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EVALUATION OF SOIL REACTION AND CONTENT OF ASSIMILABLE NUTRIENTS IN SOILS OF SOUTH-EASTERN POLAND

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A b s t r a c t. An environmental study was performed in the years 2008-2012 to evaluate actual soil reaction (pH_{KCl}) and content of nutrients in soils of south-eastern Poland and also to determine the relationship of those nutrients to soil properties. To carry out those studies, 15493 soil samples were chemically analysed in certified laboratory of Regional Agrochemical Station in Lublin. In all soil samples particle size distribution was determined using the Laser Diffraction Method, soil reaction – in 1 mol KCl dm^{-3}, phosphorus and potassium using Egner-Riehm method, and magnesium was assayed using Atomic Absorption Spectrometry method. The reaction of non-calcareous soils of south-eastern Poland was acidic (very light soils) or slightly acidic (light, medium and heavy soils), and for calcareous soils the it was alkaline. The chemical analysis revealed that supply of phosphorus was moderate (light and medium non-calcareous and very light calcareous soils), high (very light and heavy non-calcareous soils) and very high (light, medium and heavy calcareous soils), and it depended significantly on the soil reaction. The supply of potassium in non-calcareous soils was moderate and depended significantly on agronomic category and soil reaction. As for magnesium, the supply of this nutrient in calcareous and non-calcareous soils depended on agronomic category and soil reaction.

K e y w o r d s: reaction, nutrients, soil, agronomic category

INTRODUCTION

Soil reaction and content of soil nutrients are those physicochemical properties which are of crucial importance in crop production (Larsen 1967). Excessive acidification limits the yield of plants; for example, in Poland it concerns more than half of the area of arable lands (GUS 2012), and it depends not only on climatic or soil conditions (Adams and Henderson 1962, Dudziak 1973a, Filipek *et al*. 2006, Lipiński and Bednarek 1998b, Lipiński 2000), but also on human activity (Sharpley 1995, Mc Dowell and Sharpley 2003, Lipiński 2005a, Moody and Bell 2006, Siebielec *et al*. 2012). In current fertilisation practice the most important are easily accessible and assimilable nutrient forms which directly influence the yield and quality of cultivated crops. The supply of those nutrients depends not only on soil properties, but also on agrotechnical treatments (Wondrausch 1960, Kaniuczak 1998, Tyler and Olsson 2001, Lipiński 2005b,c,d), treatments from which fertilisation using mineral, natural or organic fertilisers has the biggest influence (Dudziak 1973a,b, Lipiński and Bednarek 1998a, Lipiński and Walendziuk 2005, Fotyma *et al*. 2006). As current acidification of the soil and its supply of nutrients are of crucial importance in crop production, therefore knowledge about these parameters is very important for the farmer, as he can make reasonable and accurate decisions about using (or not) mineral (Kulczycki 2012), natural or organic fertilisers and also liming treatments.

The main objective of this study was to evaluate soil reaction and content of phosphorus, potassium and magnesium in the soils of south-eastern Poland and also to determine the relationship of those nutrients to agronomic category and reaction of non-calcareous and calcareous soils. The results of this study are important information related to crop production, e.g. fertilisation and soil liming.

MATERIALS AND METHODS

In the years 2008-2012 an environmental study was performed to evaluate the actual soil reaction and the content of essential nutrients (P, K, Mg) in soils of south-eastern Poland. The relationship of these contents to soil properties, such as agronomic category and reaction of calcareous and non-calcareous soils, was also determined. This relationship is important information which can be the basis for decisions related to fertilisation of soils and plants, as well as soil liming. The most common parent material for soils of south-eastern Poland is loess. The thickness of the loess cover varies from approx. 1 up to 30 m. A characteristic feature of loess is the predominance of silt fraction. The sandy fraction does not exceed 10% (usually approx. 5%), the silt fraction exceeds 50% (usually approx. 65%) and the content of clay is in the range of 5 to 15%. The mineral composition is usually dominated by quartz, while feldspar (approx. 5%), mica (approx. 15%), carbonates (approx. 10%) and iron compounds (approx. 5%) are found in smaller amounts (Polish soil classification 2011). To carry out the study, chemical analysis of 15493 soil samples was conducted, including 385 very light, 4269 light, 7182 medium and 1800 heavy non-calcareous soils (HCl fizzing not detected, carbon content < 1% in whole profile) and 11 very light, 272 light, 730 medium and 844 heavy calcareous soils (HCl fizzing detected, carbon content > 1% in whole profile) (see Tab. 1).

