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Status of Essential Elements in Soil and Grain of Organically Produced Maize, Spelt, and Soybean

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Abstract: Organic agriculture offers many benefits through the increased nutritional quality of produced crops, agro-ecosystem preservation, and climate change mitigation. The development of an efficient nutrient management strategy in low-input systems, such as organic agriculture, which supports soil fertility and essential nutrients absorption by crops, is continually exploring. Thus, a study with maize–spelt–soybean rotation during a 5-year period in organic production was established to evaluate the variability in soil organic matter (SOM) and the status of available elements: N, P, K, Ca, Mg, Fe, Cu, Mn, Zn, and Si from the soil, as well as grain yield (GY) and the content of protein, P, K, Ca, Mg, Fe, Cu, Mn, Zn, and Si concentration in the grain of spelt, maize, and soybean. Significant variations in mineral elements in the soil, GY, and grain composition were detected. Spelt achieved the highest average GY, while soybean grain was the richest in a majority of examined nutrients. The soil Ca content was important for GY, while the protein level in grain was generally tied to the Mn level in the soil. It was recognized that soil–crop crosstalk is an important strategy for macro- and micro-nutrients management in the soil and grain of organically produced spelt, maize, and soybean. While a reduction in the GY and protein concentration in grain was present over time, it was established that a low-input system under dry-farming conditions supports nutrient availability and accumulation in grain, under semi-arid agro-ecological conditions of central Serbia.

Keywords: grain yield; mineral nutrients; organic fertilizers; protein status ingrain; soil organic matter; three crops rotation

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1. Introduction

Sustainability has become an important part of food security, particularly when agricultural production is considered. Climate change, limited resources, worldwide devastation of the agro-ecosystem, and increasing requirements for nutrient-dense food have brought about low-input agricultural systems, including tolerant genotypes, as a basis for stable yields with increased concentrations of various nutrients.

When compared with conventional systems, organic agricultural systems are low-yield but more resilient and provide nutrient-dense food without pesticide residues [1]. They include many beneficial practices, such as the application of organic and related fertilizers from renewable sources, enabling nutrient recycling and savings in fertilizers [2]. Organic agriculture implies all other natural forces and sources that support, in parallel, growing plants, as well as the agro-ecosystem as a whole. Thus, it contributes to climate change mitigation and agro-ecosystem preservation [3]. Greater resilience of organic agriculture is supported by the joint use of various practices, as well as genotypes that are highly efficient and tolerant to variable environments, pests, and low inputs, resulting in greater nutrient density in the edible parts of plants [4,5]. Therefore, organic agriculture is a low-impact system that offers products with enhanced quality, richer in vitamins and minerals [6].

Crop rotation is one of the oldest agricultural strategies aimed at controlling weeds, pests, and diseases, as well as managing nutrient availability from the soil. By introducing a greater number of crops into the rotation, agro-biodiversity was maintained, while the size and complexity of the cropping area increased, thus aggravating the appearance and spread of undesirable organisms [7]. The prolonged and real effect of rotation could be visible after several rotation cycles, increasing crop productivity parameters [8]. Rotation and crop residues from sequencing crops play an important role in nutrient management. Long-term experiments demonstrated that rotation, particularly when combined with reduced amounts of fertilizer, could improve soil pH, organic matter status, soil microbial biomass, infiltration and the soil's ability to hold water, rainfall use efficiency, as well as nutrient status over time [9–11]. It is important to underline that soybean/maize rotations, particularly when combined with tillage practices such as no-till, could have a significant impact on the level of P and K and other important nutrients in the soil [12]. Legume crops, in rotation, could play an important role in increasing the grain yield of upcoming crops, especially when mineral and/or organic fertilizers are applied after the legume harvest [13]. The application of organic fertilizers and cover crops is essential to maintain N status, including nutrient recycling, and is also able to preserve optimum levels of Zn, B, Fe, and Mn in the 0–5 cm soil layer [14], thus increasing not only yield, but also Mg, Fe, Mn, and Zn levels, as well as some antioxidants in grains [15].

It is also possible to increase the availability and efficient use of nutrients from the soil, such as P [16,17], and enable savings in fertilizer use as well as yield stability via proper rotation establishment. It was shown that maize residues, in combination with organic fertilizer, positively affects the protein content, as well as NPK content, in soybean grains [18]. Hejcmanet al. [19] accentuated that the selection of a proper preceding crop for winter wheat is very important for yield traits improvements, particularly when low-input systems were considered: Low or no N fertilization or growing on poorly fertile soils. From this viewpoint, it is of particular importance to develop an efficient strategy for nutrient management in organic agriculture to increase soil fertility and biodiversity [20].

Extremes in the variation of temperature and precipitation levels are the main sources of production uncertainty, food insecurity, and poor-quality produce. The gap between high yield and crop and agro-ecosystem sustainability is an open question. There is a lack of available literature regarding how low-input systems (considering various agro-chemicals) impact the crop yield, quality, and environment. To explore whether these systems are devastating for agricultural production and the environment from this standpoint, the aim of this study was to examine how organic, low-input systems impact soil and crop production, focusing on a maize–spelt–soybean rotation considering a 5-year period. The novelty of this research is reflected in the soil–crop crosstalk powered by crop rotation as a strategy to employ all available ecosystem services that could potentially enhance crop efficiency and grain quality.

