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ORIGINAL PAPER

LONG-TERM CROP ROTATION AND CONTINUOUS CROPPING EFFECTS ON SOIL CHEMICAL PROPERTIES*

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Abstract

Soil is the crucial element of the environment and sustainable agriculture calls for more attention to be paid to the influence of cropping systems on soil properties. During a field experiment on Luvisols (north-eastern Poland), the effects of crop rotation (CR) (potato – oats – fibre flax – winter rye – faba bean – winter triticale), and long-term continuous cropping (CC) of oats (49 years), rye (49 years) and triticale (24 years) on the content of soil organic carbon (SOC), total nitrogen (TN), the available forms of phosphorus (P), potassium (K), magnesium (Mg), boron (B), manganese (Mn), copper (Cu), zinc (Zn), and iron (Fe), the pH, the hydrolytic acidity and the exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) of the soil were investigated. Based on the results, the sorption capacity and the index of sorption complex saturation with alkalis were calculated. Soil analyses were performed after cereals harvest in 2016. The SOC soil content in oats fields under the CR and CC system was similar. The SOC soil in rye fields was lower and in triticale fields higher under the CR than under the CC system. The cropping system usually did not differentiate the contents of macronutrients or micronutrients in the soil. The CR system promoted the K accumulation in the soil, while the CC of oats and rye reduced the pH and increased the sorption capacity of soils. Studies have shown that the continuous cropping system usually does not cause deterioration of soil chemical properties if manure and mineral fertilisers are applied systematically. The results indicate the need to monitor the properties of soil, particularly the SOC content and the soil pH, regardless of the cropping system. Such measures are essential in the protection of the soil against degradation.

Keywords: cropping system, continuous monoculture, macronutrients, micronutrients, soil pH, soil sorption capacity.

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INTRODUCTION

In the agricultural production space, soil is the crucial element of the environment. In recent years, due to the influence of human activity, changes in the forms of land use have been observed on both the local and global scale. The losses of large areas of agricultural land as a result of their allocation for the urbanisation, industry and transport purposes raise concerns about ensuring sustainable production and food security (Blum 2013). Moreover, several soil degradation forms are mentioned. These include water and wind erosion, the loss of organic matter, pollution, the loss of biological diversity of the soil, compaction, salinity, flooding, nutrient mining and desertification (Blum 2013) The European Union's activities appear to be aimed at rendering the protection of soils equally important to the protection of air and water (Pikuła 2015).

Soil quality is determined *inter alia* by its chemical properties. The basic characteristics include the content of humus or soil organic carbon (SOC) and total nitrogen (TN) – Cuvardic et al. 2004, Blecharczyk et al. 2005*b*, Liu et al. 2005, Woźniak 2019, Liu et al. 2021. The source of SOC are the organic substances incorporated into the soil in the form of manure, post-harvest residues and cover crop biomass (Bolinder et al 2020). Numerous studies emphasise the relationship between the SOC content in the soil with the TN content (Blecharczyk et al. 2005*b*, Liu et al. 2005, Degu et al. 2019, Liu et al. 2021). This relationship is complemented by the C:N ratio (Cuvardic et al. 2004, Degu et al. 2019, Woźniak 2019, Liu et al. 2021) which indicates the intensity and the trend in the transformations of the soil's organic substance (Jastrzębska 2009) as a result of the activity of soil microflora and the biochemical processes related to its functioning (Kucharski, Niewolak 1996, Woźniak 2019). The macro- and micronutrients released from the organic substance are reserves of a particular chemical element in the soil and are retained by the soil's sorption complex. The sorption capacity of soils varies greatly (Mazur et al. 2015, Kazula et al. 2017, Degu et al. 2019, Stępień, Kobiałka 2019, Woźniak 2019, Kwiatkowski, Harasim 2020, Neugschwandtner et al. 2020) depending on many environmental factors, including the type of the parent rock from which the soil was formed (Kabała et al. 2013).

