VOL. 12, NO. 20, OCTOBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EVALUATION OF PLOUGH LAYER THICKNESS IN GREY FOREST SOILS USING SPECTROPHOTOMETRIC AND MAGNETIC MEASUREMENTS

L. A. Fattakhova[1], A. A. Shinkarev[1], L. Yu. Ryzhikh[2] and L. R. Kosareva[3]
[1]Department of Soil Science, Kazan Federal University, Kazan, Russia
[2]Agricultural Center of the Republic of Tatarstan, Kazan, Russia
[3]Department of Geophysics and Geoinformation Technologies, Kazan Federal University, Kazan, Russia
E-Mail: L.a.fattakhova@yandex.com

ABSTRACT

This paper considers the possibility of objective and reliable location of the plough layer's lower boundary by determining color characteristics and magnetic susceptibility of the samples. It is shown that magnetic susceptibility profile can provide more reliable assessment of the plough layer thickness than color curves in CIELAB. The formal analysis using magnetic measurements eliminates subjective mistakes. Magnetic measurements can be a useful tool for the tillage induced erosion estimation while monitoring soil characteristics for the purposes of precision agriculture.

Keywords: arable gray forest soil, magnetic susceptibility, CIELAB chromaticity coordinates, lower boundary of the plough layer, tillage induced erosion.

1. INTRODUCTION

Spatial heterogeneity of composition and properties is one of the fundamental features of the soil and can be caused by both natural and anthropogenic factors. For agricultural soils, it was found that the soil properties can vary significantly even within the borders of a small agricultural field [1]. The main causes of spatial variability in this case are considered to be erosion processes in the classical sense of the term. However, the last two decades show a growing recognition of tillage erosion [2, 3, 4, 5, 6]. This type of erosion is defined as a displacement of the cultivated layer during tillage. For instance, tractor mounted ploughs can easily move the humous material from microelevations to microdepressions. In its turn, the spatial heterogeneity of the plough layer thickness (which is due to the tillage induced erosion) has a direct impact on the agricultural fields' productivity. Therefore, it should be taken into account while monitoring soil characteristics and organizing plot experiments for agricultural purposes and crop farming.

The common practice suggests that the plough layer thickness is determined on the basis of morphological descriptions which are subjective and rely heavily on the individual researcher's experience. Of special importance are analytical and relatively simple methods which can be used to locate the lower boundary of the layer disturbed by tilling.

Before tilling, the vast majority of southern taiga and northern forest-steppe soils in eastern part of European Russia showed mature eluvial/illuvial differentiated profile with a complete set of specific genetic horizons. The characteristic feature of gray forest soils is eluvial/illuvial R_2O_3 distribution profile, in particular, accumulation of non-silicate Fe minerals in the illuvial layer. In its turn, Fe minerals are responsible for a wide variety of soil colors and shades. The plough layer of gray forest soils is formed during a systematic tilling by mixing organogenic horizons with underlying mineral layers. This is reflected in a sharp change in Fe mineral content on the boundary with the undisturbed part of the layer. Therefore, CIELAB chromatic components (hue, saturation) should probably be used to locate the lower boundary of the plough layer.

In the last decades, magnetic properties of various environmental objects, including soils, has drawn increasing scientific attention [7, 8, 9]. Magnetic properties of soils depend primarily on the iron content, its phase composition and dispersion [10]. It was found that magnetic properties can naturally vary with depth, forming a magnetic profile that shows close relationship to the type and intensity of the soil-forming processes [7]. It was shown that magnetic susceptibility profiles may be of both eluvial/illuvial and accumulative nature [7, 11, 12]. It was also noted that periodic tillage operations have the greatest impact on soil magnetism due to 'equalization' of the magnetic parameters [7]. Therefore, the magnetic susceptibility of gray forest soils should change at the boundary of ploughed and subsurface layers.

This paper considers the possibility of objective and reliable location of the plough layer's lower boundary by determining color characteristics and magnetic susceptibility of the samples.

2. MATERIALS AND METHODS

Experiments were conducted on arable gray forest loamy soil derived from a Quaternary deluvial loam (according to the USSR classification). According to WRB soil classification, the soil was classified as Cutanic Luvisols (Anthric). The 1-ha plot is located in Laishevskii district of Central Volga region (55°37′46.42″ N, 49°21′16.38″ E). It is a flat agricultural field, which was used for multiple-factor experiment (the year before sampling) and divided into 36 individual plots with areas of 161 m^2 and dimensions 23×7 m (Figure-1). After the experiment, the field was plowed and sown with winter

ARPN Journal of Engineering and Applied Sciences

wheat. Samples were taken in May 2015, at the center of each individual plot and at two additional points separated by 1 m from the center along the long axis; a nonmagnetic semi-cylindrical soil sampler made was used. Layer samples were taken every 5 cm to a depth of 45 cm. Samples taken at the same depth were combined, forming a composite sample for each layer.