2. Material and Methods

2.1. Plant Material

Organic production included the growing of spelt (*Triticum spelta* L.), cv "Nirvana" (Institute of Field and Vegetable Crops, Novi Sad, Serbia), maize (*Zea mays* L.) variety "Rumenka" (Maize Research Institute "Zemun Polje", Belgrade, Serbia), and soybean cv. "Galina" (Institute of Field and Vegetable Crops, Novi Sad, Serbia).

2.2. Soil Properties

The soil was slightly calcareous chernozem, with 30% silt, 17% clay, and 53% sand; the texture was silty clay loam; the pH in H_2O was 6.86 and in KCl was 7.23. The initial status of organic matter (SOM) was 2.88%, and the status of available minerals included 113.35 kg ha^{-1} N, 23.13 mg kg^{-1} P, 2275.77 mg kg^{-1} K, 5275.00 mg kg^{-1} Ca, 244.10 mg kg^{-1} Mg, 56.78 mg kg^{-1} Fe, 2.55 mg kg^{-1} Cu, 239.98 mg kg^{-1} Mn, 7.54 mg kg^{-1} Zn, and 28.58 mg kg^{-1} Si in the 0–30 cm layer.

2.3. Field Experiment

The experiment encompassed total area of 1 ha under organic production, on the Experimental Field of the Maize Research Institute at Zemun Polje, Belgrade (44°52′ N; 20°20′ E) in dry farming conditions. The environment was semi-arid, including dry and hot summers, and mild to cold winters. Meteorological data (temperature and precipitation) during the experimental trial are described in detail in Section 2.6.

2.3.1. Experimental Design

The experimental trial was established by a randomized block design in four replications, where the elementary plot encompassed 33 × 25 m, meaning that each crop species was grown across a total area of 3.300 m^2 each year (season), following the same rotation pattern: Maize–spelt–soybean. The experimental period encompassed the growing seasons of 2011–2016, whereas 2011–2013 was the conversion period that included all growing practices recommended for organic production. Organic crop production, as a low-input system, includes highly adaptable sowing material designed for this production type. Cropping practices exclude the application of synthetic agro-chemicals, while the application of fertilizers and other pesticides was based on the list recommended for organic production by the Ministry of Agriculture, Forestry, and Water Management of the Republic of Serbia. Certification is based on annual control by the Control bodies.

2.3.2. Cultivation Measures

The sowing of spelt was performed at the end of October and beginning of November each year, according to the meteorological conditions present, after soil cultivation (Table 1), using uniform no-ridge broadcasting + a cultivator, with a sowing rate of 550 seeds m^2. For maize and soybean, deep ploughing was performed at the end of October. It was followed by one pass with a disk harrow (when fertilizers were incorporated) and one with a field cultivator in spring, prior to sowing (at the end of April or the first week of May). Maize sowing was performed using a maize drill, with 70 cm of inter-row distance, enabling 65,000 seeds ha^{-1}. Soybean sowing was also performed using drilling, with an inter-row distance of 50 cm, enabling 500,000 seeds ha^{-1}. After harvesting, each year, part of the grains was used as the sowing material for the season to come. Maize fertilization included the application of organic fertilizers (according to the requirements): The incorporation of DIX 10N fertilizer (Greenco Agrobusiness, Thessaloniki, Greece; derived from feather meal and chicken dried manure; containing 72% organic matter, 42% organic C, 10% organic N, 3% P, 3% K, 7% moisture, pH = 7) (Table 1). Spelt fertilization included the incorporation of Italpollina 4:4:4 (HELLO NATURE®, former Italpollina, Verona, Italy; derived from chicken manure; containing 70.7% organic matter, 41% organic C, 4% N, 4% P, 4% K, 0.5% Mg, 0.8% Fe, 0.2% B, 5% humic acids, 12% fulvic acids, 12% moisture, pH = 7) DIX 10N ha^{-}. Weeds were removed mechanically, by cultivation and hoeing in maize and soybean, depending on weed infestation (1–2 times during vegetation; Table 1). All remaining weeds (close to the maize and soybean plants) were removed by hoeing, 1–2 days after harrowing. The weeds were not present or occurred very rarely in spelt crops, so there was no need for any measure. Since selected genotypes were highly tolerant to stressful conditions and diseases, there was no need for the application of other protective measures. The protection zone of the fennel (*Foeniculium vulgare* L.) crop sown around the whole organic area (width of 2 m) enabled pest (insects) control.

At the end of each growing season, the crops were harvested by a combine harvester, changing adapters for each crop species. Harvesting was performed at full ripening (Table 1). The whole amount of crop residue was incorporated into the soil. Grain yield (GY) was measured and calculated with 14% moisture for spelt and maize and 13% moisture for soybean.

Table 1. Calendar of main cropping practices in experiment during 2011–2016 period.

