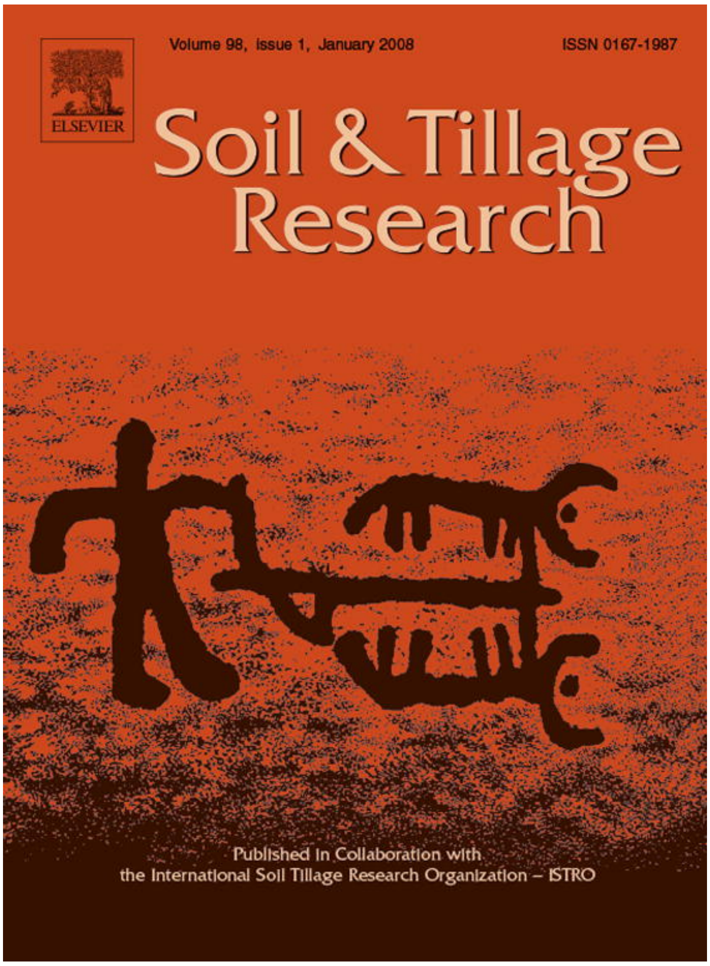
Volume 98, Issue 1, January 2008
ISSN 0167-1987
ELSEVIER
Soil & Tillage Research
Published in Collaboration with
the International Soil Tillage Research Organization – ISTRO

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Soil & Tillage Research 98 (2008) 106–111
Soil & Tillage Research
www.elsevier.com/locate/still

# Mulching effects on selected soil physical properties

Lukman Nagaya Mulumba *, Rattan Lal

*Carbon Management and Sequestration Center, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210-1085, USA*

Received 6 December 2006; received in revised form 25 October 2007; accepted 29 October 2007

**Abstract**

The suitability of soil for sustaining plant growth and biological activity is a function of physical and chemical properties, many of which depend on the quantity and quality of soil organic matter. The equilibrium level of soil organic matter depends on the balance between input through plant residues and other biosolids and output through decomposition, erosion and leaching. However crop residues have numerous competing uses such as fodder, fuel and construction material. Similarly, costs are incurred in its application and these increase with mulch level. Therefore, it is necessary to establish optimum mulch application rates. Empirical data on soil organic matter in relation to input residue of residue are needed to understand management impact on soil quality. Long-term field plots were setup in 1989 to study the effects of mulching on soil physical properties of a Crosby silt loam (Aeric Ochraqualf or stagnic luvisol) soil in central Ohio. Treatments included mulch application at 0, 2, 4, 8 and 16 Mg $ha^{-1}$ $year^{-1}$ without crop cultivation. Soil samples from 0 to 10 cm depth were obtained in December 2000, 11 years after establishing the plots. The results demonstrated that mulch rates significantly increased available water capacity by 18–35%, total porosity by 35–46% and soil moisture retention at low suctions from 29 to 70%. At high suctions, no differences in soil moisture content were observed between mulch levels. Soil bulk density was not affected by mulch rate. High correlations were obtained between mulch rate and soil mean weight diameter ($R^2$ = 0.87) and percent stable aggregates ($R^2$ = 0.84). The study was able to determine optimum mulch rates of 4 Mg/ha for increased porosity and 8 Mg/ha for enhanced available water capacity, moisture retention and aggregate stability.