Soil chemical properties are primarily changed through fertilisation (Cuvardic et al. 2004, Blecharczyk et al. 2005*b*, Mazur et al. 2015, Stępień, Kobiałka 2019) but also through other agronomic practices, including cropping system (Blecharczyk et al. 2005*b*, Negash et al. 2018, Kwiatkowski, Harasim 2020, Orzech, Załuski 2020). Crop rotation is one of the cropping systems defined as a cycle of crops grown in successive years on the same land (Yates 1954). Its opposite is the continuous growing of a single species over many years (continuous cropping). The effects of crop rotation system on the weed infestation of crops, the health status of crops, the occurrence of pests and the soil habitat have been confirmed by many studies, and the tangible result is higher crop yields (Blecharczyk et al. 2005*a*, Negash et al. 2018, Jastrzębska et al. 2019). The environmental and production functions of crop rotation are fulfilled by selecting appropriate species and their sequence. This issue has been addressed in numerous experiments, primarily those involving the cultivation of wheat, maize, and soybean (different sequences of these crops and various rotation durations have been taken into account) (Cuvardic et al. 2004, Liu et al. 2005, Kazula et al. 2017, Woźniak 2019, Haruna, Nkongolo 2019), and, less often, involving the cultivation of other crop species (Blecharczyk et al. 2005*b*, Degu et al. 2019, Stępień, Kobiałka 2019, Bogužas et al. 2022). Previous studies have shown both changes and lack of any changes in soil chemical properties under different cropping systems (crop rotation vs. continuous cropping) – Blecharczyk et al. 2005*b*, Liu et al. 2005, Degu et al. 2019, Haruna, Nkongolo 2019. Such divergent effects should not come as a surprise since the changes to the soil's properties, especially physical and chemical ones, are a long-term process (Soman et al. 2017), which can be best demonstrated by long-term experiments (Blanchet et al. 2016).

Taking soil under oats, rye and triticale as examples, the study focused on comparing soil chemical properties determined after 49 or 24 years of growing these cereals in crop rotation (CR) with the soil properties after the same long period of their continuous cropping (CC). The contents of soil organic carbon (SOC), total nitrogen (TN), available forms of phosphorus (P), potassium (K), magnesium (Mg), micronutrients (B, Mn, Cu, Zn, Fe), pH and sorption capacity of soil were investigated.

MATERIALS AND METHODS

Site description

The study is based on a long-term field experiment located at the Production and Experimental Plant "Bałcyny" Sp. z o.o. in Bałcyny (Warmińsko-Mazurskie Voivodeship, Poland, 53°60′N, 19°85′E). The experiment was established in a slightly undulating area, on Luvisols formed from silty light loam. The content of silt (0.1-0.02 mm) in the 0-30 cm soil layer ranged from 26% to 39%; floatable particles (0.02-0.002 mm) ranged from 17 to 22% and clay particles (<0.002 mm) ranged from 2% to 4% (Rychcik et al. 2006).

The area under study is characterised by high weather variability. Rainfalls are evenly distributed over the year, but there are short periods of dry spells (in July and August) and drought (in August, September, and October) – Hutorowicz et al. 2008. The total annual precipitation is 587.5 mm and the average annual air temp. is 7.9°C (data for the years 1981-2015) (according to the data provided by the weather station in Bałcyny). The weather conditions (precipitation and average air temperatures) during the growing period of 2015/2016 are presented in Table 1.

