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Mineral Composition of Soil and the Wheat Grain in Intensive and Conservation Cropping Systems

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Abstract: Tillage methods and intensity can be used as means of improving macronutrient and trace element concentration in soil and crops. A two-year field experiment was conducted to examine the impact of two cropping systems—intensive (ICS) and conservation (CCS), on the macro- and microelements in the soil and their accumulation in the grain of two cultivars of winter wheat. The experiment was conducted in a randomized complete block design with three replications of each tillage treatment. The results showed that the content of available N (0.7 kg ha^{-1}) and organic matter (0.04%) slightly increased in CCS compared to ICS. The concentrations of Ca, K, and S macroelements and microelements such as Ba, Cr, Hg, and Sr in the soil were significantly higher in CCS than in ICS. Higher concentrations of macroelements K and P, microelements such as Fe, Zn, and As, and the greater value of the bioaccumulation factor for elements essential to humans such as P, Cu, Fe, and Zn, were also found in CCS compared to ICS. On the other hand, wheat cultivars grown in ICS were more efficient at accumulating macroelements and some trace elements than ones grown in CCS. While it is not without challenges, the conservation cropping system could represent an important part of the long-term strategy to sustainably improve soil fertility and the nutritional quality of the wheat grain.

Keywords: intensive cropping system; conservation cropping system; soil; organic matter; climate changes; wheat; macro-elements; micro-elements; nutritional quality; yield

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1. Introduction

Climate change is hampering national economies and affecting people's livelihood globally [1]. It significantly contributes to the fluctuation of crop production, stocks, and food prices in the global market and the potential increase in food insecurity and malnutrition [2,3]. Given the vulnerability of the food production sector, numerous studies have examined the impact of climate change on the production of major crops, such as wheat, which feeds about 35% of the world's population [4]. The assessment of the agroclimatic trends in Europe indicates the risk of extremely unfavorable conditions in the coming years, likely to result in poor economic returns and an increase in the variability of climatic suitability for crop production [5]. However, the reduction in crop yields due to climate change may be significantly higher on the local level compared to the global average. In Europe, estimates of declining wheat yields due to climate change range from 5% in France [6], over 10% in Poland [7] to 15% in Russia [6].

Wheat grain is a prominent source of various mineral elements (Cu, Zn, Fe, Ni, and Mn) that are important for both plants and humans, which could be essential, but also toxic in higher concentrations. Wheat grain also contains several toxic elements, such as As, Pb, Hg, and Cd [8]. Therefore, the focus on winter wheat production, besides availability, is shifted to the chemical composition and methods to improve it. This emphasizes the fact that human nutrition can be affected by wheat grain as an important staple food and source of essential elements. Various factors contribute to the elementary composition of wheat grain, such as climate, soil characteristics, genotype, grain ripeness, application of different agrochemicals (pesticides, fertilizers, growth regulators), irrigation, etc., [9,10].

Tillage plays an important role in managing minerals in the soil [11]. Intensive tillage has been shown to be the primary cause of accelerated mineralization and loss of organic matter, and thus loss of building blocks such ascarbon and nitrogen [12–14]. In this context, conservation agriculture has been promoted as a system capable of achieving sustainable intensification of crop production needed to meet the global food needs together with conservation and protection of land, water, and biological resources [15], which depend on the time since management change [16] but also the soil sampling methodologies themselves [17]. Depending on the mentioned specifics, a large number of studies reported different increases in the content of organic matter, and thus carbon stocks in the soil under conservation agriculture [18,19]. Changes in the content of organic matter in the soil under the conservation management system vary from −0.15 Mg ha^{-1} year^{-1} up to +0.93 Mg ha^{-1} year^{-1} [20].

The conservation land management system has the potential to influence the circulation of nitrogen, phosphorus, sulfur, and other elements related to organic matter, thus reducing the loss of minerals and increasing the efficiency of their use [21]. Earlier studies have shown that the cropping approach can significantly affect As, B, Cd, Co, Cu, Ni, and Si concentration in soil [22]. Studying the long-term changes of soil chemical characteristics in no-till, rotational tillage, and conventional tillage in maize, Sithole, and Magwaza (2019) [11] have reported higher carbon stock (27.1 t ha^{-1}), nitrogen (1.54 t ha^{-1}), phosphorus (0.0213 t ha^{-1}), and potassium (9.73 t ha^{-1}) in no-till systems, while the concentration of calcium showed no significant differences between the tillage systems. In some studies, higher concentrations of Zn, Pb [23], and Cu [24] were found in the soil under conventional tillage, while the content and availability of Cd shrank gradually with decreasing tillage intensity [25]. Other authors have reported higher concentrations of Zn, Cu, Mn, Fe, Pb, Cr, and Ni in the system of reduced tillage and no-till compared to conventional treatment [26–28], especially in the top layer of the soil, up to 10 cm deep [26].

Shaping the physical, chemical, and biological properties of the soil, tillage has a significant impact on wheat grain quality [29]. Studies of the effect of different tillage systems on durum wheat grain quality have shown that the content of potassium and magnesium [29], as well as calcium, manganese, phosphorus, and copper [30] in reduced tillage systems, is higher compared to conventional tillage. On the other hand, Yousefian et al. [31] reported significantly higher ash content in common wheat grain in conventional cultivation (2.56%) than in reduced (2.38%) and no-till (2.43%), while studies by other authors show that soil tillage systems did not affect mineral composition of the wheat grain, except for the higher content of Fe in conventional tillage [32]. Given the significant variation in the obtained test results, the impact assessment of crop management practices on the chemical composition of soil and wheat grains remains an important task in the coming period.

Scientific literature is still deficient in information regarding the impact of the growing system on the accumulation and elemental composition in the soil, as well as in the wheat grain. The introduction of new machinery, management adaptations, new varieties, and increasing pressure on soil require permanent monitoring and verification of progress in both grain yield and quality. Thus, the aim of this research was (1) to study the effects of different cropping systems on the concentration of the essential and potentially toxic elements in soil, (2) to determine the impact of cropping systems and specific cultivars on the differences in the concentration of the essential and potentially toxic elements in the wheat grain, (3) to calculate bioaccumulation factors in order to determine the effect of different cropping systems on the mineralogical profile of modern wheat cultivars.

2. Materials and Methods

2.1. Study Site

The field experiment was conducted at the research field "Radmilovac", Faculty of Agriculture (44°45′ N, 20°35′ E Serbia, 130 m a.m.s.l.) (Figure 1). The research is part of a multi-year trial on different wheat production systems, which has been going on since 1990. This paper discusses the results from two years (2015/2016−2016/2017). The soil type on the site is a luvicchernozem. According to the soil texture, the study site belongs to the silty clay loam soil. The share of physical silt in analyzed profiles varies from 50.76% (in ICS) to 61.68% (in CCS), and the share of physical clay (dust + clay) was 38.32−49.24%, ensuring good water permeability and development of the plants' root system.

