Original Research

Nutritive Components, Sodium and Heavy Metals in Soils from Onion Production (*Allium cepa* L.) in Środa Wielkopolska District

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Abstract

The main aim of studies carried out in the years 2006-2008 was the estimation of macro- and microelements as well as sodium and heavy metals (cadmium and lead) contents in soils from production cultivations of onion (*Allium cepa* L.) in Środa district (Środa Wielkopolska, Wielkopolska province). In the summer, salinity (EC) and reaction (pH) of the majority of soils were within correct ranges. In the majority of cultivations, standard contents of nitrogen, potassium and calcium were found in the soil but, at the same time, there was an excess of phosphorus, magnesium and sulphur. The majority of studied cultivations were characterized by correct contents of iron and managnese, but at the same time there was an extreme deficit of zinc and copper in the soils. No soil contamination with heavy metals (cadmium and lead) was found. Consideration of the chemical soil analyses in the fertilization programs can contribute to further optimization of the quantitative and qualitative yields of onion and protect the soil environment in Środa production farms.

Keywords: soil analyses, agricultural soils, production farms, Środa Wlkp. district

Introduction

An assortment of fresh vegetables in a daily diet, should include carotene, mineral salts and vitamins [1]. One of the most important vegetable species in the consumption structure is onion [2, 3]. It is estimated that most of the greatest suppliers of many vegetable species (mainly onion, carrot, cabbage) to the Poznań markets originate from the Środa district (Środa Wlkp., 30 km from Poznań). That district occupies an area of 62,328 ha, including about 46,693 ha of arable land, while the area of vegetable crops (mainly the mentioned onion, carrot and cabbage) occupies about 1,800 ha [4]. This fact places Środa district in the first place in the Poznań subregion.

Farmers seldom apply controlled soil fertilization based on cyclical chemical soil analyses. This fact, a result of excessive use of mineral fertilizers, may contribute to harmful soil salinity and, in consequence, may lead to the deterioration of plant yield and degraded biological value. Meanwhile, optimal quantitative and qualitative plant yield is obtained in the range of the so-called critical values of nutritive components in the soil [5-7]. The availability of nutritive components contained in soils can be modified by adequate mineral and organic fertilization. While maintaining the proper soil richness of nutrients, the use of controlled fertilization based on the cyclical chemical analyses recommended in "Integral Vegetable Production" is helpful [6]. It can help to prevent the chemical degradation of soils resulting from the huge quantity of fertilizers used in conventional agriculture. By water precipitation, the nutritive

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components not utilized by plants may contribute, particularly in the autumn-winter period, to the contamination of ground waters with easily washed out components such as nitrate nitrogen ($N-NO_3$), potassium (K) or chlorides (Cl). This process is especially intensified in the case of light and very light soils.

The main objective of the presented studies was the estimation of chemical parameters of soils from production cultivations of onion (*Allium cepa* L.) in Środa Wlkp. district. The following analyses were carried out: soil salinity (EC), pH values, content of macro- and microelements, sodium (treated as ballast ion) and heavy metals (cadmium and lead). The results of soil chemical analyses were compared with the critical values for onion growing [5-7]. On the basis of chemical analyses carried out in the summer season, an estimation was made of the nutrient availability in the production soil which exerts a direct effect on plant yield. Results of the studies can be regarded as source material for the instruction of plant producers. In spite of the fact that yields obtained by the farmers were satisfactory, the consideration of chemical soil analyses in the fertilization programs may contribute to further improvement of the productivity and payability of the crops by an optimization of plant nutrition and reduction of excessive fertilization. An additional advantage will be soil protection against possible contamination with excessive mineral fertilizers.

Material and Methods

Sampling the Soil

In the years 2006-08, in the area of Środa Wlkp. district (Wielkopolska province), a monitoring of soil sampled from production cultivations of onion (obtained from seeds) was carried out. The contents of macroelements: $N-NH_4$, $N-NO_3$, P, K, Ca, Mg, $S-SO_4$ and microelements: Fe, Mn, Zn, Cu, B, Cl and sodium (as ballast ion) were analyzed. In 2008 additional analyses were carried out in order to estimate any possible contaminations with heavy metals: cadmium and lead.

