Abstract. The research was carried out in 2006/2007–2008/2009, using the experiment started in 2005 on Bezek experimental farm, the property of University of Life Sciences in Lublin. The experimental field was set on a medium-heavy mixed rendzina. The aim of the research was to estimate the impact of different tillage systems and different catch crops in spring wheat monoculture on the levels of Zn, Cu, Mn, Fe on topsoil.

Two-factor field experiment was established with split-plot method in four replications. The first factor included plough tillage (A) and two variants of conservation tillage with autumn (B) and spring disking (C) of catch crops. The second factor covered four methods of field reclamation in spring wheat monoculture in the form of undersown crops (red clover, westerwold ryegrass) and stubble catch crops (lacy phacelia, white mustard). Fields without catch crops were the control treatments.

Plough soil tillage system increased the level of Cu, Mn, and Fe in arable soil in comparison with both methods of conservation tillage. The content of zinc was significantly lower on conservation tillage treatments with autumn catch crop incorporation than on the treatments with plough soil tillage, and with conservation tillage involving spring catch crops disking. The highest level of zinc was found on the treatments with red clover seeding, a copper and iron – on the treatments with red clover and lacy phacelia, and manganese – in the control plots.

In spring, the levels of copper, manganese and iron in the soil were significantly higher than in autumn. As for zinc, its level in spring was significantly lower than in autumn. The levels of copper and iron in soil were significantly increasing, and the content of zinc – decreasing with every consecutive year. The content of micronutrients in the soils of 0–20 cm deep did not exceed their natural level, characteristic of this type of soils.

key words: tillage systems, catch crops, micronutrients

INTRODUCTION

The level of elements in the soil is highly shaped by the richness of mother rock, soil-forming processes, eolian processes, granulometric composition, and the method of soil utilization (Dudka, 1992; Kabata-Pendias, 1993, 2004). Yields of cultivated crops are determined by nutrient richness of soil (Gembarzewski, 2000). Another important feature of crops for feed and consumption use is the content of microelements (Czuba, 2000).

Conservation methods of soil tillage increase the content of soil organic matter, which positively influences physical, chemical and biological properties of the soil (Håkansson, 1994; Rasmussen, 1999; Zimny, 1999; Holland, 2004; Wróbel and Nowak-Winiarska, 2007; Weber 2010). Catch crops can have a conditioning effect in specialized cereal rotations. They can also improve the soil balance of organic matter and nutrients, including microelements (Loginow, 1985; Parylak, 1998; Parylak at al., 2002; Palys at al., 2009).

CzeKała and Jakubus (2000), as well as Strączyńska and Strączyński (2000) stated that the level of copper, zinc and manganese were higher in the soils with the highest level of organic carbon. The research by Strączyński and Wróbel (2000) showed that the content of soluble forms of Cu, Mn, Mo, Zn increased with the increase of soil silt and clay fraction. Kucharczewski and Dębowski (2000) stated that soils in Poland contain a medium content of copper, zinc, manganese and iron. They also attribute negative microelements balance in soils to the decrease in organic fertilization.

The aim of the research was an evaluation of the impact of plough tillage and two conservation tillage methods and different catch crops in spring wheat monoculture on the content of selected microelements in the topsoil.

MATERIALS AND METHODS

The research was carried out in 2006/2007–2008/2009, using the experiment started in 2005 on Bezek experi-
mental farm (N: 51°19', E: 23°25'), the property of the University of Life Sciences in Lublin. The experimental field was set on medium-heavy mixed rendzina, developed from chalk bedrock that had granulometric composition of a medium silty loam. That soil had an alkaline reaction (pH 7.35), high content of P (117.8 mg kg\(^{-1}\)) and K (242.4 mg kg\(^{-1}\)) and very low of magnesium (19 mg kg\(^{-1}\)), the content of organic carbon was 24.7 g kg\(^{-1}\). The soil belonged to IIb valuation class and to defective wheat complex.

The layout of a static, two-factor field experiment, established with split-plot method in four replications. The first factor included plough tillage (A) and two variants of conservation tillage with autumn (B) and spring disking (C) of catch crops. The second factor covered four methods of field reclamation in spring wheat monoculture in the form of catch crops: undersown crops (red clover, west-erwold ryegrass) and stubble catch crops (lacy phacelia, white mustard). Fields without catch crops were the control treatments. Harvested field area was 30 m\(^2\). Winter wheat, produced on this field for three years, was a preceding crop for the spring wheat. In 2005, treating as a pre-initial year, all crops were sown, and tillage systems were used in accordance with the methodology.