Figure 1. The location of the study area (44°45′ N, 20°35′ E Serbia, 130 m a.m.s.l) at different scales.

The meteorological conditions during the two years showed certain deviations from the multi-year average (Figure 2). The multi-year average precipitation in this area is 527.3 mm, and the mean annual temperature is 10.3 °C.

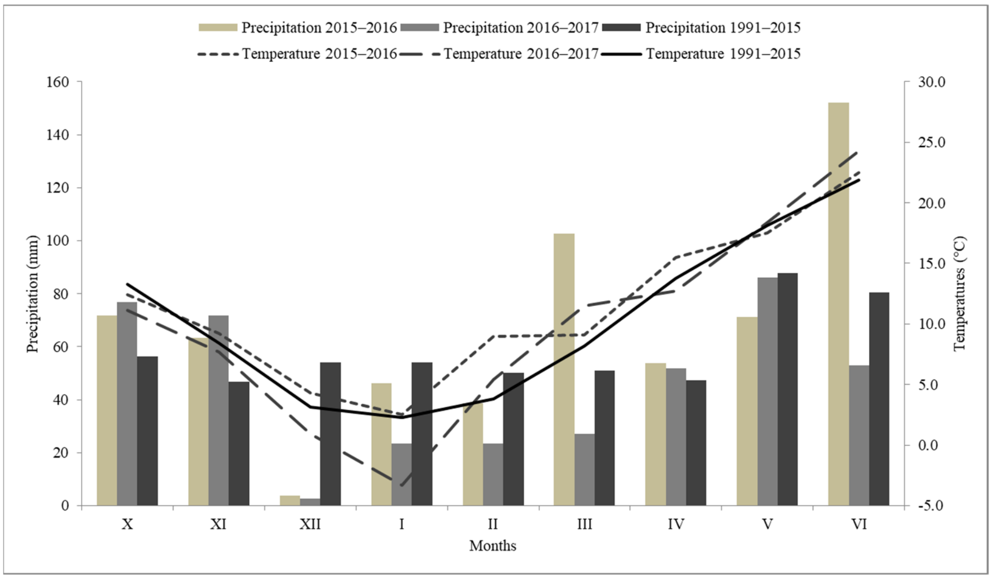


Figure 2. Average monthly mean air temperature (°C) and precipitation sum (mm) over a long-term period and during the examination.

The season 2015–2016 had higher annual sum precipitation (603.8 mm) and higher average air temperature (11.3 °C) compared to the long-term average. Extremely high levels of precipitation were recorded in March (102.6 mm) and June (152.2 mm), but also an extremely low level in December (3.8 mm). Higher monthly average temperatures in 2015–2016 were registered in December, February, and April by 1.2 °C, 5.2 °C, and 1.8 °C, respectively, compared to the long-term average.

On the other hand, the amount of precipitation during 2016–2017 was lower than the long-term average (416.0 mm), especially in December (2.6 mm), January (23.4 mm), February (23.5 mm), and March (27.0 mm). Moreover, the average air temperature (9.9 °C) was lower than the long-term average. The lower monthly average temperatures were recorded in October (11.1 °C), December (0.9 °C), January (−3.3 °C), and April (12.7 °C), while the average temperature in March (11.5 °C) was higher compared to the long-term average.

2.2. Experimental Design

An experiment including two cropping systems and two winter wheat cultivars is laid as a randomized complete block design with three replications of each cropping treatment, while the sub-plots encompassed wheat cultivars. The elementary plot was 6 m^2. The crop rotation was identical for both cropping systems and included four crops (winter wheat → spring barley + red clover → red clover→ maize).

The intensive cropping system (ICS) included ploughing using a mouldboard plough at 30 cm and pre-sowing soil preparation using a disc harrow and a harrow, basic fertilization in autumn with 600 kg ha^{-1} NPK (15:15:15) and top dressing in spring with high N dose (120 kg ha^{-1} N). Weed control was performed usingthe preparation Maton (2,4D) during tillering and stem elongation (25–30 in the BBCH scale) in the amount of 1.0 l ha^{-1}.

In the conservation cropping system (CCS), as an low-input strategy, tillage was performed using a chisel plough at 15 cm with ≥30% of maize crop residues retaining on the soil surface and the pre-sowing tillage, using a disc harrow and a harrow, basic fertilization in autumn with 600 kg ha^{-1} NPK and top dressing in spring with 60 kg ha^{-1} N. Weed control was performed usingthe preparation Maton (2,4D) during stem elongation (25–30 in the BBCH scale) in the amount of 0.5 l ha^{-1}.

Two common winter wheat cultivars "Ilina"and "Zvezdana"were used in experiment, with seeding rate of 550 seeds m^{-2}. Cv. "Ilina"is an excellent winter hardiness cultivar of medium-late maturity. Cv. "Zvezdana"is a very good winter hardiness cultivar of medium early maturity. Both cultivars are very resistant to *Erysiphegraminis* DC. and well-tolerant to *Pucciniastriiformisf*. sp. *tritici* (Pst). The used cultivars well tolerate frost and morphologically are very similar, produced in Institute of Field and Vegetable Crops (Novi Sad, Serbia).

Sowing was conducted manually, on 24 October 2015 and 28 October 2016. Wheat grain was harvested using a plot harvester, during full ripeness (89 on the BBCH scale) (1 July 2016 and 29 June 2017).

2.3. Samples Preparation and Chemical Analyses

2.3.1. Soil Sampling

Soil sampling was performed during the last week of February 2016 and 2017, on plots under wheat, prior to top dressing. Soil samples were taken from three randomly selected positions of each sub-plot at depth 0–30 cm, using a soil auger. The representative sample was made using a random square method as described by Korunović and Stojanović [33].

2.3.2. Grain Sampling

Wheat was harvested in July 2016 and June 2017 using a plot harvester, and the grain yield for different cropping treatments and wheat cultivars was measured for each plot. After yield determination, the grain samples were ground on the laboratory mill SJ-500 (producer "Metron", Novi Sad, Serbia).