Samples were randomly taken from 47 production fields of onion localized in the Środa district. The monitoring of soil richness included an area of about 150 ha. Samples were taken in the following periods: winter (January-February), summer (June-July) and autumn (September-October). Each time, using Egner's sampling stick, samples were taken from the arable layer (0-20 cm), where the greatest agglomeration of plant root systems occurs. One mean sample consisted of 15-20 individual samples representing 2-3 ha of field [5, 8]. Soils from the studied onion cultivations belonged to medium good soils (class IIIa, IIIb). Because of phytosanitary reasons (risk of disease and pest transfer), a long-term crop rotation was applied, i.e. on the given plot onion was grown only in one vegetation season in a period of several years.

Analytical Methods

The collected samples were chemically analyzed by the universal method of Nowosielski [9]. Extraction of macroelements ($N-NH_4$, $N-NO_3$, P, K, Ca, Mg, $S-SO_4$), Cl, B and Na was carried out in 0.03 M CH_3COOH. After extraction, $N-NH_4$, $N-NO_3$ were determined by microdistillation according to Bremner in Starck's modification, P was colorimetrically analyzed with ammonium vanadomolibdate; K, Ca, Na – with the use of photometry; Mg – by atomic absorption spectrometry (ASA, on Carl Zeiss, Jena – apparatus); $S-SO_4$ – nephelometrically with $BaCl_2$; Cl – nephelometrically with $AgNO_3$. Microelements (Fe, Mn, Zn and Cu) and heavy metals (Cd, Pb) were extracted from soil using Lindsay's solution and then determined by ASA method. Salination was analyzed by conductometric method and electrical conductivity (EC in $mS \cdot cm^{-1}$). Reaction pH was measured potentiometrically (soil : water proportion = 1:2) [10].

Range of Nutrients

The obtained results of chemical analyses were compared with the ranges of limit values recommended for onion cultivation by different authors [5-7]. Optimal ranges of component content in the soil for onion growing are the following (in $mg \cdot dm^{-3}$): $N-NO_3$ + $N-NH_4$ 50.0-130.0, P 60.0-80.0, K 175.0-225.0, Ca 250.0-400.0, Mg 60.0-120.0, $S-SO_4$ 20.0-40.0, Na<50.0, Cl<50.0, pH in H_2O 6.0-6.5 [5]. The methodics of "Integrated Onion Production" [6] presents similar ranges (in $mg \cdot dm^{-3}$): $N-NO_3$ + $N-NH_4$ 90.0-100.0, P 60.0-70.0, K 160.0-190.0, Ca 1000.0-1500.0, Mg 50.0-60.0, pH in H_2O 6.5-7.0. There are also recommendations suggested as the optimal ones (in $mg \cdot dm^{-3}$): $N-NO_3$ + $N-NH_4$ 120.0-160.0, P 60.0-80.0, K 175.0-250.0, Mg 55.0-75.0, pH in H_2O 6.5-7.8 [7].

Results and Discussion

Results of chemical soil analyses on the content of macroelements pH and EC are presented in Table 1, while microelements, sodium and heavy metals (cadmium and lead) are shown in Table 2. Structures of component contents in the analyzed soils, depending on the vegetation season, are presented in Figs. 1-3.

Macroelement Contents

Development and yield of plants are directly influenced by the content of components in the soil in the summer period. On the basis of chemical analyses of soil samples taken in that period from crop production, the soil richness was estimated.

Table 1. Content of macroelements in the soils (in mg·dm^{-3}), pH and EC, depending on the season (mean values from 3 years).

Content	$N\text{-}NH_4$	$N\text{-}NO_3$	P	K	Ca	Mg	$S\text{-}SO_4$	pH (H_2O)	EC [mS·cm^{-1}]
Winter									
Minimum	4.0	0.0	30.0	51.9	315.6	20.0	0.1	6.50	0.1
Maximum	58.0	2.1	158.0	231.5	4,230.2	194.1	98.0	8.10	0.4
Mean	13.6	0.2	86.5	132.0	1,416.0	75.8	26.2	-	0.18
SD	13.9	0.3	30.9	42.3	887.5	41.6	26.9	-	0.07
Summer									
Minimum	7.0	110.0	69.0	181.0	390.0	117.2	104.0	5.34	1.11
Maximum	21.0	162.0	109.0	247.2	1,890.7	140.3	207.4	7.01	1.30
Mean	13.2	126.0	94.8	217.8	1,056.3	123.4	155.2	-	1.24
SD	4.2	8.9	14.4	26.4	479.6	8.50	32.8	-	0.05
Autumn									
Minimum	0.35	35.0	5.25	13.8	48.9	5.0	2.05	5.54	0.01
Maximum	77.0	133.0	331.9	174.0	1,165.4	528.3	250.2	9.81	2.10
Mean	30.6	57.2	97.1	99.7	473.1	148.2	74.6	-	0.55
SD	18.0	20.4	75.7	46.2	318.8	122.4	76.8	-	0.52