*Keywords:* Soil organic matter; Mulching; Aggregation; No-till; Soil bulk density; Available water capacity; Soil structure

## 1. Introduction

Returning crop residues to the soil improves soil quality and productivity through favorable effects on soil properties (Lal and Stewart, 1995). Favorable effects of residue mulching on soil organic carbon (SOC), water retention and percent water-stable aggregates have been reported for the surface layer (Duiker and Lal, 1999; Havlin et al., 1990). Application of crop residue mulches increases SOC content (Havlin et al., 1990; Paustin et al., 1997; Saroa and Lal, 2003). Duiker and Lal (1999) reported a positive linear effect of mulch application rate on SOC concentration.

No-till is usually associated with high levels of crop residues left on the soil surface. In Canada, mulching at rates as low as 2.25 Mg/ha reduced nutrient losses of $NO_3$-N and available P, K, Ca and Mg (Rees et al., 1999). The effect of crop residue on soil organic matter (SOM) content is highly related to the amount and only weakly to the type of residue applied. Reicosky et al. (1995) reported a strong relationship between residue amounts and SOM in the 0–15 cm layer. Conservation of soil moisture is one of the major advantages of mulch farming system. Mulching protects the soil from water

* Corresponding author at: Makererere University, Faculty of Agriculture, Department of Soil Science P.O.7062, Kampala-Uganda. Tel.: +256 772 507676.
*E-mail address:* Mulumba.1@osu.edu (L.N. Mulumba).

0167-1987/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.still.2007.10.011

erosion by reducing the rain drop impact. A partial covering of mulch residue on the soil can strongly affect runoff dynamics, and reduce runoff amount (Findeling et al., 2003; Rees et al., 2002). Straw mulch increases soil moisture storage (Ji and Unger, 2001). Crop residues at the soil surface shade the soil, serve as a vapor barrier against moisture losses from the soil, slow surface runoff and increase infiltration. Rathore et al. (1998) observed that more water was conserved in the soil profile during the early growth period with straw mulch than without it. Subsequent uptake of conserved soil moisture moderated plant water status, soil temperature and soil mechanical resistance, leading to better root growth and higher grain yields (Rathore et al., 1998).

SOC also helps in the amelioration of soil structure. However, this may be influenced by the type of SOC pool. For example recalcitrant C may produce long-lasting effects compared to the labile fraction (Jolivet et al., 2003; Rovira and Valejo, 2002). Soil aggregation, which is important to crop establishment, water infiltration and resistance to erosion and compaction, is also influenced by SOC content (Wright and Hons, 2005). Rapid changes in water-stable macroaggregation have been associated with variations in SOM (Cambardella and Elliot, 1993). For most soils macro-water-stable aggregates are stabilized by transient and relatively undecomposed organic binding agents (Tisdall and Oades, 1982). High correlation between aggregate stability and SOM has been reported by Chaney and Swift (1984) and others.

Mulching effects on soil bulk density are often variable. While some researchers have observed reduced soil bulk density under mulch (Unger and Jones, 1998), others have observed increased bulk density (Bottenberg et al., 1999) and yet others no mulch effect on bulk density (Blevin et al., 1983; Acosta et al., 1999; Duiker and Lal, 1999). The effects of mulching on bulk density may vary due to soil type, antecedent soil properties, type of mulch, climate and land use.

Although the beneficial effects of mulching are known, there are instances when its availability is limited. Crop residues have numerous competing uses (e.g. fodder, fuel and construction material). Similarly, costs are incurred in its application and these increase with mulch level. Therefore, it is necessary that an optimum mulch application rate be established if one is to enhance or maintain high soil quality in a cost-effective manner.

It is hypothesized that there is a threshold level of mulch beyond which the effect on soil properties is negligible. This critical level of mulch rate needs to be established for site-specific soil and environmental conditions.