	Sowing	Fertilization	Weed Control (Harrowing)	Harvesting
Spelt	25 October2011			6 July 2012
	9 November 2012	Italpollina 4:4:4, 200 kg ha^{-1}, 16 October 2012		16 July 2013
	11 November 2013			6 July 2014
	11 November 2014	300 kg DIX 10N ha^{-1}, 29 October 2014		6 July 2015
	13 November 2015			22 July 2016
Maize	6 May 2012	200 kg ha^{-1} DIX 10N, 13 April 2012	6 June 2012	28 September 2012
	28 April 2013		1 and 11 June 2013	13 October 2013
	6 May 2014	200 kg ha^{-1} DIX 10N, 14 April 2014	7 and 17 June 2014	18 October 2014
	8 May 2015		8 and 18 June 2015	16 October 2015
	6 May 2016	200 kg ha^{-1} DIX 10N, 15 April 2016	7 and 17 June 2016	17 November 2016
Soybean	4 May 2012		7 June 2012	22 October 2012
	27 April 2013		2 and 12 June 2013	25 October 2013
	7 May 2014		8 and 18 June 2014	30 October 2014
	8 May 2015		9 and 19 June 2015	2 November 2015
	6 May 2016		8 and 18 June 2016	17 November 2016

2.4. Chemical Analysis

Besides the sampling for the initial status, performed on 24 October 2011, soil samples for analysis were taken in the spring prior to sowing maize and soybean, to estimate the impact of the previous crop rotation and the status of essential nutrients in the soil. At that moment, spelt was at the beginning of the stem elongation phase, so it was not able to express an impact on the nutrient status in the soil. Samples were taken from five spots per elementary plot (and diagonally from the end of the square), by drilling to the depths of 0–30 cm, 30–60 cm, and 60–90 cm. Samples from each depth were combined into the average sample, which was then handled, by the method of a square, to form 1 kg of the sample for analysis. Available N was determined by the method of Scharpf and Wehrmann [21], from the 0–90 cm layer (collected from all three layers separately, and then assembled and expressed as the amount of available N per ha), while soil organic matter (SOM), including the available P, K, Ca, Mg Fe, Cu, Mn, Zn, and, Si, was determined from the 0–30 cm layer. The SOM was obtained by the method of Magdoff et al. [22], available P with the method of Watanabe and Olsen [23], while extractable K, Ca, Mg Fe, Cu, Mn, Zn, and Si were obtained by inductively coupled plasma-optical emission spectrometry (ICP-OES; Spectroflame, 27.12 MHz and 2.5 kW, model P, Spectro Analytical Instruments, Kleve, Germany) after extraction with Mechlich 3 [24]).

The average sample made from grains of each crop (about 0.5 kg) was dried in a ventilation oven at 60 °C (EUinstruments, EUGE425, Novo Mesto, Slovenia) and then milled on Perten 120—Hägersten, Sweden (particle size < 500 µm). The protein content was determined using the micro Kjeldahl method, while the concentration of P, K, Ca, Mg Fe, Cu, Mn, Zn, and Si was determined after wet digestion with $HClO_4$ + HNO_3 using ICP-OES.

2.5. Statistical Analysis

The acquired data were processed by analysis of variance ANOVA (F test), with $p < 0.05$ as a significance level. Results obtained from the analysis of soil and kernels of spelt, maize, and soybean were presented as the mean ± standard deviation (SD). Correlation analysis (Pearson's coefficients) included the interdependence between grain yield and protein content in grain and elements from the soil (N, P, K, Ca, Mg, Fe, Cu, Mn, Zn, and Si); the interdependence between SOM and N in soil and P, K, Ca, Mg, Fe, Cu, Mn, Zn, and Si in grain; and the correlation between each analyzed elements (P, K, Ca, Mg, Fe, Cu, Mn, Zn, and Si) in the soil and grain. Furthermore, Principal Component Analysis (PCA) was used for the evaluation of interdependence between the concentration of analyzed elements in the soil and the grain of all three crops. Statistical analysis was performed by SPSS 15.0 (IBM Corporation, Armonk, NY, USA) with the Windows Evaluation version.

2.6. Meteorological Conditions

Meteorological conditions (Table 2) were highly variable across the experimental seasons. Average data for the spelt growing season (November–June) underscored 2013/14 as the period with the highest precipitation (476.6 mm) and average temperature (11.2 °C), with the highest precipitation quantity achieved in May (192.5 mm). It is also important to underline that the beginning of spelt growth was followed by relatively dry periods in November 2011 and December 2013, as well as drought during the grain-filling period in 2012 (June) with 24.6 °C and 14.8 mm of precipitation. A similar trend, with a high total precipitation level, was also present during the maize/soybean growing season in 2014 (709.1 mm), with the highest values achieved in May and July (192.5 mm and 187.4 mm, respectively). Nevertheless, 2012 could be considered the driest season, with 216.1 mm of precipitation and the highest average temperature, with 21.1 °C. In the same season, during the grain-filling period of maize/soybean, the highest average temperature was achieved in July and August (27.1 and 26.2 °C, respectively), followed by just 4.8 mm of precipitation in August. A similar trend was present in 2015, where July and August also had a high average temperature (26.4 and 25.7 °C, respectively) and 7.2 mm of precipitation in July.

Table 2. Mean temperature (°C) and precipitation sum (mm) at Zemun Polje during the 2011–2016 period for spelt vegetative season (XI–VI) and maize/soybean vegetative season (IV–X).