2.3.3. Chemical Analysis

The soil samples were subjected to the process of "wet digestion" with an acid mixture HNO_3 + HCl (15:5) [34]. The grain samples were prepared by wet digestion, with an acid mixture HNO_3 + H_2O_2 (7:1) [34] and then analyzed using the inductively coupled plasma-optical emission spectroscopy (ICP–OES), Thermo Scientific and CAP 6500 Duo ICP (Thermo Fisher Scientific, Cambridge, UK). The macro- and micro-elements: arsenic (As), barium (Ba), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), potassium (K), magnesium (Mg), manganese (Mn), nickel (Ni), phosphorus (P), lead (Pb), sulfur (S), selenium (Se), strontium (Sr), vanadium (V), and zinc (Zn) were determined. The concentration of Cd, Pb, and Se in all samples of soil and grains were under the limit of detection (<LOD), so they were not taken into consideration for further statistical analysis. The calibration of the instrument was performed by means of two certified multielement ICO-OES standards: Multi–Element Plasma Standard Solution 4, Specpure® (Alfa Aesar GmbH & Co KG, Karlsruhe, Germany) and SS–Low Level Elements ICV Stock (10 mg L^{-1} K) (VHG Labs, Inc–Part of LGC Standards, Manchester, NH 03103 USA). The analytical procedure was verified by the certified reference material EPA Method 200.7 LPC Solution (ULTRA Scientific, Santa Clara, CA, USA), with the correlation of the measured concentrations with the certified values to 96–104%. The two-year averages values of examined soil characteristics and concentration of macro- and micro-elements for both cropping systems are given in Table 1, while two-year averages concentrations of examined macro- and micro-elements in grain for both cultivars of winter wheat are given in Table 2.

Table 1. Soil characteristics and elemental composition of the soil under ICS and CCS cropping systems.

Soil Characteristics	Intensive Cropping System	Conservation Cropping System	ANOVA		
			F	*p*	LSD(0.05)
pH in H_2O	8.03 ± 0.6	7.91 ± 0.5	0.060	0.819	-
pH in KCl	7.24 ± 0.4	7.13 ± 0.3	0.113	0.753	-
N available (kg ha^{-1})	34.30 ± 3.5	35.00 ± 3.6	0.060	0.819	-
$CaCO_3$ (%)	1.40 ± 0.01	1.52 ± 0.02	0.120	0.784	-
Organic matter (%)	3.26 ± 0.25	3.30 ± 0.26	0.038	0.854	-
Total content of macroelements in the soil (mg kg^{-1})					
	Mean ± S.D.		F	*p*	LSD (0.05)
Ca	2577 ± 52	3283 ± 52	276.50	0.000	0.009
K	2114 ± 16	2369 ± 23	248.50	0.000	0.010
Mg	3113 ± 62	3130 ± 42	0.15	0.714	-
P	640 ± 2	622 ± 2	121.50	0.000	0.021
S	224 ± 2	236.7 ± 0.8	104.28	0.001	0.024
Total content of microelements in the soil (mg kg^{-1})					
	Mean ± S.D.		F	*p*	LSD (0.05)
As	5.2 ± 0.4	5.19 ± 0.03	0.002	0.968	-
Ba	70.7 ± 0.2	74.2 ± 0.3	282.69	0.000	0.009
Co	12.89 ± 0.03	11.83 ± 0.006	8266.78	0.000	0.000
Cu	62.09 ± 0.5	17.1 ± 0.2	142,877.65	0.000	0.000
Cr	13.85 ± 0.42	16.28 ± 0.548	36.93	0.004	0.064
Fe	17,050 ± 138	16,857 ± 88	4.17	0.111	-
Hg	<LOD	0.04 ± 0.02	11.08	0.029	0.179
Mn	464 ± 6	452 ± 3	9.60	0.036	0.199
Ni	38.10 ± 0.3	28.4 ± 0.2	6901.47	0.000	0.000
Sr	12.59 ± 0.06	14.15 ± 0.06	1014.00	0.000	0.003
V	19 ± 2	21 ± 2	1.50	0.288	-
Zn	157.3 ± 2	44.8 ± 0.2	474,609.37	0.000	0.000

Table 2. Mean concentration of the macro- and microelements in the wheat grain in ICS and CCS cropping systems.

Elements	Intensive Cropping System		Average	Conservation Cropping System		Average
	"Ilina"	"Zvezdana"		"Ilina"	"Zvezdana"	
	Mean ± S.D.			Mean ± S.D.		
Concentration (mg kg^{-1}) macroelements						
Ca	160 ± 3	142.6 ± 0.8	151.3	129 ± 5	130 ± 3	129.50
K	3282 ± 45	2759 ± 40	3020.50	3158 ± 21	3163 ± 12	3160.50
Mg	1124 ± 11	948 ± 22	1036.00	988 ± 18	1075 ± 18	1031.50
P	3923 ± 9	3303 ± 12	3613.00	3636 ± 13	3889 ± 18	3762.50
S	1002.4 ± 0.8	1141 ± 5	1071.70	922 ± 5	1015 ± 4	968.50
Concentration (mg kg^{-1}) microelements						
As	<LOD	0.02 ± 0.009	0.01	0.17 ± 0.003	0.17 ± 0.003	0.17
Ba	1.30 ± 0.02	1.85 ± 0.04	1.57	1.07 ± 0.010	1.29 ± 0.02	1.18
Co	0.6 ± 0.2	0.05 ± 0.006	0.33	0.01 ± 0.002	0.02 ± 0.002	0.02
Cu	1.38 ± 0.04	6.11 ± 0.08	3.74	1.28 ± 0.06	2.52 ± 0.09	1.90
Fe	26.8 ± 0.4	20.9 ± 0.3	23.85	38.3 ± 0.6	19.7 ± 0.2	29.00
Mn	22.8 ± 0.2	18.7 ± 0.3	20.75	19.2 ± 0.5	18.82 ± 0.10	19.01
Ni	0.63 ± 0.04	0.37 ± 0.05	0.50	<LOD	<LOD	-
Sr	0.41 ± 0.004	0.43 ± 0.002	0.42	0.45 ± 0.003	0.25 ± 0.002	0.35
V	0.046 ± 0.004	1.43 ± 0.03	0.74	0.36 ± 0.004	<LOD	0.18
Zn	26.58 ± 0.10	23.02 ± 0.02	24.80	24.33 ± 0.06	27.32 ± 0.10	25.82

2.4. Bioaccumulation Factor

The parameter used for determining mobility, i.e., the degree of accumulation of elements from the soil into the plant, is called the bioaccumulation factor (BAF). It presents ratio between element concentration in grain and element concentration in soil, by calculation [35]:

$$\text{BAF} = \frac{\text{Concentration of element in plant}}{\text{Concentration of element in the soil}} \quad (1)$$

where the concentration of elements in the soil and plant was taken in mg kg^{-1}.

2.5. Statistical Analysis

The data were statistically processed using statistical package, IBM SPSS Statistics Version 25 (ANOVA, principal component analysis—PCA). The one-way analysis of variance was used to analyze the content of macro- and microelements in the soil, while the two-way analysis of variance was used to analyze the nutrient content in the grain, BAF values, and parameters of wheat grain yield. Since the variables were distributed log-normally rather than normally, the data were log-transformed before statistical analysis. Statistical significance was computed by analysis of variance (ANOVA), whereas the significance of differences between mean values for cropping systems and wheat cultivars was determined with an LSD test, $p < 0.05$. Regression analysis was performed using Microsoft Excel 10.

