Healthy soil is a basic prerequisite for the growth and development of plants, animals and humans. It is assessed on the basis of "indicators" of physical, chemical or biological quality. The present paper evaluates the quality of the upper layer of loamy soil using basic indicators of physical and chemical quality, i.e. texture, density, porosity, maximum water capacity, minimum air capacity, saturated hydraulic conductivity, humus content, pH and conductivity. These indicators were determined by standard laboratory methods from collected intact soil cores and grab samples. Experimental research took place in years 2016–2018 near the village Šardičky (K1) and Bohaté Málkovice (K2) in the South Moravian Region. Upper layer of these plots was cultivated by reduced tillage technology. The plot K1 was sown with poppy seed (Papaver somniferum L., 2016) and spring barley (Hordeum vulgare conv. distichon var. nici, 2017–2018), the plot K2 with spring barley (Hordeum vulgare conv. distichon var. nici, 2016–2017) and sunflower (Helianthus, 2018). The long-term reduced tillage technology showed small changes in selected physical and chemical parameters of soil quality in the monitored period 2016–2018, the soil quality was good for both plots. With regard to achieving or exceeding critical values for measured soil quality indicators, the experimental plot K1 has shown a better quality in upper layer of soil than plot K2.

KEY WORDS: soil quality indicators, no-tillage, bulk density, porosity, air capacity, hydraulic conductivity, organic carbon

Introduction

Soil is the natural wealth of our country, an essential element of the food chain and a medium for plant growth. Besides the production function it has many other functions, e.g. filtering, buffering, transformation and socio-economic. Soil quality can be defined as "the capacity of soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran et al., 1996).

An agricultural soil with good quality have all the physical, chemical and biological attributes necessary to promote and sustain good productivity in agriculture with negligible environmental degradation. A soil with poor quality can then aggravate the environmental degradation through wind/water erosion and contaminate surface and subsurface water resources in the landscape. The quality of agricultural land with regard to the different composition of the soil environment is divided into "physical", "chemical" and "biological" (Dexter, 2004). These components are interconnected and can’t be separated from each other. Physical soil quality refers primarily to the soil’s strength and fluid transmission and storage characteristic in the crop root zone as a result of soil physical properties (e.g. structure and texture), management practices (e.g. technology of soil cultivation, crop types), climate and various chemical and biological processes (faunal activity, mineralization). The upper layer of soil (0–10 cm) is particularly important because it controls many critical agronomic and environmental processes (e.g. seed germination and early growth, impacts of applied technology, erosion, aggregation, surface crusting, aeration, infiltration, and runoff). Soil chemistry is dominated by the interaction between its solid constituents and the water phase, it is the basis for assessing soil fertility and provides the necessary knowledge to understand the differences in fertility of different soils and their response to fertilization. Chemical analysis without knowledge of physical conditions may fail to assess soil fertility if microbial activity is adversely affected.

In practice, we face the problem how to measure and evaluate the quality of the soil. There are established methods for assessing the quality of water and air, but determining standards for assessing soil is complicated with respect to its variability, heterogeneity and an ongoing process. Texture, bulk density, porosity, aeration, saturated hydraulic conductivity, organic carbon content, pH/H₂O and electrical conductivity will form the basic set of parameters indicating the physical and chemical quality of the soil.
The objectives of this study was to measure selected physical and chemical quality parameters in the upper layer of loamy soil processed by reduced tillage in the monitored period 2016–2018, to monitor changes of physical and chemical quality of this soil and to compare the measured parameter values with “ideal, optimal or critical” levels proposed in our and foreign literature.

**Materials and methods**

**Description of experimental plots**

Both experimental plots are located in sugar beet production area in the District Vyškov, the plot K1 is close to the village Šardičky and the plot K2 near the road between Bučovice and Bohaté Málkovice (Fig. 1). The plots are approximately 3.2 km apart. They are a part of the river basin Svratka and the main river basin of Morava. The average altitude for both plots is around 275 m above the sea level. Data from the meteorological station Bohaté Málkovice were used to characterize climatic conditions. It is a warm area with a mild, humid climate. Annual precipitation and long-term average of precipitation are shown in Table 1, average temperature is around 10.5°C and 8.4°C (1901–1950). If we compare measured precipitation with the long-term average in the growing season, then precipitation was 1/2 (2016) and 3/4 (2017, 2018). The genetic soil representative is Haplic Chernozem (FAO) and the pedogenic substrate is loess. These soils are very deep with weakly acidic-alkaline soil reaction. Representation of CaCO$_3$ is low.