The objectives of this study, therefore, were to:

(1) determine the optimum level of mulch application beyond which additional mulch results in minimal changes in soil properties, and;
(2) determine mulch level effects on soil bulk density, aggregation, soil moisture release characteristics and overall soil physical quality.

## 2. Materials and methods

### 2.1. Location and treatment

The experiment was initiated in 1989, and sited at the Waterman Farm of The Ohio State University, Columbus, OH (40°00′N latitude and 83°01′W longitude). The experimental site has an annual average temperature of 11 °C and precipitation of 932 mm (USDA-SCS, 1980). The soil at the study site is classified as a Crosby silt loam soil (fine, mixed mesic Aeric Ochraqualf in the USDA Classification (USDA, 1996), and stagnic Luvisol in the FAO classification (FAO, 1988).

Wheat straw mulch was applied at 0, 2, 4, 8 and 16 Mg $ha^{-1}$ $year^{-1}$ on untilled and uncropped soil. The plot sizes were 2 m × 2 m, replicated three times according to the randomized block design. No crop was planted and no fertilizer applied. Herbicides (usually glyphosphate) were used to control weeds when necessary.

### 2.2. Measurements and analysis

Soil samples were collected from each plot at 0–10 cm depth with a 5.4 cm diameter core in October 2000. Both disturbed and undisturbed samples were collected. The disturbed samples were used in determining aggregate stability and moisture retention characteristics. Determination of wet aggregate stability involved sieving aggregates that had passed through an 8 mm sieve, but retained on a 5 mm sieve. The aggregates were placed on the top sieve of a nest of sieves having diameters of 5, 2, 1, 0.5 and 0.25 mm. They were allowed to equilibrate in shallow water and then sieved under water for 30 min at a frequency of 30 strokes per minute with a stroke length of 32 mm. The water-stable aggregates in each size fraction were dried at 105 °C and corrected for the coarse fraction. The proportion of aggregates remaining on the sieves was used to compute water-stable aggregates (Yodder, 1936). The percentage of water-stable aggregates (WSA) >0.25 mm, the mean weight diameter (MWD) and geometric mean diameter (GMD) were calculated according to the method described by Kemper and Rosenau (1986). Soil bulk density was measured on undisturbed cores (Blake and Hartage, 1986). Soil moisture release characteristics were determined using core samples on a tension table (0–6 kPa) and pressure plates were used for higher suctions (Klute, 1986). The available water capacity was calculated as the difference in moisture retention between 30 and 1500 kPa suctions, expressed on a volumetric basis.

### 2.3. Statistical analysis

Data were analyzed using ANOVA for completely randomized block design. Soil parameters analyzed included soil bulk density, aggregation and soil moisture retention characteristics. The least square difference was computed to separate means when differences were significant at $P = 0.05$ level. Correlations were run to determine the relationship between mulch rate as the independent variable and soil properties as the dependent variables (Steel et al., 1996).

## 3. Results and discussion

### 3.1. Soil moisture retention characteristics

Significant effects of mulch rate on soil volumetric moisture content were observed at low suction (Fig. 1). Moisture content at saturation varied and was the highest for 16 and 8 Mg/ha mulch rate and the least under unmulched treatment. The differences between treatments were more at low than at high suctions (Fig. 1). At 1500 kPa suction, there was no significant difference in moisture content among mulch rates (Fig. 1). The mulch effect on moisture retention diminished with an increase in the mulch rate, and there was no effect at the 1500 kPa suction (Fig. 2). There was also no significant difference in moisture retention between the 16 and 8 Mg/ha mulch rates. Soil moisture content at field capacity was influenced by mulch rate ($P = 0.05$), being higher at high mulch rates and the least where no mulch was applied (Fig. 2). Beyond 10 Mg/ha of mulch, no incremental benefit of mulch on moisture retention was observed.