3. Results

3.1. Effects of Cropping Systems on Soil Elemental Composition

There was no statistically significant variability of basic soil characteristic among the studied cropping systems (Table 1). The most pronounced differences were found in the content of available N, which was higher under the CCS system compared to ICS, for 0.7 kg ha^{-1}. The conservation cropping system had a little increase on $CaCO_3$ of soil than the intensive cropping system (by 0.12%). Moreover, a slightly higher content of organic matter and a lower pH value were determined in the CCS compared to ICS (0.04%, and 0.12 units, respectively). On the other hand, the cropping system had a strong impact on the elemental profile of the soil, except for As, Fe, Mg, and V. The higher impact on the concentration of macroelements in soil was achieved under CCS. Compared to ICS, a significantly higher concentration of macroelements Ca (27.4%), K (12.1%), and S (5.7%) were determined in the CCS. The ICS resulted in significantly higher concentrations of P (2.9%) and microelements, Cu (263.1%), Zn (251.1%), Ni (34.2%), Co (14.2%), and Mn (2.7%) compared to CCS (Table 1).

3.2. Effects of Cropping Systems on Grain Elemental Composition

The concentration of macro- and microelements in the grain of the examined wheat cultivars grown in the ICS and CCS are shown in Table 2. When Cr and Hg were excluded, due to concentrations < LOD, the lowest concentrations were obtained for As (0.012 mg kg^{-1}) in ICS, while the highest values were obtained for P (3762.5 mg kg^{-1}) in CCS.

The results showed the statistically significant variability of elements concentration in the wheat grain among the studied cropping systems, except for Mg (Tables 2 and 3). ICS resulted in a higher concentration of macroelements when compared to CCS: Ca (16.8%) and S (10.7%), as well as micro-elements Ba (33.5%), Co (1670.3%), Cu (97.1%), Mn (9.1%), Ni (100.0%), Sr (21.9%), and V (306.6%) in the wheat grain. On the other hand, higher concentrations of macroelement K (4.6%) and P (4.1%), and microelements such asFe (21.6%) and Zn (4.1%) were found in the CCS wheat grain compared to ICS grain.

Table 3. Analysis of variance of the macro- and microelements concentration in the wheat grain in ICS and CCS cropping systems.

Elements	Cropping System			Cultivar			Cropping System × Cultivar		
	F	*p*	LSD (0.05)	F	*p*	LSD (0.05)	F	*p*	LSD (0.05)
Concentration (mg kg^{-1}) macroelements									
Ca	130.68	0.000	3.468	18.49	0.003	3.468	23.27	0.001	5.664
K	55.87	0.000	34.064	191.20	0.000	34.064	198.66	0.000	55.627
Mg	0.19	0.671	-	18.96	0.002	18.584	165.61	0.000	30.347
P	300.98	0.000	15.497	455.35	0.000	15.497	2604.01	0.000	25.307
S	1917.81	0.000	4.286	2414.70	0.000	4.286	93.61	0.000	6.999
Concentration (mg kg^{-1}) microelements									
As	2949.82	0.000	0.005	20.48	0.002	0.005	14.67	0.005	0.009
Ba	748.92	0.000	0.16	711.48	0.000	0.16	130.68	0.000	0.260
Co	28.61	0.001	0.05	21.52	0.002	0.05	22.99	0.001	0.082
Cu	2073.52	0.000	0.074	5427.55	0.000	0.074	1854.84	0.000	0.120
Fe	489.65	0.000	0.423	2770.38	0.000	0.423	744.41	0.000	0.691
Mn	93.16	0.000	0.328	154.39	0.000	0.328	106.45	0.000	0.535
Ni	731.71	0.000	0.034	49.46	0.000	0.034	49.46	0.000	0.055
Sr	2100.36	0.000	0.003	2945.45	0.000	0.003	4480.36	0.000	0.005
V	3987.45	0.000	0.016	3355.50	0.000	0.016	9824.06	0.000	0.026
Zn	525.31	0.000	0.018	40.61	0.000	0.018	5362.81	0.000	0.133

The concentration of elements in the wheat grain significantly varied between cultivars. The grain of the cultivar "Ilina" had a higher concentration of macroelements Ca (6.0%), K (8.7%), Mg (4.4%), and P (5.0%), as well as microelements Co (687.2%), Fe (60.3%), Mn (11.9%), Ni (70.3%), Sr (26.5%), and Zn (1.1%) compared to the cultivar "Zvezdana". On the other hand, the cultivar "Zvezdana" grain had a higher concentration of S (12.0%), followed by As (15.6%), Ba (32.5%), Cu (224.4%), and V (249.6%) relative to cultivar "Ilina".

Observing the interaction between the cropping systems and the cultivars, a significantly higher concentration of examined macroelements in the "Ilina" cultivar grain in ICS can be noted. The "Zvezdana" cultivar grain in CCS had a higher concentration of K, Mg, and P compared to ICS. Regarding microelements, significantly higher concentrations were detected in "Ilina" grain in ICS compared to CCS, excluding As, Fe, Sr, and V. Likewise, cultivar "Zvezdana", also showed significantly higher concentrations of microelements in ICS compared to CCS, except for As, Mn, and Zn.

3.3. The Element Bioaccumulation in Wheat Grain from Different Cropping Systems and Cultivars

The significant variability of BAF values was found between examined cropping systems (Tables 4 and 5). Namely, significantly higher BAF were in ICS than in the CCS: macroelementsCa (48.8%), K (7.1%), Mg (1.0%), S (16.9%), as well as microelements, Ba (40.0%), Co (680.8%), Mn (6.0%), Ni (100.0%), Sr (37.1%), and V (349.0%). Nevertheless, higher BAF values were obtained in CCS for P, Cu, Fe, and Zn compared to ICS.

Table 4. The bioaccumulation factor of the macro- and microelements in ICS and CCS cropping systems.

