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Basic soil chemical properties after 15 years in a long-term tillage and crop rotation experiment**

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A b s t r a c t. Basic soil chemical properties were assessed in a long-term tillage and crop rotation experiment 15 years after its establishment on a Chernozem in Raasdorf (Austria) with four tillage treatments – mouldboard ploughing, no-till, deep conservation tillage and shallow conservation tillage – and two crop rotations. The following parameters were assessed: pH_{CaCl_2}, pH_{H_2O}, electrical conductivity, cation exchange capacity, total nitrogen, total organic carbon and total carbon. Among which, pH_{CaCl_2}, pH_{H_2O}, and total carbon increased with soil depth while electrical conductivity, cation exchange capacity, total nitrogen, and total organic carbon decreased with soil depth. The differences between tillage treatments occurred after 15 years in the upper soil layer from 0-5 cm with higher values of electrical conductivity under no-till, deep conservation tillage and shallow conservation tillage than with mouldboard ploughing, higher values of cation exchange capacity and total nitrogen for no-till than for mouldboard ploughing (with deep conservation tillage and shallow conservation tillage showing intermediate values) and more total organic carbon for no-till and deep conservation tillage than for mouldboard ploughing. At a 5-10 cm depth, electrical conductivity was higher for no-till than for mouldboard ploughing. Values of pH_{CaCl_2} and pH_{H_2O} did not differ between tillage treatments in any soil layer. In deeper soil layers, tillage did not affect the analysed parameters. Crop rotation did not affect any of the analysed soil chemical properties.

K e y w o r d s: tillage, soil depth, long-term experiment, soil properties, no-till

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INTRODUCTION

Tillage systems are generally categorized in terms of conventional tillage using a mouldboard plough to turn over the soil, conservation tillage using a chisel plow, disk plow, harrow disk or cultivators, and no-till where seeds are sown directly into the untilled soil. In conventional tillage, all crop residues are incorporated while in conservation tillage or no-till these residues remain partly or completely on the soil surface.

From a global perspective, the conventional tillage system is increasingly being superseded by the reduced tillage approaches. Whereas the plough is still dominant in Europe, conservation tillage and no-till are broadly applied in North and South America and in Australia (Derpsch *et al.,* 2010). In a review of crop yields from several European countries, yields from no-till were within the 5% range of those obtained by mouldboard ploughing (Soane *et al.,* 2012). Under Pannonian climate conditions on a Chernozem in Eastern Austria, winter wheat yields were generally at similar levels for conventional, conservation and no-till with no-till resulting in higher yields in very dry years and conventional and conservation tillage resulting in higher yields with higher amounts of rainfall during the vegetation period (Neugschwandtner *et al.,* 2015a). Moitzi *et al.* (2019) reported for this experiment, that the direct energy input in no-till and shallow conservation tillage during crop cultivation was considerably lower than in mouldboard ploughing.

This may result in an increase in the energy efficiency of these tillage systems, especially during dry years, when ploughless tillage systems tended to respond with competitive yields (Neugschwandtner *et al*., 2015a).

The economic benefits of no-till include a reduction in fuel consumption and working time; both could be reduced by establishing wheat with no-till on a silty loam Chernozem as opposed to conventional establishment (*i.e.* using a heavy cultivator for stubble cultivation and a mouldboard plough and subsequent seeding, using a power harrow and a seeding machine) by about 85% (Moitzi *et al.,* 2013; Szalay *et al.,* 2015). The ecological benefits of no-till include an increase in biotic activity, especially earthworms, and of soil organic carbon, less soil erosion and lower carbon emissions (due to less fuel consumption) (Derpsch *et al.,* 2010).

Tillage operations alter nutrient dynamics on a short-term scale through changes in the physical properties of the soil and the incorporation of crop residues and mineral or organic fertilizers. These effects accumulate in the long-term and an additional system effect builds up (Pekrun *et al.* 2003). Soil physical characteristics like soil aggregate stability, bulk density, pore volume and pore size distribution, infiltration and penetration resistance (Liebhard, 1993b; Liebhard, 1994; Liebhard *et al.,* 1994; Liebhard *et al.,* 1995) and soil chemical characteristics such as soil pH, soil organic matter and soil nutrients (Liebhard, 1993a; Neugschwandtner *et al.,* 2014) are influenced by these long-term changes.