Season	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	Aver. Spelt	Aver. Maize/Soyb.
	Temperature (°C)													
2011/12	4.4	5.5	2.7	−2.5	10.1	14.4	17.9	24.6	27.1	26.2	22.1	15.4	9.6	21.1
2012/13	11.1	2	3.3	4.6	6.6	14.9	19.7	21.9	23.8	23.7	16.9	15.3	10.5	19.5
2013/14	10.1	3.2	5.3	7.8	10.8	13.7	17.4	21.1	23.2	22.6	18	14.1	11.2	18.6
2014/15	9.7	3.8	3.3	4.2	8.1	12.9	19.1	22.1	26.4	25.7	20.2	12.4	10.4	19.8
2015/16	8.1	4.3	2.6	8.9	8.8	15.3	17.6	23	24.2	22.3	19.4	11.2	11.1	19.0
	Precipitation (mm)												Sum spelt	Sum maize/soyb.
2011/12	2.7	41.9	64.3	33.5	10.7	56.2	58.5	14.8	19.8	4.8	20.7	41.3	282.6	216.1
2012/13	24.6	47.1	80.8	51.9	96.2	14.9	93.9	37.8	16	12.7	70.1	21.9	447.2	267.3
2013/14	25.4	5.2	30.7	19.9	46.9	84.8	192.5	71.2	187.4	41	75.6	56.6	476.6	709.1
2014/15	10.5	41.3	46.7	44	99.1	19.7	97.8	31.1	7.2	56	73.6	65.1	390.2	350.5
2015/16	44.1	3.3	47.8	40.5	71.1	51.9	47.4	107.4	33.6	43.2	36.6	60.3	413.5	380.4

3. Results

3.1. Variations in Chemical Composition of Soil

When the initial value of SOM and mineral nutrients in the soil were compared to the 5-year average, it was obvious that SOM was slightly increased. The greatest differences regarding the initial status of analyzed elements were present for N, P, K, Mn, and particularly for Si, with a decrease in K and Mn content and an increase in Si content in the soil. The highest impact of the growing season was present for K, Ca, Mg, Fe, Cu, Mn, Zn, and Si, particularly under spelt and prior to maize sowing (Table 3). On average, a greater K and Cu amount was observed in the soil prior to maize sowing (1695 mg kg^{-1} and 3.75 mg kg^{-1}, respectively), when soybean was a previous crop, while higher N and P contents were in the soil under spelt sowing (202.17 kg ha^{-1} and 50.53 mg kg^{-1}, respectively), i.e., maize as a previous crop, as well as greater Fe content in the soil before soybean sowing (62.12 mg kg^{-1}), i.e., spelt as a previous crop. Irrespective of the fact that slight variability in SOM was present, a slightly higher value of 4.09% was present in the spring, prior to soybean sowing, with spelt as a previous crop.

Table 3. Analysis of variance for the effect of the year (Y) on the variation of organic matter (OM), and status of available mineral elements in soil: N, P, K, Ca, Mg, Fe, Cu Mn, Zn, and Si in the soil of organically grown maize, spelt, and soybean.

	SOM	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn	Si
	%	kg ha^{-1}					mg kg^{-1}				
Initial content	2.88	113.35	23.13	2275.77	5275.00	244.10	56.78	2.55	239.98	7.54	28.58
					5 year average						
Spelt	3.99	202.17	50.53	1440.1	4644	279.80	48.08	2.89	174.9	7.12	36.75
Maize	3.86	191.32	39.62	1695.1	4870	287.87	51.86	3.75	178.8	8.40	36.35
Soyb.	4.09	108.15	18.29	1210.0	4835	302.15	62.12	2.91	195.9	8.27	35.26
					F (year)						
Spelt	0.00	0.00	0.00	169.44	643.34	799.35	359.38	40.38	3339.4	307.24	1386.5
Maize	0.00	0.00	0.00	1183.1	103.88	880.76	19.42	28.74	3015.3	117.98	80.67
Soyb.	0.00	0.00	0.00	135.25	429.63	594.09	22.15	37.31	4870.2	2038.6	861.72
					p 0.05 (year)						
Spelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maize	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soyb.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

When variability in SOM and the mineral composition of soil across seasons were considered, higher SOM was present prior to the sowing of spelt (4.50%) and maize (4.17%) in 2015, while before soybean, the highest SOM was in 2016 (4.35%) (Figure 1). A similar trend was observable in N content, under spelt and before maize sowing, having the highest value in 2016 (336.87 and 451.79 kg ha^{-1}, respectively), while prior to soybean sowing, it was 192.11 kg ha^{-1} in 2013.

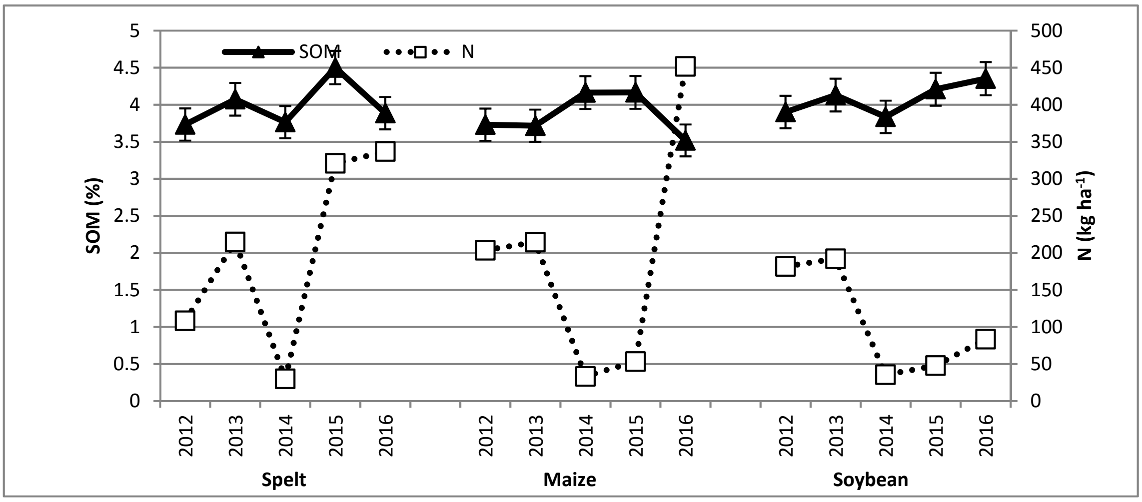

Figure 1. The status of soil organic matter (SOM) and available N in soil across seasons, under organic production (bars represent SD values).