Plough tillage, as a part of seedbed preparation for spring wheat, was started with skimming and harrowing after preceding crop harvest. Medium-deep ploughing was performed before winter. Harrowing was done in spring, cultivating with harrowing – before sowing. At that time phosphorus and potassium fertilizers were delivered, as well as the first dosage of nitrogen fertilizers 60 kg N ha\(^{-1}\) in ammonium nitrate form. Phosphorus fertilizers at a rate of 30.5 kg ha\(^{-1}\) P in triple superphosphate form, and potassium at a rate of 74.7 kg ha\(^{-1}\) K in the 60% potash salt form, were applied in spring. Second nitrogen dose, at a rate of 40 kg ha\(^{-1}\) was applied at shooting (30-33 development phases BBCH). Spring wheat cv. ‘Zebra’ was sown at the number of 5 millions of seeds per ha in rows 10 cm apart. The seed was treated with Panocit 350 SL (350 g l\(^{-1}\) of guazatine in an acetate form) seed dressing. The red clover of ‘Dajana’ variety – 20 kg ha\(^{-1}\) and westerdowlolium multiflorum of ‘Moweste’ variety – 20 kg ha\(^{-1}\) were sown on the same date as spring wheat. Lacy phacelia of ‘Stala’ variety – 20 kg ha\(^{-1}\) and white mustard of ‘Borowska’ variety 20 kg ha\(^{-1}\) were sown after spring wheat harvest and post-harvest tillage.

On the treatments with conservation tillage (B and C) after preceding crop harvest on the plots without red clover and westerdowlolium multiflorum grubbing and harrowing were performed (18–20 cm deep). Next, lacy phacelia and white mustard were sown, analogous with plough tillage variants. Catch crops were disked before winter (B) or they were left as mulch for winter, and disk harrowed in spring (C). On the treatments with autumn catch crops disked (B), spring soil tillage was the same as in ploughed ones. On the plots with another variants of conservation tillage (C), the field was harrowed after being disked, and then harrowed again before spring wheat sowing.

The programme for spring wheat field protection included: Chwastox Extra 300 SL 3.5 l ha\(^{-1}\) (300 g l\(^{-1}\) MCPA) – 23-29 BBCH, Alert 375 SC 1 l ha\(^{-1}\) (125 g l\(^{-1}\) of flusilazole and 250 g l\(^{-1}\) of carbendazim) – 26-29 BBCH.

The soil samples for analysis were first taken in the autumn of 2006 and the spring of 2007 (the subsequent dates of taking samples are autumn 2007 and spring 2008 as well as autumn 2008 and spring 2009). Samples were taken in spring from a depth of 0–20 cm, before field works, and in late autumn before ploughing on plough tillage plots, and disking in conservation tillage variant with autumn catch crop incorporation. At the same time were soil samples taken on treatment where catch crops spring disking.

From each plot, soil samples were taken with the use of Egner’s sampling stick in five randomly chosen places. Next, the samples collected in that way from four plots, constituting replications in the experimental model, were combined into one collective sample. In a cumulative samples from combinations of three repetitions Cu (PN-92R-04017), Zn (PN-92/R-04016), Mn (PN-93/R-04019), Fe (PN-R-04021:1994) were determined with ASA method. The results were statistically processed using the analysis of variance. Mean values were tested for the least significant differences based on Tukey’s test (P = 0.05).

RESULTS

In the soil with conservation tillage with autumn catch crop disking, the level of zinc and manganese was significantly lower than in the soils with plough tillage and the soil with conservation method combined with spring catch crop disking (Tables 1 and 2). The level of manganese in an arable layer of plough tillage treatments was significantly higher than on conservation tillage treatments with catch crops preserved for winter (Table 2). The level of copper and iron were the highest in the soil taken from plough tillage treatments, significantly lower on mulch-free conservation tillage treatments, and the lowest on the conservation tillage variant with spring catch crop incorporation (Tables 2 and 4).

The level of Zn in soil was the highest on the treatments with red clover seeding, significantly lower on the plots with catch crop of lacy phacelia and white mustard, and the lowest – on the treatments with westerdowlolium multiflorum and on the control treatment (Table 1). The level of copper was the highest in the soil under lacy phacelia, significantly lower on red clover, control, and undersown with westerdowlolium multiflorum treatments, and the lowest on white mustard treatments (Table 3). The level of manganese was the highest in the soil taken from the control plots, significantly lower on the plots with stubble catch crops of white mustard and lacy phacelia, lower from the westerdowlolium multiflorum treatments, and the lowest on red clover treatments (Fig.
Table 1. Content of Zn [mg kg\(^{-1}\)] in topsoil (mean in the years of study).

