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# LONG-TERM EFFECTS OF TILLAGE AND FERTILIZATION ON pH AND SORPTION PARAMETERS OF HAPLIC LUVISOL*

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**Abstract**

The influence of different tillage and fertilization practices on changes in soil pH and sorptive parameters of loamy haplic Luvisol was evaluated in a long-term field experiment (established in 1994, in the locality of Dolná Malanta, at the experimental station of the Slovak University of Agriculture in Nitra). The field experiment included two types of soil tillage (conventional tillage – CT and reduced tillage – RT) and also three treatments of fertilization (1. Co – control, 2. PR+NPK – crop residues together with added NPK fertilizers, and 3. NPK – with added NPK fertilizers). The soil was sampled from all treatment sites throughout 1994-2011. The results showed a statistically significant influence of tillage and fertilization on pH and sorptive complex of haplic Luvisol. The values of pH were higher (by 4%) in RT than in CT. The sum of basic cations (SBC), cation exchangeable capacity (CEC) and base saturation (BS) were all higher in RT, by 11%, 8% and 3% respectively, than in CT. In NPK (by 16%) and in PR+NPK (by 20%) the values of hydrolytic acidity (Ha) were decreased in comparison to the control. On the other hand, SBC was elevated. This led to the increase of CEC and BS. Conventional tillage and application of crop residues together with NPK fertilizers increased pH by 0.06 and 0.03 units per year, respectively, which means that the pH in the soil increased by14% and 8%, correspondingly, between 1994 and 2011. In CT and in PR+NPK, an increase of SBC occurred at an average rate of 3.17 and 1.93 mmol $kg^{-1}$ $year^{-1}$, respectively. A positive correlation between the content of soil organic carbon (TOC) and Ha ($r$ = 0.334, $P \leq 0.01$, $n$ = 54), as well as a negative correlation between TOC and BS ($r$ = -0.307, $P \leq 0.05$, $n$ = 54) were determined only in CT.

**Keywords:** soil management practice, hydrolytic acidity, cation exchange capacity, base saturation.

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## INTRODUCTION

The world's soil resources are finite, essentially non-renewable, unequally distributed in different eco-regions, and fragile to drastic perturbations. Despite inherent resilience, soil is prone to degradation or decline in its quality due to misuse by the agricultural industry. Intensive use of soils leads to alterations in their chemical (Thomas et al. 2007, Šimanský, Tobiašová 2010) and physical characteristics (Šimanský et al. 2008, Šimanský et al. 2013). For example, commercial fertilizers, manure and lime, substances which are very important for crops, are applied to soil; however, fertilizers can change electrolyte concentrations in soil, which is associated with a change of soil pH (Whalen et al. 2000, Neff et al. 2002) and sorptive parameters (Hartman et al. 1998, Ersahin et al. 2006). In general, soils with high ion-exchange capacity are fertile and have good, lasting quality for crop production; that is, they are depleted more slowly than soils with a low ion-exchange capacity (Millar et al. 1962). At present, for a farmer to be successful it is very important to have sound knowledge and "understanding" of soil. On this basis, with the knowledge of chemistry (soil pH, sorptive parameters, soil organic matter etc.) and soil physics, one is able to design proper soil management practices, ensuring the soil's protection and sustainable production. Sustainable use of soil resources, therefore, requires a thorough understanding of the properties and processes that govern soil quality, so as to be able to maximise the benefits soils can give to their human users (Lal, Shukla 2004).

Hence, the objective of this study was to determine the effects of different tillage and fertilization practices on changes in soil pH and sorptive parameters of intensively cultivated haplic Luvisol, over a period of 18 years.

