Evaluation of conservation tillage by means of physical soil quality indicators

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Abstract

Water erosion is a widespread phenomenon in Belgium. In order to abate erosion problems, conservation tillage is proposed as an alternative tillage technique. In this study, a set of indicators are calculated in order to compare physical soil quality under conventional tillage and conservation tillage by deep and shallow non-inversion tillage. Two fields located in the loess belt in Flanders, Belgium and Northern-France were sampled. The field in Flanders was tilled under wet conditions, largely influencing the measured penetration resistance, infiltration rate, macroporosity and air capacity, thus resulting in a poor soil quality. The field in France was tilled under better circumstances, resulting in less compaction and a better infiltration rate. No significant differences between conventional and conservation tillage could be found for these parameters. The higher soil organic matter (SOM) at the surface of the non-inversion tillage plots rendered the aggregates a higher aggregate stability.

Key Words

Physical soil quality, soil quality indicator, conservation tillage, compaction, hydraulic properties

Introduction

Water erosion is a widespread phenomenon in Belgium. Because of its texture and its hilly topography, the loess belt in central Belgium is especially prone to erosion (Verstraeten *et al.,* 2003). This situation is aggravated by the highly mechanised agriculture of row crops (sugar beets, potatoes, maize) leaving large areas of soil vulnerable to water erosion. Conservation tillage is proposed as an alternative tillage technique to diminish erosion problems. Recent research indicates that non-inversion tillage is also a promising technique to maintain soil quality.

Methods

Study area

Different tillage techniques were compared on two fields located in the loess belt in Flanders (Belgium) and Northern-France. A texture analysis can be found in Table 1. The field in Flanders is located in the village of Heestert and has been under non-inversion tillage since 2003. Long term non-inversion tillage was applied in Radinghem in Northern-France (since 1997). Maize, which is an erosion-sensitive crop, was cultivated on both fields in a maize–wheat rotation. The fields were divided into strips, each strip being tilled by an alternative tillage technique. In Heestert, tillage techniques under investigation were: conventional tillage (mouldboard plough), two types of deep non-inversion tillage (erosion plough and subsoiler) and shallow non-inversion tillage (tine cultivator). In Radinghem, conventional tillage by mouldboard plough was compared to shallow non-inversion tillage by a tine cultivator.

Table 1. Texture analysis of the experimental fields.

Location	Clay (0-2 µm) g kg^{-1}	Silt (2-50 µm) g kg^{-1}	Sand (50-2000 µm) g kg^{-1}	SOC g kg^{-1}	$CaCO_3$ g kg^{-1}
Heestert	120	512	368	20	6
Radinghem	174	725	99	196	110

Soil sampling

Per cultivation method, 5 plots of 36 m² (6 m × 6 m), each spaced 15 metres apart, were selected. All plots were located at least 15 m from the border of the strip in order to minimize edge effects. On all plots, disturbed soil samples were taken from 0-10 cm soil layer to determine aggregate stability, soil water content and texture. From the soil layers 0-10, 10-20, 20-30, 30-40, 40-50, 50-60 cm, disturbed soil samples were taken for the determination of soil organic matter (SOM) and soil water content. From the plots of Heestert, undisturbed samples were taken for three out of five plots at depths of 5, 15, 25, 40 and 60 cm to determine the soil-water retention curve (SWRC) and bulk density. Penetration resistance was measured by means of a penetrologger (Eijkelkamp Agrisearch Equipment, Giesbeek, The Netherlands) on every plot in 10 replicates. Field saturated hydraulic conductivity K_{fs} was determined in 2 replicates on every plot by means of a pressure disc infiltrometer (Soil Moisture Equipment, Santa Barbara, CA). K_{fs} was calculated by a double head approach using the equation proposed by Reynolds and Elrick (1990).

Laboratory analysis

SOM was analysed according to the method of Walkley and Black (1934). Soil texture was determined using the combined sieve and pipette method (De Leenheer, 1959). The three methods of Le Bissonnais (1996) were used for the determination of aggregate stability. In a first method, a heavy rain storm is simulated by fast wetting of the aggregates. The second method consists of a slow wetting of the aggregates on a sand box at a matric potential of -0.3 kPa. The third method tests the wet mechanical cohesion of the aggregates independently of slaking by stirring the aggregates in ethanol. SWRC was determined as described by Cornelis *et al.* (2005). Several soil quality parameters were calculated from the SWRC (Reynolds *et al.* 2007). The macroporosity (MacPOR) defines the amount of macropores present in the soil and can be calculated as:

$$\text{MacPOR} = \theta_s - \theta_m \qquad (1)$$

with θ_s ($m^3\ m^{-3}$) the saturated volumetric water content and θ_m ($m^3\ m^{-3}$) the matrix porosity, being the porosity of the soil matrix excluding the macropores. θ_m was calculated at pressure heads of -1 and -6 kPa, corresponding to pore sizes of 0.3 and 0.05 mm. Pores larger than 0.05 mm are considered here as macropores, corresponding to transmission pores facilitating air movement and drainage of excess water. Air capacity (AC) is an indicator for soil aeration and is calculated as:

$$\text{AC} = \theta_s - \theta_{FC} \qquad (2)$$

with θ_{FC} ($m^3\ m^{-3}$) the field capacity, which is the volumetric water content at a pressure head of -10 kPa. The soil's capacity to provide water available to plant roots is defined as the plant available water content (PAWC) and is calculated as:

$$\text{PAWC} = \theta_{FC} - \theta_{PWP} \qquad (3)$$

with θ_{PWP} ($m^3\ m^{-3}$) the permanent wilting point, calculated at a pressure head of -1500 kPa. The soil's capacity to store water relative to the total pore volume is given by the relative water capacity (RWC) which is the proportion of θ_{FC} to θ_s.

Results and discussion

Penetration resistance

On the plots of Heestert, no clear plough layer could be detected (Figure 1). Although the different tillage techniques were able to decompact the soil to the same extent at the surface, the mouldboard plough could clearly loosen the soil more at deeper soil layers (15 – 35 cm). The subsoiler was not able to loosen the soil throughout the whole profile. The cause of the high penetration resistance is the harvest in wet conditions of the preceding crop. Non-inversion tillage proved not to be able to loosen the soil to the same extent as the mouldboard plough. The slightly better results of the shallow non-inversion tillage can be explained by the build up of a better soil structure at shallow depth.

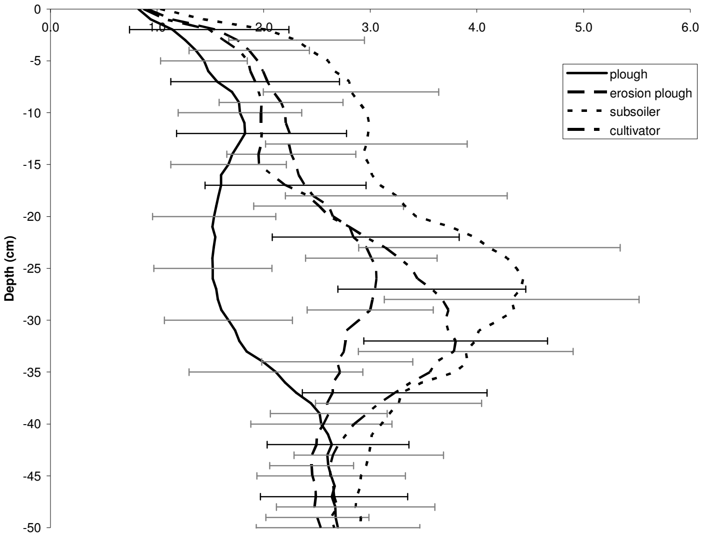

Figure 1. Penetration resistance profiles for the different tillage techniques applied in Heestert. Error bars represent standard deviations.

On the plots at Radinghem, similar results were obtained, though to a lesser extent. Mouldboard plough was able to loosen the soil the most throughout the tillage layer, the cultivator rendering a higher (though not significant) penetration resistance at depths between 10 – 35 cm.

Organic matter content

As a consequence of several years of non inverting the soil, a stratification in organic matter content can be observed (Figure 2). Organic matter content stays fairly constant with depth in the tillage layer for mouldboard plough, while organic matter decreases steadily with depth for non-inversion tillage. While SOM is higher in the first 10 cm of the profile for non-inversion tillage, the SOM is lower in the layer of 20-30 cm. At a depth of 30-40 cm, similar levels of SOM are reached. This stratification is a direct effect of keeping the organic matter at the surface in non-inversion tillage. The strongest stratification was observed for shallow non-inversion tillage. In Radinghem, the same stratification of organic matter content for the shallow non-inversion tillage can be found (data not shown).

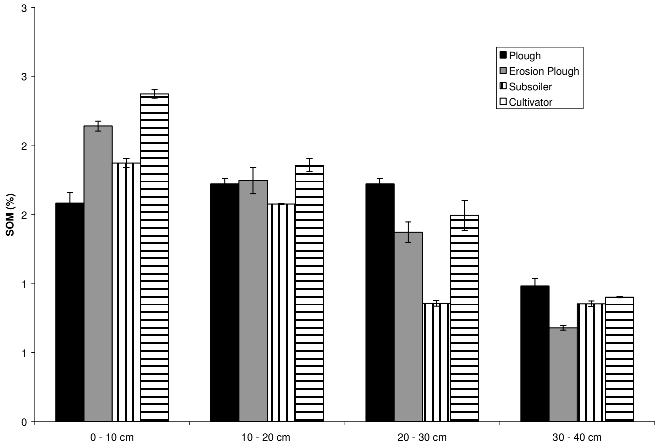

Figure 2. Organic matter content for the different tillage techniques applied in Heestert. Error bars represent standard deviations.