The highest P amount in the soil was observable in 2013, 2014, and 2016 under soybean, spelt, and maize crops, with 23.13 mg kg^{-1}, 57.26 mg kg^{-1}, and 71.91 mg kg^{-1}, respectively (Figure 2), while the highest K amount was present in 2012 under all three crops, with 2018 mg kg^{-1}, 2328 mg kg^{-1}, and 1278 mg kg^{-1} for spelt, maize, and soybean, respectively. Some similar trends were observable with Ca content in the soil, having the highest values in 2013 under spelt, maize, and soybean, with 5405 mg kg^{-1}, 5275 mg kg^{-1}, and 5380 mg kg^{-1} (14.1%, 7.7%, and 10.1% higher than multi-year average, respectively), as well as with Mg content in the soil, having the highest values in 2014 under spelt, and prior to maize and soybean sowing, with 343.9 mg kg^{-1}, 340.3 mg kg^{-1}, and 348.7 mg kg^{-1} (18.6%, 15.4%, and 13.4% higher than multi-year average, respectively) (Figure 3). The greatest fluctuations and differences across seasons were present in the content of Fe, Si, and Cu (Figure 4), indicating the highest Fe values in 2012 before maize (58.6 mg kg^{-1}; 11.4% higher than multi-year average), in 2013 under spelt (60.5 mg kg^{-1}; 20.5% higher than multi-year average), and in 2014 before soybean (74.5 mg kg^{-1}; 16.6% greater than multi-year average). Nevertheless, the highest values of Si in soil were present in 2014 under spelt (53.1 mg kg^{-1}; 30.8% higher than multi-year average), and in 2015, prior to maize and soybean sowing (53.3 mg kg^{-1} and 69.9 mg kg^{-1}, respectively; 31.6% and 41.3% higher than multi-year average, respectively), while the highest value of Cu was obtained in 2016 (4.34 mg kg^{-1}, 4.87 mg kg^{-1}, and 3.34 mg kg^{-1}, for spelt, maize, and soybean, respectively; 33.5%, 23.0%, and 13.2% higher than multi-year average, respectively). Moreover, some similarities in the dynamics of Mn and Zn in the soil were present (Figure 5). Hence, in the soil under spelt, and prior to maize and soybean sowing, the highest values of Mn were detected in 2012 (240.0 mg kg^{-1}, 240.2 mg kg^{-1}, and 252.35 mg kg^{-1}, respectively; 27.1%, 25.4%, and 22.4% higher than multi-year average, respectively), while the highest values of Zn were present in 2016 (10.14 mg kg^{-1}, 12.69 mg kg^{-1}, and 12.39 mg kg^{-1}, respectively; 29.8%, 33.8%, and 33.3% higher than multi-year average, respectively).

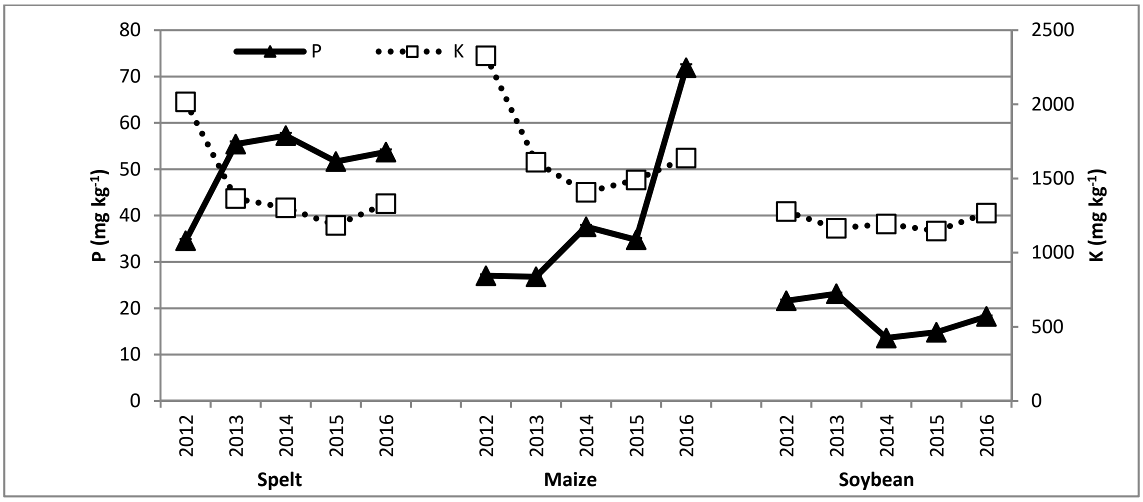

Figure 2. The status of available P and K in soil across seasons, under organic production (bars represent SD values).

3.2. Variations in the Chemical Composition of Grain of Organically Produced Spelt, Maize, and Soybean

When grain yield and its chemical composition were considered, year expressed the highest impact on GY, protein content, and concentration of P, Cu, and Mn in spelt grain, the concentration of K, Ca, Mg, and Fe in maize grain, and the concentration of Zn and Si in soybean grain (Table 4). Among all crops, the highest average value of GY and Ca concentration was present in spelt grain, while the highest concentration of protein, P, K, Mg, Cu, Mn, Zn, and Si was observed in soybean grain.