Elements	Intensive Cropping System		Average	Conservation Cropping System		Average
	"Ilina"	"Zvezdana"		"Ilina"	"Zvezdana"	
	Mean ± S.D.			Mean ± S.D.		
BAF for macro-elements						
Ca	0.062	0.055	0.059	0.039	0.040	0.039
K	1.552	1.305	1.429	1.333	1.335	1.334
Mg	0.361	0.305	0.333	0.316	0.343	0.329
P	6.130	5.166	5.648	5.846	6.252	6.049
S	4.475	5.094	4.784	3.895	4.288	4.092
BAF for micro-elements						
As	0.000	0.005	0.002	0.032	0.136	0.084
Ba	0.018	0.026	0.022	0.014	0.017	0.016
Co	0.047	0.004	0.025	0.004	0.002	0.003
Cu	0.002	0.010	0.006	0.075	0.147	0.111
Fe	0.002	0.001	0.001	0.002	0.001	0.002
Mn	0.049	0.04	0.045	0.042	0.042	0.042
Ni	0.002	0.001	0.001	-	-	-
Sr	0.033	0.034	0.034	0.032	0.017	0.024
V	0.002	0.076	0.039	0.017	-	0.009
Zn	0.017	0.015	0.016	0.543	0.61	0.576

Table 5. Analysis of variance of the bioaccumulation factor of the macro- and microelements in ICS and CCS cropping systems.

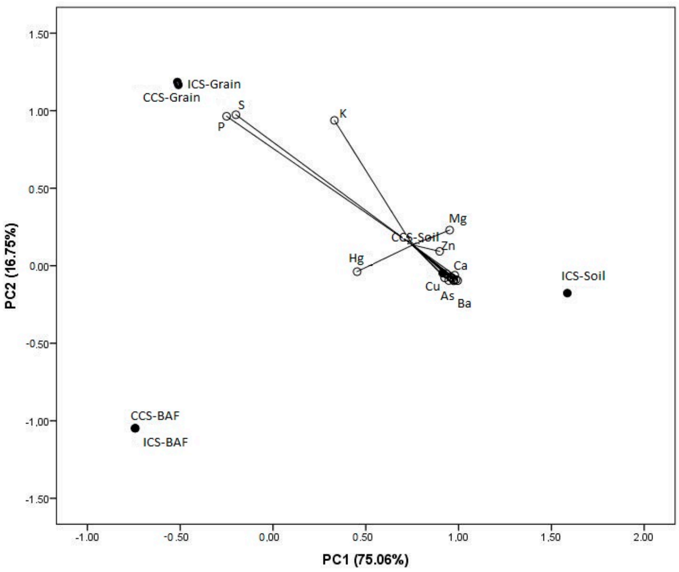
Elements	Cropping System			Cultivar			Cropping System × Cultivar		
	F	*p*	LSD (0.05)	F	*p*	LSD (0.05)	F	*p*	LSD (0.05)
BAF for macroelements									
Ca	2727.216	0.000	0.001	76.808	0.000	0.0007	91.722	0.000	0.001
K	423.186	0.000	0.010	712.433	0.000	0.0097	735.847	0.000	0.014
Mg	7.302	0.027	0.003	139.038	0.000	0.0026	1195.969	0.000	0.004
P	8129.438	0.000	0.003	3919.925	0.000	0.0093	23,718.818	0.000	0.013
S	2983.927	0.000	0.027	1589.999	0.000	0.0266	79.200	0.000	0.038
BAF for microelements									
As	2.49	0.153	-	1.09	0.326	-	0.92	0.366	-
Ba	1241.63	0.000	0.000	853.33	0.000	0.0003	182.53	0.000	0.000
Co	21.90	0.002	0.010	22.30	0.001	0.0099	17.70	0.003	0.014
Cu	1437.97	0.000	0.003	3089.08	0.000	0.0028	1.91	0.204	-
Fe	400.00	0.000	0.000	1936.00	0.000	0.0000	400.00	0.000	0.000
Mn	108.50	0.000	0.000	358.46	0.000	0.0005	245.15	0.000	0.001
Ni	736.84	0.000	0.001	48.17	0.000	0.0010	48.17	0.000	0.001
Sr	13,104.39	0.000	0.000	6311.35	0.000	0.0001	10,059.17	0.000	0.000
V	256.19	0.000	0.003	216.77	0.000	0.0035	570.95	0.000	0.006
Zn	11,799.33	0.000	0.008	44.28	0.000	0.0082	109.88	0.000	0.012

The significant variability between cultivars was also present. The cultivar "Ilina" had higher BAF values obtained for macroelements such as Ca (6.8%), K (9.3%), Mg (4.4%), and P (4.9%), and microelements Co (710.7%), Fe (60.2%), Mn (11.8%), Ni (68.8%), and Sr (24.3%) compared to the cultivar "Zvezdana". On the other hand, the cultivar "Zvezdana" had higher BAF values for S (12.1%), Cu (153.2%), V (281.5%), and Zn (7.4%) than the cultivar "Ilina".

A significant interaction of cropping systems × cultivar was present, for all elements, except As and Cu. It was determined that cultivar "Ilina" had significantly higher BAF of the examined 10 microelement in ICS than in the CCS. However, in the grain of cultivar "Zvezdana", a higher BAF was determined in CCS compared to ICS for macroelements such as K (2.3%), Mg (12.8%), and P (21.0%). Regarding microelements, significantly higher BAF of Ba, Co, Mn, Ni, and Sr were detected in ICS than in CCS for cultivar "Ilina" For the cultivar "Zvezdana", a higher BAF was determined in ICS for Ba, Co, Fe, Ni, Sr, and V. It has been observed that both cultivars have higher BAF of As, Cu, and Zn in CCS, while in the ICS, they have higher BAF of Ba, Co, Ni, and Sr.

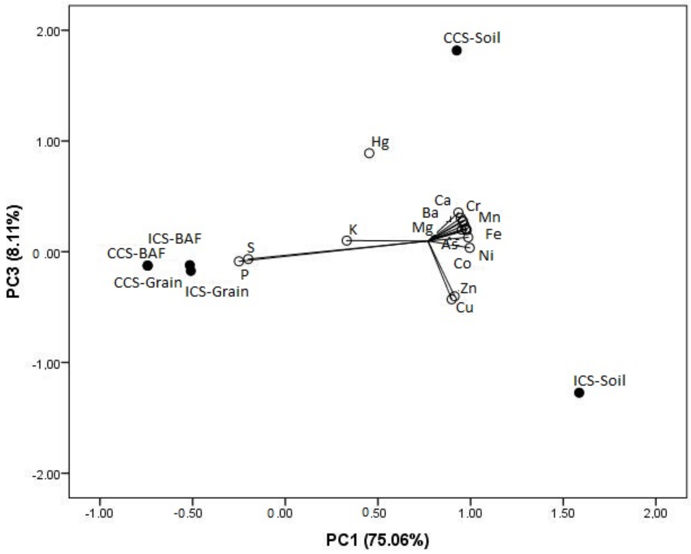
3.4. Principal Component Analysis for ICS and CCS Impact on Elemental Composition of Soil and Grain and BAF

PC analysis revealed that the 1st axis contributed 75.0% in total variability, the 2nd axis 16.7% and the 3rd axis contributed 8.1%. Among analyzed elements, As, Ba, Ca, Co, Cu, Cr, Fe, Mg, Mn, Ni, Sr, V, and Zn correlated positive and significantly with the 1st axis, while K, P, and S correlated also positive and significantly with the 2nd axis, and only Hg correlated positive with the 3rd axis. The highest variability in P and S concentration, and to a lesser variability of K concentration, was present in wheat grain grown in both systems (Figure 3), while lesser variability of BAF for all three elements: P, S, and K was noted for both cropping systems. It is important to underline that the highest variability of BAF for Hg was observable, in both cropping systems. Nevertheless, when soil was considered, PCA shown that the highest variations in the concentration of As, Co, and Fe, and to a lesser extent, of Zn and Cu, were observed in the ICS, while the highest variations in CCS were observed in the concentration of Cu, Cr, Ba, and Ca, and to a lesser extent of Hg, Zn, and Mn.