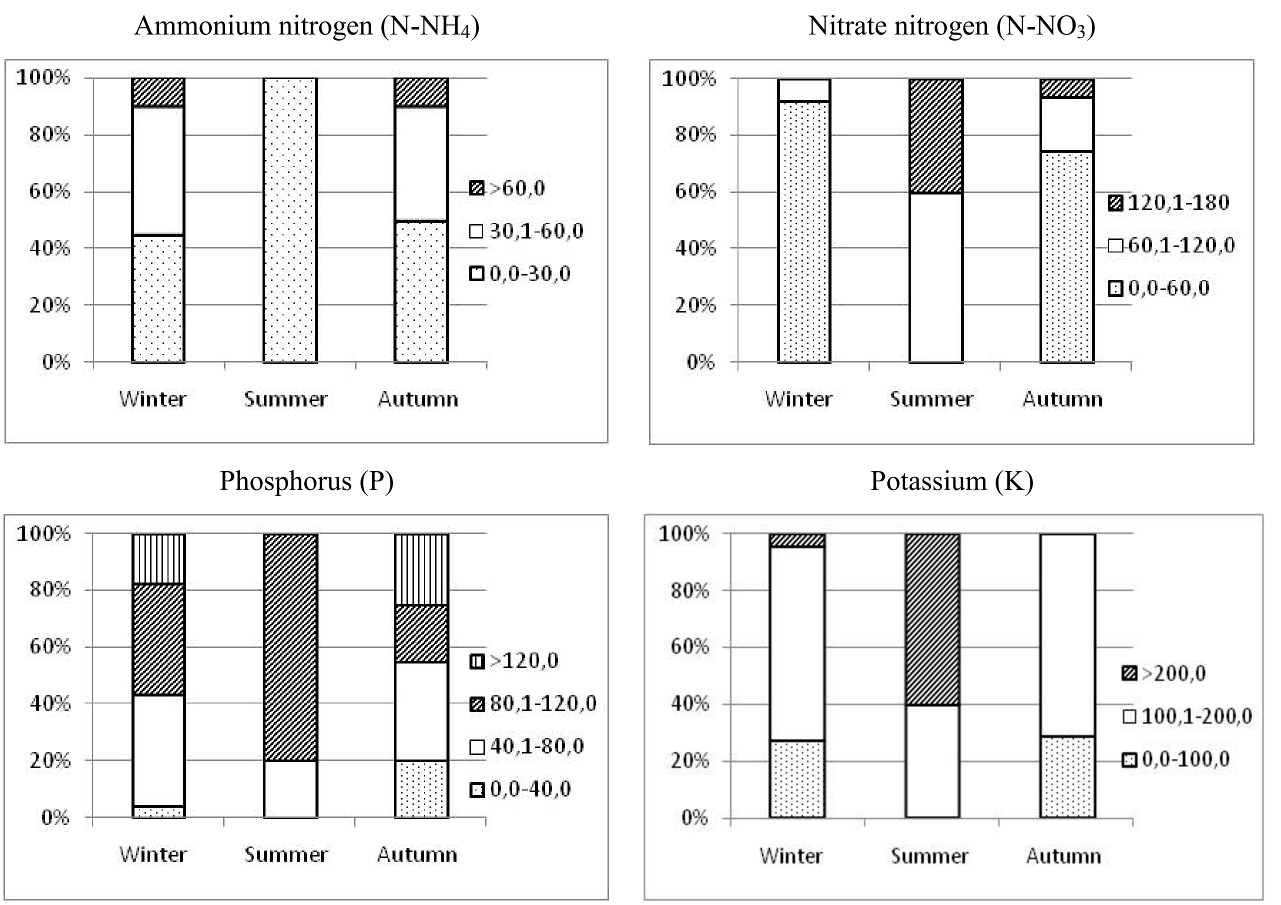

Fig. 1. Structure of ammonium nitrogen ($N\text{-}NH_4$), nitrate nitrogen ($N\text{-}NO_3$), phosphorus (P) and potassium (K) contents (in mg·dm^{-3}) in soils from production cultivations (mean values from 3 years).

