Journal of Central European Agriculture, 2014, 15(3), p.254-262 DOI: 10.5513/JCEA01/15.3.1483

# Change of chosen soil physical properties of chernozem after seven years of no-till soil cultivation

# Zmena vybraných fyzikálnych vlastností černozeme hnedozemnej po siedmich rokoch bezorbového spracovania

Katarína HRČKOVÁ[1*], Štefan ŽÁK[1], Roman HAŠANA[1], Rastislav BUŠO[1] and Mariana ŠVANČÁRKOVÁ[1]

[1] Plant Production Research Center Piešťany, Bratislavská cesta 122, 921 68 Piešťany, Slovakia, hrckova@vurv.sk *correspondence

## Abstract

Soil physical properties were investigated in two types of growing systems - integrated no-till system and conventional system with ploughing, in 1999 – 2005 on chernozem in maize growing region. Bulk density decreased and total porosity increased during 7 years in both growing systems. In integrated system the improvement of soil physical properties could be explained by remaining of plant residues on soil surface. In conventional system the plant residues were incorporated into soil by ploughing. This led to the higher proportion of organic matter in soil. Soil cultivated conventionally had significantly higher value of reduced bulk density, significantly lower porosity and significantly higher values of soil moisture compared to soil in integrated no-till system. Maximum capillary water capacity was not significantly influenced by soil cultivation. Values of investigated soil physical properties in both systems were not markedly different from the typical values of cultivated chernozem.

**Keywords**: bulk density, maximum capillary water capacity, soil cultivation, soil moisture, total porosity

## Abstrakt

Počas siedmich rokov 1999 – 2005 boli na černozemi hnedozemnej, v kukuričnej výrobnej oblasti, sledované fyzikálne vlastnosti pôdy v dvoch pestovateľských systémoch – v integrovanom bezorbovom a v konvenčnom s orbou. Počas sedemročného obdobia došlo k zníženiu objemovej hmotnosti redukovanej a k zvýšeniu celkovej pórovitosti pôdy pri oboch spôsoboch obrábania pôdy. Zlepšenie fyzikálnych vlastností pôdy možno vysvetliť ponechávaním rastlinných zvyškov na povrchu pôdy v integrovanom systéme a ich zaorávaním v konvenčnom systéme pestovania plodín, čo zvýšilo podiel organickej hmoty v pôde. Pôda obrábaná konvenčným spôsobom sa vyznačovala štatisticky preukazne vyššou objemovou hmotnosťou redukovanou a štatisticky preukazne nižšou pórovitosťou. Tiež ju charakterizovala štatisticky významne vyššia momentálna pôdna vlhkosť v porovnaní s pôdou v integrovanom bezorbovom pestovateľskom systéme. Maximálna kapilárna vodná kapacita nebola spôsobom obrábania pôdy štatisticky významne ovplyvnená. Hodnoty sledovaných pôdnych fyzikálnych charakteristík sa v oboch pestovateľských systémoch výrazne nelíšili od hodnôt typických pre černozeme hnedozemné.