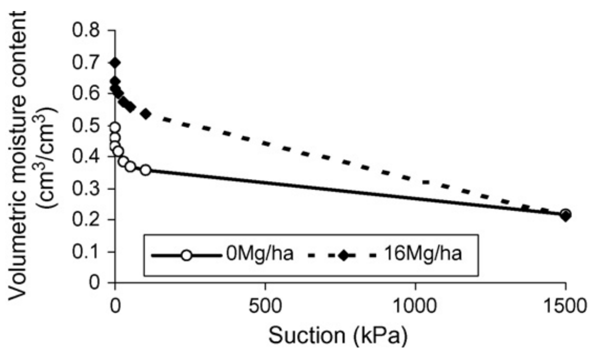


Fig. 1. Variation of volumetric moisture content ($cm^3/cm^3$) with suction (kPa) for the 0 and 16 Mg/ha mulch rate.

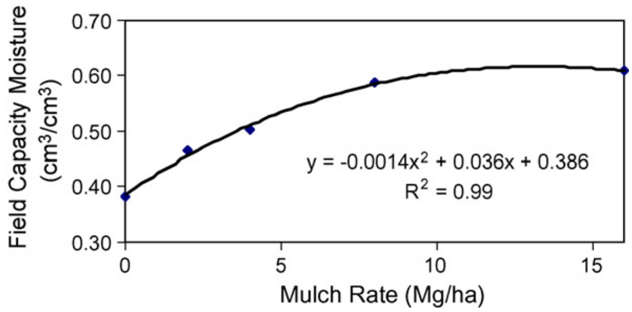


Fig. 2. Variation of field capacity moisture content with mulch rate.

The available water capacity (AWC) was also influenced by mulching (Fig. 3), being significantly lower in unmulched compared to mulched treatments. Although AWC increased with the increase in mulch rate, the differences were not significant beyond 2 Mg/ha mulch rate. The application of 2 Mg/ha of mulch increased the AWC but it was not significantly different from that under 16 Mg/ha. By applying 5 Mg/ha of mulch it is possible to increase AWC by 75% of what is obtained when 16 Mg/ha mulch is used. The implication of this is that applying mulch even at low rates can have a strong impact on the AWC. At Wooster, Ohio, Mahboubi et al. (1993) reported high AWC under no-till which is usually associated with high application of crop residues and mulch. Similar observations were made by Duiker and Lal (1999).

The relationship between AWC and mulch rate was best explained by a polynomial function ($R^2 = 0.95$) as

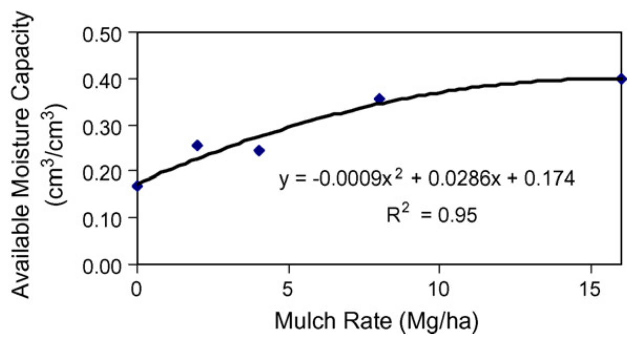


Fig. 3. Variation of available water capacity (AWC) with mulch level.

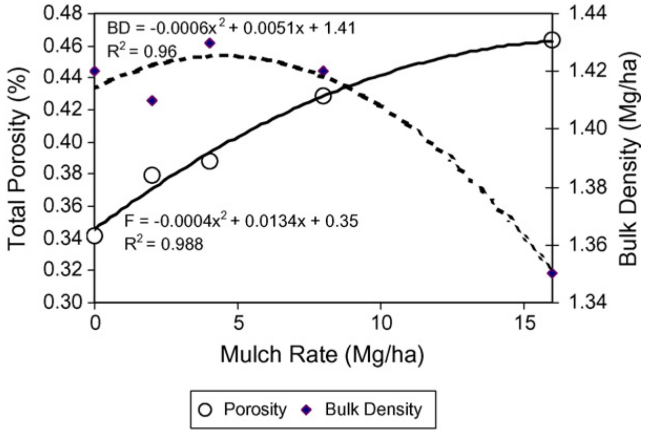


Fig. 4. Relationship between soil bulk density, total porosity and mulch rate.