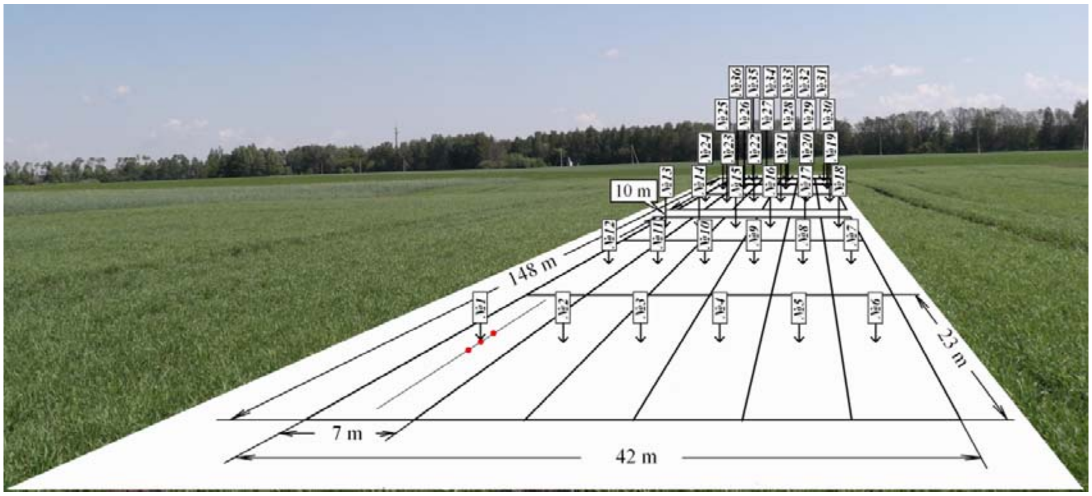

Figure-1. Studied site and soil sampling scheme.

Preparation of soil samples was carried out in line with the regulations issued by International Organization for Standardization [13]. The color characteristics were determined using X-RiteColor Digital Swatchbook DTP22 spectrophotometer and X-Rite ColorPoint 2.0.5 software. To do this, the samples were ground, and passed through a 0.5-mm sieve. Magnetic susceptibility was determined at high frequency (0.460 kHz) χ_{lf} with AGICO MFK1-FA magnetic susceptibility meter. To do this, the samples were ground in an agate mortar and mass normalized.

The data obtained were processed in MS Excel. According to χ^2 and Shapiro-Wilk test for the significance level $\alpha = 0.05$, chromatic values and magnetic susceptibility (grouped into two sets - before and after depthwise distribution inflection point) are characterized by a normal distribution. Therefore, parametric indexes were used to assess differences between the measured data. When creating thickness cartograms with the isoline method, graphical interpretation of spectrophotometric and magnetic measurements can be performed using Surfer.

3. RESULTS AND DISCUSSIONS

Theoretical assumptions behind usage of spectrophotometry and magnetometry are based on the idea of regular vertical differentiation of soil's color and magnetic properties. At the initial stage of the experiment, we determined the magnetic susceptibility and color characteristics of virgin gray forest soils derived from Quaternary diluvial loam. Samples were taken from the excavated pit in broadleaved forest in the vicinity of the studied agricultural field (55°37′13.0′′ N, 49°21′07.5′′ E). Experimental records presented in Figure-2 in the form of distribution curves are in agreement with theoretical expectations set forth in the introductory part of the article.

In order to locate the lower boundary of the plough layer using spectrophotometric methods, CIELAB chromatic components (hue, saturation) were determined. It was assumed, that the lower boundary starts at the depth corresponding to distinct curve breaks and increasing values of redness (+a) and yellowness (+b). Inflection points for the layers above the plowing depth (23 cm) are not taken into account.

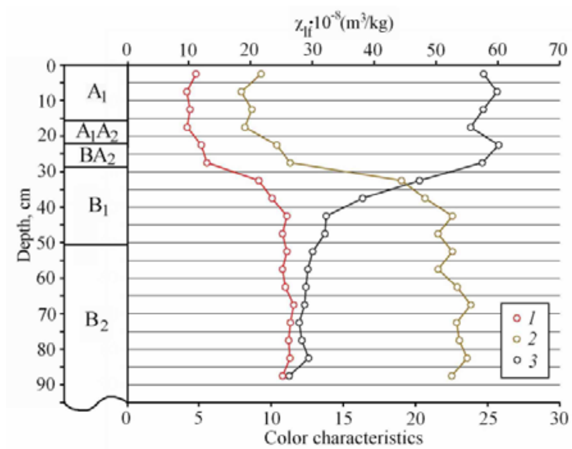

Figure-2. Color and magnetic properties as a function of depth in the profile of virgin gray forest soil: *1* - redness (+a); *2* - yellowness (+b); *3*- magnetic susceptibility.