Table 1

Total precipitation and average air temperatures during the growing period of 2015/2016

Month												Sum/ average
Sept	Oct	Nov	Dec	Jan	Feb	March	Apr	May	Jun	Jul	Aug	
Atmospheric precipitation (mm)												
51.2	20.8	80.8	80.4	28.7	50.5	20.5	33.1	70.8	66.3	138.6	71.9	713.6
Daily air temperature (°C)												
14.2	6.6	5.1	3.8	-3.8	2.7	3.6	8.8	14.9	18.0	18.5	17.6	9.2

The experiment was established in the autumn of 1967. Initially, it included continuous cropping of nine crop species (winter rye, winter wheat, spring barley, oats, maize, sugar beet, faba bean, winter rape, and fibre flax). In 1972, the experiment was modified: potato was introduced into the study and two five-field crop rotation systems comprising species with varying degrees of habitat requirements were introduced as comparative objects for the continuous growing of crops. During the experiment, changes were introduced in fertilisation and crop protection. Until 1982, only mineral fertilisation was applied, and then, due to the noted reduction in the organic matter content in the soil, fertilisation with manure was introduced. Until 1982, crops were protected exclusively with herbicides, as compared to the unprotected objects, and since 1983, crops have also been protected with herbicides and fungicides. In 1993, winter triticale and field pea were introduced into the experiment and, consequently, the crop rotation was extended to six years. The experiment covers an area of 1 ha. Currently, the experimental factors include (i) the cropping system, (ii) the cultivars and (iii) the chemical plant protection level. Experimental treatments were performed in 3 replications (on three experimental plots of 27 m^2 each).

Experimental design and agronomic management

This study analysed the soil after harvesting oats, winter rye and winter triticale cultivated during the growing period of 2015/16 and only one experimental factor – a cropping system was investigated, with two levels: crop rotation (CR): potato *Solanum tuberosum* L. – oats *Avena sativa* L. – fibre flax *Linum usitatissimum* L. – winter rye *Secale cereale* L. – faba bean *Vicia faba* L. – winter triticale *x Triticosecale* Wittm., and continuous cropping (CC): oats – for 49 years, winter rye – for 49 years, winter triticale – for 24 years.

The crop sequence pattern on the experimental fields in the years 2011-2016 is presented in Figure 1.

The agronomical practices for the cereals growing under the CR and CC systems were the same. The basic elements of the agronomical practices for the cereals concerned are presented in Table 2. Fertilisation of each species cultivated under the CR and CC system was the same. Table 3 presents

Year	crop rotation fields 1	2	3	4	5	6	continuous cropping fields		
2011	oats	flax	rye	bean	triticale	potato*	oats*	rye*	triticale*
2012	flax	rye	bean	triticale	potato*	oats	oats	rye	triticale
2013	rye	bean	triticale	potato*	oats	flax	oats	rye	triticale
2014	bean	triticale	potato*	oats	flax	rye	oats*	rye*	triticale*
2015	triticale	potato*	oats	flax	rye	bean	oats	rye	triticale
2016	potato*	oats‡	flax	rye‡	bean	triticale‡	oats‡	rye‡	triticale‡

Fig. 1. Crop sequence during the six-year rotation and long-term continuous cereal growing: * fertilisation with farmyard manure (FYM): under crop rotation, once during a rotation. 30 t ha^{-1} (in the autumn of 2010, before potato planting), in cereal monocultures, every 3 years, 15 t ha^{-1} (in the autumn of 2010, before the growing period of 2011, and in the autumn of 2013, before the growing period of 2014), ‡ – the fields from which soil samples were collected for testing in 2016

Table 2

Selected elements of the agronomical practices for cereals

Item	Oats	Winter rye	Winter triticale
Soil tillage system	plough tillage	plough tillage	plough tillage
Sowing date	30 March 2016	17 September 2015	17 September 2015
Expected plant density at emergence (No m^{-2})	550	350	400
Harvest date	12 August, 2016	29 July, 2016	8 August, 2016