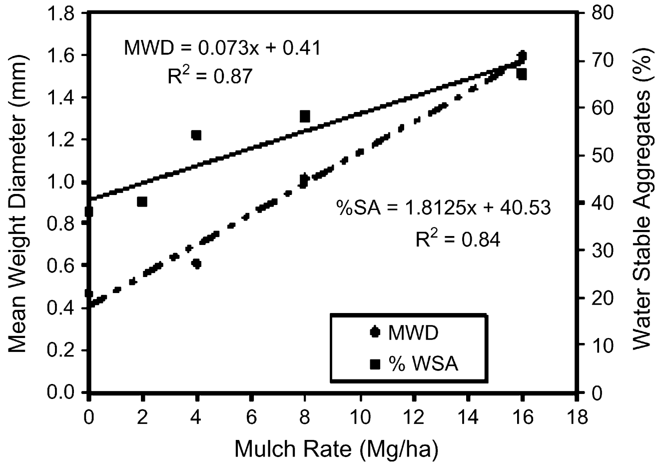


Fig. 5. Variation of stable aggregates and mean weight diameter with mulch level.

shown in Fig. 3. No increment in AWC was observed beyond 12.5 Mg/ha of mulch.

### 3.2. Bulk density and total porosity

The relationship between soil bulk density and mulch rate was best described by a second-order polynomial function (Fig. 4). Blevin et al. (1983) and Acosta et al. (1999) also found no linear relationship between mulch rate and soil bulk density. The effects of crop residues on soil bulk density were highly variable. In some cases high bulk density has been observed under mulch relative to conventional tillage (Bottenberg et al., 1999) and in other instances low bulk densities have been reported (Oliveira and Merwin, 2001). The mixed results may be due to differences in management practices, soil type and the type of mulch material used.

Total porosity increased with increase in mulch rate (Fig. 4) and was significantly lower under the 0 mulch treatment. 95% of the maximum porosity (obtained under 16 Mg/ha of farmyard) was obtained with 8 Mg/ha of mulch. Increased porosity due to mulch application was also reported by Oliveira and Merwin (2001). The increased porosity is especially important to crop development since it may have a direct effect on soil aeration and can enhance root growth (Sugiyanto et al., 1986). The improved root growth makes it possible for the plant to absorb soil water and nutrients from the subsoil.

### 3.3. Aggregate stability

The water-stable aggregates ranged from 38% to 67% and were the highest under the 16 Mg ha$^{-1}$ year$^{-1}$ mulch rate (Fig. 5). Water-stable aggregation was the lowest under the 0 Mg ha$^{-1}$ year$^{-1}$ mulch rate. Aggregate stability, a measure of the soil's resistance to externally imposed disruptive forces, therefore increased with increase in mulch rate (Fig. 5). Mean weight diameter (MWD) ranged from 0.47 to 1.59 mm and was the highest under the 16 Mg ha$^{-1}$ year$^{-1}$ mulch rate and lowest under the 0 Mg ha$^{-1}$ year$^{-1}$ mulch rate. A strong correlation ($R^2$ = 0.84 and 0.87) of mulch rate was observed on water-stable aggregates and the MWD, respectively (Fig. 5).

The stability of aggregates is determined by the ability of the cohesive forces between the particles to withstand an applied force. Prove et al. (1990) and Getachew et al. (1997) also reported that direct drilling and stubble retention had positive effects on aggregate size distribution and resistance to abrasion. Aggregation is maintained by the presence of organic matter in the soil (Lynch and Bragg, 1985). Therefore, changes in soil organic matter content can lead to changes in aggregation (Hamblin, 1985; Dexter, 1988; Paustin et al., 1997; Datta and Hundal, 1984). The energy dissipation effect of organic matter helps to reduce aggregate breakdown by raindrop impact.

Increased aggregation due to residue application can also be attributed to increase in fungal and bacterial activity. Hadas et al. (1994) concluded that the size and strength of aggregates caused by fungi increased during the first week due to external reinforcement by hyphae, while changes appearing after the sixth week could be attributed to internal reinforcement by bacterial secretions.