In Figure 2, the values of yellowness (+b) are combined in accordance with inflection points which are more or less clearly observed in the layers at 20-25 cm, 25-30 cm, 30-35 cm. Independent two-sample t-test results show significant differences between +b values before and

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

after the inflection points. The t_{cal} values are 6.25, 10.01 and 12.94 at t_{tab} = 2.00, 1.98 and 1.96, respectively.

However, the graphical analysis of several curves does not provide clear location of the plough layer lower boundary. Distribution curves are either non-differentiated or show insignificant upward trend in the values of yellowness (+b), starting at 35-40 cm. It was also assumed that the lower boundary of the cultivated layer within the aforesaid individual plots lays at 35-40 cm.

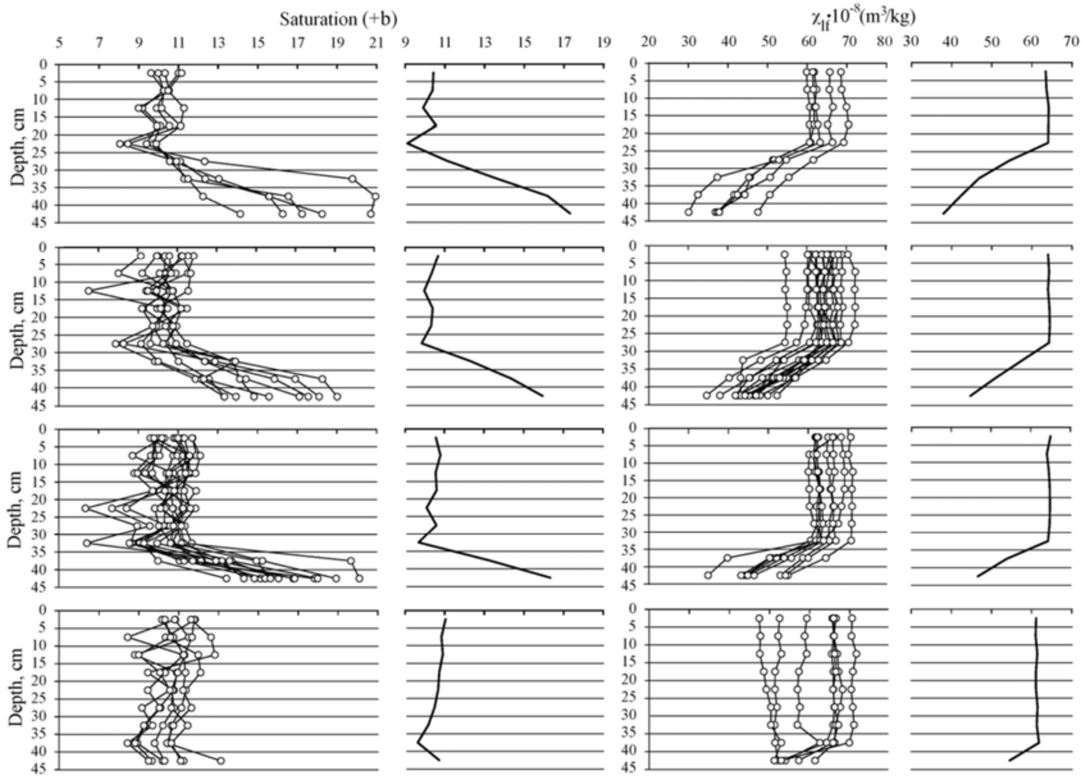

Figure-3. Chromatic values and magnetic susceptibility of arable gray forest soils as a function of depth. Average distributions are shown on the right.

Analysis of magnetic data revealed that the plough layer's lower boundary is located at the depth corresponding to distinct curve breaks and decreasing values of magnetic susceptibility. Magnetic data suggest that the plough layer includes five, six and seven layers (Figure-3). Independent two-sample t-test results show significant differences between χ_{lf} values before and after the inflection points in the layers at 20-25 cm, 25-30 cm and 30-35 cm. The t_{cal} values are 10.12, 12.61 and 11.89 at t_{tab} = 2.00, 1.96 and 1.98, respectively.