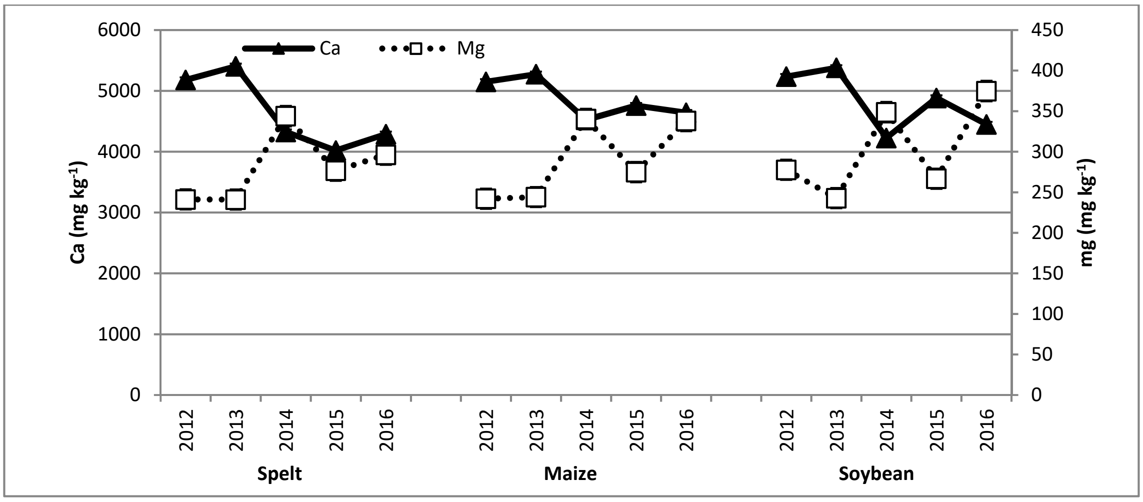

Figure 3. The status of available Ca and Mg in soil, across seasons under organic production (bars represent SD values).

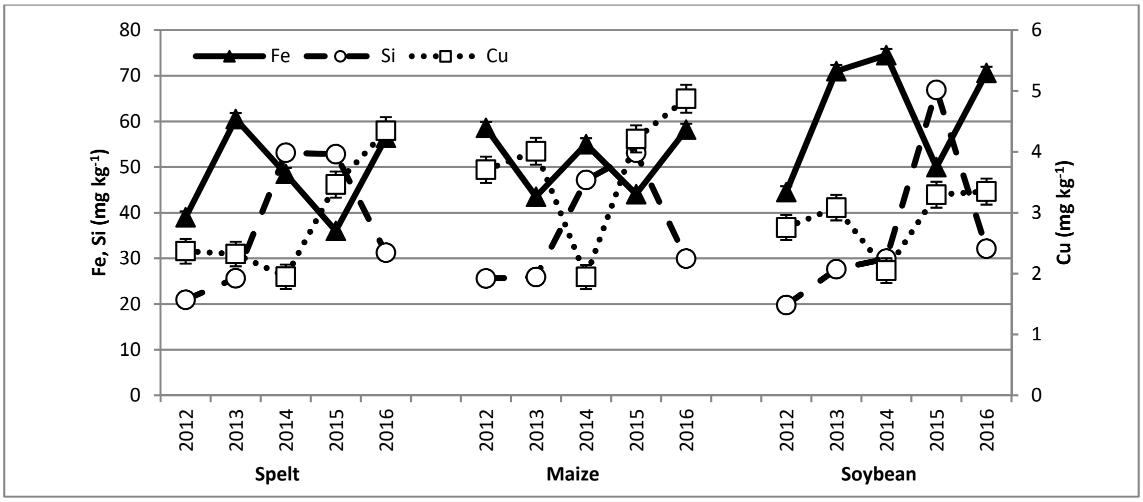

Figure 4. The status of available Fe, Si, and Cu in soil, across seasons, under organic production (bars represent SD values).

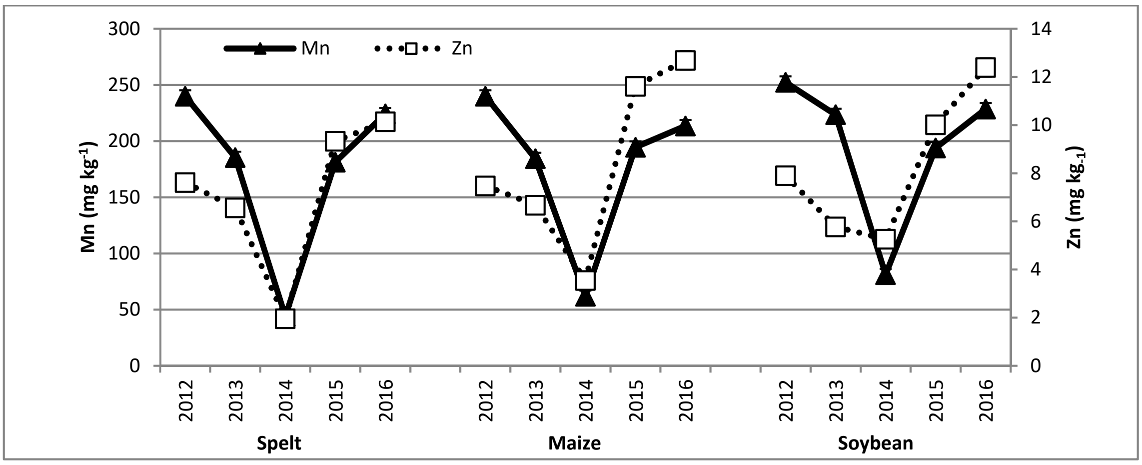

Figure 5. The status of available Mn and Zn in soil, across seasons, under organic production (bars represent SD values).