**Kľúčové slová:** maximálna kapilárna kapacita, objemová hmotnosť pôdy, obrábanie pôdy, pórovitosť, pôdna vlhkosť

## Detailný abstrakt

V rokoch 1999 – 2005 bol na stacionárnom poľnom pokuse na výskumnom pracovisku CVRV – VÚRV v Borovciach, v kukuričnej výrobnej oblasti (nadmorská výška 167 m. n. m.), skúmaný vplyv dvoch rôznych pestovateľských systémov – integrovaného bezorbového a konvenčného s orbou na vybraté fyzikálne vlastnosti černozeme hnedozemnej. Pôdne vzorky boli odoberané v troch termínoch (jar, leto, jeseň) z troch vrstiev (0.0 – 0.10 m; 0.10 – 0.20 m; 0.20 – 0.30 m). Stanovila sa v nich objemová hmotnosť redukovaná, celková pórovitosť, momentálna pôdna vlhkosť a maximálna kapilárna vodná kapacita. Spôsob obrábania pôdy ovplyvnil štatisticky významne všetky skúmané fyzikálne vlastnosti s výnimkou maximálnej kapilárnej vodnej kapacity. Pôda v integrovanom bezorbovom systéme sa vyznačovala štatisticky preukazne nižšou objemovou hmotnosťou, vyššou celkovou pórovitosťou a nižšou vlhkosťou ako pôda obrábaná konvenčne. Štatisticky významný vplyv mali na sledované fyzikálne vlastnosti pôdy aj poveternostné podmienky v jednotlivých rokoch, termín a hĺbka odberov pôdnych vzoriek. Vlastnosti pôdy charakterizované objemovou hmotnosťou redukovanou a celkovou pórovitosťou sa v priebehu rokov 1999 – 2005 zlepšili v oboch porovnávaných pestovateľských systémoch. Ich zlepšenie možno vysvetliť ponechávaním rastlinných zvyškov na povrchu pôdy v integrovanom systéme a ich zaorávaním v konvenčnom systéme pestovania poľných plodín. Hodnoty sledovaných pôdnych fyzikálnych charakteristík sa v oboch pestovateľských systémoch výrazne nelíšili od hodnôt typických pre obrábané černozeme hnedozemné.

## Introduction

Optimal soil physical properties are important requirements of soil fertility preservation. The productive soils are characterized by water-stability of soil aggregates, good permeability of topsoil and subsoil and also by optimal retention ability. Soil cultivation markedly influences soil physical properties. Ploughing should improve soil physical properties throughout topsoil profile which means to increase total porosity and to decrease its bulk density. But improper usage of ploughing causes compaction of soil and decrease the resistance against the erosion. In compare with conventional ploughing, no-till system leaves the plant residues on soil surface. It leads to higher content of organic carbon and higher stability of soil aggregates which is important for soil ability to resist the erosion and supply the plant by nutrients (Arshad, et al., 1999; Hussain, et al., 1999; Rasmussen, 1999; Tebrügge, Düring, 1999; Kováč, at al., 2010; Žák, et al., 2011).

The aim of this study was to assess the changes of soil physical properties of chernozem after seven years of no-till soil cultivation in compare with conventional soil cultivation.

## Material and methods

Field experiment was established in Research Station of Plant Production Research Center in Borovce. Locality belongs to maize growing region. Average air temperature is 9.1 °C per year. Average air temperature per vegetation season is 15.6 °C. Average amount of precipitation is 545 mm per year and 325 mm per vegetation season (table 1). Soil type is chernozem, with appropriate potassium and magnesium content and middle of phosphorus. Soil reaction ranges from slightly acid to neutral. Humus content is 1.8 – 2.0 %.

Table 1. Weather conditions in 1999 – 2005

Tabuľka 1. Meteorologické údaje v rokoch 1999-2005

| Period | n30[1] | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|
| Precipitation (mm) | | | | | | | | |
| Year (I – XII) | 544.9 | 529.3 | 524.5 | 532.4 | 627.7 | 384.3 | 470.7 | 622.6 |
| Year (% of long-term normal) | 100 | 97.1 | 96.3 | 97.7 | 115.2 | 70.5 | 86.4 | 114.3 |
| Vegetation season (IV – IX) | 326.0 | 354.0 | 217.5 | 348.1 | 347.3 | 210.1 | 202.1 | 396.4 |
| Vegetation season (% of long-term normal) | 100 | 108.6 | 66.7 | 106.8 | 106.5 | 64.4 | 62.0 | 121.6 |
| Average air temperature (°C) | | | | | | | | |
| Year (I – XII) | 9.1 | 9.95 | 9.92 | 8.24 | 10.96 | 10.79 | 10.04 | 9.62 |
| Year (difference from normal) | 0 | 0.85 | 0.82 | -0.86 | 1.86 | 1.69 | 0.94 | 0.52 |
| Vegetation season (IV – IX) | 15.6 | 17.44 | 16.31 | 14.96 | 18.39 | 18.58 | 16.57 | 16.84 |
| Vegetation season (difference from normal) | 0 | 1.84 | 0.71 | -0.64 | 2.79 | 2.98 | 0.97 | 1.24 |