Table 1. Dependence of soil reaction and content of essential nutrients in soils (0-30 cm) on agronomic category (in mg kg^{-1})

Soil agronomic class	Sample size	pH_{KCl}	P	K	Mg
Non-calcareous					
Very light	385	5.30b*	67.4a	69.1c	26.5a
Light	4269	5.55c	65.2a	106.6d	44.5c
Medium	7182	5.70d	63.1a	142.1a	59.1d
Heavy	1800	6.30e	80.2c	182.9b	97.2f
Calcareous					
Very light	11	7.75a	64.2abc	104.3abcd	18.9abcd
Light	272	7.49a	111.3b	151.7b	30.8ab
Medium	730	7.43a	112.9b	191.5b	37.7b
Heavy	844	7.45a	107.9b	212.0e	66.2e
In total	15493	5.93	71.4	141.5	57.5

a, b, c, d, e, f – *averages labelled with the same letter are not significantly different at significance level $\alpha = 0.05$

Locations of soil sample collecting points were selected beforehand to cover the surface of the studied area uniformly. They were situated at selected farms representing each of the agronomy classes: very light soils (up to 10% of fraction of diameter < 0.02 mm), light soils (11-20% of fraction < 0.02 mm), medium soils (21-35% of fraction < 0.02 mm) and heavy soils (> 35% of fraction < 0.02 mm). If in a selected area a given soil class was occurring in an amount lower than 10% of agricultural land, then for this area collecting points were not appointed. The mass of the sample taken from the 0-30 cm layer was approximately 500 g. Samples were collect using Egner sticks, and the position of sampling point was determined using a GPS system. The number of points on the studied area was determined on the basis of livestock density. If it was fewer than 40 LU (Livestock Unit)/100 ha AL (Agricultural Land) – 1 point was selected, in the range 40-80 LU/100 ha AL – 2 points were selected, and if livestock density were higher than 80 LU/100 ha AL – 3 points were selected (according to IUNG-PIB). Chemical analyses were conducted in the accredited lab of the Regional Agrochemical Station in Lublin. In the collected soil samples, particle size distribution (PSD) was measured using the Laser Diffraction Method (LDM), soil reaction (pH_{KCl}) in 1 mol KCl dm^{-3}, phosphorus and potassium using the Egner-Riehm (DL) method, and magnesium was assayed after the extraction of 0.0125 mol $CaCl_2$ dm^{-3} from soil, using the Atomic Absorption Spectrometry (AAS) method (Catalogue of methods 2011). The results obtained were evaluated statistically using one-way non-orthogonal analysis of variance with Tukey's confidence intervals ($p = 0.05$). Also the relationship between the content level of nutrients assayed and the PSD of calcareous and non-calcareous soils was calculated. In Figures 1-3 very light soils are indicated by 1, light – 2, medium – 3 and heavy soils are indicated by 4.

RESULTS AND DISCUSSION

The soil reaction of the studied non-calcareous soils was strongly dependent on the agronomic category, which means that it increased considerably with increasing content of the particles < 0.2 mm. In very light soils soil reaction was 5.30, light – 5.55, medium – 5.70 and heavy – 6.30, therefore soil reaction of the very light soils was acidic and for the light, medium and heavy soils – slightly acidic. This kind of relationship was not found in calcareous soils, in which soil reaction did not depend on the agronomic category of the soil and it was alkaline in each soil class (Tab. 1 and Fig. 1).

