TILLAGE EFFECT ON SOIL QUALITY INDICATORS IN SLOVAKIA

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Abstract.
In this study we compare some chemical and biological soil properties using the no tillage and conventional systems. In 2003 and 2004 the soil characteristics were observed on the precise field experiment plots in Borovce (near Piešťany, in the western part of the Slovak Republic) where no tillage management has taken place since 1995. The experimental plots were situated in the area where there is a continental character of weather (average annual temperature of 9.2 ^{0}C and the mean annual precipitation of 593 mm). A large variability of temperature and unequal precipitation are a characteristic of this area. The soil representative is loam and clay, loam degraded Chernozem on loess (pH 5.5 – 7.2, humus content 1.8 – 2.0 %, good available potassium store, medium phosphorus content and high magnesium content). The chemical and biological soil properties were determined within two farming systems: no tillage and conventional (mouldboard plough). The soil samples were taken four times during the vegetation period, from the depth of 0.02 – 0.2 m. The air dried soil samples were used for the chemical analysis (pH/KCl, C_{ox}, N_t, N_{in}). The biological analyses were determined in the fresh soil samples. The results were statistically evaluated by the Wilcoxon pair test. The lower values of soil reaction and the higher contents of organic matter and inorganic nitrogen in the soil were measured under conventional treatment. No tillage management and the use of organic residues and compost also positively affected microbial biomass content, ammonification and nitrification activity. The earthworm population was more developed at the no tillage variant. During the years 2003 and 2004, after eight years of no tillage management utilisation, the tendency of increased biological activity in the soil under no tillage management was observed.

INTRODUCTION

Soil quality is a research area of increasing importance (Wilson and Maliszewska-Kordybach, 2000). Soil quality indicators can be defined as the soil processes and properties that are sensitive to changes in soil functions

(Doran and Jones, 1996). Soil quality indicators can be used to evaluate sustainability of land use and soil management practices (Shukla et al., 2006). Tillage accelerates oxidation of organic matter by soil microorganisms through changes in soil water, aeration and temperature regimes, aggregation and nutritional environment (Doran and Smith, 1987). Therefore, soils under no-till (NT) generally contain greater organic C and N and microbial biomass than under conventional till (CT), especially closer to the soil surface. Differences in distribution of immobile nutrients and exchangeable cations in surface layers of soil also occur between NT and CT, due to the absence of inversion and mixing of surface soil by tillage. The progressive increase in organic matter content in the first few cm of the soil profile increases the availability of the main nutrients (Rhoton et al., 2002) that are released to the rhizosphere at a faster rate than in conventionally tilled soils (Fox and Bandel, 1987). Therefore, directly drilled soils are, in general, more fertile than conventionally tilled ones. Managing the frequency and type of tillage can stop soil degradation and improve soil quality (Franzluebbers et al., 1999). Soil microorganisms mediate mineralization of soil organic matter (SOM) and nutrients. The microbial biomass is a small but important reservoir of nutrients (C, N, P and S) and many transformations of these nutrients occur in the biomass (Dick, 1992). Soil disturbance can cause significant modifications of soil habitat, which affects the microbial community. This has been shown in numerous examples where SOM and microbial biomass decline under agricultural or land disturbance (Sparling, 1997). Currently, there is a strong interest in sequestration of C in soils as a means to help decrease atmospheric CO_2 and to gain side benefits of improving soil quality and plant productivity (Burras et al., 2001 and Sa et al., 2001). Microbial biomass measurements can detect tillage and crop rotation effects on soil earlier than total organic C or N measurements in soil (Saffigna et al., 1989 and Balota et al., 1998) and therefore they may be an indicator of potential C sequestration (Sa et al., 2001). In this context, microbial biomass can be a valuable tool for understanding changes in soil properties and in the degree of soil degradation or soil quality (Doran and Parkin, 1994; Brookes, 1995 and Sparling, 1997).

Despite the recent interest in conservation agriculture, little research has been carried out in this area in the Slovak Republic and only a small amount of data is available to assess the long-term effects of no tillage management. Since the management systems react differently in different soil-climatic regimes with respect to soil quality, the objective of this study was to evaluate the impact of no tillage management on soil quality in the western part of the Slovak Republic where no tillage system has been carried out since 1995. Several chemical and microbiological indicators from conventionally and no tillage managed soils were measured and the soil quality was compared within the precise field experimental plots on degraded Chernozem on loess.