The aim of this study was to assess the influence of four different soil tillage systems and two crop rotations on basic soil chemical parameters in soil layers fifteen years after establishing a static field trial on a Chernozem in eastern Austria. Several soil characteristics which were assessed in 2003, seven years after the start of the experiment, have been reported earlier by Neugschwandtner *et al.* (2014).

MATERIALS AND METHODS

The long-term experiment was carried out in Raasdorf (48° 14' N, 16° 33' E; altitude: 153 m a.s.l) in eastern Austria on the experimental farm of BOKU University. Raasdorf is located close to the east of Vienna, Austria, on the edge of the Marchfeld plain, an important crop production region in the north-western part of the Pannonian Basin. The silty loam soil is classified as a Chernozem of alluvial origin and is rich in calcareous sediments. The mean annual temperature is 10.7°C and the mean annual precipitation is 543 mm (1983-2012).

The long-term experiment, which was established in 1996, is set up with a split-plot design using four replication blocks and involves two factors: the tillage system is assigned to the main plots (24 × 40 m) and crop rotation to the subplots (12 × 40 m). Fertilization is performed on a crop specific basis according to good agricultural practice, *e.g.* winter wheat was fertilized with calcium ammonium nitrate (27% N) at a rate of 130 kg N ha^{-1}.

The tillage variants include: (1) Mouldboard ploughing (MP) after harvest to a soil depth of 25-30 cm. The loosened soil is turned over and therefore residues are fully incorporated into the soil. (2) No-till (NT): Direct drilling in un-tilled soil with a disc drill without the previous removal of residues. A total herbicide (glyphosate) is applied before sowing for weed control. (3) Deep conservation tillage (CTd) to a soil depth of 20-25 cm is performed using a wing share cultivator and every four years a subsoiler is used to a depth of 35 cm. A part of the plant residues remain on the soil surface. (4) Shallow conservation tillage (CTs) to a soil depth of 8-10 cm using a wing share cultivator. A high share of the plant residues remain on the soil surface.

Two flexible crop rotations are performed on subplots with sugar beet (rotation A; grown in four years) or maize (rotation B; grown in four years) as central crops. Both rotations frequently included winter wheat (in a total of seven years), as rotation effects on this crop shall be tested within this long-term experiment. Rotation A had a further two years of maize and in one year each, sunflower and spring durum wheat. Rotation B had a further two years of oilseed rape and one year each of sugar beet and soybean. Both rotations had in the four years (2008-2011) before sampling, the same crops but in a different time course: Rotation A – maize, winter wheat, sugar beet and winter wheat; Rotation B – winter wheat, maize, winter wheat and sugar beet. Crop residues were left on the field.

Soil sampling was performed with soil probes (Purckhauer type, core diameter: 30 mm) in 5 cm steps at depths ranging from 0-30 and in 10 cm steps at depths ranging from 30-50 cm from the 7th to 9th of November, 2011. A mixed sample was composed per plot for each sampled layer consisting of 30 equally sized subsamples randomly collected from the individual plots. The samples were air-dried, homogenized and sieved (2 mm). The crops grown before sampling were harvested in July (rotation A: winter wheat) and in October (rotation B: sugar beet).

The soil pH was determined in a distilled water extract (pH_{H_2O}; 50 ml, w/v = 1:10) after 1 h of extraction and in a 0.01 mol l^{-1} calcium chloride solution (pH_{CaCl_2}; $CaCl_2$; w/v = 1:2.5) after 2 h of extraction (ÖNORM L 1083, 1999) using a Multi 3420 Multiparameter Meter (WTW GmbH, Weilheim, Germany). Electrical conductivity (EC) was measured simultaneously with pH_{H_2O}. The cation exchange capacity (CEC) was determined from the sum of Ca, Mg, K, Na and Al after extraction with 0.1 mol l^{-1} $BaCl_2$ (w/v = 1:10) for 2 h (ISO, 1994). Inductively coupled plasma-atomic emission spectrometry (ICP-OES) using an Agilent 720 (Agilent Technologies Inc., USA) was applied for element determination in the extracts. The total organic carbon (TOC) content was determined spectrophotometrically after the oxidation of organic matter by H_2SO_4 and $K_2Cr_2O_7$ (Sims and Haby, 1971). The amount of total C and total N was determined from about 50 mg of soil by the modified Dumas combustion method at 960°C with a CNS elemental analyser (vario MACRO cube CNS; Elementar Analysensysteme GmbH, Langenselbold, Germany).