[1]n30 – long-term normal (1971 – 2000)

Field experiment was established in 1999 – 2005 on experimental area, which was cultivated conventionally before. Two variants of soil cultivation were tested (Žák et al., 2011):

- Integrated growing system (IS) – was characterized by no-till soil cultivation with integrated fertilization and plant nutrition. Targeted plant protection was applied and also intercrops were grown. Straw was crushed and remained on the soil surface.

- Conventional growing system (KS) – ploughing was used to depth of 0.18 – 0.22 m. Nitrogen was supplied by fertilizers (urea, DAM-390). Doses of nitrogen were reduced. Herbicides and pesticides were applied. In 1999 – 2002 plant residues were removed. In 2003 – 2005 plant residues were incorporated into the soil and also animal manure was applied.

Crop rotation was the same in both variants of soil cultivation: field pea – winter wheat – maize – spring barley.

Soil was sampled for soil physical properties in spring, summer and autumn. Kopecky´s cones were used. Volume of single Kopecky´s cones is 100 $cm^3$. There were three depths of sampling: 0 – 0.1 m; 0.1 – 0.2 m; 0.2 – 0.3 m in four repetitions. Bulk density reduced, total porosity, soil moisture and maximum capillary water capacity were determined.

Experimental data were processed by analysis of variance and multiple range tests in Statgraphics Plus software package.

## Results and discussion

**Bulk density reduced and total porosity**

Bulk density reduced is one of the basic soil physical parameters. Bulk density is related to total porosity. Higher values of bulk density lead to lower values of total porosity. Both parameters are changed during the year and both are related to crop rotation or soil management. Soils like chernozem can be compacted softly by heavy machineries beneath the top layer as a result of higher clay content in this soil layer. Their bulk density ranges from 1.5 to 1.6 $g*cm^{-3}$ and their total porosity ranges from 43 to 44 % (Fulajtár, 1986).

Average bulk density in experimental site decreased significantly during 7 years in both variants of soil cultivation in general (table 2). Differences of individual years were statistically significant. During the first three years of cultivation in integrated system the trend of soil bulk density was balanced. The fourth year was the crucial one. Since this time soil bulk density has declined rapidly. Similar progress appeared in conventional system one year later. Over the experimental period, more favourable values were achieved in integrated system. Difference of soil bulk density between cultivation systems has become significant since 2001. Progress of total porosity was in close relation to bulk density but inverted (table 2). Improvement of soil physical properties could be explained by remaining of plant residues on soil surface in integrated system during the whole period 1999-2005 and also by incorporation of plant residues into soil in conventional system since 2003. Higher amount of organic matter in soil has positive influence on soil physical properties.

Higher bulk density values and lower porosity values of conventional system described SIRIDAS et al. (2001) in confrontation of conventional and no-till cultivation. In contrast with these facts, there are lot of authors who describe higher bulk density and lower total porosity in no-till cultivation in compare with conventional system with deep ploughing (HUSSAIN et al., 1999; Tebrügge, Düring, 1999; Basic et al., 2004; Guzman et al., 2006; Javůrek, Vach, 2006; Singh, Malhi, 2006; Kotorová, 2007; Mühlbachová, Růžek, 2007; Neudert, 2007; Kováč et al., 2010; Žák et al., 2011). If spring crop is sowed in conditions of high amount of precipitation and high soil moisture level, then soil could be compacted by machines and soil bulk density could increase in conventional technology in contrast to direct sowing without ploughing (Kotorová, 2007). Blanco-Canqui and Lal (2007) concluded, that long-term no-till soil management has only little influence on soil compaction and soil structure. Pikul, at al. (2006) mentioned different tendencies of topsoil bulk density changes in case of conventional and no-till technology. Increase and also decrease of bulk density in no-till technology was recorded in experimental localities. Various soil types and climatic conditions can lead to unclear results of impact of tillage technology on bulk density and porosity.