## MATERIAL AND METHODS

A long-time experiment was established in 1994 by the Department of Plant Production of SAU-Nitra at the experimental station of the Slovak University of Agriculture in Nitra (48°19'00"N; 18°09'00"E), set up in a split-plot design with four replications. Two factors were measured: tillage and fertilization. Overall, the experimental area is flat, slightly inclining southwards. The geological substratum consisted of scarce parent rock and high quantities of fine materials. Young Neogene deposits were made up of various clays, loams and sand gravels, on which loess was deposited in the Pleistocene. The soil type was classified as haplic Luvisol (WRB 2006). In the topsoil layer (0-20 cm), the soil contained 15% clay, 49% silt, 36% sand and 1.29% soil organic carbon. The cation exchange capacity was 147.18 mmol $kg^{-1}$, base saturation was 92.6% and soil pH was 6.96. The average annual temperature was 9.8°C and precipitation per year was 573 mm. More information about the experimental station of SUA-Nitra (Dolná Malanta) and the evaluation of chemical and physical properties of soil was published by Šimanský et al. (2008). The field experiment had the following crop rotation: 1) cow-grass *(Trifolium pratense* L.*)*, 2) pea *(Pisum sativum* L. subsp. *Hortense (*Neitr.*)*, 3) winter wheat *(Triticum aestivum* L.*)*, 4) maize *(Zea mays* L.*)*, 5) spring barley *(Hordeum vulgare* L.*)*. Two tillage treatments were used, which were: 1. Conventional tillage (CT) – which consisted of mouldboard ploughing (22-25 cm deep) in autumn, followed by disking, rolling/levelling and planting. 2. Reduced tillage (RT), which consisted of disking to a depth of 10-12 cm in autumn, followed by rolling/levelling and planting. The three fertilization treatments were: 1) without fertilization (Co), 2) crop residues added together with NPK fertilizers (PR+NPK), 3) added NPK fertilizers (NPK). Crop residues were incorporated into the surface layer of soil in PR+NPK treatments but in NPK treatments the crop residues were removed. Soils were fertilized with N, P, K according to crop requirements and soil analyses. The average annual doses of fertilizers were: N 80 kg $ha^{-1}$, P ($P_2O_5$) 45 kg $ha^{-1}$ and K ($K_2O$) 72 kg $ha^{-1}$. The fertilizers used were mainly nitre ammonium with dolomite (LAD 27), potassium chloride (KCl) and triple superphosphate ($Ca(H_2PO_4)_2.H_2O$).

Soil sampling was performed in the spring throughout the 18-year period (1994-2011). Samples were taken from the depth 0-20 cm. For each sampled zone (which included areas from all the treatments of tillage and fertilization type), six different locations were chosen randomly. On each location, soil samples were collected and mixed to produce an average sample. Soil samples were air-dried and sieved to pass through 2 mm mesh. We determined a range of measures including the chemical parameters: soil pH – potentiometrically (soil:water = 1:2.5), the sorptive parameters such as hydrolytic acidity (Ha), the sum of basic cations (SBC) by the Kappen method, cation exchange capacity (CEC), and the base saturation (BS) (Fiala et al. 1999). Total organic carbon (TOC) was determined by wet digestion using potassium dichromate along with $H_2SO_4$ at 120°C for 20 minutes with titration using Mohr's salt according to Tyurin (Dziadowiec, Gonet 1999).

Multifactor analysis of variance (Anova) was used to determine the effects of tillage and fertilization on soil pH and sorptive parameters. The treatment means were compared using an LSD test. All statistical analyses, including equations of regression analysis as well as calculations of the coefficient of the determination ($R^2$), were performed using the Statgraphics Centurion XV.I (Statpoint Technologies, Inc., USA). In all analyses, differences were considered to be significant at $P \leq 0.05$.

## RESULTS AND DISCUSSION

Results of our statistical evaluation of soil pH and sorptive parameters given the different tillage systems and fertilization in loamy haplic Luvisol during the years 1994-2011 are shown in Table 1. The soil tillage systems

Table 1

Statistical evaluation of mean values of sorptive parameters and soil pH

| Specification | Ha | SBC | CEC | BS | pH |
|---|---|---|---|---|---|
| Tillage | | | | | |
| Conventional tillage | 12.97*b* | 159.6*a* | 172.6*a* | 92.2*a* | 7.01*a* |
| Reduced tillage | 9.61*a* | 176.6*b* | 185.9*b* | 94.7*b* | 7.30*b* |
| Fertilization | | | | | |
| Control | 12.86*b* | 163.3*a* | 175.9*a* | 92.4*a* | 7.08*a* |
| Crop residues together NPK fertilizers | 10.79*a* | 169.0*ab* | 179.7*a* | 93.8*b* | 7.18*ab* |
| Added NPK fertilizers | 10.23*a* | 171.9*b* | 182.0*a* | 94.1*b* | 7.20*b* |