Statistical analyses were performed using software SAS version 9.2. An analysis of variance (PROC MIXED) was performed and the means were separated by the least significant differences (LSD), while the F-test indicated the factorial effects at the significance level of $p<0.05$. Based on analysis of variance results, the data are presented as the main effects of depth or as tillage × depth interactions. As no significant differences were observed for crop rotation, means are indicated for each rotation (overall depths and tillage treatments). The Pearson correlation coefficient for analysed parameters was calculated for the depth of 0-5, 5-30, and 30-50 cm.

RESULTS AND DISCUSSION

The experimental site is characterized by a calcareous soil with an alkaline reaction. Values of pH_{CaCl_2} were lower than those of pH_{H_2O} as soil extraction with $CaCl_2$ causes a higher release of hydrogen ions into the solution compared to a soil extraction with H_2O (Gavriloaiei, 2012).

Both pH_{CaCl_2} and pH_{H_2O} decreased with soil depth with pH_{CaCl_2} (Fig. 1A) showing a more homogenous distribution up to a 25 cm depth while pH_{H_2O} gradually decreased with every sampled layer (except for similar values between a 10-15 and 15-20 cm depth). The vertical gradient of pH_{CaCl_2} has already been reported for this experiment after seven years (Neugschwandtner *et al.,* 2014). Similarly to pH, an increase in calcium carbonate ($CaCO_3$) was found in this experiment seven years after its initiation (Neugschwandtner *et al.,* 2014), as $CaCO_3$ buffers the soil pH (Blume *et al.,* 2019).

There were no differences in pH between tillage treatments. This finding is consistent with those of other long-term tillage experiments; *e.g.* on a sandy loam soil in the Northern Great Plains after 12 years (Aase and Pikul, 1995), under temperate conditions on a Luvisol in France after 32 years (Limousin and Tessier, 2007), and in a semi-arid, subtropical environment on a Luvisol in Australia after 9 years (Thomas *et al.,* 2007). A higher acidity with no-till in the upper soil layers was reported from other studies which attributed this effect to acidification processes