The co-operative farm Zemo, Bohaté Málkovice, has been processing land with reduced tillage technology (RT) since 1992 (e.g. during autumn the cultivation of spring crops is done by vertical hoeing of soil to a depth of 20 cm). Cultivated crops on experimental plot K1: 2016 poppy seed (*Papaver somniferum* L.), 2017–2018 spring barley (*Hordeum vulgare* conv. *distichon* var. *nici*). The second plot K2: 2016–2017: spring barley (*Hordeum vulgare* conv. *distichon* var. *nici*), 2018 sunflower (*Helianthus*).

**Soil quality parameters**

The intact soil cores (cylinder of Kopecký with uniform volume 100 cm$^3$) and accompanying soil grab samples were collected each year from the 0–10 cm depth of each experimental plot. A total of 100 intact soil samples were taken during 10 sampling, ten intact soil samples in each sampling (5 for saturated hydraulic conductivity $K_s$ and 5 for basic soil analysis). The samples were collected...
during April–July during active crop growth, and always were taken from the same place (K1: 49° 10’ 33.2” N 17° 02’ 47.4” E and K2: 49° 10’ 42.2” N 17° 00’ 07.2”E).

In the pedological laboratory of the Institute of Landscape Water Management at Brno University of Technology, selected soil quality physical and chemical indicators (texture, bulk density, porosity, maximum capillary capacity, minimum air capacity, saturated hydraulic conductivity, organic carbon content, pH/H₂O and electrical conductivity) were analyzed using standard methodology (Jandák et al., 2003).

The texture shows the size and proportional representation of individual soil fractions. It is involved in pedogenetic processes but also in agronomic and ecological characteristics of the soil. It affects virtually all soil properties, especially the water and air ratio, content and composition of edaphon, chemical and biological processes occurring in the soil. A combined method was used to determine the pore size distribution, i.e. sieve analysis and the hydrometer method for smaller fraction. Subsequently, the soil was classified according to Novák and the USDA triangle diagram. The analysis of the intact soil sample determined the bulk density, porosity, humidity and air characteristics.

Bulk density (BD) is often used to express the degree of compaction or as an index of soil’s mechanical resistance to root growth (Carter, 1988, 1990, Reynolds et al., 2003; Drewry, 2006); and is defined by following equation:

$$BD = \frac{\dot{G}_f}{V_5} \quad [\text{g cm}^{-3}]$$  \hspace{1cm} (1)

where

- $\dot{G}_f$ – mass of the sample after drying to a constant weight [g].

- $V_5$ – bulk volume of intact soil sample [cm$^3$].

On the basis of bulk density, we can evaluate the critical value expressing the harmful soil compaction (Lhotský et al., 1984), approximately evaluate the structural condition of the humus horizon (Kutílek, 1978) and the growth reduction of roots according to USDA categories (Arshad et al., 1996).

Porosity ($P$) is characterized by the total pore volume, its shape, size and spatial spacing. It has a decisive influence on the fertility of the soil, it allows the penetration of the roots of plants, water and air into the soil and their movement in the soil and the existence of soil microorganisms. When increasing humidity, it increases, decreasing as the soil dries. Porosity was determined using next equation:

$$P = \frac{\rho_s \cdot BD}{\rho_s} \cdot 100 \quad [%]$$  \hspace{1cm} (2)

where

- $P$ – total porosity [%],

- $\rho_s$ – particle density of soil [g cm$^{-3}$],

- $BD$ – bulk density [g cm$^{-3}$].

On the basis of porosity, we can classify compactness of topsoil by Bretfeld (Kutílek, 1978) and assess critical porosity values (Lhotský et al., 1984).

Maximum capillary capacity according Novák ($\theta_{KMK}$) represents the amount of water that the soil in its natural habitat is able to retain for extended periods of time in its capillary pores after the previous saturation. For loamy soils it should not exceed 36%, otherwise soil is damaged and water is poorly absorbed into the soil.

$$\theta_{KMK} = B_2 - C \quad [%]$$  \hspace{1cm} (3)

where

- $B_2$ – state of the intact soil sample after 2 hours of drainage [%],

- $C$ – state of the intact sample after drying at 105°C to a constant weight [%].

Minimum air capacity (AC) indicates the difference between porosity and maximum capillary capacity. Optimal minimum air capacity values range from 15 to 24%. AC≥10% has traditionally been recommended to achieve minimum susceptibility to crop-damaging aeration deficits in the root (O’Connell, 1975, de Witt and McQueen, 1992) and topsoil is in critical condition and requires agromelioratory intervention (Lhotský et al., 1984). Minimum air capacity is defined as:

$$AC = P - \theta_{KMK} \quad [%]$$  \hspace{1cm} (4)

where

- $P$ – total porosity [%],

- $\theta_{KMK}$ – maximum capillary capacity [%].