## 4. Conclusions

The data presented supports the following conclusions:

Mulch application increased total porosity, AWC, soil aggregation and moisture content at field moisture capacity. However, mulch rate effect on soil bulk density was not linear.

Mulch rates as low as 2 Mg/ha resulted in dramatic increases in soil porosity compared to no mulch at all. Similarly, beyond 8 Mg/ha of mulch no significant increases in available water capacity were observed. At high suction, no treatment differences in soil moisture content were observed. The threshold level of mulch rate for this soil is therefore 8 Mg/ha.

## References


Acosta, M.V., Reicher, Z., Bischoff, M., Turco, R.F., 1999. The role of tree leaf mulch and nitrogen fertilizer on turfgrass soil quality. Biol. Fertil. Soils 29 (1), 55–61.

Blake, G.R., Hartage, K.H., 1986. Bulk density. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods, 2nd ed. Agronomy Monograph No. 9, pp. 363–382.

Blevin, R.L., Smith, M.S., Thomas, G.W., Frye, W.W., 1983. Influence of conservation tillage on soil properties. J. Soil Water Conserv. 38, 301–305.

Bottenberg, H., Masiunas, J., Eastman, C., 1999. Strip tillage reduces yield loss of snapbean planted in rye mulch. HorTechnology 9 (2), 235–240.

Cambardella, C.A., Elliot, E.T., 1993. Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils. Soil Sci. Soc. Am. J. 57, 1071–1076.

Chaney, K., Swift, R.S., 1984. The influence of organic matter on aggregate stability in some British soils. J. Soil Sci. 35, 223–230.

Datta, S.K., Hundal, S.S., 1984. Effects of organic matter management on land preparation and structural regeneration in rice based cropping systems. Organic matter and rice. Int. Rice Res. Inst., Los Banos, Laguna (Philippines), pp. 399–416.

Dexter, A.R., 1988. Advances in characterization of soil structure. Soil Till. Res. 11, 199–238.

Duiker, S.W., Lal, R., 1999. Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. Soil Till. Res. 52, 73–81.

FAO, 1988. Soil Map of the World: Revised Legend. Food and Agricultural Organization of the United Nations, Rome, p. 119.

Findeling, A., Ruy, S., Scopel, E., 2003. Modeling the effects of a partial residue mulch on runoff using a physically based approach. J. Hydrol. 275, 49–66.

Getachew, A., Unger, P.W., Jones, O.R., 1997. Tillage and cropping system effects on selected conditions of a soil cropped to grain sorghum for twelve year. Commun. Soil Sci. Plant Anal. 28, 63–71.

Hadas, A., Rawitz, E., Etkin, H., Margolin, M., 1994. Short-term variations of soil physical properties as a function of the amount of C/N ratio of decomposing cotton residues. I. Soil aggregation and aggregate tensile strength. Soil Till. Res. 32, 183–198.

Hamblin, A.P., 1985. The influence of soil structure on water movement, crop root growth and water uptake. Adv. Agron. 38, 95–158.

Havlin, J.L., Kissel, D.E., Maddus, L.D., Claassen, M.M., Long, J.H., 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci. Soc. Am. J. 54, 448–452.

Ji, S., Unger, P.W., 2001. Soil water accumulation under different precipitation, potential evaporation, and straw mulch conditions. Soil Sci. Soc. Am. J. 65, 442–448.

Jolivet, C., Arrouays, D., Lévèque, J., Andreux, F., Chenu, C., 2003. Organic carbon dynamics in soil particle-size separates of sandy spodosols when forest is cleared for maize cropping. Eur. J. Soil Sci. 54, 257–268.

Kemper, W.D., Rosenau, R.C., 1986. Aggregate stability and size distribution. In: Klute, A. (Ed.), Methods of Soil analysis. Part 1. Physical and Mineralogical Methods, 2nd ed. Agronomy Monograph No. 9, pp. 425–442.

Klute, A., 1986. Water retention: laboratory methods. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods, 2nd ed. Agronomy Monograph No. 9, pp. 635–662.