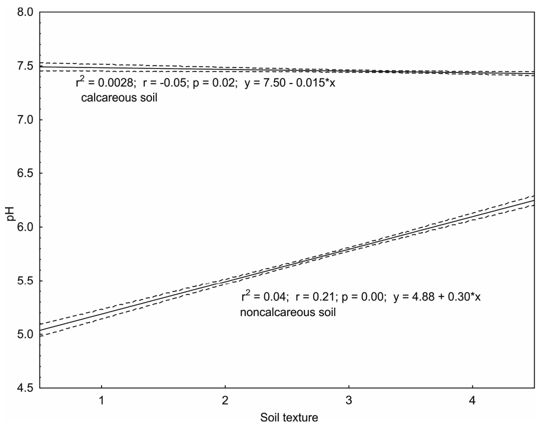

Fig. 1. Soil reaction dependence on agronomic category of the soils (1 – very light, 2 – light, 3 – medium and 4 – heavy soils)

Optimal reaction of the soil, adapted to grain size composition and crop species grown, is one of the most important physicochemical properties of the soil (Dudziak 1973a, Lipiński and Bednarek 1998b, Lipiński 2000, 2005a; Tkaczyk and Bednarek 2011, Filipek and Skowrońska 2013).

Studies conducted in the years 1994-96 by Lipiński and Bednarek (1998b) showed that soils of, for example, Lubelskie region were characterised by strong acidification, regardless of their grain size composition. This situation, despite some fluctuations, still persists (Dudziak 1973a, Lipiński 2000, Tkaczyk and Bednarek 2011, Siebielec *et al*. 2012). Lipiński (2005a), who evaluated the soil reaction of the soils in Poland, found that the most acidic soils are present in the eastern and central parts of Poland, however a systematic improvement can be observed, even if it is slow. Nearly one half of the studied soil samples were characterised by very high liming needs. The substantial acidification of arable lands in Poland results from soil-forming processes, anthropogenic impacts and insufficient use of lime fertilisers. In this regard the situation is much worse in Poland than in other neighbouring countries (Jasiewicz *et al*. 1999, Filipek *et al*. 2006, Filipek and Skowrońska 2013, Rogóż and Tabak 2015).

In non-calcareous soils the content of phosphorus did not depend unambiguously on agronomic category (Tab. 1). In very light, light and medium soils it ranged from 63.1 up to 67.4 mg P kg^{-1}, but it was not significantly different among the soils studied. In heavy soils, phosphorus content was much higher (80.2 mg P kg^{-1}) and differed statistically significantly from the three soil categories mentioned previously. The supply of phosphorus in light and medium soils, according to the Egner-Riehm limit values, was moderate, and in very light (relatively low number of investigated soil samples – 385 should be noted) and heavy soils – high. In very light calcareous soils the content of phosphorus was the lowest (64.2 mg P kg^{-1}), in light, medium and heavy soils it was definitely higher, but very balanced (107.9-112.9 mg P kg^{-1}). The level of phosphorus in very light soils was moderate, and in light, medium and heavy soils it was high (Tab. 1). However, the phosphorus content in soils from all those classes did not differ significantly. Phosphorus is one of the basic crop nutrients, therefore the optimal supply of this nutrient in soil, in its easily soluble forms, is extremely important (Larsen 1967, Sharpley 1995, Fernandes *et al*. 2000, Mc Dowell and Sharpley 2003, Lipiński 2005b, Kulczycki 2012). Lipiński (2005b) found that 38% of Polish soils have very low and low supply of phosphorus and most of them are located in eastern and south-eastern Poland. He also noted that a systematic increase of very high supply of phosphorus in soils can be observed. Compared to the soils of southern Poland, where the content of phosphorus ranged from 11 up to 376 mg P kg^{-1} in the area of Cracow (Rogóż and Tabak 2015) and from 21,6 to 94 mg P kg^{-1} (Jasiewicz *et al*. 1998) in the area of Katowice, a insignificantly larger share of soils with moderate or high phosphorus content was observed, but the results were quite similar. On the other hand, comparison with the study by Andruszczak (1991), covering the whole area of Poland, where the content of phosphorus ranged from 20 to 50 mg P kg^{-1}, indicates a much larger share of soils with high phosphorus content for south-eastern Poland than for the rest of the country. Rationalisation of soil supply in this element may be achieved by precise phosphorous fertilisation which changes the supply class in favour of optimum supply compartments (Kulczycki 2012).