Significant decrease in magnetic susceptibility can be observed within five individual plots, starting at 35-40 cm (t_{cal} = 5.17, t_{tab} = 2.02). It can also be seen that magnetic susceptibility curves are not differentiated up to a depth of 45 cm within two individual plots (№14, №15). They are shown in Figure-3, together with the curves on which the plough layer's lower boundary is observed at 35-40 cm.

Magnetic susceptibility curves are much more differentiated than CIELAB saturation (+b) curves. Quite obviously, deviation of the yellowness (+ b) from its average values can be explained by the fact that the color characteristics of Fe compounds may be concealed by the organic matter. At the same time, magnetic susceptibility values do not vary significantly with depth.

Spectrophotometric measurements allow visual location of the plough layer's lower boundary basing on color. This approach is suitable only for experienced soil scientists and does not eliminate the chance of errors – aside of any psychophysical or physical factor. At the same time, formal analysis using magnetic measurements eliminates subjective mistakes. On the other hand, any practitioner (even with passing knowledge of soil science) is able to correctly locate the plough layer's lower boundary using magnetic susceptibility distribution curves. The analysis accuracy can be increased by reducing the sampling spacing. Portable magnetic susceptibility meter can be used to perform the analysis in the field.

The final result of any agrochemical (agrophysical) field survey is usually the cartogram of soil composition or soil properties. So, similar cartograms of the plough layer thickness were created for each individual plot (Figures-4).

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

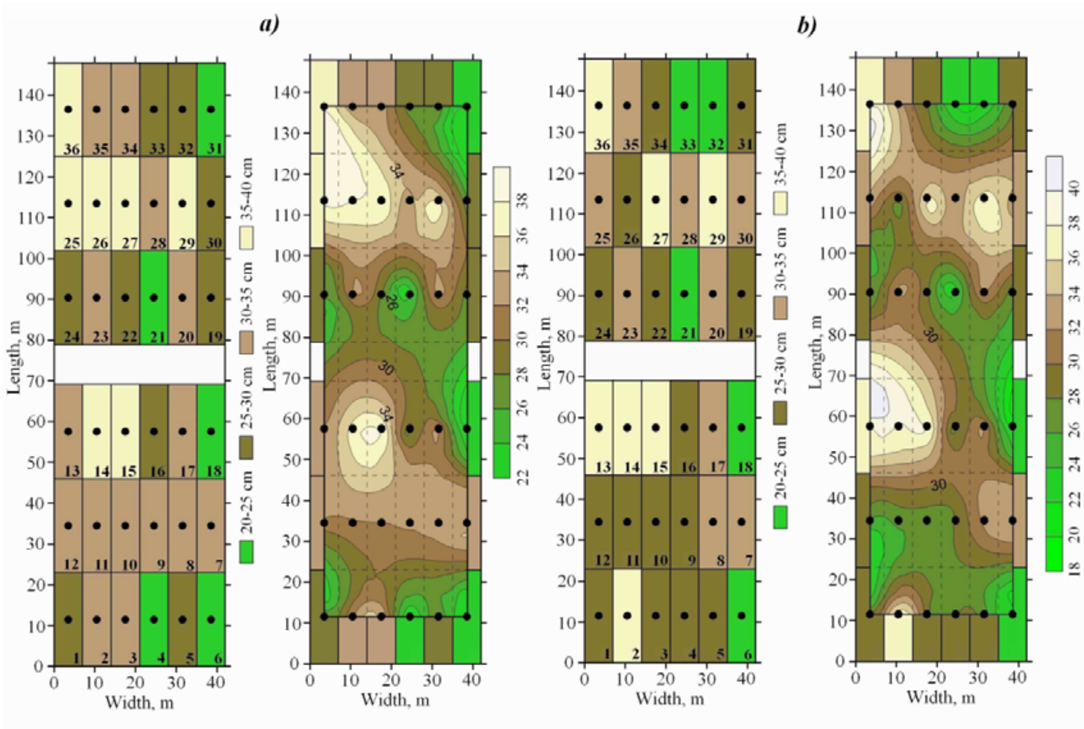

Figure-4. Cartogram of the plough layer thickness within the individual plots according to spectrophotometric (a) and magnetic (b) measurements.