Table 2. Soil physical properties in 1999 – 2005

Tabuľka 2. Fyzikálne vlastnosti pôdy v rokoch 1999-2005

| | | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 1999 -2005 |
|---|---|---|---|---|---|---|---|---|---|
| Bulk density | IS | 1.54 | 1.52 | 1.55* | 1.45** | 1.41* | 1.33** | 1.40 | 1.46** |
| | KS | 1.56 | 1.54 | 1.58* | 1.52** | 1.45* | 1.43** | 1.42 | 1.50** |
| reduced | | | | | $LSD_{0.05}$ = 0.027 | | | | 0.014 |
| ($g*cm^{-3}$) | | | | | $LSD_{0.01}$=0.035 | | | | 0.019 |
| | IS | 39.21 | 40.08 | 38.73 | 42.59** | 44.58* | 47.49** | 45.03 | 42.53** |
| Total | KS | 38.04 | 39.02 | 37.42 | 39.71** | 42.89* | 43.82** | 43.73 | 40.71** |
| porosity | | | | | $LSD_{0.05}$ = 1.07 | | | | 0.57 |
| (%) | | | | | $LSD_{0.01}$=1.40 | | | | 0.75 |
| | IS | 17.11 | 14.54 | 13.96** | 15.66 | 14.74** | 12.65 | 17.72** | 15.19** |
| Soil | KS | 17.63 | 15.41 | 16.81** | 16.67 | 15.71** | 12.35 | 19.21** | 16.26** |
| moisture | | | | | $LSD_{0.05}$ = 0.54 | | | | 0.28 |
| (%) | | | | | $LSD_{0.01}$=0.71 | | | | 0.38 |
| Maximum | IS | 31.58 | 29.12* | 32.15 | 27.18** | 32.90 | 33.10** | 34.66 | 31.52 |
| capillary | KS | 31.69 | 30.68* | 31.95 | 25.03** | 33.64 | 34.73** | 35.26 | 31.85 |
| capacity | | | | | $LSD_{0.05}$ = 0.63 | | | | 0.34 |
| (%) | | | | | $LSD_{0.01}$=0.83 | | | | 0.44 |

IS – integrated growing system (without ploughing), KS – conventional growing system (with ploughing), $LSD_{0.05}$ – threshold limit for α = 0.05, $LSD_{0.01}$ – threshold limit for α = 0.01, * – significant at P < 0.05, ** – significant at P < 0.01

Sampling date and sampling depth were another experimental factors, which significantly influenced soil bulk density and soil porosity too. Top-soil (0.00 – 0.10 m) was significantly more porous than soil in deeper layers (0.10 – 0.20 m and 0.20 – 0.30 m) in both system of soil cultivation (table 3). These values correspond with Neudert (2007), who published that bulk density increased and soil porosity decreased in connection with depth of ploughing in conventional tillage and also in no-till system. In general assessment, the values of Neudert (2007) were more beneficial than values in our experiment. Direct sowing led to lower values of soil bulk density and higher values of porosity in all examined soil depths according to our results (table 3). Significant difference between conventional and integrated system was clear only in soil layers in depth of 0.00 – 0.20 m (0.0 – 0.10 m: IS 1.38 $g*cm^{-3}$, 45.54 %; KS 1.46 $g*cm^{-3}$, 42.20 %; 0.10 – 0.20 m: IS 1.48 g*cm$^{-3}$, 41.51 %; KS 1.53 g*cm$^{-3}$, 39.70 %). Difference in depth of 0.20 – 0.30 m was not statistically significant (IS 1.51 g*cm$^{-3,}$ 40.54 %; KS 1.51 g*cm$^{-3}$, 40.21 %).