The content of potassium in non-calcareous soils depended significantly on agronomic category (Tab. 1 and Fig. 2). In very light soils it was equal to 69.1 mg K kg^{-1}, in light soils – 106.6 mg K kg^{-1}, in medium soils 142.1 mg K kg^{-1} and in heavy soils 182.9 mg K kg^{-1}. The supply of this element in soils from all categories (very light, light, medium and heavy) was, according to the Egner-Riehm limit values, moderate. Higher level of potassium was found in calcareous soils. However, comparing it to the other agronomic categories, it was significantly higher only in heavy calcareous soils. The supply of potassium in very light soils was moderate, and in the light, medium and heavy soils it was high.

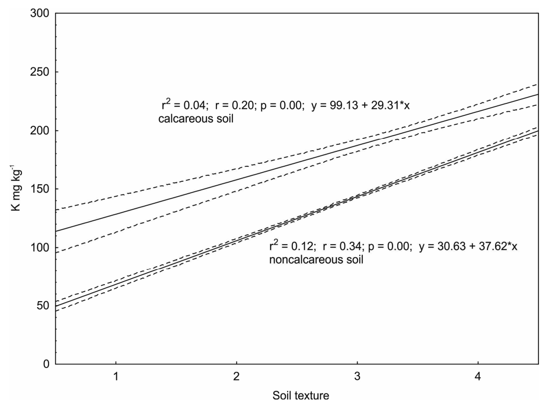

Fig. 2. Dependence of potassium supply on agronomic category of the soils (1 – very light, 2 – light, 3 – medium and 4 – heavy soils)

Potassium is also one of the most important nutrients for plants, therefore the optimal supply in soils, especially of its assimilable forms, is very important (Adams and Henderson 1962, Basker *et al*. 1994, Lipiński and Walendziak 2005, Lipiński 2005c, Siebielec *et al*. 2012). According to research conducted in the years 1955-1999, percentage of soils with very low and low supply of assimilable forms of phosphorous and potassium was decreasing until the nineties, and nowadays impoverishment of soils in these elements can be observed (Dudziak 1973a, Lipiński 2000, Siebielec *et al* 2012). Lipiński (2005c) and Lipiński and Walendziuk (2005) noted that soils deficient in assimilable forms of potassium occupy in Poland nearly half of the area, and also that it is the most deficient plant nutrient in soils in Poland. For example, in soils of southern Poland, where the content of potassium ranged from 32.1 up to 306.4 mg K kg^{-1} (Jasiewicz *et al*. 1999), a smaller share of soils with moderate or high phosphorus content was observed, but soils of southern Poland had greater spread (a larger share of soils with very low or low potassium content).

The content of assimilable forms of magnesium in non-calcareous soils depended significantly on agronomic category (see Tab. 1 and Fig. 3). In very light soils it was equal to 26.5, in light – 44.5, medium – 59.1 and in heavy soils – 97 mg Mg kg^{-1}. The supply of this element in soils from all categories (very light, light, medium and heavy) was moderate. In calcareous soils the content of this element increased with increasing content of particles < 0.2 mm, but it was significantly greater only in heavy soils, compared to very light, light and medium soils. The supply of this element in very light, light and medium soils, according to limit values, was low, and in heavy soils – moderate.

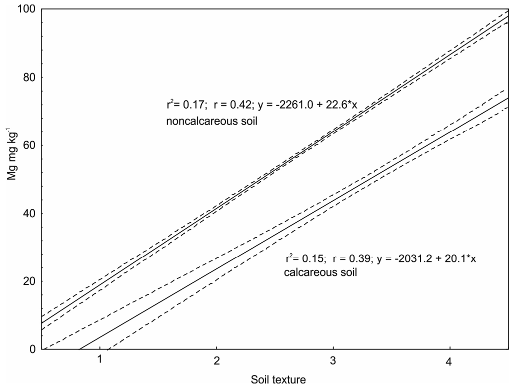

Fig. 3. Dependence of magnessium supply on agronomic category of the soils (1 – very light, 2 – light, 3 – medium and 4 – heavy soils)