<table>
<thead>
<tr>
<th>Experimental factors</th>
<th>Tillage systems(^a)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Catch crops</strong></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Control</td>
<td>23.09</td>
<td>20.79</td>
</tr>
<tr>
<td>Red clover</td>
<td>22.66</td>
<td>20.79</td>
</tr>
<tr>
<td>Westerwold ryegrass</td>
<td>23.12</td>
<td>20.79</td>
</tr>
<tr>
<td>Lacy phacelia</td>
<td>23.12</td>
<td>20.79</td>
</tr>
<tr>
<td>White mustard</td>
<td>23.12</td>
<td>20.79</td>
</tr>
</tbody>
</table>

### LSD(0.05)
- tillage systems 0.041
- catch crops 0.061
- sampling date 0.028
- years 0.041
- tillage systems x catch crops 0.132
- tillage systems x sampling date 0.070
- tillage systems x years 0.093

\(^a\) A – Plough tillage  
B – Conservation tillage with autumn catch crops disking  
C – Conservation tillage with spring catch crops disking

Table 2. Content of Mn [mg kg\(^{-1}\)] in topsoil (mean in the years of study).

<table>
<thead>
<tr>
<th>Experimental factors</th>
<th>Tillage systems(^a)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Catch crops</strong></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Control</td>
<td>197.15</td>
<td>202.66</td>
</tr>
<tr>
<td>Red clover</td>
<td>200.62</td>
<td>187.41</td>
</tr>
<tr>
<td>Westerwold ryegrass</td>
<td>197.51</td>
<td>188.34</td>
</tr>
<tr>
<td>Lacy phacelia</td>
<td>199.54</td>
<td>190.82</td>
</tr>
<tr>
<td>White mustard</td>
<td>200.58</td>
<td>189.51</td>
</tr>
</tbody>
</table>

### LSD(0.05)
- tillage systems 0.265
- catch crops 0.399
- sampling date 0.181
- years 0.265
- tillage systems x catch crops 0.859
- tillage systems x sampling date 0.456
- tillage systems x years 0.609

\(^a\) for explanations see Table 1

3). The level of Fe was the highest on the treatments with lacy phacelia, significantly lower on plots undersown with red clover, on control treatments, on stubble catch crop treatments with white mustard, and the lowest in variant with westerdew ryegrass (Table 4).

In spring, the levels of copper, manganese and iron were significantly higher than in autumn. But the level of zinc was significantly lower than in autumn (Tables 1, 2, 3, 4).

In plough tillage system on red clover treatments the levels of Zn, Cu and Fe in the soil were significantly higher than on other catch crop treatments and the control treatment (Tables 1, 3, 4). At the same time, the level of copper and iron on plough tillage fields on all catch crop treatments were higher than on all variants of conservation tillage (Tables 3, 4). Similar dependence for zinc and manganese was recorded on the red clover and white mustard treatments, and for manganese – additionally on lacy phacelia plots (Tables 1, 2).

In the soil of conservation tillage treatments with autumn disk harrowing of catch crops, the highest level of zinc was recorded on the lacy phacelia and white mustard plots. On conservation tillage treatments with spring catch crop incorporation, the highest level of zinc was recorded on lacy phacelia plots (Table 1). On catch crop treatments, the highest levels of copper and iron in a conservation variant with autumn disking were found in the soil under red clover, whereas in another conservation variant, in the treatments with lacy phacelia (Tables 3, 4). In both conser-
The levels of Cu and Mn in the soils with all tillage systems was higher in autumn than in spring. Similar dependence for Fe was found in both conservation tillage treatments with spring disking of catch crops, the level of zinc in the soil 0–20 cm deep was slightly higher than on plough tillage treatments, and by 11.2% higher than on conservation tillage treatments with autumn catch crop incorporation. Blecharczyk at al. (2007) observed the increase in Zn level in the soil 0–5 cm deep on ploughless cultivation treatments and direct sowing in comparison with plough tillage. In the layer 10–20 cm deep, this dependency was reversed. The introduction of red clover undersowing into the monoculture of spring wheat resulted in the increase of zinc by 4.5% in comparison with lacy phacelia treatments, by 6.5% with white mustard, by 12.5% with westerdow ryegrass, and by 12.9% with the control plots without catch crop but with voluntary spring wheat seedling.