In 1999-2005 values of bulk density in integrated system were significantly higher and values of soil porosity were significantly lower in spring (1.49 g*cm$^{-3}$, 41.44 %) and autumn sampling date (1.49 g*cm$^{-3}$, 41.40 %) in comparison with summer sampling date (1.39 g*cm$^{-3}$, 44.87 %). Bulk density increased and soil porosity decreased in conventional system from spring to autumn sampling date, but the differences were not significant (spring: 1.49 g*cm$^{-3}$, 41.10 %; summer: 1.50 g*cm$^{-3}$, 40.76 %; autumn: 1.51 g*cm$^{-3}$, 40.26 %). Statistically significant difference in bulk density and porosity between integrated and conventional system was noticed only in summer sampling date. In spring and autumn the differences were not statistically significant (table 3).

Table 3. Soil physical properties in 1999 – 2005 in different depths and in different sampling dates.

Tabuľka 3. Fyzikálne vlastnosti pôdy v rokoch 1999-2005 v rôznych hĺbkach a termínoch odberu vzoriek.

| Soil parameters | | Bulk density – reduced (g.cm$^{-3}$) | | Total porosity (%) | | Soil moisture (%) | | Maximum capillary capacity (%) | |
|---|---|---|---|---|---|---|---|---|---|
| Sampling events | | IS | KS | IS | KS | IS | KS | IS | KS |
| Soil layer (m) | 0-0.1 | 1.38$^{**}$ | 1.46$^{**}$ | 45.54$^{**}$ | 42.20$^{**}$ | 15.73$^{**}$ | 16.43$^{**}$ | 32.27 | 31.97 |
| | 0.1-0.2 | 1.48$^{**}$ | 1.53$^{**}$ | 41.51$^{**}$ | 39.70$^{**}$ | 15.12$^{**}$ | 16.51$^{**}$ | 31.19 | 31.74 |
| | 0.2-0.3 | 1.51 | 1.51 | 40.54 | 40.21 | 14.75$^{**}$ | 15.83$^{**}$ | 31.22 | 31.86 |
| | $LSD_{0.05}$ | 0.017 | | 0.70 | | 0.35 | | 0.41 | |
| | $LSD_{0.01}$ | 0.023 | | 0.92 | | 0.46 | | 0.54 | |
| Sampling date | A[1] | 1.49 | 1.49 | 41.44 | 41.10 | 17.91$^{**}$ | 18.39$^{**}$ | 32.60 | 32.70 |
| | B[2] | 1.39$^{**}$ | 1.50$^{**}$ | 44.75$^{**}$ | 40.76$^{**}$ | 13.43$^{**}$ | 15.10$^{**}$ | 31.29$^{**}$ | 31.90$^{**}$ |
| | C[3] | 1.49 | 1.51 | 41.40 | 40.26 | 14.25$^{**}$ | 15.28$^{**}$ | 30.68 | 30.96 |
| | $LSD_{0.05}$ | 0.017 | | 0.70 | | 0.35 | | 0.41 | |
| | $LSD_{0.01}$ | 0.023 | | 0.92 | | 0.46 | | 0.54 | |

[1]Spring, [2]Summer, [3]Autumn, for more details – see Table 2

**Soil moisture and maximum capillary capacity**

Water in soil is a basic power for various mechanical, physical, chemical and biological events. It is irretrievable factor for plants and soil edaphon. Soil water content depends on precipitation, ground water, plant cover, soil texture, soil structure, porosity, soil bulk density and many others.

Soil moisture varied in both growing systems during experimental years (table 2). It reflected weather conditions in particular years (table 1). The lowest values of soil moisture were recorded in both growing systems in 2004 (IS 12.65 %, KS 12.35 %). This year was characterised by the lowest precipitation during vegetation season from April to September (202.1 mm which means 62% of long-term normal). It explains very low soil moisture level in both growing systems. Differences in soil moisture between growing systems in 2004 were not statistically significant (table 2).