(**a**)

Figure 3. *Cont.*



(**b**)

Figure 3. Principal component analysis (PCA) (**a**) PCA for elemental composition of soil under ICS and CCS; (**b**) PCA for elemental profile of the wheat grain grown in ICS and CCS.

3.5. Productivity Parameters and Dependence between Grain Yield and BAF

The results indicate that the cropping system and genotype have a significant impact on wheat productivity (Table 6). There was a greater 1000-grain weight and grain yield in ICS (44.56 g and 7100 kg ha^{-1}, respectively) in comparison to CCS (41.17 g and 5850 kg ha^{-1}, respectively). In addition, the cultivar "Ilina" provided a considerably higher grain yield than the cultivar "Zvezdana". The regression analysis showed that BAF for all examined elements is significantly correlated with the achieved grain yield in ICS (Figure A1): Ca, Co, Fe, K, Mg, Mn, Ni, P, and Zn correlated positive, while As, Ba, Cu, S, Sr, and V correlated negative. Likewise, a significant positive correlation between grain yield and BAF was found in the CCS for Fe, Mn, Sr, and V, and a negative correlation for Ba, Cu, Mg, P, S, and Zn (Figure A2).

Table 6. Yield (kg ha^{-1}) and 1000-grain weight (g) of the examined wheat cultivars in different cropping systems.

Cropping System	Cultivar	1000-Grain Weight (g)	Yield kg ha^{-1}
Intensive cropping system	"Ilina"	41.11	7700
	"Zvezdana"	48.00	6500
	Average	44.56	7100
Conservation cropping system	"Ilina"	40.90	6300
	"Zvezdana"	41.44	5400
	Average	41.17	5850
ANOVA			
Cropping system	F	68.159	1.336
	p	0.000	0.000
	LSD (0.05)	0.863	226.826
Cultivar	F	82.355	0.171
	p	0.000	0.000
	LSD (0.05)	0.863	226.826
Cropping system × Cultivar	F	59.984	0.000
	p	0.000	0.202
	LSD (0.05)	1.221	-

4. Discussion

The conservation cropping system is recognized as an important tool that can contribute to the stability and sustainability of agricultural production under extreme climate events [20]. The key driving force of this system is the increase of organic matter content in the soil, especially in the top layers [14]. In this study, the conservation cropping system had a little increase on the organic matter of soil than the intensive cultivation system (by 1.2%). In finding the possibility of adaptation in the face of global climate change, maintaining the existing organic matter content in the soil is extremely important, and improvement, as a long-term strategy, is an additional benefit. Page et al. [20] found that in regions with favorable conditions for the production of vegetative crop biomass, conservation cultivation systems result in higher organic matter content in the surface layers of the soil. However, it should be noted that the content of plant residues and their decomposition rate significantly depend on the temperature regimen. Therefore, a scenario with increased temperature can lead to an increase in "priming effects" and stimulation of the decomposition of relatively stable organic matter [36].

Although the cropping system did not display a significant effect on soil acidity, a slightly higher pH in KCl value was determined in the ICS (7.24) compared to CCS (7.13). Our findings are consistent with those of other long-term tillage experiments on silty loam Chernozem [37] and with global meta analyses [38]. The higher organic matter content in CCS is related to the accumulation of plant residues and higher organic acid content [15]. These differences may have contributed to the higher release of hydrogen ions associated with organic anions and enhanced nitrification [39] that affected soil and grain chemical properties. Although red clover was part of crop rotation in both systems, in conditions of optimal soil moisture (due to mulch) and other favorable soil qualities, a little increase of available N was found in CCS compared to ICS (2.0%).

The availability of elements from the soil does not only depend on their concentration and mutual relationship, but also on the cropping system [40,41], which has a decisive role in managing the dynamics of nutrients and soil fertility [42]. Namely, long-term usage of a cropping system has an impact on the physical and chemical properties of the soil, which affects availability of elements [43]. The ICS is characterized by regular ploughing with soil inversion, intensive application of mineral N fertilizers, leading to greater accumulation or deficiency of some macro- and trace elements [44], which was confirmed in this study with the higher concentrations of macro- and trace elements in soil under CCS, including P (640 mg kg^{-1}), Co (12.89 mg kg^{-1}), Cu (62.09 mg kg^{-1}), Mn (464.0 mg kg^{-1}), Ni (38.1 mg kg^{-1}), and Zn (157.3 mg kg^{-1}). On the other hand, partial incorporation of residues from previous crops + low mineral N input in CCS, resulted in greater concentrations of macro- (Ca, K, Mg, S) and some microelements (Ba, Cr, Hg, Sr, V). Despite the possibility of accumulation of some toxic elements in the soil, the CCS cropping system can enhance amount of macroelements that play a key role in increasing soil fertility.

It is meaningful to emphasize that cropping systems, parallel to the changes in soil, expressed greater impact on elementary composition of wheat grain. On average, ICS resulted in greater concentrations of macroelements in the grain such as Ca, Mg, and S, as well as microelements such as Ba, Co, Cu, Mn, Ni, Sr, and V. The CCS resulted in greater average concentration of macroelements such as K and P, micro-elements as As, Fe, and Zn, but also lower concentrations of potentially toxic elements such asSr and V compared to ICS. Therefore, CCS strategy could be safe considering the accumulation of potentially toxic elements. Although Ni presence was detected in the soil under the CCS system, the concentration of this element in the grain was <LOD for both cultivars. It is also important to underline that the difference was minor between both cropping systems in the accumulation of most elements, as well as BAF, except macroelements P, K, and S, which varied to a greater extent. Studies in which the CCS contributed to the increase of organic matter content report greater reserves of P, K, and Zn in plants [15,45]. Accordingly, other studies have reported lower content of P, Fe, and Zn in plants grown under ICS [46,47].