Lal, R., Stewart, B.A. (Eds.), 1995. Managing soils for enhancing and sustaining agricultural production. Soil Management: Experimental Basis for Sustainability and Environmental Quality. CRC Lewis Publishers, Boca Raton, FL, pp. 1–9.

Lynch, J.M., Bragg, E., 1985. Microorganisms and soil aggregate stability. Adv. Soil Sci. 198, 133–171.

Mahboubi, A.A., Lal, R., Faussey, N.R., 1993. Twenty-eight years of tillage effects on two soils in Ohio. Soil Sci. Soc. Am. J. 57, 506–512.

Oliveira, M.T., Merwin, I.A., 2001. Soil physical conditions in a New York orchard after eight years under different groundcover management systems. Plant Soil 234, 233–237.

Paustin, K., Collins, H.P., Paul, E.A., 1997. Management controls of soil carbon. In: Paul, E., et al. (Eds.), SOM in Temperate Agroecosystems: Long Term Experiments in North America. CRC Press Inc., pp. 15–49.

Prove, B.G., Loch, R.J., Foley, J.L., Anderson, V.J., Younger, D.R., 1990. Improvement in aggregation and infiltration characteristics of a kraznozem under maize with direct drill and stubble retention. Aust. J. Soil Res. 28, 577–590.

Rathore, A.L., Pal, A.R., Sahu, K.K., 1998. Tillage and mulching effects on water use, root growth, and yield of rainfed mustard and chickpea grown after lowland rice. J. Sci. Food Agric. 78, 149–161.

Rees, H.W., Chow, T.L., Walker, D.F., Smith, O.M., 1999. Potential use of underseeded barley to increase carbon inputs to a loam soil in New Brunswick potato belt, Canada. Can. J. Soil Sci. 79, 211–216.

Rees, H.W., Chow, T.L., Loro, P.J., Lovoie, J., Monteith, J.O., Blaauw, A., 2002. Hay mulching to reduce runoff and soil loss under intensive potato production in Northwestern New Brunswick, Canada. Can. J. Soil Sci. 82, 249–258.

Reicosky, D.C., Kemper, W.D., Langdale, G.W., Douglas, C.L., Rasmussen, P.E., 1995. Soil organic matter changes resulting from tillage and biomass production. J. Soil Water Conserv. 50, 253–261.

Rovira, P., Valejo, R.M., 2002. Labile and recalcitrant pools of carbon and nitrogen in organic matter decomposing at different depths in soil: an acid hydrolysis approach. Geoderma 107 (1–2), 109–141.

Saroa, G.S., Lal, R., 2003. Soil restorative effects of mulching on aggregation and carbon sequestration in a Miamian soil in Central Ohio. Land Degrad. Dev. 14, 481–493.

Steel, R.G.D., Torrie, J.H., Dickey, D.A., 1996. Principles and Procedures of Statistics: A Biometrical Approach, 3rd ed. McGraw-Hill, New York.

Sugiyanto, Y., Soekodarmodjo, S., Suparnawa, S.H., Notohadisoewarno, S., 1986. Soil physical properties affecting the roots distribution of mature rubber on Red-Yellow Podsolic soil, North Sumatra (Indonesia). Bull. Perkaretan (Indonesia) 4, 82–88.

Tisdall, J.M., Oades, J.M., 1982. Organic matter and water-stable aggregates in soils. J. Soil Sci. 33, 141–163.

Unger, P.W., Jones, O.R., 1998. Long-term tillage and cropping systems affect bulk density and penetration resistance of soil cropped to dryland wheat and grain sorghum. Soil Till. Res. 45, 39–57.

USDA-NRCS, 1996. Key to Soil Taxonomy, 7th ed. Soil Survey Staff, NRCS, Washington, DC.

USDA-SCS, 1980. Soil Survey of Franklin County, Ohio. USDA, SCS, Columbus, OH.

Wright, A.L., Hons, F.M., 2005. Soil carbon and nitrogen storage in aggregates from different tillage and crop regimes. Soil Sci. Soc. Am. J. 69, 141–147.

Yodder, R.E., 1936. A direct method of aggregate analysis and a study of the physical nature of erosion losses. J. Am. Soc. Agron. 28, 337–351.