Aggregate stability

The fast wetting method produced very low values for Mean Weight Diameter (MWD) (see Table 2). As both soils contain considerable amounts of clay (see Table 1), slaking occurs to a large extent and most aggregates are destroyed. Both on the plots of Heestert and Radinghem, the aggregates from non-inversion tillage proved to withstand the fast wetting slightly more, though the difference is not significant. Slaking is prevented in the second method by prewetting the aggregates. This is reflected in the higher values of MWD. This method is preferred for unstable soils as a better discrimination can be expected (Le Bissonnais, 1996). The aggregates under non-inversion tillage proved to be significantly more stable with this method. The higher SOM content at the surface may have strengthened the aggregates for the non-inversion tillage applications. The mechanical cohesion for aggregates of Heestert proved to be similar except for the subsoiler. In Radinghem, aggregates of the plot cultivated with the cultivator proved to be less stable than those at Heestert, but still significantly more stable than those for conventional tillage.

Table 2. Mean Weight Diameter (mm) after fast wetting (MWD_{fast}), after prewetting at -0.3 kPa (MWD_{slow}) and after stirring (MWD_{stir}) measured by the three methods of Le Bissonnais (1996). Standard deviations are given between brackets. Same letter indicates no significant difference between plots at P = 0.05.

Location	Management	MWD_{fast} (mm)			MWD_{slow} (mm)			MWD_{stir} (mm)		
Heestert	Plough	0.29	(0.03)	a	2.85	(0.31)	a	0.54	(0.10)	a
	Erosion Plough	0.36	(0.04)	a	3.20	(0.14)	b	0.53	(0.02)	a
	Subsoiler	0.35	(0.06)	a	3.14	(0.16)	b	0.45	(0.07)	b
	Cultivator	0.43	(0.06)	a	3.08	(0.29)	ab	0.57	(0.09)	a
Radinghem	Plough	0.30	(0.61)	a	2.65	(0.21)	a	1.43	(0.16)	a
	Cultivator	0.44	(0.08)	a	2.92	(0.22)	b	1.06	(0.28)	b

Hydraulic conductivity and soil quality indicators obtained from the SWRC

Hydraulic conductivity for the plots of Heestert was strongly influenced by the compacted subsoil. As deep non-inversion tillage suffered more from compaction, these plots had the lowest K_{fs}. The plough and the cultivator had similar K_{fs}. Also in Radinghem, the mouldboard plough and the cultivator had similar K_{fs}, as was expected as this field didn't suffer compaction.

From the SWRC, several soil quality indicators could be deduced (see Table 3). Nevertheless, for none of the calculated indicators could a significant difference between the different plots be observed. There was also no significant difference with soil layers at -15 and -25 cm. The plot tilled with the mouldboard plough showed slightly less macropores and a slightly higher air capacity. Nevertheless, all plots showed a value of the AC lower than 0.15, which is recommended for clay loam soils, according to Reynolds *et al.* (2007). As a result, aeration deficits in the root zone may occur. The low values for macroporosity and AC can be explained by the compacted soil. PAWC proved to be higher than the recommended value of 0.20 and increased at increasing soil depth. Recommended values for RWC fall between 0.6 and 0.7 in order to keep the optimal balance between soil water capacity and soil air capacity. All plots showed values higher than 0.7, indicating a possible problem with soil aeration.

Table 3. Soil quality indicators deduced from the SWRC of samples taken at a depth of 5 cm from the plots of Heestert.

Soil quality indicator	Plough	Erosion plough	Subsoiler	Cultivator
MacPor (m^3 m^{-3}) (-0.1kPa)	0.01	0.02	0.02	0.02
MacPor (m^3 m^{-3}) (-0.6kPa)	0.06	0.09	0.08	0.08
AC (m^3 m^{-3})	0.09	0.12	0.12	0.11
PAWC (m^3 m^{-3})	0.22	0.21	0.25	0.26
RWC	0.77	0.7	0.73	0.75

Conclusion

Making use of a set of soil quality indicators, the physical soil quality of two selected soils could be described. In order to get a deeper insight into the soil's processes, the interaction between the different indicators was investigated. The soil's history proved to play a major role in the measured values. As such, information on preceding crop and soil state (especially soil water content) at harvest and tillage operation should always be taken into account.

The field plots in Heestert were heavily influenced by the wet conditions at harvest and seeding. As non-inversion tillage proved not able to loosen the soil to the same extent as the mouldboard plow, compacted soil layers and a lower infiltration rate could be observed. Nevertheless, this was not reflected in differences in macroporosity, AC and PAWC. As the field plots of Radinghem were tilled under optimal soil water conditions, no significant differences in penetration resistance and infiltration rate were observed. The higher SOM at the surface of the non-inversion tillage plots resulted in aggregates with a higher stability.

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