The highest soil moisture values were recorded in 2005 (IS 17.72%, KS 19.21%). During vegetation season in 2005 there was the highest precipitation too (396.4 mm which means 121.6% of long-term normal). Soil moisture in conventional system was significantly higher compared to integrated system (table 2). In general, higher values of soil moisture in this field experiment were detected in conventional system with ploughing. Usually opposite results are published. According to many authors the conservation technology can be characterized by higher amount of soil moisture (Hussain, et al., 1999; Sidiras, et al., 2001; Neudert, 2007) and its uniform distribution in particular soil layers (Neudert, 2007). During the experimental period the uniform distribution of soil moisture in particular soil layers was observed in conventional system (15.83% - 16.51%, table 3), where the differences of soil moisture in sampling depths were not significant. In integrated system the soil moisture was decreasing significantly in relation to sampling depth. In top layer 0.00 – 0.10 m it was significantly higher (15.73 %) than soil moisture in sampling depth of 0.10 – 0.20 m (15.12 %) and 0.20 – 0.30 m (14.75 %). Soil moisture difference in top layer 0.00 – 0.10 m between conventional and integrated system was not significant. But in deeper soil layers the values of soil moisture were higher in conventional system in comparison to integrated system.

Difference of soil moisture between both systems in spring sampling date was not significant (IS 17.91%, KS 18.39%). But in summer (IS 13.43%, KS 15.10%) and autumn (IS 14.25%, KS 15.28%) sampling date the differences were more obvious. Significantly more soil water was present in conventional system (table 3).

Maximum capillary capacity is indicator of soil water balance status in soil. It is amount of water, which can be stored in soil in capillary pores for longer period after the saturation. Typical values for chernozem are in range 33 – 37 % (Fulajtár, 1986).

Maximum capillary capacity values varied significantly during 7 years. The highest values were recorded in 2003 and 2005 and the lowest values were recorded in 2000 and 2002 (table 2). In final assessment, the maximum capillary capacity was not affected by soil cultivation significantly (IS 31.52 %, KS 31.85 %). Similar results were published by other authors (Kotorová, Mati, 2008; Kováč, et al., 2010; Žák, et al. 2011). But in particular years 2000 (IS 29.12 %, KS 30.68 %), 2002 (IS 27.18 %, KS 25.03 %) and 2004 (IS 33.10 %, KS 34.73 %), values of maximum capillary capacity of both systems differed significantly. Results are not clear, because higher value of maximum capillary capacity was obtained in integrated system in 2002. On the other side, in 2000 and 2004 higher value of maximum capillary capacity was noticed in conventional system.

Maximum capillary capacity decreased significantly in relation to sampling depth in integrated system. In case of conventional system values of maximum capillary capacity did not differ significantly. Annual trend of maximum capillary capacity was decreasing in both systems. Values obtained in summer (IS 31.29 %, KS 31.90 %) and autumn (IS 30.68 %, KS 30.96 %) sampling date were significantly lower than values in spring sampling date (IS 32.60 %, KS 32.70 %).

## Conclusions

In 1999 – 2005 soil properties of chernozem were monitored in two soil cultivation systems – integrated no-till system and conventional system with ploughing. During 7 year period, bulk density – reduced decreased and total porosity increased in both systems. Improvement of physical soil properties can be explained by remaining of plant residues on the soil in integrated system. In conventional system plant residues were incorporated into soil by ploughing which finally increased amount of organic matter in soil. Plots, which were cultivated conventionally, were characterized by significantly higher values of bulk density – reduced and significantly lower values of porosity. There were also higher values of soil moisture in compare with soil in integrated system. Maximum capillary capacity was not affected by soil cultivation significantly. Measured values of soil physical properties in this experiment were not diametrically different from typical values for chernozem.

## Acknowledgements

This study was supported by project „Development and installation of lysimeters equipment for the rational farming on land in sustainable crop production“, ITMS 26220220106, founded by the Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic for the Structural Funds of European Union.