Saturated hydraulic conductivity ($K_s$) is an indicator of the soil’s ability to absorb and transfer water to the root zone and to drain excess water out of the root zone (Topp et al., 1997). $K_s$ value in the range, 5 $10^{-3}$ cm s$^{-1}$ to 5 $10^{-4}$ cm s$^{-1}$ may be considered “ideal” for promoting rapid infiltration and redistribution of needed crop-available water, reduced surface runoff and soil erosion, and rapid drainage of excess soil water (Reynolds et al., 2007). For laboratory determination of saturated hydraulic conductivity $K_s$ was used permeameter with constant gradient in which were placed the saturated soil samples with volume of 100 cm$^3$. The calculation is done using Darcy’s relation, 1856:

$$K_s = \frac{V \cdot L}{S \cdot \Delta H \cdot t} \quad [\text{cm s}^{-1}]$$  \hspace{1cm} (5)

where

- $V$ – volume of water passed through the soil sample [cm$^3$],

- $L$ – height of soil sample in the direction of water flow [cm],

- $\Delta H$ – difference of levels before and behind sample [cm],

- $S$ – flow area of sample [cm$^2$],

- $t$ – time [s].
**Organic carbon (OC)** indicates the total amount of organic material in the soil (i.e., living and dead plants, animal and microbial materials, highly stable humic substances). The total humus content, respectively the oxidometric determination of the soil organic matter was done by the Walkley-Black method, by modification of the Novák-Pelišek. Soil organic matter influences not only the soil quality and soil fertility, but also the physical and chemical properties of the soil. OC range of 3–5 wt % is cited in Reynolds et al. (2007) as being optimal for establishment and maintenance of plant in constructed landscaping soils (e.g., urban parks, sports fields, etc.).

**Stability index (SI)** indicates the risk of soil degradation (Reynolds et al., 2007), and is calculated according to the following equation:

$$SI = \frac{1.92 \times OC}{(\text{clay+silt})} \times 100 \quad [\text{wt} \%]$$

(6)

where

- $SI$ – soil structural stability index [%],
- $OC$ – organic carbon content [wt %],
- (clay+silt) – soil’s combined clay and silt content [wt %].

$SI \leq 5\%$ indicates structurally degraded soil due to extensive loss of organic carbon, $5\% < SI \leq 7\%$ shows high risk of structural degradation due to insufficient organic carbon loss, $7\% < SI \leq 9\%$ shows low risk of soil structural degradation and $SI > 9\%$ indicates sufficient soil organic carbon to maintain structural stability.

**Active soil reaction ($pH/H_2O$)** belongs to significant chemical characteristics, significantly affects the fertility of the soil, it influences soil processes and the presence of soil organisms. The active soil reaction was determined by potentiometrically. Fertility decreases rapidly at $pH < 5$. If $pH < 3$, the plants are generally unable to grow. In the Czech Republic most of the surface layers show a slight to slightly acidic reaction.

**Electrical conductivity (EC)** characterizes the degree of salt load. Soil salinity greatly influences the chemical and biological properties of the soil and greatly reduces soil fertility. For analysis was used with the electrode pH meter for measuring the electrical conductivity.

**Results and discussions**

The results of the physical and chemical properties of the soil from the experimental plots K1 and K2 are presented in graphical form (Fig. 2A-H, 3A-H). They represent the average values of measured soil quality indicators from the years 2016–2018.

**Locality K1 Šardičky**

On the basis of the results obtained, it can be stated that the physical and chemical quality of soil on the plot K1 is good. The average soil texture in the Ap horizon (0–30 cm): 19.23% sand, 69.78% silt and 11% clay. Soil classification: medium heavy loamy soil (Novák) and silt loam (USDA).