Table 3

Mineral fertilisation

Element	Potato	Oats	Fibre flax	Winter rye	Faba bean	Winter triticale
N (kg ha^{-1})	80 $50^{\#}+30^{\wedge}$	70 $50^{\#}+20^{*}$	70 $50^{\#}+20^{‡}$	70 $50^{\#}+20^{!}$	$40^{\#}$	70 $50^{\#}+20^{!}$
P_2O_5 (kg ha^{-1})	$70^{\#}$	$70^{\#}$	$70^{\#}$	$70^{\#}$	$70^{\#}$	$70^{\#}$
K_2O (kg ha^{-1})	$100^{\#}$	$100^{\#}$	$100^{\#}$	$100^{\#}$	$100^{\#}$	$100^{\#}$
Total (kg ha^{-1})	250	240	240	240	210	240

before planting/sowing, ^ before the closure of interrows, * beginning of the stem elongation, ‡ the plant height of approx. 10 cm, ! after the resumption of growing in the spring

mineral fertilisation for all crops cultivated in the experiment taking into account the chemical properties of soils.

N, P, and K were introduced in fertilisers: N – urea and/or ammonium nitrate, P – superphosphate 40%, K – potassium salt 60%. After the completion of the rotation cycle, in 2011, regardless of the cropping system, dolomite lime containing approx. 30% CaO and 15-20% MgO was applied to all crops at a dose of 3 t ha^{-1}. After the harvest, cereal straw was removed from the fields.

Soil sampling and analysis

Soil samples were collected in 2016 following the completion of the eighth crop rotation cycle. The soil samples were collected using a hand-held twisting probe (an Egner's soil sampler) from the 0-25 cm tillage layer, 2-3 days after harvesting the cereals. Sampling was performed at evenly spaced points in each plot. A total of about 1 kg of soil was taken from an individual plot. The collected soil material was air-dried at room temperature for several days, mixed and sieved to remove impurities (e.g., plant remnants). Then, portions of approximately 300 g were transferred to the accredited laboratory of the Chemical and Agricultural Station in Olsztyn, Poland (Accreditation Certificate No. AB 277 issued by the Polish Center for Accreditation in Warsaw). In the soil, the following were determined: the soil organic carbon (SOC) content by calorimetry via oxidation with a solution of $K_2Cr_2O_7$ + H_2SO_4 and measuring the absorption on a spectrophotometer, the total N content by the Kjeldahl method, the available P and K content with the Egner–Riehm method, and Mg according to the Schachtschabel method, the manganese (Mn), copper (Cu), zinc (Zn), iron (Fe) by the flame atomic absorption spectroscopic (FAAS) method; available boron (B) by the spectrophotometric method; the pH in 1 M KCl by the potentiometric method in 1 M KCl; hydrolytic acidity (Hh) by the Kappen method and the exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) by the flame photometric method. Based on the results, the sum of exchangeable cations (S; S=Ca^{2+} + Mg^{2+} +, K^+ + Na^+), the sorption capacity (T; T=Hh + S) and the index of sorption complex saturation with alkalis (V; V=100 x S/T) were calculated.

Statistical analysis

The results were analysed statistically by one-way analysis of variance (ANOVA). The Shapiro-Wilk *W*-test and Levene's tests were used to check whether the variables (each of the soil properties tested) met the assumptions of the analysis of variance regarding normality of distribution and homogeneity of variance, respectively. Statistical analyses were carried out using the Statistica software (data analysis software system), version 12, StatSoft (2014).

RESULTS AND DISCUSSION

Soil organic carbon (SOC) and total nitrogen (TN)

The SOC contents in the soil after harvesting oats growing under the CR and CC systems did not differ while, in the field of rye, the SOC content under the CR system was lower than that under the CC system and, in the field of triticale, there was more SOC in the soil under the CR system than under the CC system (Table 4). Similar results were noted in this experiment in the years 1992-2004 (Kucharski, Niewolak 1996, Rychcik et al. 2006).