The contents of ammonium nitrogen in the studied soils in different vegetation periods were differentiated (Table 1, Fig. 1). The greatest amount of ammonium was found in the autumn period (on the average 30.6 mg $N\text{-}NH_4 \cdot dm^{-3}$), while the least amount was shown in summer (13.2 mg $N\text{-}NH_4 \cdot dm^{-3}$). In the period of plant growth, the contents of the ammonium form, in the case of all analyzed soils, was within the range below 30.0 mg $N\text{-}NH_4 \cdot dm^{-3}$.

Differentiation of nitrate nitrogen was typical of the soils used for horticultural purposes. The greatest amount of nitrates was determined in the summer period (directly after fertilization with this component), while the least amount of nitrate nitrogen was found in winter (on the average 0.2 $mg \cdot N\text{-}NO_3 \cdot dm^{-3}$) (Table 1, Fig. 1). In the presented monitoring studies, in 40% of soils analyzed in summer, an excess (reaching 50%) of nitrogen content was found. Excessive content of nitrates in soil can exert a negative effect on onion quality; it can decrease, among other things, their storage quality.

Mean phosphorus content determined in the studied vegetation periods was similar (from 86.5 mg $P \cdot dm^{-3}$ in winter to 97.1 mg $P \cdot dm^{-3}$ in autumn). In summer period, a standard or increased content of phosphorus was found (Table 1, Fig. 1). In winter period, 4.5% of soils and 20% of soils analyzed in autumn showed a phosphorus deficit. In the case of 80% of soils examined in summer, an excessive phosphorus content was found which, although without any toxic effect, could cause some difficulties in the uptake of other components, e.g. zinc.

In the summer the content of potassium in the majority of the studied soils was within the standard range (Table 1, Fig. 1). In winter and in autumn the content of potassium was not sufficient, showing 28.6 and 27.3%, respectively.

Distinct differences were found in calcium content in the soil (Table 1, Fig. 2). The greatest amount of this component was determined in winter (1,416.0 mg $Ca \cdot dm^{-3}$), while the least amount was found in autumn directly after harvest (473.1 mg $Ca \cdot dm^{-3}$). In the summer period, 60% of the analyzed soils were characterized by correct content, while in 20% of cases an excess of this component was found. Excessive content of calcium, a result of ion antagonism, can ruin the uptake of other components, including potassium, magnesium and the majority of microelements [11]. 20% of summer soils and 60% of soils in autumn required calcium. The decrease of calcium content – and thereby an acidification of soils in autumn – could be the result of the removal of this component together with the yield, but it also could result in the consequence of its leaching out in the form of calcium carbonate into the deeper soil levels [5, 11].