Overall, images depicting the plough layer thickness obtained with spectrophotometric and magnetic measurements are similar. There are areas with minimum and maximum plough layer depths, against the general depth of 25-35 cm. At the same time, several separate or adjacent individual plots show peculiar plough layer depth which is 1.5 times greater than the preset depth of plowing. Growing conditions will now depend on the humus layer thickness. Those individual plots where the thickness of plough layer is the same as the preset depth of plowing (23 cm) a priori can only lie within microelevations. Humus reserves and major nutrients are scarce within these plots. Those individual plots where the thickness of plough layer is more than 35 cm lie within microdepressions. Humus reserves and major nutrients are abundant within these plots Thus; microrelief tends to flatten due to soil moving from elevations to depressions. The actual depth of the soil layers mixed by the plowing ceases to accurately replicate the soil surface. Soil loss (on elevations) and soil accumulation (in depressions) rates decrease gradually [14, 15], however, it is hard to tell whether the plough layer thickness is now balanced throughout the entire surveyed field.

4. CONCLUSIONS

In this work, arable gray forest soils (Cutanic Luvisols (Anthric) were used to demonstrate that magnetic susceptibility curves can provide more reliable and objective assessment of the plough layer thickness (and its variability) than CIELAB color characteristics. Therefore, magnetic data can be a useful tool for the tillage induced erosion estimation while monitoring soil characteristics for the purposes of precision agriculture and agricultural field experiments.

ACKNOWLEDGEMENTS

The work is performed in accordance with the Russian Government Program of Competitive Growth of Kazan Federal University.

REFERENCES

[1] Shein E.V., Ivanov A.L., Butylkina M.A., Mazirov M.A. 2001. Spatial and temporal variability of agrophysical properties of gray forest soils under intensive agricultural use. Eurasian Soil Science. 34: 512-517.

[2] Marques da Silva J.R., Soares J.M. 2001. Spatial variability of soil quality indicators a consequence of soil erosion // Soil Erosion Research for the 21st Century Proceedings, January 3-5, Honolulu, Hawaii, USA. pp. 59-62. doi:10.13031/2013.3202.

[3] Marques da Silva J.R., Soares J.M.C.N., Karlen D.L. 2004. Implement and soil condition effects on tillage-induced erosion. Soil and Tillage Research. 78: 207-216. doi: 10.1016/j.still.2004.02.009.

[4] Marques da Silva J.R., Alexandre C. 2004. Soil carbonation processes as evidence of tillage-induced erosion. Soil and Tillage Research. 78: 217-224. doi:10.1016/j.still.2004.02.008.

[5] Blanco-Canqui H., Lal R. 2010. Tillage Erosion. Principles of Soil Conservation and Management Dordrecht. Springer. pp. 109-135. doi: 10.1007/978-1-4020-8709-7.

[6] Wysocka-Czubaszek A., Czubaszek R. 2014. Tillage erosion: the principles, controlling factors and main implications for future research. Journal of Ecological Engineering. 15: 150-159. doi: 10.12911/22998993.1125470.

[7] Babanin V.F., Trukhin V.I., Karpachevskii L.O., Ivanov A.V., Morozov V.V. 1995. Soil Magnetism. Moscow. Yaroslavl. YaGTU. p. 222. [In Russian].

[8] Evans M.E., Heller F. 2003. Environmental Magnetism: Principles and Applications of Enviromagnetics. San Diego. Acad. Press. p. 311.

[9] Liu Q., Robersts A.P., Larrasoaña J.C., Banerjee S.K., Guyodo Y., Tauxe L., Oldfield F. 2012. Environmental magnetism: Principles and applications. Rev. Geophys. 50: 1-50. doi: 10.1029/2012RG000393.

[10] Vodyanitskiy Yu. N. 2003. Chemistry and Mineralogy of the Soil Iron. Moscow. V.V. Dokuchaev Soil Science Institute of Russian Academy of Agricultural Sciences. p. 236. [In Russian].

[11] Busorgina N.A. 2002. Magnetic susceptibility of soils of the Middle Cis-Ural region as their genetic and diagnostic indicator: Synopsis Dis. PhD. agric. sci., Ufa. p. 23. [In Russian].

[12] Obydenova L.F. 2013. Magnetic susceptibility of soils of the Middle Cis-Ural region as an indicator of an agroecological estimation of their properties: Synopsis Dis. PhD. biol. sci., Moscow. p. 23. [In Russian].

[13] ISO 11464. 1994. Soil Quality - Pretreatment of samples for physico-chemical analysis. p. 11.

[14] Li Y., Tian G., Lindstrom M.J., Bork H.R. 2004. Variation of surface soil quality parameters by intensive donkey-drawn tillage on steep slope. Soil Sci. Soc. Am. J. 68: 907-913.

[15] Li S., Lobb D.A., Lindstrom M.J., Farenhorst A. 2008. Patterns of water and tillage erosion on topographically complex landscapes in the North American Great Plains. J. Soil Water Conserv. 63(1): 37-46. doi: 10.2489/jswc.63.1.37.