Table 4

The contents of soil organic carbon (SOC), total nitrogen (TN) and the C:N ratio in the soil

Species	Cropping system	SOC	TN	C:N ratio
		(g kg^{-1} d.m.)		
Oats	CR	12.2*a*	0.78*a*	15.8*a*
	CC	12.0*a*	0.77*a*	15.6*a*
Rye	CR	9.3*b*	0.83*a*	11.2*b*
	CC	12.5*a*	0.87*a*	14.6*a*
Triticale	CR	10.4*a*	0.81*a*	13.1*a*
	CC	8.9*b*	0.73*a*	12.4*a*

a, b – homogeneous groups (for a species, the values marked with the same letter do not differ significantly at $p \leq 0.05$), d.m. – dry matter

Maintaining the SOC content is a key factor in conserving soil fertility and thus in making cropping systems sustainable (Blanchet et al. 2016). The SOC sources, as well as macro- and micronutrients, are organic substances incorporated into the soil in the form of manure, post-harvest residues and the intercrop biomass (Liu et al. 2005, Blanchet et al. 2016, Bolinder et al. 2020, Liu et al. 2021). Long term studies by other authors have shown that annual FYM application significantly increases the soil organic matter content (Blecharczyk et al. 2005*b*, Johnston, Poulton 2018). In the present study, the total amount of FYM applied in the CR and CC systems over a 6-year period was the same. Thus, the reported significant changes in the SOC content after cereal harvest may be due to the varying quantity and quality of crop residues of the cultivated species (Římovský 1987). For example, flax is distinguished by the lower weight of the root system than that of leguminous plants (Klimek-Kopyra et al. 2015). This feature may have resulted in the lower SOC content, as noted in the present study, in the rye field under the CR system, where fibre flax was the preceding crop of rye, in relation to the CC system, where rye was growing every year on the same field. It should be added that fibre flax is pulled out with the roots to increase the technical length of the straw and, at the same time, the fibre yield. On the other hand, according to Campbell et al. (2000), the presence of legumes in crop rotation, leaving crop residues with a narrow C:N ratio, may increase the efficiency of C conversion from crop residues to SOC. In the present experiment, the significant increase in SOC content after harvesting winter triticale growing in the CR system was also probably a consequence of growing this cereal after faba bean. According to Římovský (1987), faba bean provide considerably more post-harvest residues (especially aerial parts) than cereals do.

The results of studies conducted to date do not indicate that the changes in the SOC content, resulting from the crop sequence, are clearly targeted. There are reports on the lack of differentiation of this feature between the cultivation under the CR and CC system, e.g. in rye (Blecharczyk et al. 2005*b*) and maize (Zuber et al. 2015). Numerous papers indicate a decrease in the SOC soil content under the influence of continuous growing of potato (Blecharczyk et al. 2005*b*), barley (Blecharczyk et al. 2005*b*), wheat (Liu et al. 2005), soybean (Liu et al. 2005, Degu et al. 2019) and maize (Liu et al. 2005, Degu et al. 2019) or under the cereal rotation systems (Cuvardic et al. 2004, Börjesson et al. 2018). It follows from other studies that the changes in the SOC content in the soil are determined by the species under cultivation (Blecharczyk et al. 2005*b*, Liu et al. 2005, Mc Daniel et al. 2018, Degu et al. 2019, Woźniak 2019).

The cropping system had no effect on the TN content in the soil (Table 4). This may be the result of applying the same doses of N in mineral fertilisers in CC and CR under each cereal species compared. Similarly, the absence of differences in the TN soil content in the cultivation under CC and CR system was noted by Blecharczyk et al. (2005*b*) in the experiment with rye, and Kazula et al. (2017) – with maize. According to Liu et al. (2005), continuous cropping of wheat, corn, or soybean reduced the N content in soil. Blecharczyk et al. (2005*b*) showed that continuous cultivation of spring barley or potato also reduces the N content in soil. According to Cuvardic et al. (2004), the saturation of crop rotation systems with cereals results in a reduction of TN in the soil. The noted reduction in the TN soil content under continuous growing of crops usually corresponds to the reduction in the SOC content (Blecharczyk et al. 2005*b*, Liu et al. 2005, Degu et al. 2019).