In plough tillage treatments, the level of manganese in the soil was by 1.2% to 3.8% higher than in conservation tillage treatments. Similarly, Blecharczyk at al. (2007) recorded the decrease in Mn level in the soil layer of 10–20 cm deep of ploughless tillage treatments with direct sowing in comparison with plough tillage treatments, whilst in the layer of 0–5 cm, only in direct sowing treatments. In non-catch crop control treatment, the level of Mn in the soil was higher by 2.2% to 3.4% than in spring wheat monocultures with undersown catch crops or stubble catch crops.

On plough tillage treatments, the level of copper was by 57.3% to 124%, and iron – by 28.2% to 128% as high as in non-plough tillage soil. Also Blecharczyk at al. (2007) observed that the level of copper in upper layer of soil was by 19.4% higher in plough tillage in comparison with a ploughless one, whilst the level of iron did not change significantly in different tillage systems. Wróbel and Nowak-Winiarska (2007) recorded a higher level of copper, manganese, iron and zinc in 0–10 cm layer of non-plough cultivated soil in comparison with plough cultivation, whilst in the layer of 10–20 cm deep, the level of these elements was lower in reduced tillage and no-tillage in comparison to conventional one. In other studies, Wróbel at al. (2007) confirmed this dependency for 0–5 cm soil layer in comparison to 20–25 cm layer.

In plough tillage treatments, the levels of copper and iron in all plots with catch crop, of zinc in red clover and white mustard plots, and of manganese additionally in lacy phacelia treatments, by 6.5% with white mustard, by 12.5% with westerdow ryegrass, and by 12.9% with the control plots without catch crop but with voluntary spring wheat seedling.

In conservation tillage variant with spring disking of catch crops, the level of zinc in the soil 0–20 cm deep was slightly higher than on plough tillage treatments, and by 11.2% higher than on conservation tillage treatments with autumn catch crop incorporation. Blecharczyk at al. (2007) observed the increase in Zn level in the soil 0–5 cm deep on ploughless cultivation treatments and direct sowing in comparison with plough tillage. In the layer 10–20 cm deep, this dependency was reversed. The introduction of red clover undersowing into the monoculture of spring wheat resulted in the increase of zinc by 4.5% in comparison with lacy phacelia treatments, by 6.5% with white mustard, by 12.5% with westerdow ryegrass, and by 12.9% with the control plots without catch crop but with voluntary spring wheat seedling.

In conservation tillage variant with spring disking of catch crops, the level of zinc in the soil 0–20 cm deep was

<table>
<thead>
<tr>
<th>Experimental factors</th>
<th>Tillage systems ¹</th>
<th>Średnio Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catch crops</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Control</td>
<td>218.00</td>
<td>210.06</td>
</tr>
<tr>
<td>Red clover</td>
<td>271.56</td>
<td>208.72</td>
</tr>
<tr>
<td>Westerdow ryegrass</td>
<td>235.28</td>
<td>153.72</td>
</tr>
<tr>
<td>Lacy phacelia</td>
<td>241.28</td>
<td>204.56</td>
</tr>
<tr>
<td>White mustard</td>
<td>229.50</td>
<td>155.78</td>
</tr>
</tbody>
</table>

Sampling date
- Autumn 2006–2008: 244.37, 179.67, 89.53, 171.19

<table>
<thead>
<tr>
<th>Years</th>
<th>LSD(0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006/2007</td>
<td>162.83, 73.03, 154.49</td>
</tr>
<tr>
<td>2007/2008</td>
<td>184.10, 105.97, 175.94</td>
</tr>
<tr>
<td>2008/2009</td>
<td>212.77, 134.77, 199.84</td>
</tr>
</tbody>
</table>

Mean: 186.57, 104.59

¹ for explanations see Table 1
of positive influence of catch crop biomass – the source of micronutrients. Andrzejewska (1999), as well as Kuś and Jończyk (2000) emphasize the special role of catch crops due to their multilateral impact on biological and physico-chemical soil properties.

CONCLUSIONS

1. In the cultivation of spring wheat grown in monoculture, plough tillage system fostered the occurrence of higher level of copper, manganese and iron in surface layer of soil (0–20 cm) in comparison with conservation tillage.

2. The levels of iron and copper in soil surface layer were higher when catch crops were disk harrowed in autumn, whereas zinc and manganese – when this procedure was done in spring.

3. All the catch crops decreased the level of manganese in the soil, but increased the level of zinc. The level of copper in the soil decreased in the treatments where white mustard was grown as a catch crop, and the level of iron – on the treatments with westerwold ryegrass.

4. The highest level of zinc was recorded in the soils where red clover was grown, and copper and iron – where lacy phacelia and red clover were used as catch crops. The highest level of manganese was observed in non catch crop treatments.

5. The level of copper, manganese and iron in the soil was higher in spring, and zinc – in autumn.

LITERATURE


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