The course of bulk density in the monitored period including a critical value according to Lhotský et al. (1984) and Arshad et al. (1996) is seen in Fig. 2A, with average BD values ranging from 1.35 to 1.46 g cm$^{-3}$. In 2016–2017 the critical value proposed by Lhotský et al. (1.45 g cm$^{-3}$) was not exceeded and the structural condition of the upper layer was good. In the last year of monitoring, the critical value was exceeded (agricultural machinery travels and natural soil compaction due to various factors), and the structural state was insufficient. Critical value according to Arshad et al. (2002) (1.55 g cm$^{-3}$) was not reached during the monitored period. The course of porosity, including the critical value for loamy soil, can be seen in Fig. 2B, the average P values ranged from 44.77 to 49.31%. First two years the critical value was not exceeded and the upper layer of the soil, according to Bretfeld, was compact (Kutilek, 1978). In 2018 critical value was exceeded and the upper layer was very compact. The course of maximum capillary water capacity, including reaching or exceeding the critical value for loamy soil is shown in Fig. 2C, the average $\theta_{MK}$ values ranged from 29.05 to 33.69% and the critical value of 36% was not exceeded.

The course of the minimum air capacity including the indication of the optimum range is shown in Fig. 2D, the average AC values ranged from 15.62 to 17.95% and in the monitored period met the condition of optimum air capacity, i.e., in the soil is enough air for the roots of plants. If we compare the results of the research with the results of the basal monitoring of agricultural soils (Khákal, 2000: $BD=1.4$ g cm$^{-3}$, $P=47.08\%$, $\theta_{MK}=35.24\%$), the achieved values of physical indicators do not show agreement.

The course of $K_s$, including the limit for ideal range $K_s$ is shown in Fig. 2E. In 2016, the average $K_s$ value was high due to preferential flow, in 2017 decreased and stabilized and in 2018 was without significant change. In 2016, the soil was classified according to Kutilek (Holý et al., 1984) as a high permeability soil (2–6 m day$^{-1}$) and in 2017–2018 was moderately permeable (0.5–2 m day$^{-1}$). Average values (0.0020–0.0048 cm s$^{-1}$) fall within the optimal range (5 $10^{-3}$ cm s$^{-1}$ to 5 $10^{-4}$ cm s$^{-1}$) and can be considered “ideal” (Reynolds et al., 2003).

The chemical properties of the soil can be characterized by a high organic carbon content, the course of which can be seen in Fig. 2F. Humus affects soil fertility and soil function in the ecosystem, average values were higher than 5% (5.66 to 5.68%), i.e., the soil is highly humous (Kutilek, 1978). The high proportion of humus is probably related to the long-term applied reduced tillage technology and to leaving plant residues on the soil surface.

High content of humus is likely to be related to long-term reduced tillage treatment and plant residues in the soil. Based on the humus content and gran size distribution, the stability index SI we used to classify the soil into classes of structural degradation risks. In the monitored period SI values are unchanged (7.0–7.03%), showing low risk of soil structure degradation. The electrical
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Fig. 2.  A) average BD values in the 0–10 cm depth from the plot K1 with RT. The two horizontal lines demark a critical value according Lhotský et al. (1984) and Arshad et al. (1996). B) average P values in the 0–10 cm depth from the plot K1 with RT. The horizontal line demarks a critical value according Lhotský et al. (1984). In both pictures the vertical T-bars indicate range of measured values.

Fig. 2.  C) average $\theta_{KMK}$ values in the 0–10 cm depth from the plot K1 with RT. The horizontal line demarks a critical value for loamy soils. D) average AC values in the 0–10 cm depth from the plot K1 with RT. The horizontal lines demark a proposed minimum and optimal AC values for adequate root-aeration. In both pictures the vertical T-bars indicate range of measured values.

Fig. 2.  E) average $K_s$ values in the 0–10 cm depth from the plot K1 with RT. The two horizontal lines demark a proposed optimum $K_s$ range. F) average OC values in the 0–10 cm depth from the plot K1 with RT. The horizontal lines demark a proposed optimal OC range (Reynolds et al., 2007). In both pictures the vertical T-bars indicate range of measured values.
conductivity is shown in Fig. 2G, with average EC values ranging from 0.15 to 0.22 mS cm\(^{-1}\), without negative effect of fertilization on the soil. The course of the soil reaction including the range for the weakly acidic reaction is shown in Figure 2H, the average pH/H\(_2\)O values ranged from 6.33 to 6.7, the active soil reaction was weakly acidic. The results of chemical indicators are not consistent with the results of the evaluation of basal monitoring of agricultural soils (Kňákal, 2000).

The physical properties of the upper soil layer on plot K2 are also in good condition. The average soil texture in the Ap horizon (0–30 cm): 9.7% sand, 75.49% silt and 14.81% clay. The soil is classified by Novák as a medium-heavy loamy soil, by USDA classification as a silty loam.