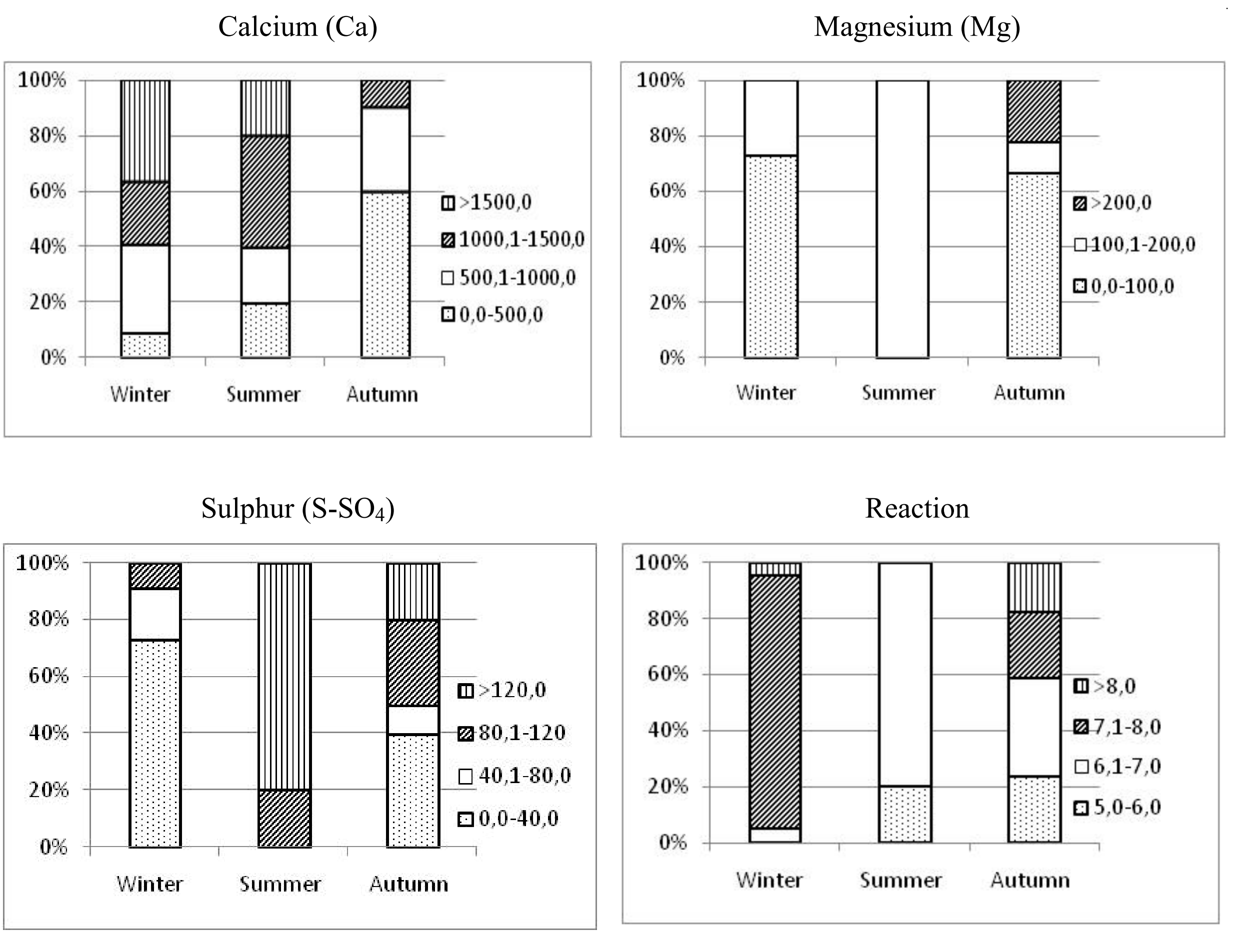

Fig. 2. Structure of calcium (Ca), magnesium (Mg), sulphur ($S\text{-}SO_4$) contents (in $mg \cdot dm^{-3}$) and reaction of the soils from production cultivations (mean values from 3 years).

Table 2. Contents of microelements, sodium and heavy metals in soils (in mg·dm^{-3}) depending on the season (mean values from 3 years).

Content	Fe	Mn	Zn	Cu	Cl	Na	Cd*	Pb*
Winter								
Minimum	12.4	0.8	1.41	0.13	9.0	6.0	0.12	1.90
Maximum	117.0	9.3	10.33	1.01	130.0	213.1	0.16	4.40
Mean	53.1	3.4	3.98	0.49	50.3	70.5	0.14	3.31
SD	28.7	2.0	1.80	0.31	34.3	43.5	0.01	0.24
Summer								
Minimum	48.7	5.8	2.84	0.84	19.2	40.0	0.10	2.01
Maximum	76.1	24.9	5.53	1.37	81.4	270.6	0.15	4.22
Mean	62.9	14.7	3.65	1.10	54.4	130.7	0.13	3.20
SD	9.6	7.0	0.72	0.23	21.4	53.4	0.01	0.28
Autumn								
Minimum	64.9	12.0	1.77	0.72	21.4	0.0	0.11	1.97
Maximum	142.1	34.6	5.22	2.10	275.2	433.9	0.15	4.43
Mean	96.2	21.5	3.12	1.17	51.9	94.7	0.13	3.28
SD	18.2	6.2	0.86	0.28	25.8	87.2	0.01	0.25

* Results in the year 2008.

Similarly, as in case of calcium, a differentiation of soil richness was found in reference to magnesium (Table 1, Fig. 2). The least amount of this component was determined in winter (on the average 75.8 mg Mg·dm^{-3}) and the greatest amount was identified in autumn (148.2 mg Mg·dm^{-3}). The determined contents of magnesium in the summer period exceeded the limit values (>120 mg Mg·dm^{-3}).