Ha – hydrolytic acidity, SBC – sum of basic cations, CEC – cation exchange capacity, BS – base saturation, pH – soil pH.
Different letters between lines (*a*, *b*) indicate that treatment means are significantly different at $P \leq 0.05$ according to LSD multiple-range test.

and fertilization had a statistically significant influence on soil pH, whose values in RT were higher (by 4%) in comparison to CT. These results are consistent with those reported by Šimanský et al. (2008) for the same experimental site during the 13-year period of 1994-2007. Our results showed that the addition of fertilizers increased the average values of soil pH. Neff et al. (2002) and Whalen et al. (2000) findings showed that fertilizers change electrolyte concentrations in soil, which is associated with soil pH. Thomas et al. (2007) showed that N fertilizer application resulted in a significant reduction of soil pH. However, our results were different (Table 1). The exclusive application of NPK fertilizers significantly increased values of soil pH. However, crop residues added together with NPK fertilizers (PR+NPK) did not have a significant effect on increasing soil pH during the 1994-2011 test period. The main reason for pH increase can be the application of N fertilizers (LAD 27) with Mg. During the 18-year study period, the soil pH statistically increased (a linear trend) in all tillage systems and fertilization treatments (Table 2). The highest increase of soil pH was observed in CT and PR+NPK. Conventional tillage and application of crop residues together with NPK fertilizers increased pH at the average rate of 0.06 and 0.03 pH units per year, respectively, which means that an increase of 14% and 8%, respectively, occurred in the soil during the years 1994-2011.

The results also indicate a higher value of Ha in CT samples (12.97±0.8) than in RT samples (9.61±1.0), although a reverse trend within other sorp-

Table 2

Trend of sorptive parameters and soil pH ($y$ = sorptive parameters or soil pH) with time ($x$ = years) in dependence on tillage ($n$ = 54) and fertilization ($n$ = 36) treatments

| Treatments | Equations | $R^2$ | Trend | Probability |
|---|---|---|---|---|
| Hydrolytic acidity | | | | |
| Conventional tillage | $y = -0.684x + 1382$ | 0.344 | decrease | *** |
| Reduced tillage | $y = -0.142x + 293.3$ | 0.014 | decrease | n.s. |
| Crop residues together NPK fertilizers | $y = -0.321x + 654.3$ | 0.076 | decrease | n.s. |
| Added NPK fertilizers | $y = -0.243x + 496.9$ | 0.051 | decrease | n.s. |
| Sum of basic cations | | | | |
| Conventional tillage | $y = 3.168x – 6184$ | 0.498 | increase | *** |
| Reduced tillage | $y = 1.339x – 2504$ | 0.076 | increase | n.s. |
| Crop residues together NPK fertilizers | $y = 1.926x – 3689$ | 0.173 | increase | ** |
| Added NPK fertilizers | $y = 1.120x – 2071$ | 0.056 | increase | n.s. |
| Cation exchange capacity | | | | |
| Conventional tillage | $y = 2.482x – 4797$ | 0.436 | increase | *** |
| Reduced tillage | $y = 1.172x – 2161$ | 0.078 | increase | n.s. |
| Crop residues together NPK fertilizers | $y = 1.588x – 3001$ | 0.159 | increase | * |
| Added NPK fertilizers | $y = 0.861x – 1542$ | 0.047 | increase | n.s. |
| Base saturation | | | | |
| Conventional tillage | $y = 0.494x – 897.4$ | 0.370 | increase | *** |
| Reduced tillage | $y = 0.130x – 164.8$ | 0.033 | increase | n.s. |
| Crop residues together NPK fertilizers | $y = 0.246x – 399.2$ | 0.109 | increase | * |
| Added NPK fertilizers | $y = 0.200x – 304.7$ | 0.080 | increase | n.s. |
| Soil pH in $H_2O$ | | | | |
| Conventional tillage | $y = 0.055x – 102.9$ | 0.604 | increase | *** |
| Reduced tillage | $y = 0.021x – 35.16$ | 0.118 | increase | ** |
| Crop residues together NPK fertilizers | $y = 0.034x – 60.05$ | 0.229 | increase | ** |
| Added NPK fertilizers | $y = 0.026x – 44.69$ | 0.133 | increase | * |