Table 4. Analysis of variance for the variation of grain yield (GY) and protein content in grain, as well as the concentration of P, K, Ca, Mg, Fe, Cu Mn, Zn, and Si in grain of organically grown maize, spelt, and soybean.

5 Year Average	GY t ha^{-1}	Prot. %	P	K	Ca	Mg	Fe mg kg^{-1}	Cu	Mn	Zn	Si
Spelt	2.29	13.03	3797.0	1178.1	2987.0	1173.5	40.19	12.48	18.81	22.06	31.56
Maize	1.89	9.49	4923.5	1199.4	105.0	1079.8	37.66	6.39	7.43	19.96	41.40
Soyb.	0.84	24.89	6889.2	2474.6	1629	1415.6	60.09	16.53	21.12	34.16	105.59
					F (year)						
Spelt	591.35	82.15	1312.6	36.59	295.70	6122.4	2422.9	39.38	8718.8	39.54	112.21
Maize	0.00	0.02	0.10	2456.9	1364.0	20,434.1	4582.6	3.39	835.06	10.55	227.28
Soyb.	14.16	17.47	66.48	14.74	22.05	105.81	32.76	30.68	61.08	223.14	300.11
					p 0.05 (year)						
Spelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maize	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soyb.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The highest grain yield of spelt was present in 2013, with 1.97 t ha^{-1} (>34.6% higher than multi-year average), while in 2014, maize and soybean achieved the highest yield, with 1.52 t ha^{-1} and 1.04 t ha^{-1}, respectively (>22.7% and 28.5% higher than multi-year average, respectively) (Figure 6). These values were followed by the lowest protein level of 7.9%, 10.7%, and 21.7%, respectively, for spelt, maize, and soybean. The highest protein content in the grains of all three crops was observed in 2012 (11.8, 18.3, and 31.1%, for spelt, maize, and soybean, respectively). The highest P concentration in the grains of spelt maize and soybean were achieved in 2016, with 6848 mg kg^{-1}, 5672 mg kg^{-1}, and 10,006 mg kg^{-1}, respectively (31.2%, 32.5%, and 28.2% higher than multi-year average, respectively) (Figure 7), while the K concentration had the highest values in 2014, with 2243 mg kg^{-1}, 3387 mg kg^{-1}, and 6800 mg kg^{-1}, respectively (42.1%, 61.7%, and 58.6% greater than multi-year average, respectively). Some similarities in the fluctuations of Ca and Mg concentrations in the grain of spelt, maize, and soybean were also present (Figure 8), with the highest values present in 2016, i.e., 157.5 mg kg^{-1}, 588.2 mg kg^{-1}, and 2531.2 mg kg^{-1}, respectively, for Ca (31.8%, 48.1%, and 30.6% higher than multi-year average, respectively), as well as 2100 mg kg^{-1}, 2730 mg kg^{-1}, and 2383 mg kg^{-1}, respectively, for Mg (51.4%, 56.6%, and 38.6% higher than multi-year average, respectively). Moreover, the highest Fe concentrations were again observed in 2016, with 110.4 mg kg^{-1}, 96.5 mg kg^{-1}, and 99.2 mg kg^{-1}, respectively, for spelt, maize, and soybean (67.9%, 57.8%, and 36.2% higher than multi-year average, respectively) (Figure 9), while the highest Cu concentrations were observed in 2015, with 8.3 mg kg^{-1}, 17.8 mg kg^{-1}, and 29.1 mg kg^{-1}, respectively (21.7%, 28%, and 40.9% higher than multi-year average, respectively). Hence, fluctuations in the Si concentration followed a different pattern, though the highest values in spelt and soybean grain were achieved in 2015 (61.2 mg kg^{-1} and 189.7 mg kg^{-1}, respectively; 36.0% and 43.5% higher than multi-year average, respectively), while in maize grain, the highest Si concentration was in 2012, with 56.7 mg kg^{-1} (>43.8% than multi-year average). The Zn concentration in spelt, maize, and soybean grain had the highest values in 2016, again, with 32.6 mg kg^{-1}, 35.9 mg kg^{-1}, and 68.1 mg kg^{-1}, respectively (42.3%, 38.7%, and 48.4% greater than multi-year, respectively) (Figure 10). Nevertheless, in spelt and soybean grain, the Mn concentration was the highest in 2016 (12.6 mg kg^{-1} and 29.0 mg kg^{-1}, respectively; 37.1% and 24.8% higher than multi-year average, respectively), while in maize grain, it was in 2012 (41.1 mg kg^{-1}; 54.3% greater than multi-year average).