Greater Co and Ni concentration in soil under ICS was followed by the increased concentration in wheat grain. In CCS, only K concentration in grain depended on soil concentration. Some authors point out the possibility of stratification of nutrients with low mobility in the surface layers of the soil in CCS. The stratification occurs due to the less intense mixing of the soil, which significantly depends on the volume and distribution of precipitation in the area [48]. It was also noticeable that tillage systems showed a significant impact on grain productivity. As expected, a greater dose of mineral fertilizer applied in ICS resulted in the significantly greater grain yield in comparison to CCS (7100 vs. 5850 kg ha^{-1}). The CCS could unfavorably affect the growth and development of crops due to increased pest, disease, and weed pressure, but also due to lower temperatures and soil compaction [20], which cause decreased yields [49].

BAF shows the possibility of element accumulation by plants, depending on the concentration of elements and their bioavailability in the soil [50]. BAF average values differed significantly between the cropping systems. Higher BAF values of macro- (Ca, K, Mg, S) and some microelements (Ba, Co, Mn, Ni, Sr, V) were obtained in ICS, in comparison to CCS. Whereas greater BAF for macro-elements Ca, K, Mg, and P, as well as for microminerals Co, Fe, Mn, Ni, and Sr were detected in the cultivar "Ilina". Genotype × production system interaction emphasized in the cultivar "Zvezdana" with significantly higher BAF values for Ca and S, and microelements Ba, Ni, Sr, and V in ICS, and greater BAF values for K, Mg, P, Mn, and Zn in CCS. Obtained results were supported by the findings that the interaction of the production system and genotype has a significant impact on the absorption and accumulation of specific elements in the grain [51]. Moreover, the grain yield increase in ICS was followed by the increased BAF values for Ca, K, S, but also Ba, Co, Mg, Mn, Ni, Sr, and V compared to CCS, indicating the importance of these elements for plant growth, development, and yield potential, while BAF values for some other essential elements, such as P, Fe, Cu, and Zn, correlated negatively with grain yield. Since there is a lack of studiesregarding the mechanism of absorption and accumulation of Co and V in wheat grain, this could be considered as an important result and contribution to the field, regarding how ICS and CCS affect accumulation of the mentioned elements in wheat grain. The lower levels of Zn and other essential and trace elements in the ICS grain can be the result of the "dilution effect". The low-input cropping approach (CCS) was followed by the lesser and positive dependence of grain yield and accumulation of elements, such asFe and Mn, and potentially toxic Sr and V.

Selection of the variety is one of the most significant factors for ensuring stable and high-quality yield, which is particularly important considering low input systems. Although the cultivars "Ilina" and "Zvezdana" are similar in agronomic properties, they differed significantly in terms of grain weight and grain yield, and element concentration in ICS and CCS. Grown under ICS, the cultivar "Ilina" had a significantly higher grain weight, yield, and concentration of essential elements such as Ca, K, Mg, and P, as well as microelements like Co, Fe, Mn, Ni, Sr, and Zn, in comparison to the cultivar "Zvezdana". On the other hand, the cropping system × cultivar interaction shows that the "Zvezdana" grain in CCS has significantly higher K, Mg, P, As, Mn, and Zn content compared to "Ilina". Thus, this cultivar could be characterized as a highly efficient variety in low-input systems. The obtained results show that certain wheat cultivars are more efficient in absorbing and accumulating micro- and trace elements in grains, depending on the cultivation system.

Aside from maintaining of soil fertility through increased organic matter inputs, together with low pesticide inputs, CCS is advantageous from the point of view of nutritional quality, with high content of essential minerals like K, P, Fe, and Zn. Given the probability of temperature increase and increased risk of adverse climatic events, some authors [52] indicate that conservation practices could play an important role in increasing soil organic matter and potential mitigation of climate change.

5. Conclusions

This study indicates increasing long-term impacts of growing systems on soil fertility, i.e., organic matter content, including concentration and absorption of macro- and microelements. Changes in cultivation systems in line with the global climate change are inevitable to achievinghigh productivity of wheat grains with optimal quality. The CCS was shown to be advantageous, achieving a higher content of macroelements (Ca, K, and S) in the soil, as well as the content of essential elements (K, P, Fe, and Zn) in the wheat grain. The long-term application of mineral fertilizers in the ICS increased the pH value of soil and thus affected the concentrations and availability of essential elements (P, Cu, Mn, Zn) and potentially toxic elements (Co, Ni). This led to greater concentrations of Ca, S, as well as Ba, Co, Cu, Mn, Ni, Sr, and V in the wheat grain.

The novelty of this research was presented through an increase in ICS grain yield followed by the increased BAF values for Ca, Co, Fe, K, Mg, Mn, Ni, P, and Zn. The grain yield in CCS was lower, but a positive connection with the BAF of examined elements (mainly Fe, Mn, Sr, and V) was observed. Obtained results suggest that the sustainable systems are a meaningful basis for conserving soil fertility and represent a beneficial strategy for the production of nutritionally-dense food in the future. The inclusion of high-yield genotypes, with enhanced utilization efficiency into low-input and conservation cropping system could be the next step in developing the sustainable green agenda programs in Serbia.

Author Contributions: Conceptualization, Ž.D. and J.P.D.; methodology, Ž.D. and S.R.N.; software, S.R.N.; validation, J.P.D. and J.M.; formal analysis, J.M. and J.P.D.; investigation, Ž.D. and J.P.D.; resources, Ž.D. and J.P.D.; data curation, Ž.D.; writing—original draft preparation, S.R.N.; writing—review and editing, Ž.D., J.P.D., S.Š., V.D. and Z.J.; visualization, S.R.N.; supervision, Ž.D., J.P.D., S.Š., V.D. and Z.J.; project administration, Ž.D.; funding acquisition, Ž.D. and J.P.D. All authors have read and agreed to the published version of the manuscript.