The intensity of organic substance transformations in the soils is expressed by the C:N ratio (Cuvardic et al. 2004). In the present study, the cropping system had an effect on the C:N ratio in the soil only in the rye fields (Table 4). The broader C:N ratio in the soil under the CC system (noted in the current study) when compared to the CR resulted from the higher SOC content under the CC system. The literature provides information on a broader C:N ratio under frequent cereal growing (Cuvardic et al. 2004) and its narrowing where leguminous plants are cultivated (Blecharczyk et al. 2005*a*,*b*, Degu et al. 2019, Woźniak 2019). The lack of effect of the selection of crops to the CR system on the C:N ratio was noted as well (Haruna, Nkongolo 2019). According to Kazula et al. (2017), the habitat conditions differentiate the C:N ratio more strongly than the crop sequence and, according to Kwiatkowski and Harasim (2020), the cropping system is more important for the C:N ratio than the crop species. The values of this index range from 11.2 to 15.8, noted in the present study, indicate the possibility for maintaining a balance between mineralisation and the immobilisation of organic compounds (Jastrzębska 2009). At a C:N ratio in the soil <11, the N contained in the organic substance is not only utilised by microorganisms, but it is available to plants as well (Kazula et al. 2017).

Available phosphorus (P), potassium (K), and magnesium (Mg)

The cultivation of crops under the CR system, as compared to the CC system, promoted the accumulation of K in the soil after harvesting cereals and of Mg in the cultivation of rye (Table 5). The results of our research

Table 5

Macronutrient content in the soil

Species	Cropping system	P	K	Mg
		available forms (mg kg^{-1} d.m.)		
Oats	CR	130.7*a*	215.8*a*	60.2*a*
	CC	125.4*a*	193.7*b*	59.2*a*
Rye	CR	102.2*a*	252.5*a*	66.3*a*
	CC	108.7*a*	213.0*b*	59.2*b*
Triticale	CR	69.5*a*	213.0*a*	45.8*a*
	CC	60.6*a*	134.2*b*	44.2*a*

a, *b* – homogeneous groups (for a species, the values marked with the same letter do not differ significantly at $p \leq 0.05$), d.m. – dry matter

partially correspond to those presented by Woźniak and Kawecka (2016). The cited authors found that the soil sampled from crop rotation contained higher amounts of available P, K and Mg than the soil from the field of winter wheat continuous cropping. The observed decrease in soil Mg content in the CC system may be related to soil acidification (Nazarkieiwcz, Kaniuczak 2012*b*), and Mg migration to deeper soil layers (Haruna, Nkongolo 2020). The cropping system had no effect on the P content or Mg content in the oats and triticale fields. The noted values were usually higher under the CR system than those under the CC system, although the differences were only a tendency in nature. Previous studies usually indicate the lack of effect of a crop sequence on the nutrient content in the soil (Cuvardic et al. 2004, Blecharczyk et al. 2005*b*, Haruna, Nkongolo 2020). According to Blecharczyk et al. (2005b), the type of fertilisation is a factor that has a stronger effect on the macronutrient content than the cropping system.

Soil pH

The CC system, as compared to the CR system, promoted the acidification of soil only in the oats fields (Table 6). In other cereals, the cropping system had no effect on the pH of the soil. The results of the studies conducted to date are not clear in this regard. The literature provides both information on the lack of differences in the soil pH between the crop cultivation

Table 6

The pH and properties of the sorption complex

Species	Cropping system	pH 1 M KCl	Hh	S	T	V (%)
			mmol(+) kg^{-1}			
Oats	CR	6.1*a*	17.2*b*	35.0*a*	52.2*b*	67.0
	CC	5.9*b*	23.0*a*	33.3*b*	56.3*a*	59.1
Rye	CR	5.7*a*	18.2*b*	33.3*a*	51.5*b*	64.7
	CC	5.5*a*	25.6*a*	29.5*b*	55.1*a*	53.3
Triticale	CR	5.2*a*	26.0*a*	29.0*a*	55.0*a*	52.7
	CC	5.2*a*	26.4*a*	28.2*a*	54.6*a*	51.6

Hh – hydrolytic acidity, S – the sum of alkaline cations, T – sorption capacity, V – the index of sorption complex saturation with alkalis, *a*, *b* – homogeneous groups (for a species, the values marked with the same letter do not differ significantly at $p \leq 0.05$)

under the CR and the CC systems (Blecharczyk et al. 2005*b*, Haruna, Nkongolo 2019) and reports on an increase in the pH under the CR system with a large share of cereals (Cuvardic et al. 2004).