Magnesium is also a plant nutrient, the content of which significantly affects the quality and yield of crops (Salmon 1964, Dudziak 1973b, Lipiński and Bednarek 1998a, 1998b, Lipiński 2005d, Tyler and Olsson 2001). Wondrausch (1960) noted that sandy podzolic soils, with acidic reaction, are deficient in assimilable forms of magnesium. Podzolic soils developed from boulder loam and silt deposits are richer in these forms, and brown earth and chernozem soils – rich. Determination of the soil type, its particle size distribution and reaction allows one to identify soil supply with assimilable forms of magnesium and to evaluate, with high probability, its fertilisation needs. Dudziak (1973b), after carrying out the research in the years 1963-1970, pointed out that 53% of arable lands of south-eastern Poland had low supply of assimilable forms of magnesium. Most of soils with very low and low supply of magnesium can be found in the areas of the Chełm and Lublin regions, and least of them in the Zamość region (Lipiński and Bednarek 1998a, Lipiński 2000). Lipiński (2005d) and Siebielec *et al.* (2012) reported systematic improvement of soil supply with assimilable forms of magnesium and that the most of the soils deficient in this element are in the belt of central-western and south-eastern Poland (Opole, Lodz, Mazovia and Lublin regions). Compared to the soils of southern Poland, where the content of magnesium ranged from 13 up to 1010 mg Mg kg^{-1} in the area of Cracow (Rogóż and Tabak 2015), a significantly larger share of soils with very low and low magnesium content was observed. Particle size distribution and soil reaction played a decisive role in forming of the content of assimilable forms of magnesium (Wondrausch 1960, Lipiński and Bednarek 1998b).

Table 2. Dependence of macroelements content in soils (0-30 cm) on soil reaction (in mg kg^{-1})

Soil pH class	Sample size	P	K	Mg
Strong acidic	2385	44.3a*	97.2a	31.5b
Acidic	3716	49.9b	125.1b	55.8a
Slightly acidic	4167	65.9c	145.7c	71.4d
Neutral	2713	97.7d	164.7d	65.3c
Alkaline	2512	109.7e	175.9e	53.4a
In total/average	15493	71.4	141.5	57.5

a, b, c, d, e – * averages labelled with the same letter are not significantly different at significance level $\alpha = 0.05$

It can also be observed that the content of assimilable forms of phosphorus significantly depended on the class of soil reaction. In strongly acidic soils it was equal to 44.3; acidic – 49.9; slightly acidic – 65.9; neutral – 97.7, and alkaline soils – 109.7 mg P kg^{-1}. The supply of this nutrient in strongly acidic and acidic soils was low, and in slightly acidic – moderate. In contrast, for neutral and alkaline soils the supply of phosphorus was very high (Tab. 2). The content of assimilable forms of potassium also depended significantly on soil reaction class (Fotyma *et al*. 2006), and in strongly acidic soils it was equal to 97.2, acidic – 125.1, slightly acidic – 145.7, neutral – 164.7, and in alkaline soils – 175.9 mg K kg^{-1} (Tab. 2). The content of assimilable forms of magnesium in soils depended significantly on the class of the soil reaction and was increasing up to the slightly acidic category. In strongly acidic soils it was equal to 31.5, acidic – 55.8, slightly acidic – 71.4, neutral – 65.3, and in alkaline soils – 53.4 mg Mg kg^{-1}, but it did not differ significantly between the acidic and alkaline categories (Tab. 2).

In non-calcareous soils soil reaction depended significantly and positively on the content of particles < 0.02 mm ($r_{xy} = 0.211$) and on the content of assimilable forms of phosphorus ($r_{xy} = 0.058$), potassium ($r_{xy} = 0.340$) and magnesium ($r_{xy} = 0.417$); in calcareous soils soil reaction also depended significantly on the content of the fraction < 0.02 mm, but the correlation coefficient was negative ($r_{xy} = -0.053$). In contrast, the content of assimilable forms of potassium ($r_{xy} = 0.205$) and magnesium ($r_{xy} = 0.391$) depended significantly and positively on the content of the fraction < 0.02 mm (Tab. 3).

Table 3. Dependence of soil reaction and assimilable forms of phosporous, potassium and magnesium on soil type (values of correlation coefficients)

Soils	pH_{KCl}	mg P kg^{-1}	mg K kg^{-1}	mg Mg kg^{-1}
Non-calcareous	0.211	0.058	0.340	0.417
Calcareous	–0.053	*	0.205	0.391

sample sizes (n) for non-calcareous soils: 13648-13663, calcareous soils: 1863-1881, $p = 0.05$,
* – insignificant dependence

Knowledge of current soil reaction and its supply of assimilable forms of basic nutrients (P, K, Mg) is extremely important information which can help the farmer in accurate and reasonable calcium, calcio-magnesium, phosphate and potassium fertiliser management on the farm, as well as to enable and to facilitate agricultural services those kind of activities on the area covered by the studies.