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Appendix A

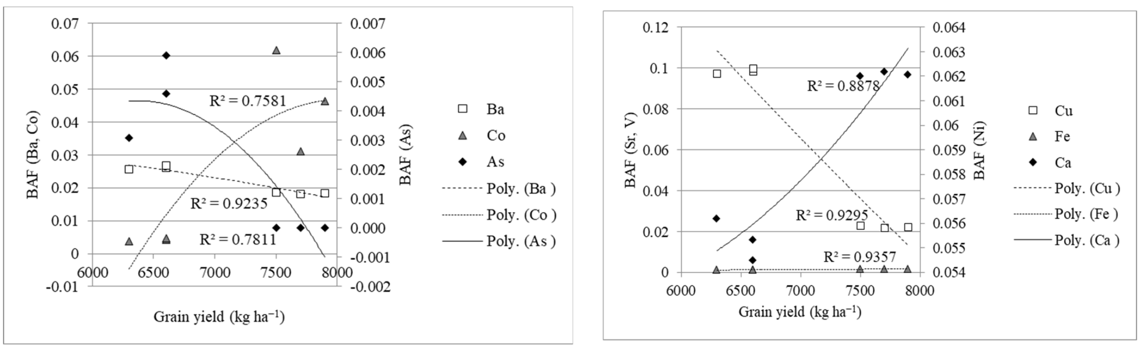

Figure A1. *Cont.*

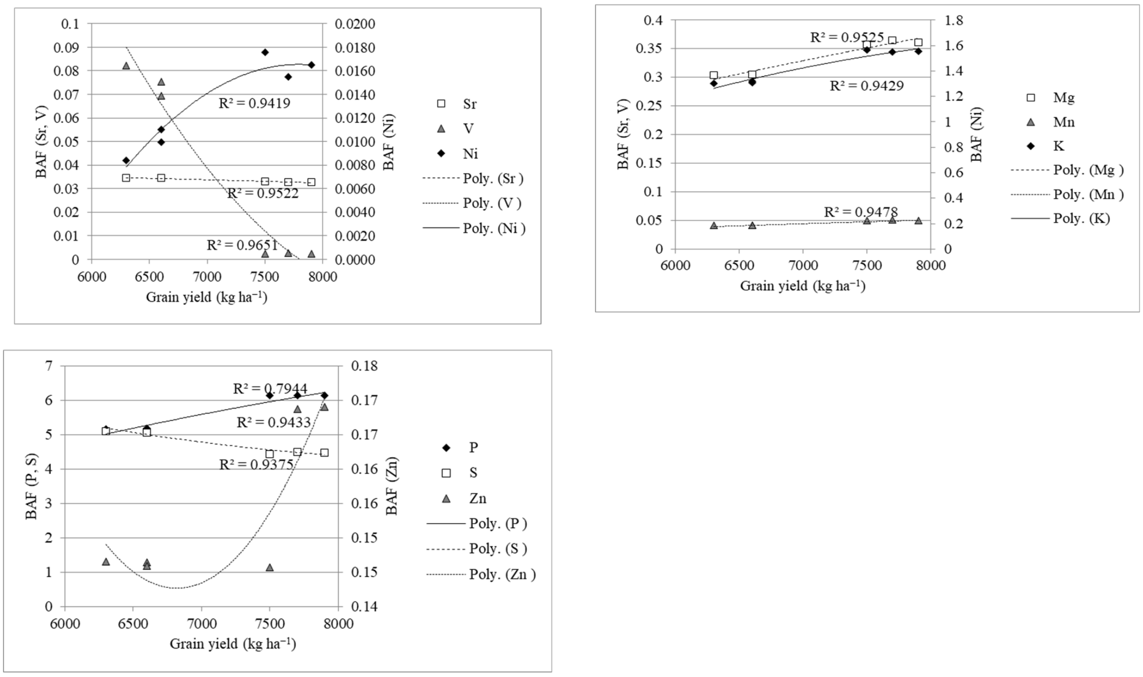

Figure A1. Interdependence (regression analysis) between grain yield and bioaccumulation factor (BAF) in wheat grain from intensive cropping system (ICS).

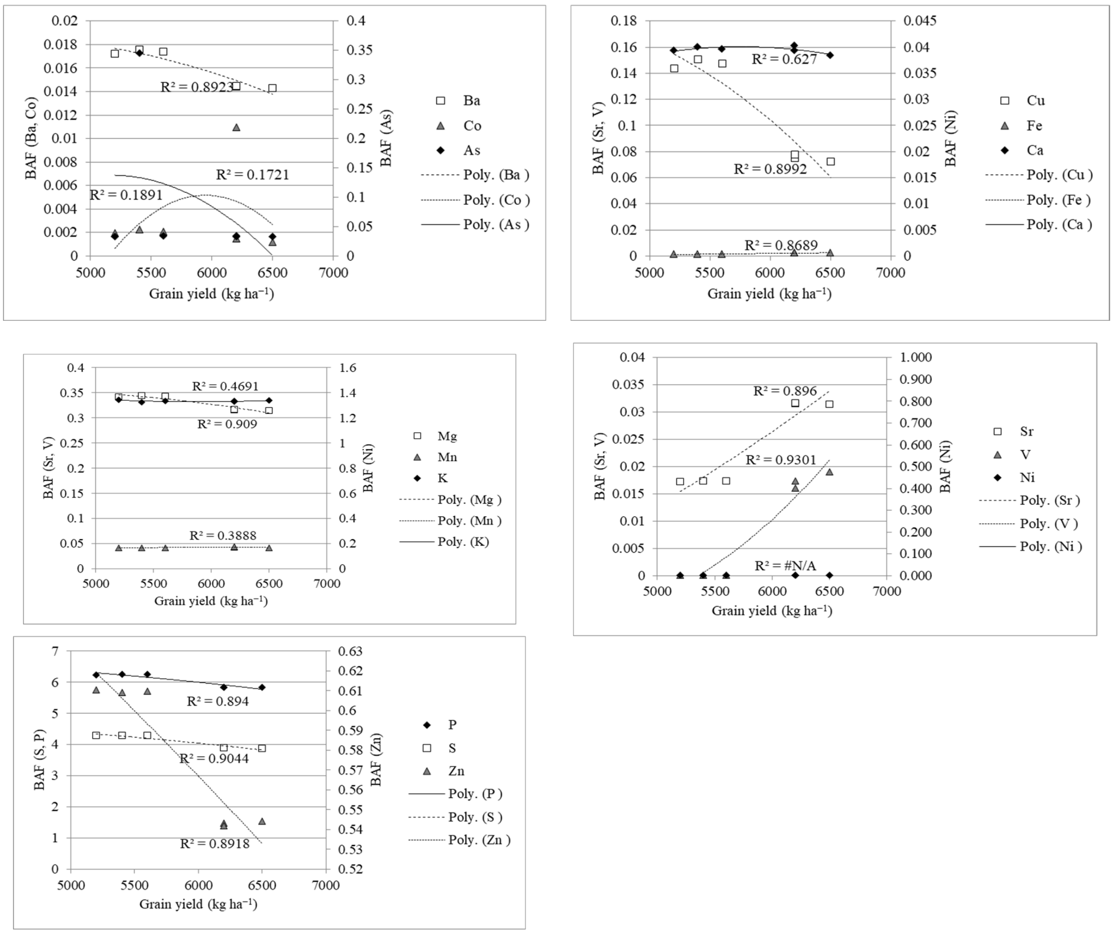

Figure A2. Interdependence (regression analysis) between grain yield and bioaccumulation factor (BAF) in wheat grain from conservation cropping system (CCS).

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