*** $P \leq 0.001$, ** $P \leq 0.01$, * $P \leq 0.05$, n.s. – non-significant

tive parameters was observed. SBC, CEC and BS were higher in RT by 11%, 8% and 3%, respectively, than in CT. The reason may be intensive aeration of arable soils caused by cultivation, leading to more intensive mineralization, which is reflected in the soil sorptive parameters (Nardi et al. 2004). In RT, due to the higher accumulation of soil organic matter (SOM), the acidification of upper layers of no-tilled soil (reduced tilled soil) could have increased the dissolution of clay minerals, resulting in an enhanced release of basic cations (Limousin and Tessier 2007). According to the results published by Šimanský et al. (2008) for the same experimental site, there were not any significant differences in the TOC content, regardless of soil management practices, although a higher TOC concentration was determined in RT than in CT. Organic matter is a very important component controlling the soil sorption capacity (STEVENSON 1994, SZOMBATHOVÁ 2010, ŠIMANSKÝ, POLLÁKOVÁ 2014). Therefore, the correlations between TOC and the sorptive parameters of soil were calculated under different tillage and fertilization treatments. A hypothesis was established that a higher pool of organic matter in soil would result in better parameters of soil sorption capacity. Our results are surprising because a high positive correlation between TOC and Ha ($r$ = 0.334, $P \leq 0.01$, $n$ = 54) as well as a negative correlation between TOC and BS ($r$ = -0.307, $P \leq 0.05$, $n$ = 54) were detected, although these were verified only in the CT treatment. In RT and fertilization treatments, no significant correlations were observed. ŠIMANSKÝ, POLLÁKOVÁ (2014) published findings indicating that as a higher SOM pool was associated with a lower sorption capacity of organic matter, from which it could be concluded that the key factor affecting the sorption capacity of soil was the SOM quality and not the quantity. Since we have not completed SOM quality data in our experimentation, we are unable to produce comparative data on these findings in the intensively farmed loamy haplic Luvisol during the 1994-2011 period. In comparison to the control, the addition of only NPK fertilizers (NPK by 16%) and crop residues applied together with NPK fertilizers (PR+NPK by 20%) decreased values of Ha, but increased SBC, CEC and BS. As presented by PANAK et al. (1996), high nitrogen fertilization doses frequently result in a decrease in the saturation of the sorption complex with cations $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$. Our results of sorptive parameters have revealed the same trend as implicated by ŠIMANSKÝ et al. (2008). As mentioned by Šimanský (ŠIMANSKÝ et al., 2008), this is associated with factors such as high buffering of soil, $Ca^{2+}$ and $Mg^{2+}$ content and the application of N fertilizers (LAD 27) with Mg. The research by GRAHAM et al. (2002) showed that the acidification of soil decreased the content of basic cations ($Ca^{2+}$, $Mg^{2+}$) as well as CEC. STEVENSON (1994), LORANDI (2012) and SZOMBATHOVÁ (2010) demonstrated that in soils with a high pool of SOM, the CEC increased. In all soil management practices (tillage and fertilization) on the haplic Luvisol during the period of the 18-year study, a decrease of the Ha in soil was observed. Contrary to that, other sorptive parameters increased (Table 2). Likewise, only conventional tillage – unlike the other soil management practices – resulted in a significant linear decline of Ha (0.68 mmol $kg^{-1}$ $year^{-1}$) being retained in the soil during the 1994-2011 period, when it declined by 62%. Comparatively, in the treatments involving conventional tillage or crop residues added together with NPK fertilizers, there was a build-up of SBC at an average rate of 3.17 and 1.93 mmol $kg^{-1}$ $year^{-1}$, respectively, which translates to an increase of SBC in the soil by 40% and 22%, respectively, during the years 1994-2011. The same trends (of a linear increase) in the same treatments were observed with respect to the CEC and BS parameters (Table 2).

# CONCLUSION

The results showed that soil management practices in haplic Luvisol cause changes in soil pH and sorptive parameters that are significant. In the treatments conventional consisting of tillage or crop residues applied together with NPK fertilizers, the linear trends of a decline or increase of soil pH and sorptive parameters suggest that no equilibrium has not been reached yet, after 18 years management practices in haplic Luvisol. In the future, soil pH and sorptive parameters will probably change further if the inappropriate soil management practices are not discontinued. The dynamics of changes in soil pH and sorptive parameters can be used as one of the most important indicators of the quality of the soil environment under different soil management practices.

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