Depending on the vegetation season, there was a differentiation of sulphur ($S\text{-}SO_4$) content in soils (Table 1, Fig. 2). The least amount of this component was found in winter (on average 26.2 mg $S\text{-}SO_4$·dm^{-3}), while the greatest amount was found in summer (155.2 mg $S\text{-}SO_4$·dm^{-3}). In summer, the content of sulphur distinctly exceeded the standards. This excess could increase the contents of alliins (cysteine sulphoxide) in plants, which improves their value for the pharmaceutical industry [12] and increases the content of dry matter [13]. Onion belongs to the group of sulphur-loving plants [14]. Excess of sulphate sulphur ($S\text{-}SO_4$) in soil could follow from its introduction into the soil in mineral fertilizers as an ion accompanying nitrogen [$(NH_4(SO_4)_2$], potassium [K_2SO_4] or magnesium [$MgSO_4$]. Actually, it is estimated that the majority of soils in Poland have an insufficient amount of sulphur. This is caused, among other things, by a decrease of rainfalls, the use of fuels (and fuel oils) with a decreased sulphur content, or sulphur-less fuels. A deficit of sulphur in soil constitutes a factor that can significantly decrease the yield and quality of plants [15, 16].

Reaction, Salinity

A differentiation was found in soil reaction (Table 1, Fig. 2). In summer, in 80% of the analyzed soils, the soil reaction was correct (pH = 6.1-7.0). With a slightly acid reaction, the assimilability both of macro- and microelements is optimal. Twenty percent of soils analyzed in summer required liming (pH was below 6.0). In winter and autumn season, 4.5% and 17% of soils, respectively, showed an alcalic reaction (pH>8.0). Salinity in the majority of soils (78.7%) was within the admissible range. Low salinity is favourable because salt excess in soil may deteriorate the growth and development of plants.

Chlorides, Sodium and Heavy Metals Content

Determined values of chlorides (as microelements) and of sodium (treated as ballast ion) were also, in the majority of soils, in the ranges below 60 mg·dm^{-3}. Contents of heavy metals (cadmium, lead) were in the admissible ranges [17, 18].

Microelement Contents

A differentiation was found in the content of iron in production cultivations (Table 2, Fig. 3). The greatest amount of this component was found in autumn (on average 96.2 mg Fe·dm^{-3}) and the lowest content was in winter

(53.1 mg Fe·dm^{-3}). In 20% of soils analyzed in summer, Fe contents were insignificantly below the standard requirements [7].

The greatest amounts of manganese were determined in the soils in autumn (on the average, 21.5 mg Mn·dm^{-3}). In the summer period the content of this component was correct in all soils (Table 2, Fig. 3).

The majority of the studied soils were characterized by an insufficient content of zinc (Table 2, Fig. 3). This component, in the case of onion, increases the content of dry matter and improves its after-harvest storage life [19].

All analyzed soils were characterized by insufficient copper content (Table 2, Fig. 3). The least amount of this component was contained in soils in winter (0.49 mg Cu·dm^{-3}) and the greatest amount was shown in autumn (1.17 mg Cu·dm^{-3}).

Onion belongs to the species with particularly high nutritional requirements in reference to copper and manganese [7]. The recommended ranges of microelements in soils are the following (in mg·dm^{-3}): Fe 5-100, Mn 5-25, Zn 5-50, Cu 3-10, Mo 0.1-2.0, B 0.5-2.0. In our own studies carried out in production cultivations, an insufficient content of copper was found in all studied soils, and in the majority of soils there was an extreme lack of zinc. The deficit of these microelements may have a negative influence on the development and yield of onion, including affecting the proper development of onion bulb scale and storage quality.

Taking into consideration the summer period in which vegetation and plant development were taking place, it was found that the majority of the analyzed soils contained the standard amounts of nitrogen, potassium and calcium, but at the same time, there was an excess of phosphorus, magnesium and sulphur. Furthermore, the majority of soils in the production cultivations were characterized by a standard content of iron and manganese with an extreme deficit of zinc and copper. Salinity and reaction of the majority of soils was correct. The studied soils from the production cultivations were not contaminated with cadmium or lead.

In the opinion of the producers, the yield of the studied cultivations, in each of the study years, visibly exceeded the mean value for the whole country (above 20 ton·ha^{-1}). The consideration of the presented results in the fertilization programs – particularly in reference to microelements – may contribute to further improvement in the quantitative and qualitative yield of the production systems in Środa district, and help to prevent chemical degradation of soils as a result of huge quantities of fertilizers used in conventional agriculture.

Conclusions

1. In the summer the majority of the analyzed soils showed standard contents of nitrogen, potassium and calcium, but at the same time there was an excess of phosphorus, magnesium and sulphur. Salinity and reaction, in the majority of soils, was correct.