CONCLUSIONS

1. The reaction of non-calcareous soils of south-eastern Poland was acidic (very light soils) or slightly acidic (light, medium and heavy soils), reaction of calcareous soils was alkaline.

2. The supply of phosphorus in non-calcareous light and medium soils was moderate, in very light and heavy soils – high. The supply of phosphorus in calcareous very light soils was moderate, in light, medium and heavy – very high. The supply of phosphorus depended significantly on class of soil reaction.

3. The supply of assimilable forms of potassium in non-calcareous soils depended significantly on agronomic category and class of soil reaction, and for all soils from all of the categories it was moderate. The supply of potassium in very light calcareous soils was moderate, and in other categories (light, medium, heavy) – high.

4. The supply of magnesium in non-calcareous and calcareous soils significantly depended on agronomic category and class of soil reaction. In non-calcareous soils from all categories it was moderate, in calcareous soils it was low (very light, light and medium soils) and moderate (heavy soils).

5. The soil reaction and supply of assimilable forms of P, K and Mg in non-calcareous soils depended significantly and positively on agronomic category; reaction of calcareous soils depended significantly and negatively on agronomic category, and supply of assimilable forms of potassium and magnesium of calcareous soils depended significantly and positively on agronomic category.

6. Evaluation of the current soil reaction and its supply of assimilable forms of phosphorus, potassium and magnesium allows one to conduct accurate and reasonable fertiliser management in the area of performed studies.

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OCENA ODCZYNU I ZASOBNOŚCI W PRZYSWAJALNE FORMY MAKROELEMENTÓW GLEB POŁUDNIOWO-WSCHODNIEJ POLSKI

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S t r e s z c z e n i e. W latach 2008-2012 przeprowadzono badania środowiskowe, których celem była ocena aktualnego odczynu (pH_{KCl}) i zasobności gleb południowo-wschodniej Polski w podstawowe składniki pokarmowe oraz określenie zależności tych składników od niektórych właściwości gleby. Do przeprowadzania badań wykorzystano wyniki analiz chemicznych 15493 próbek glebowych. Analizy chemiczne wykonano w akredytowanym laboratorium Okręgowej Stacji Chemiczno-Rolniczej w Lublinie. W pobranych próbkach skład granulometryczny oznaczono metodą laserową, odczyn w 1 mol $KCl \cdot dm^{-3}$, fosfor i potas przyswajalny metodą Egnera-Riehma (DL) a magnez przyswajalny po ekstrakcji z gleby 0,0125 mol $CaCl_2 \cdot dm^{-3}$ i oznaczeniu zawartości tego pierwiastka metodą ASA. Odczyn gleb bezwęglanowych południowo-wschodniej Polski był kwaśny (gleby bardzo lekkie) lub lekko kwaśny (gleby lekkie, średnie i ciężkie), a węglanowych – zasadowy. Zasobność gleb bezwęglanowych lekkich i średnich w fosfor przyswajalny była średnia, bardzo lekkich i ciężkich – wysoka. Zasobność gleb węglanowych bardzo lekkich była średnia, a lekkich, średnich i ciężkich – bardzo wysoka. Zasobność ta zależała istotnie od klasy odczynu gleby. Zawartość potasu przyswajalnego w glebach bezwęglanowych zależała istotnie od kategorii agronomicznej i klasy odczynu; zasobność gleb wszystkich kategorii w ten pierwiastek była średnia. Zasobność gleb węglanowych bardzo lekkich w potas przyswajalny była średnia, a pozostałych kategorii (gleb lekkich, średnich, ciężkich) – wysoka. Zawartość magnezu przyswajalnego w glebach bezwęglanowych i węglanowych zależała od kategorii agronomicznej oraz klasy odczynu. Zasobność gleb bezwęglanowych w ten pierwiastek była średnia, a węglanowych niska (gleby bardzo lekkie, lekkie i średnie) i średnia (gleby ciężkie).

S ł o w a k l u c z o w e: odczyn, składniki pokarmowe, gleba, kategoria agronomiczna