MATERIAL AND METHOD

The experimental plots are situated in an area with a continental character of weather (average annual temperature of 9.2 ^{0}C and the mean annual precipitation of 593 mm). A large variability of temperature and unequal precipitation are a characteristic of this area. The soil representative is loam and clay loam degraded Chernozem on loess (pH 5.5 – 7.2, humus content 1.8 – 2.0 %, good available potassium store, medium phosphorus content and high magnesium content). The chemical and biological soil properties were determined within two farming systems:

No tillage system: In this system we used direct drilling and the residues were left on the soil surface until it decays. There were six crops used in the crop rotation: pea, winter wheat + intercrop, maize, spring barley + intercrop. Compost fertilisation took place once during the crop rotation to maize for the grain (the rate represented 30 t/ha). The synthetic N fertilizers were used to all crops in the crop rotation and P and K mineral fertilisation was defined by the balance method. Chemical protection was used against pests and diseases.

Conventional system: This system had the same crop rotation as the no tillage system and also the same compost fertilisation was used. The synthetic N fertilisers were used at all crops in the crop rotation and P and K mineral fertilisation was defined by the balance method. Chemical protection was used against pests and diseases. In this system we used mouldboard plough and all the residues were removed from the soil surface.

The same varieties were used in both farming systems. The soil samples were taken four times during the vegetation period, from the depth of 0.02 – 0.2 m. The air dried soil samples were used for the chemical analysis (pH/KCl, C_{ox}, N_t, N_{in}). The biological analyses were determined in the fresh soil samples.

Used methods: pH/KCl measured by Ion Analyser (JENWAY, VB), C_{ox} measured by analyser CNS-2000 (LECO, Corp. St. Joseph, MI, USA), N_t measured by analyser CNS-2000 (LECO, Corp. St. Joseph, MI, USA), inorganic nitrogen ($N\text{-}NH_4^+$ + $N\text{-}NO_3^-$) – ($N\text{-}NH_4^+$) measured by Spekol 11 (Carl Zeiss, Jena, SRN), ($N\text{-}NO_3^-$) izotachophoretic determination by analyser EA 100 (VILLA Labeco Spišská Nová Ves, SR). Ammonification activity = inorganic forms of nitrogen increase $N\text{-}NH_4^+$ + $N\text{-}NO_3^-$ after 14 days of aerobical soil cultivation. Nitrification activity = $N\text{-}NO_3$ increase after 14 days of aerobical soil cultivation. Microbial biomass C_{mic} defined by fumigation – extraction method. Cellulolytic bacteria number on mineral agar, ammonification bacteria number on agar No.2. The number of earthworms sorted by hand from the sonde, 0.25 x 0.25 x 0.3 m on a PVC sheet directly in the field, earthworms' biomass and average weight of one earthworm in the laboratory conditions.

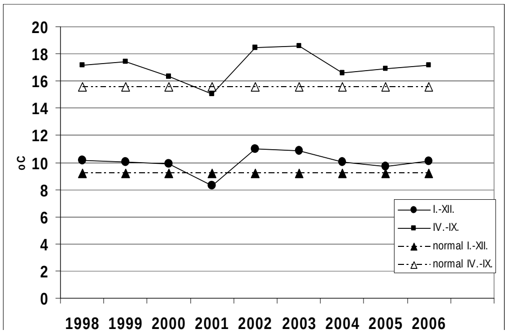
The obtained results were statistically evaluated by non-parametric method by means of the Wilcoxon pair test.

RESULTS AND DISCUSSION

Climate conditions of the evaluated experimental years were extremely dry and warm comparing that with 30 years average (normal I.-XII.) valid for the experimental station of the Research Institute of Plant Production in Borovce, near Piešťany (Graph 1 and Graph 2).

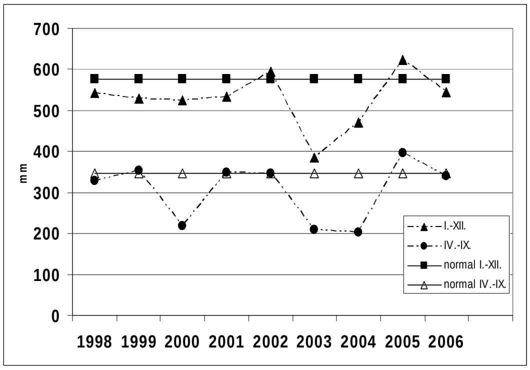
Graph 1

Average temperatures in the years 1998-2006 in comparison with the standard climatological 30 years normal



Graph 2

Average annual precipitation in the years 1998-2006 in comparison with the standard climatological 30 years normal



The two farming systems (no tillage and conventional with ploughing) compared in Borovce, near Piešťany has emphasised interesting differences in soil quality after eight years of no tillage farming management utilization. Some research results presenting that soils under no tillage (NT) practice are frequently more acidic in the surface layers but less acidic in deeper layers than under conventional tillage (CT) practice as a result of an increase in organic matter and associated organic acids and changes in the proportions of cations and anions in soil under NT practice (Logan et al., 1991, Prasad and Power, 1991, Kern and Johnson, 1993 and Schomberg et al., 1994). In our conditions the soil pH was statistically significantly higher in NT than in CT after eight years of NT management application (Table 1).