The treatments that have a significant effect on maintaining the soil pH include liming (Blecharczyk et al. 2005*b*, Nazarkiewicz, Kaniuczak 2012*a*) and fertilisation with manure (Blecharczyk et al. 2005*b*, Mazur et al. 2015, Menšík et al. 2018). Having taken into account the doses and dates of the application of fertilisers in the present study, it appears that the noted significant difference between the soil pH values after oats under the CR and CC systems may be primarily related to the number of years after the application of FYM by the time of conducting an assessment of the chemical properties of the soil. This period under the CR system was two years after the application of FYM at a dose of 30 t ha^{-1}, while under the CC system, it was three years and 15 t ha^{-1}, respectively. The reduction in the pH value after harvesting winter rye and winter triticale in the 4^{th} and 6^{th} year of the CR is probably due to the diminishing effect of FYM. It is difficult, however, to explain the low soil pH in the winter triticale field under the CC system in comparison to oats and winter rye fields, given that under the CC system, the same dose of manure was applied under each cereal species at the same time. The results indicate the need to monitor the soil pH, which will allow timely measures to be taken to prevent the acidification of soil.

Sorption properties of soil

The properties of the soil, such as the pH and macronutrient content, reflect the hydrolytic acidity (Hh) and the sum of alkaline cations (S), respectively. The values of the Hh index, obtained in the present study, show that the cultivation of oats and winter rye under the CC system, in relation to the CR system, promoted the saturation of the soil with acid cations, and the increase in the sorption capacity of soils (Table 6). At the same time, the S index was lower under the CR system than that under the CC system. On the other hand, the V index under the CR system was higher than that under CC system because of the lower H^+ concentration. A similar effect in the cultivation of rye was noted by Stępień and Kobiałka (2019). In the present study, in triticale the cropping system had no effect on the sorption properties of the soil. The results from the present study confirm the previous observations that a lower pH of the soil is associated with high hydrolytic acidity and the poor saturation of the sorption complex with bases (Kabała et al. 2013), in particular with Ca^{2+} cations (Mazur et al. 2015). There are reports on both the lack of effect (Neugschwandtner et al. 2020) and the significant effect of the cropping system on the sorption capacity of the soil (Degu et al. 2019). What is important in this regard is the selection of crops and their sequence. Šimanský and Tobiašová (2010) report that the soil under spring barley cultivated after sugar beet exhibited a greater sorption capacity than the soil under winter triticale cultivated after maize. Kwiatkowski and Harasim (2020) demonstrated a greater sorption capacity of the soil after potato and faba bean than after the cultivation of wheat and spring barley. On the other hand, Woźniak (2019) noted no differentiation of this characteristic in peas and durum wheat fields under the CC system.

In the present study, regardless of the cereal species and the cropping system, the share of alkaline cations in the overall sorption capacity of the soil (T) can be put in the following order: $Ca^{2+} > K^+ > Mg^{2+} > Na^+$ (Figure 2). Similar relations were presented by Mazur et al. (2015). Studies by other authors show that the Ca^{2+} cation has the greatest share in the sorption complex, followed by Mg^{2+}. The results from the present study indicate the need to supplement the alkaline cation levels in the soil, in particular with Ca^{2+} and Mg^{2+}.