## References

Arshad, M.A., Franzluebbers, A.J., Azooz, R.H., (1999) Components of surface soil structure under conventional and no-tillage in northwestern Canada. Soil and Tillage Research, Vol. 53(1), 41-47

Basic, F., Kisic, I., Mesic, M., Nestroy, O., Butorac, A., (2004) Tillage and crop management effects on soil erosion in central Croatia. Soil and Tillage Research, Vol. 78(2), 197-206

Blanco-Canqui, H., Lal, R., (2007) Regional assessment of soil compaction and structural properties under no-tillage farming. Soil Science Society of American Journal, Vol. 71, 1770-1778

Fulajtár, E., (1986) Fyzikálne vlastnosti pôd Slovenska, ich úprava a využitie. Poľnohospodárska veda. VEDA, Bratislava

Guzman, J.G., Godsey, CH.B., Pierzynski, G.M., Whitney, D.A., Lamond, R.E., (2006) Effects of tillage and nitrogen management on soil chemical and physical properties after 23 years of continuous sorghum. Soil and Tillage Research, Vol. 91(1-2), 199-206

Hussain, I., Olson, K.R., Wander, M.M., Karlen, D.L., (1999) Adaptation of soil quality indices and application to three tillage systems in southern Illinois. Soil and Tillage Research, Vol. 50(3-4), 237-249

Javůrek, M., Vach, M. (2006) Změny fyzikálních vlastností půdy po dlouholeté aplikaci půdoochranných technologií a jejich vliv na výnosy pšenice ozimé. Aktuální poznatky v pěstování, šlechtění a ochraně rostlin. Brno, Česká republika, 23.-24.11.2006

Kováč, K., Nozdrovický, L., Macák, M., et al., (2010) Minimalizačné a pôdoochranné technológie. Agroinštitút, š. p., Nitra.

Kotorová, D., (2007) Zmeny vlastností ílovito-hlinitej pôdy pri jej rozdielnom obrábaní. Agriculture, Vol. 53(4), 183-190

Kotorová, D., MATI, R., (2008) The trend analyse of water storage and physical propetries in profile of heavy soils. Agriculture, Vol. 54(4), 155-164

Mühlbachová, G., Růžek, P., (2007) Vztah mezi vybranými fyzikálními a biologickými vlastnostmi půdy při různém zpracování půdy. Aktuální poznatky v pěstování, šlechtění, ochraně rostlin a zpracování produktů. Brno, Česká republika, 8.-9.11.2007

Neudert, L., (2007) Hodnocení vlivu různého zpracování půdy ke kukuřici na zrno na základní fyzikální vlastnosti půdy. Aktuální poznatky v pěstování, šlechtění, ochraně rostlin a zpracování produktů. Zborník z konf. Brno, Česká republika, 8.-9.11.2007

Pikul, J.L., Schwartz, R.C., Benjamin, J.G., Baumhardt, R.L., Merrill, S., (2006) Cropping system influences on soil physical properties in the Great Plains. Renewable Agriculture and Food Systems, Vol. 21(1), 15-25

Rasmussen, K.J., (1999) Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review. Soil and Tillage Research, Vol. 53(1), 3-14

Siridas, N., Bilalis, D., Vavoulidou, E., (2001) Effects of tillage and fertilization on some selected physical properties of soil (0-30 cm depth) and on the root growth dynamic of winter barley (Hordeum vulgare cv. Niki). Journal of Agronomy and Crop Science, Vol. 187(3), 167-176

Singh, B., Malhi, S.S., (2006) Response of soil physical properties to tillage and residue management on two soils in a cool temperate environment. Soil and Tillage Research, Vol. 85(1-2), 143-153

Tebrügge, F., Düring, R.-A., (1999) Reducing tillage intensity – a review of results from a long-term study in Germany. Soil and Tillage Research, Vol. 53(1), 15-28

Žák, Š., Beluský, J., Bušo, R., Gavurníková, S., Hašana, R., Macák, M., Kováč, K., Stanko. P., (2011) Pestovanie poľných plodín s orbou či bez orby? Piešťany, Slovakia. Centrum výskumu rastlinnej výroby – Výskumný ústav rastlinnej výroby.