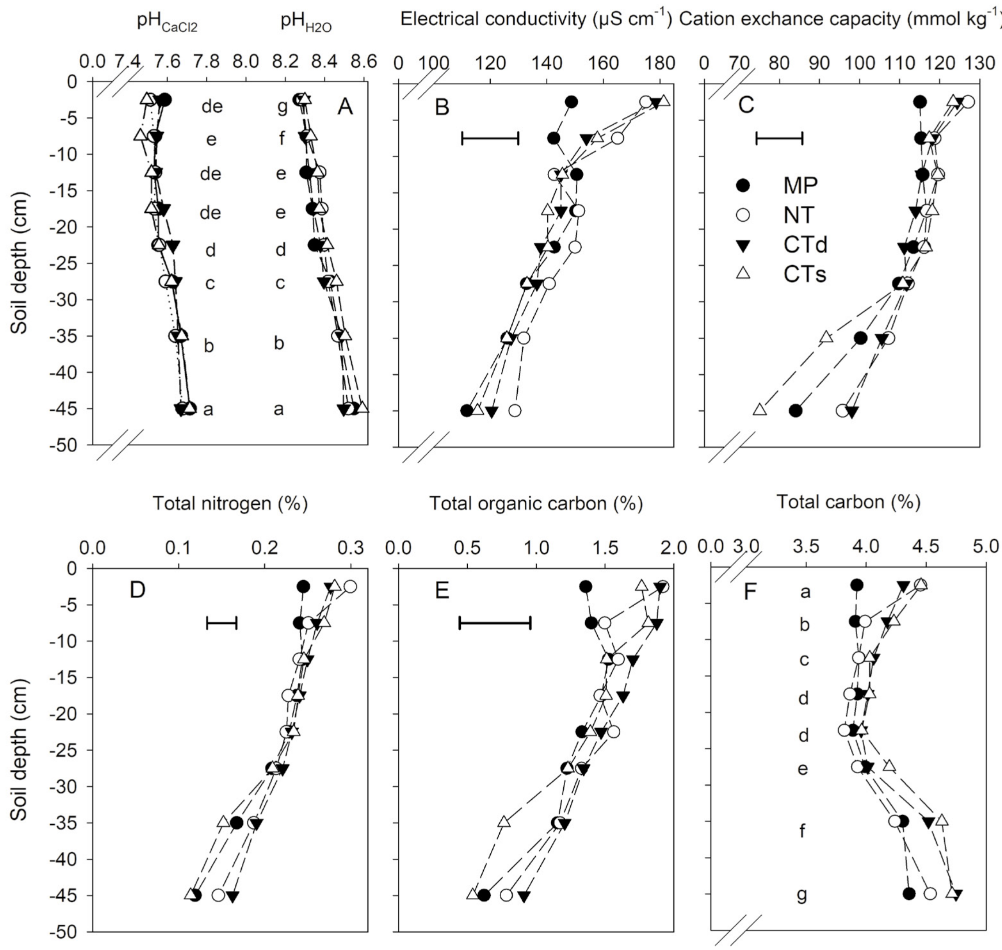

Fig. 1. Basic soil characteristics from 0-50 cm after 15 years of different tillage treatments in Raasdorf (Austria): mouldboard ploughing (MP), no-till, deep conservation tillage (CTd) and shallow conservation tillage (CTs). Different letters indicate significant differences between the soil layers ($p<0.05$). Horizontal bars indicate a significant tillage × depth interaction (LSD, $p<0.05$).

such as the mineralization of organic matter and the nitrification of surface-applied N fertilizer (Franzluebbers and Hons, 1996; Limousin and Tessier, 2007; López-Fando and Pardo, 2009). However, the effects of no-till on pH were reported to occur in a more pronounced way at an early stage; whereas no significant differences between no-till fields run for more than 6 years and conventionally tilled fields were observed (Crozier *et al.,* 1999).

Crop rotation did not affect pH_{H_2O} (A: 8.38, B: 8.40) and pH_{CaCl_2} (A: 7.58, B: 7.59). After 7 years, however, a lower pH_{CaCl_2} had been observed after oilseed rape compared to after maize (Neugschwandtner *et al.,* 2014). The effects of crop rotation can occur, as soil pH is a soil property with short-term changes, *e.g*. during the decomposition of crop residues (Hulugalle and Weaver, 2005), due to rhizosphere processes (Kotková *et al.,* 2008) and with different fertilizer systems (Vašák *et al.,* 2015). There were probably no differences, as the same crops but in a different time course have been grown in both rotations in the last four years.

There was a significant tillage × depth interaction for the electrical conductivity (EC) (Fig. 1B). The EC was lower with MP than with NT, CTd and CT_S at a 0-5 cm depth and with MP compared to NT (with CTd and CTs showing intermediate values) at a 5-10 cm depth. At a 0-5 cm depth, the EC of NT was with 175 $\mu S\ cm^{-1}$ 1.18-fold higher compared to MP with 148 $\mu S\ cm^{-1}$. Below a 10 cm soil depth, the EC did not differ among tillage treatments. A higher EC with NT compared to MP was also found by Martínez *et al.* (2013) to a depth of 2 cm with no differences below 2 cm, by Rahman *et al.* (2008) at a 0-10 cm depth and by Perez-Brandán *et al.* (2012) for NT compared to MP and CT at a 0-20 cm soil depth. Higher organic matter contents in NT caused an increase in electrolyte concentrations (Rahman *et al.,* 2008). On the other hand, Chatterjee and Lal (2009) reported diverse results for EC with no differences between NT and MP on three sites and higher values of EC on one side for either NT or MP. A lower EC with NT up to a 1.2 m depth has been described by Dalal (1989), this was attributed to an increased water movement and a higher soil aggregation with NT. Crop rotation did not affect EC (A: 145 $\mu S\ cm^{-1}$, B: 140 $\mu S\ cm^{-1}$). The EC in all treatments was well below the values causing negative yield responses (Steppuhn *et al.,* 2005).

There was a significant tillage × depth interaction for the cation exchange capacity (CEC) (Fig. 1C). In the uppermost soil layer from 0-5 cm, the CEC was ranked as follows: NT ≥ CTd, CTs ≥ MP. At a 0-5 cm depth, the CEC of NT was with 127 $mmol\ kg^{-1}$ 1.10-fold higher compared to MP with 115 $mmol\ kg^{-1}$. The CEC decreased from the first to the second layer (5-10 cm) in the treatments NT, CTd and CTs, thereby reaching similar values as MP. Further down, there was a slight decline of CEC to a depth of 30 cm nd a more pronounced decline up to 50 cm. CEC provides a rough index of the shrink-swell potential and is a measure of soil structural resilience to tillage (Triantafilis *et al.,* 2009). An increase in CEC with no-till was already reported by Lal *et al.* (1990) for coarsely textured soils. The CEC is strongly influenced by soil organic matter due to its high degree of negative charges and therefore its ability to absorb cations (Scheffer *et al.,* 2010). CEC decreases when soil organic matter depletes (Curtin *et al.,* 2015). Crop rotation did not affect CEC (A: 110 $mmol\ kg^{-1}$, B: 112 $mmol\ kg^{-1}$).