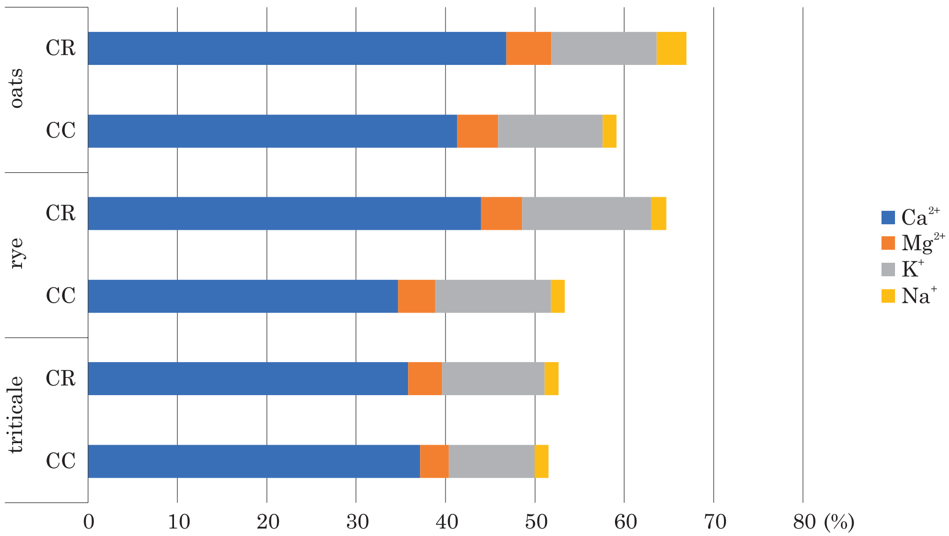

Fig. 2. The share of alkaline cations in the sorption capacity of soils (%)

Available micronutrients

The cropping system had no effect on the contents of boron (B), manganese (Mn), copper (Cu), zinc (Zn) or iron (Fe) in the soil after harvesting oats, rye and triticale (Table 7). Haruna and Nkongolo (2020) presented results

Table 7

Micronutrient content in the soil

Species	Cropping system	B	Mn	Cu	Zn	Fe
		available forms (mg kg^{-1} d.m.)				
Oats	CR	0.21*	210	2.7	11.7	2000
	CC	0.21	202	2.7	10.9	1810
Rye	CR	0.21	180	2.6	15.4	1700
	CC	0.18	178	2.2	10.1	1800
Triticale	CR	0.14	196	1.3	6.3	1630
	CC	0.18	178	1.3	6.4	1660

* no letters – insignificant differences

corresponding to the current results for maize and soybean. There are also results, however, on changes in the micronutrient content in the soil under the influence of crop sequence. Kwiatkowski and Harasim (2020) demonstrated greater accumulation of micronutrients in soil after potato and faba bean than after cereals. Woźniak and Kawecka-Radomska (2016) did not note any effects of the cropping system on the Cu content, but found an increase in the Zn content in the soil under continuous winter wheat. In general, the content of micronutrients in soil undergoes significant changes under the influence of mineral-organic fertilization, especially liming (Jaskulska et al. 2014).

CONCLUSIONS

In general, the chemical properties of soils in agroecosystems change under the influence of agrotechnical practices. In this study, the SOC soil content in oats fields under the CR and CC system was similar. The SOC soil content in rye fields was lower and in triticale fields higher under the CR system than under the CC system. The cropping system usually did not differentiate the content of macronutrients (N, P, and Mg) or micronutrients (B, Mn, Cu, Zn, and Fe) in the soil. The CR system promoted the accumulation of K in the soil, while the CC of oats and winter rye reduced the pH and increased the sorption capacity of soils. Studies have shown that the continuous cropping system usually does not cause deterioration of soil chemical properties if manure and mineral fertilisers are applied systematically. Further research is recommended to compare the effects of different cereal species in continuous cropping on soil properties. The study results, particularly for the SOC content and the pH of the soil, indicate the need to monitor the soil properties regardless of the cropping system. Such measures are essential in the protection of soils against the loss of organic matter and acidification.

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