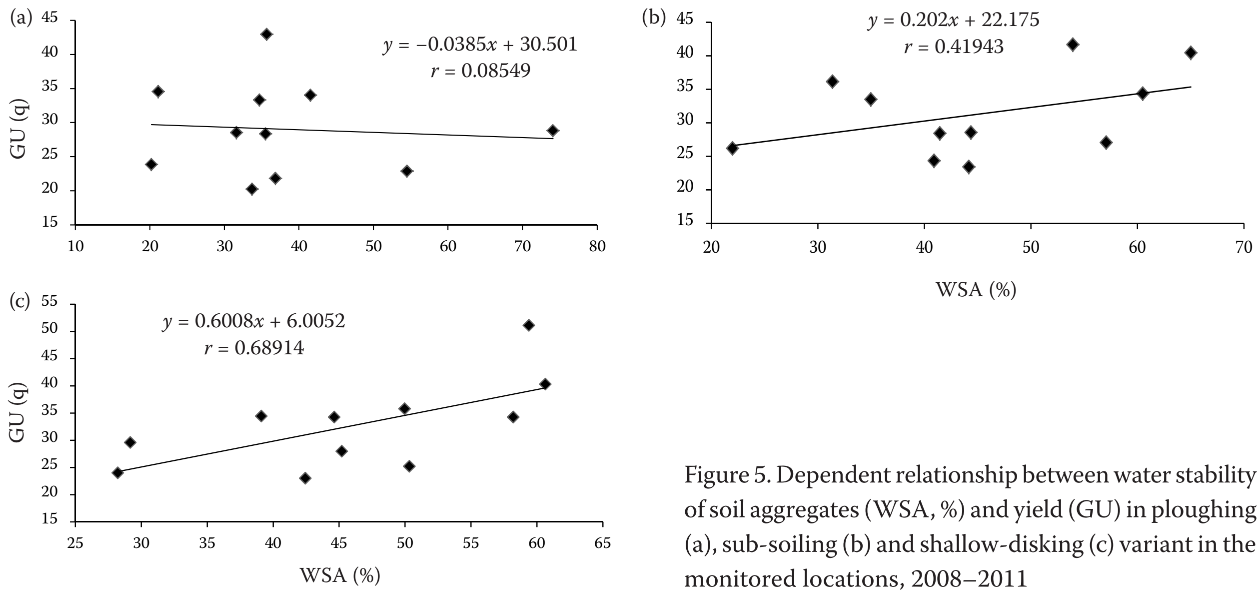

Figure 5. Dependent relationship between water stability of soil aggregates (WSA, %) and yield (GU) in ploughing (a), sub-soiling (b) and shallow-disking (c) variant in the monitored locations, 2008–2011

doi: 10.17221/132/2014-SWR

Table 2. One variable statistics

Average	41.9316
Standard error	0.9313
Median	40.2166
Mode	
Standard deviation	15.8046
Variance	249.7857
Kurtosis	–0.7252
Skewness	0.1689
Range	71.6547
Minimum	11.8377
Maximum	83.4925
Total	12 076.2969
Sample size	288.0000
Maximum	83.4925
Minimum	11.8377
95% confidence level	1.8330

Morris *et al.* (2010) also confirmed the economical merit of non-ploughing soil management.

Dependence of other parameters on WSA. In general, reduced soil tillage led to an increase in the content of humus substances in the soil (the sum of humic acids – HA and fulvic acids – FA), which significantly correlated with WSA (Table 4). In the ploughed variants no statistically provable dependence was found between the content of humus substances and WSA. This can be explained by the fact that no statistically significant increase was found in the content of humus substances. The significant correlation was also found in the interdependence of WSA and cation exchange capacity (CEC) in reduced tillage soils. The same results were obtained, after a two-year study, by Moraru and Rusu (2011). They found that reduced tillage resulted in an increased content of humus of up to 20% compared to conventional ploughing.

Table 3. Limits of intervals

Interval	Inferior limit	Superior limit
Medium	$\bar{x}$ – 0.5 SD	$\bar{x}$ + 0.5 SD
Low	$\bar{x}$ – 1.5 SD	$\bar{x}$ – 0.5 SD
High	$\bar{x}$ + 0.5 SD	$\bar{x}$ + 1.5 SD
Very low	–	$\bar{x}$ – 1.5 SD
Very high	$\bar{x}$ + 0.5 SD	–

$\bar{x}$ – average; SD – standard deviation

Table 4. Correlation between sums of humic acids (HA), fluvic acids (FA) and cation exchange capacity (CEC) in observed locations in 2008–2011 for ploughing, sub-soiling and shallow disking

	Sum of HA	Sum of FA	CEC
Ploughing	0.0572^{ns}	0.0596^{ns}	-0.714^{ns}
Subsoiling	0.2999^{ns}	0.4069*	0.5426*
Shallow disking	0.5294**	0.2529^{ns}	0.4882*

**P* = 0.05; ***P* = 0.01; ^{ns}non-significant

Kitur *et al.* (1994) studied the differences between soils worked by traditional ploughing and by subsoiling. In the topsoil layer (0–5 cm) of the subsoiling variant they found a higher content of organic carbon than in the ploughed variant. The CEC in the topsoil layer was also lower in the ploughed soils in comparison with subsoiling variants. However, in deeper layers of soil (5–15 cm) no significant differences in the content of organic carbon were found. Falatah and Aldarby (1993) also state that organic matter content and CEC are greater in subsoiled conditions than in traditionally ploughed soils.

Cultivation of land leads to changes in the chemistry of carbon intake in soils. These changes in chemical composition are generally apparent in organic material inside aggregates, whereas changes in organic material linked to clay particles are only slight (Golchin *et al.* 1995). Many authors (Golchin & Asgari 2008; Kasper *et al.* 2009; An *et al.* 2010; Vach & Javůrek 2011) have confirmed that intensive tillage of soils reduces stability of aggregate and the content of organic carbon and nitrogen, which influences the quality of soil and the long-term sustainability of agriculture.

CONCLUSION

It may be concluded that after a four-year period of various forms of tillage, the soil aggregate stability underwent a change. From the results it is evident that the best WSA was in the Hrušovany nad Jevišovkou location and the worst was in the Lesonice location, which corresponds with the soil condition in these locations. In both these locations the positive influence of reduced tillage was significantly evident. With reduced tillage there was less disturbance of soil environment compared to conventionally tilled soils which were ploughed. In Unčovice the best values of soil aggregate water stability were found in the ploughed variant, but the difference found was not statistically provable.

doi: 10.17221/132/2014-SWR

From the results it is apparent that soils with better structural composition are more stable and are not so much influenced by the form of tillage with the exception of sites with worsen moisture condition. More significant changes would probably occur only after a longer observation period.

On the basis of the results obtained, a classification scale of structural quality was proposed for agricultural practice according to the percentage of WSA.

The results of the experiment also showed an increase in the yield of monitored crops grown under reduced tillage management (without ploughing) in comparison with the ploughed variant in all locations.

A relationship of positive dependence between WSA, the content of humus substances, and CEC of soil was also found. It is obvious that the use of site adaptable tillage management can reduce degradation impact on the soil environment of the observed or similar locations. Site adaptable tillage also appears to be more convenient from the economic point of view.

Acknowledgements. The authors would like to express their thanks to the Czech National Agency for Agricultural Research (Project No. QH72039) and the Ministry of Education, Youth and Sports (for partial Institutional Funding on long-term Conceptual Development of Research Organisation) for their support in this research.

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Received for publication June 9, 2014
Accepted after corrections December 9, 2014

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