Course of BD in the years 2016–2018 is shown in Fig. 3A, the average BD values ranged from 1.35 to 1.50 g cm\(^{-3}\) and exceeded the agro-ecological limit (1.45 g cm\(^{-3}\)) only in 2018. Critical value according to Arshad was not reached. In 2016–2017 the structural condition of the humus horizon was good, in 2018 it deteriorated and was unsufficient. The course of porosity including the range for loamy soil is evident from Fig. 3B, the average P values ranged from 43.58 to 49.31%, the critical value was exceeded in 2018. In 2016–2017 the state of the topsoil was compact, in 2018 was very compact.

The course of maximum capillary water capacity, including reaching or exceeding the critical value for loamy soil is shown in Fig. 3C, the \(d_{\text{smK}}\) values ranged from 28.34 to 34.89% and was not exceeded the critical value (36%). The course of the minimum air capacity, including the minimum and optimal AC range for adequate root aeration, is shown in Fig. 3D. The average AC values ranged from 12.15% to 15.64% and did not fall below the 12% minimum level. The optimum range was reached only in 2018. The results of the physical parameters are not consistent with the results of the evaluation of the basal monitoring program for agricultural soils (Kňákal, 2000).

The course of OC is shown in Fig. 3E and average OC values were low (0.08–0.21 mS cm\(^{-1}\)) and without the effect of fertilization on soil quality (Pokorný et al., 2007). The course of the soil reaction including the range for the weakly alkaline reaction is shown in Figure 3 H, the average pH/H\(_2\)O values ranged from 7.39 to 7.58, the soil reaction was weakly alkaline (7.1–8.0). The results of chemical indicators are not consistent with the results of basal monitoring of agricultural soils (Kňákal, 2000).

**Locality K2 Bohaté Málkovice**

The physical properties of the upper soil layer on plot K2 are also in good condition. The average soil texture in the Ap horizon (0–30 cm): 9.7% sand, 75.49% silt and 14.81% clay. The soil is classified by Novák as a medium-heavy loamy soil, by USDA classification as a silty loam.

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The long-term reduced tillage technology showed small changes in selected physical parameters of soil quality. The critical BD and P value were exceeded only in 2018 and the average \(d_{\text{smK}}\) values did not exceed the limit for loamy soil. The minimum air capacity was better on the plot K1 with optimal values, on the plot K2 did not drop below the minimum limit. The average AC values for both plots meet the optimum condition and can be considered “ideal.” With regard to achieving or exceeding
Fig. 3.  A) average BD values in the 0–10 cm depth from the plot K2 with RT. The two horizontal lines demark a critical value according Lhotský et al. (1984) and Arshad et al. (1996). B) average P values in the 0–10 cm from the plot K2 with RT. The horizontal line demarks a critical value according Lhotský et al. (1984). In both pictures the vertical T-bars indicate range of measured values.

Fig. 3.  C) average θMK values in the 0–10 cm depth from the plot K2 with RT. The horizontal line demarks a critical value for loamy soils. D) average AC values in the 0–10 cm depth from the plot K2 with RT. The horizontal lines demark a proposed optimal and minimum AC value range for adequate root-aeration. In both pictures the vertical T-bars indicate range of measured values.

Fig. 3.  E) average Ks values in the 0–10 cm depth from plot K2 with RT. The two horizontal lines demark a proposed optimum Ks range. F) average OC values in the 0–10 cm depth from the plot K2 with RT. The horizontal lines demark a proposed optimal OC range for landscaping soils. In both pictures the vertical T-bars indicate range of measured values.
the critical values of the measured physical soil quality indicators, the experimental plot K1 near the village of Šardičky showed better quality of the upper layer. Soil chemical properties are good and do not require treatment. Both plots show a high proportion of humus, the plot K1 showed a higher stability index SI and a low risk of soil structure degradation. EC is low in both plots, without the effect of fertilization on soil quality. For the plot K1 the soil reaction was slightly acidic, for the plot K2 was slightly alkaline. If we compare the results of the research with the results of the evaluation of the basal monitoring of agricultural soils, the agreement is not evident in physical or chemical soil parameters. To assess soil quality in general, it is necessary to assess not only the physical and chemical properties of the soil, but also the biological ones. A comprehensive assessment will then help to identify the causes of the failures and to suggest effective measures to eliminate them.

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Ing. Ivana Kameníčková, Ph.D.
Ing. Šárka Schneiderová
Ing. Kateřina Suchá
Institute of Landscape Water Management
Brno University of Technology
Faculty of Civil Engineering
Veveří 95, 662 37 Brno
Czech Republic
E-mail: kamenickova.i@fce.vutbr.cz