The overall fertility of an agricultural soil has always been related to its content in organic matter. The maintenance of adequate levels of this parameter in the soil is of great agronomic importance as it intervenes in all the processes connected to structure dynamics, to plant growth and the macro- and microbial life sustaining it. Organic matter has lately been receiving special attention due to its potential for sequestering carbon, thus diminishing atmospheric CO_2 emissions (McCarty and Ritchie, 2002). According to a 2001 EU report (Basch and Tebrügge, 2001), the reduction in CO_2 emissions would be around 3 Gt C year^{-1} if 70% of the productive agricultural surface were to be under direct drilling and minimal tillage. The no tillage management system and the use of organic residues and compost have been shown to maintain soil organic matter at higher levels than inorganic fertilisation and soil organic matter removal from the field. This increase is particularly important in Slovakia, where the decline of organic matter content represents more than 59 % of the land area and belongs to the very important degrading process.

Microbial biomass was higher under the NT management system. Microbial biomass is among the most labile pools of organic matter and it serves as an important reservoir of plant nutrients, such as N and P (Melero, Porras, Herencia, Madejon, 2006). Microbial biomass, in response to environmental changes, can therefore have important implications for nutrient bioavailability. The number of cellulolytic and ammonification bacteria was higher in the conventional system but there were not statistically significant differences.

More intensively the processes of ammonification and also nitrification run under no tillage management. The data shows a higher activity of ammonification microflora decomposing nitrogen organic compounds and also nitrification microflora which oxidise a part of ammoniacal nitrogen.

The development of larger earthworm populations in no-till relative to conventional systems is generally attributed to lower disturbance, physical injury, and susceptibility to predation by birds combined with a more continuous food supply and favourable soil environmental conditions (Kladivko, 2001). Biomass, the abundance of earthworms and the average weight of one earthworm were statistically significantly higher in no tillage plots as compared with the conventional plots.

Table 1

Soil chemical and biological characteristics in organic and conventional system in the years 2003-2004

Indicator	**No tillage system**	**Conventional System**
pH/KCl	6,94	6.77
C_{ox} (%)	1.477	1.219
N_t (%)	0.136	0.115
N_{in} (mg.kg^{-1} dry matter)	15.2	13.9
Ammonification activity (mg.kg^{-1} dry matter)	11.7	6.9
Nitrification activity (mg.kg^{-1} dry matter)	12.2	7.4
Microbial biomass (C_{mic}.g^{-1} dry matter)	789.5	671.6
Number of cellulolytic bacteria (n.10^3 CFU.g^{-1} dry matter)	8.9	7.7
Number of ammonification bacteria (n.10^6 CFU.g^{-1} dry matter)	21.9	22.3
Number of earthworms (ks.m^{-2})	54	13
Earthworms biomass (g.m^{-2})	38.0	6.7
Average weight of one earthworm (g)	0.76	0.35

Table 2

Wilcoxon pair test (significance of differences between no tillage and conventional system) in the years 2003-2004

Indicator	**Number of no-zero differences**	**Test value**	**P-value**
pH/KCl	19	0.883883	0.376757++
C_{ox}	32	5.48008	0.000000043++
N_t	32	5.48008	0.000000043++
N_{in}	41	2.125	0.0335864+
Ammonification activity	50	4.375	0.0000121++
Nitrification activity	52	4.875	0.0000010896++
Microbial biomass	56	6.04743	0.000000001++
Number of cellulolytic bacteria	38	1.375	0.169131
Number of ammonification bacteria	30	0.375	0.707657
Number of earthworms	49	4.60933	0.00000404396++
Earthworms biomass	54	5.375	0.0000000767++
Average weight of one earthworm	51	4.78755	0.00000169++

+ Significant for $P<0.05$, ++ Significant for $P<0.01$

CONCLUSIONS

The unequal spreading of precipitation and decreasing amount of rain along with the increasing temperatures during the vegetation are seem to be the problems with accelerated importance in the Slovak Republic. There is also a need to increase the organic matter content in the soil because the decline of organic matter content represents more than 59 % of the land area and belongs to the very important degrading process.

The degraded Chernozem on loess in this study was significantly affected by 8 years of different tillage. Positive effects of NT on soil organic matter were observed. While organic matter (organic C and total N and inorganic N) and ammonification and nitrification activity was higher under NT, the higher number of cellulolytic and ammonifation bacteria was under the conventional tillage (the differences were not statistically significant). The NT management conditions didn't cause the soil pH decline. The better conditions for earthworm populations development were in no-tillage system in comparison with the conventional system. Our results indicated that no tillage management positively affected soil properties during the very extreme conditions of the evaluated years.

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