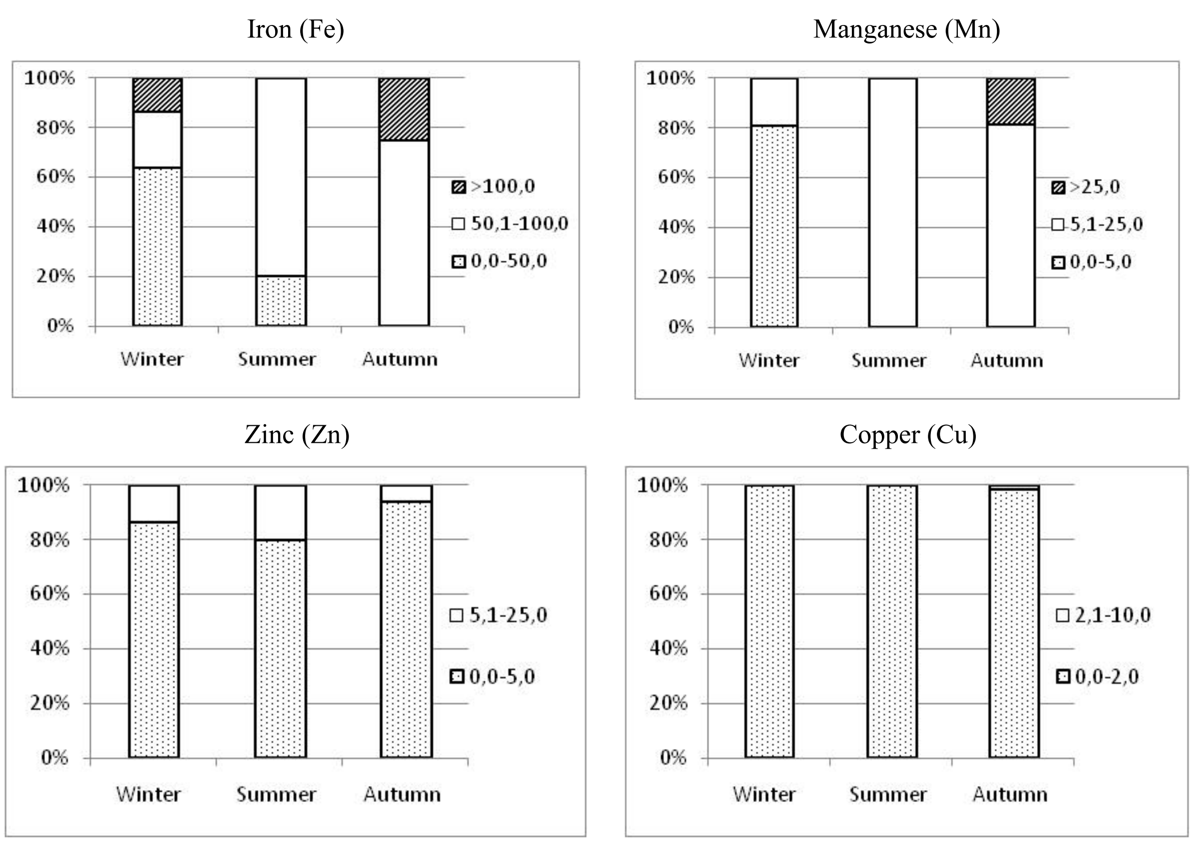

Fig. 3. Structure of iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) contents (in mg·dm^{-3}) in soils from production cultivations (mean values from 3 years).

2. The majority of soils in the production cultivations in summer were characterized by the correct content of iron and manganese but, at the same time, there was an extreme lack of zinc and copper.
3. No contaminations of the production cultivation soils with heavy metals (cadmium and lead) were found.
4. The consideration of the presented results of chemical soil analyses in the fertilization programs can contribute to a significant improvement of the qualitative and quantitative yield of the produced crops.
5. Generally when controlled fertilization based on regular chemical soil analyses has been used, no excessive contents of nutrients in soils have been observed. The controlled fertilization can prevent the chemical degradation of soils as results from huge quantities of fertilizers used in conventional agriculture.
6. Results of the studies can be regarded as source material for the instruction of plant producers. The local monitoring of soils has a practical importance in the elaboration of the strategy of agriculture development and in the organization of possible training courses for the farmers in the Środa Wlkp. district.

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