Total N (N_t) showed an interaction between tillage × depth. In the uppermost soil layer from 0-5 cm, the highest N_t contents were observed with NT and the lowest in MP (with CTs and CTd showing intermediate values). At a 0-5 cm depth, the N_t of NT was with 0.2449% 1.22-fold higher compared to MP with 0.2995%. Downward up to a 30 cm depth, there are no differences in the N_t content between tillage treatments (Fig. 1D). After seven years, the N_t had been higher in this experiment at 0-10 cm for NT, CTd and CTs than MP with no differences between tillage treatments below a 10 cm depth (Neugschwandtner *et al.,* 2014). A higher N_t with NT in the uppermost soil layer is attributed to the surface accumulation of residues whereas intensive soil mixing dilutes the concentration and accelerates the mineralization of organic matter (Salinas-García *et al.,* 2002; Spiegel *et al.,* 2007; Hou *et al.,* 2012). Furthermore, the soil nitrogen cycle is influenced through tillage operations with a slower oxidation rate of ammonium into nitrate in no-till soil (Laine *et al.,* 2018).

Crop rotation did not affect N_t (A: 0.22%, B: 0.22%) as already reported for this experiment after seven years (Neugschwandtner *et al.,* 2014). However, differences in N_t between crop rotations could have been expected, as the amount of N remaining on the field with crop residues and as soil mineral nitrogen after harvest differ significantly between crops (Neugschwandtner and Kaul, 2015; Neugschwandtner *et al.,* 2015c, d).

A higher total organic carbon content (TOC) was observed with NT and CTd than with MP in the upmost 5 cm (with CTs showing intermediate values) (Fig. 1E). Between 5-10 cm, CTd and CTs had higher TOC contents than NT and MP (not significant). The TOC of NT was compared to MP 1.41-fold higher at a 0-5 cm depth (1.92% versus 1.36%) and 1.07-fold higher at a 5-10 cm depth (1.50% versus 1.40%). A sharp decline of TOC was observed for NT (by 22%) from the first to the second soil layer and for CTs (by 16%) from the second to the third soil layer. In contrast, CTd and especially MP showed a more homogenous TOC distribution in the upper soil layers to a depth of 25 cm. From 25-50 cm, a pronounced decline of the TOC content was observed for all tillage treatments. Limousin and Tessier (2007) and Thomas *et al.* (2007) have also reported an accumulation of TOC with NT in the top soil layer and then a rapid vertical decline. Spiegel *et al.* (2007) reported a 31% higher concentration of organic carbon between 0-10 cm with minimum tillage compared to conventional tillage after 19 years on a similar Chernozem in Austria. MP showed a lower but more homogenous distribution in TOC content, which is attributed to intensive soil mixing and accelerated organic matter mineralization (Salinas-García *et al.,* 2002; Spiegel *et al.,* 2007).

Crop rotation did not affect TOC (A: 1.38%, B: 1.37%). A similar observation was made in this experiment after seven years (Neugschwandtner *et al.,* 2014). However, different crops in rotation show differences in the amount and composition of residues (Neugschwandtner and Kaul, 2016a, 2016b; Neugschwandtner *et al.,* 2015b), which might provoke differences between rotations in TOC. As stated previously, the same crops, but in a different time course have been grown in both rotations over the last four years.

Total carbon (TC) in the soil decreased with soil depth (Fig. 1F). Tillage treatments did not affect the TC. Although in the first 0-5 cm depth, the TC of NT, CTd and CTs tended to be higher compared to MP (tillage × depth – $p=0.10$, not significant). TC in the soil includes TOC and total inorganic carbon (TIC), which is primarily calcium (and magnesium) carbonate (Guo *et al.,* 2016). Calcium carbonate ($CaCO_3$) was assessed in this experiment seven years after its initiation with no differences in $CaCO_3$ between tillage treatments (Neugschwandtner *et al.,* 2014). The differences in TC among tillage treatments after 15 years reflect those of TOC, so obviously no substantial changes in TIC have occurred. No tillage effect on $CaCO_3$ was also reported by Fernández-Ugalde *et al.* (2009), but Moreno *et al.* (2006) observed that the natural leaching loss of $CaCO_3$ was notably reduced by conservation tillage due to the greater retention of water in the soil profile. Crop rotation did not affect TC (A: 4.15%, B: 4.17%).

Correlations were calculated for the analysed parameters at a 0-5 cm depth, a 5-30 cm depth (up to the end of the plow layer) and at a 30-50 cm depth (subsoil) (Table 1).

In the 0-5 cm soil layer, the following parameters did not correlate with each other: pH_{CaCl_2} with pH_{H_2O} and EC, pH_{H_2O} with N_t, pH_{CaCl_2} and pH_{H2O} with TOC, and TC with pH_{CaCl_2}, pH_{H_2O} and N_t. However, there was a significant negative correlation of pH_{CaCl_2} with CEC and N_t, and of pH_{H_2O} with EC and CEC, as well as a positive correlation among EC, CEC, N_t and TOC, and of TC with EC, N_t and TOC. Our findings at a 0-5 cm depth are partly in agreement with results from the 0-10 cm soil depth of tillage experiments performed on a Aquultic Hapludalfs (Shukla *et al.,* 2006), a Luvisol (Thomas *et al.,* 2007) and an Andisol (Rahman *et al.,* 2008), in which there was also a negative correlation of pH_{H_2O} with EC, a positive correlation among N, EC, and TOC but a negative correlation of pH_{H_2O} with N_t and with TOC.

At a 5-30 cm and 30-50 cm depth, pH_{CaCl_2} and pH_{H_2O} correlated significantly, but showed a negative correlation with EC, CEC, N_t and TOC. Furthermore, EC, CEC, N_t and TOC were positively correlated with each other. At a 5-30 cm depth, TC was positively correlated with pH_{CaCl_2} and pH_{H_2O} and negatively with CEC. No correlation was found for TC at a 5-30 cm depth with EC, N_t and TOC and also with all

Table 1. Pearson correlation coefficient for analyzed parameters

	pH_{H_2O}	EC	CEC	N_t	TOC	TC
			0-5 cm			
pH_{CaCl_2}	0.30	-0.19	-0.56***	-0.43*	-0.23	0.13
pH_{H_2O}		-0.52**	-0.35*	-0.32	-0.19	0.15
EC			0.39*	0.53**	0.46**	0.63***
CEC				0.73***	0.41*	0.17
N_t					0.54**	0.50**
TOC						0.51**
			5-30 cm			
pH_{CaCl_2}	0.46***	-0.31***	-0.55***	-0.50***	-0.42***	0.26***
pH_{H_2O}		-0.69***	-0.41***	-0.60***	-0.26***	0.23**
EC			0.37***	0.49***	0.16*	0.01
CEC				0.65***	0.30***	-0.24**
N_t					0.54***	0.03
TOC						0.05
			30-50 cm			
pH_{CaCl_2}	0.73***	-0.68***	-0.64***	-0.47***	-0.43***	-0.05
pH_{H_2O}		-0.77***	-0.76***	-0.66***	-0.53***	-0.01
EC			0.73***	0.65***	0.51***	0.18
CEC				0.92***	0.70***	-0.05
N_t					0.78***	-0.18
TOC						-0.18

Significant values at: $*p<0.05$, $**p<0.01$ and $***p<0.001$, ($n=32$ for 0-5 cm, $n=160$ for 5-30 cm, $n=64$ for 30-50 cm).

of the other parameters in the subsoil. Obviously, soil depth had a strong influence over the correlation between the analysed parameters.

CONCLUSIONS

1. Compared to mouldboard ploughing, no-till increased the electrical conductivity, cation exchange capacity, total nitrogen and total organic carbon in the uppermost soil layer (0-5 cm); whereas, pH_{CaCl_2} and pH_{H_2O} were not affected by tillage. In the uppermost soil layer, a positive correlation between electrical conductivity, cation exchange capacity, total nitrogen and total organic carbon was observed.

2. In the 5-10 cm soil depth, electrical conductivity was the only parameter significantly affected by tillage (with higher values for no-till than for mouldboard ploughing).

3. In deeper soil layers, tillage did not affect basic soil characteristics. Different crop rotations had no effect on the analysed basic soil chemical properties after 15 years.

Conflict of interest: The Authors do not declare conflict of interest.

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