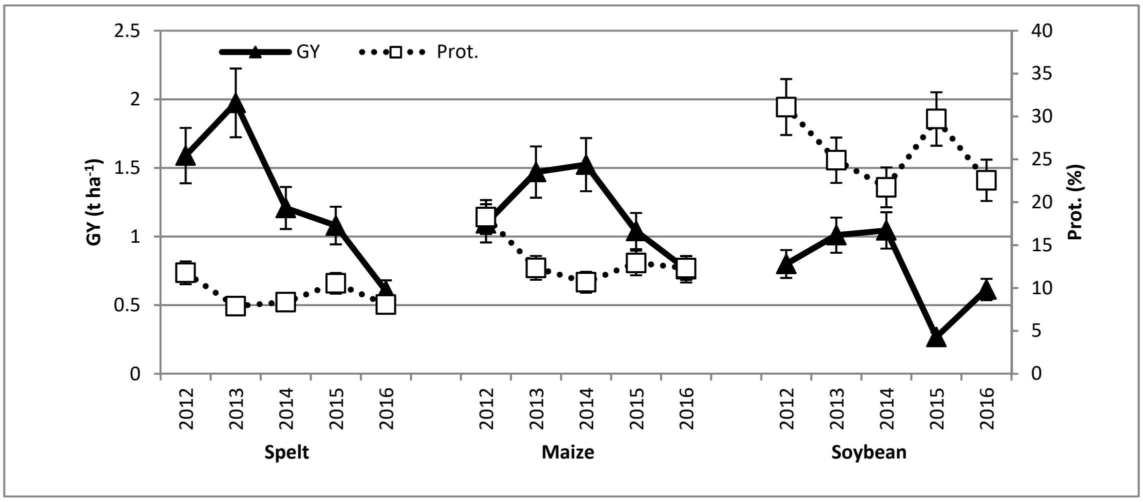

Figure 6. The variation of grain yield (GY) and protein content in grain of organically produced spelt, maize, and soybean (bars represent SD values).

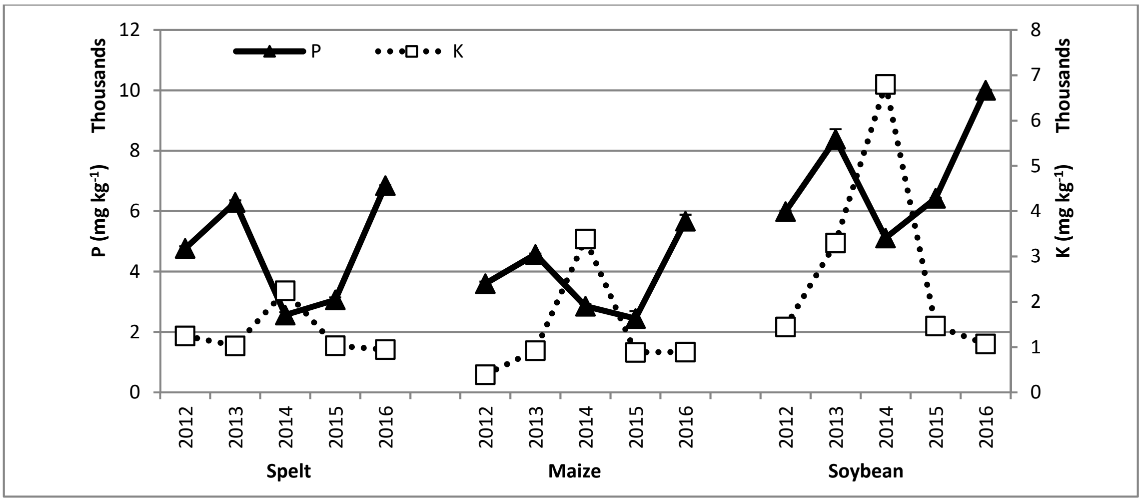

Figure 7. The variation of P and K concentration in grain of organically produced spelt, maize, and soybean (bars represent SD values).

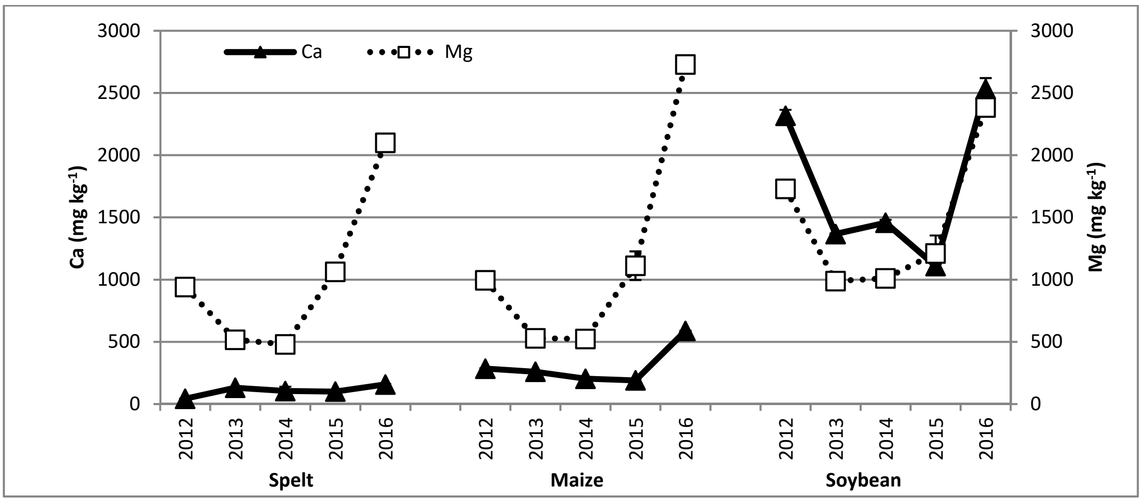

Figure 8. The variation of Ca and Mg concentration in grain of organically producedspelt, maize, and soybean (bars represent SD values).

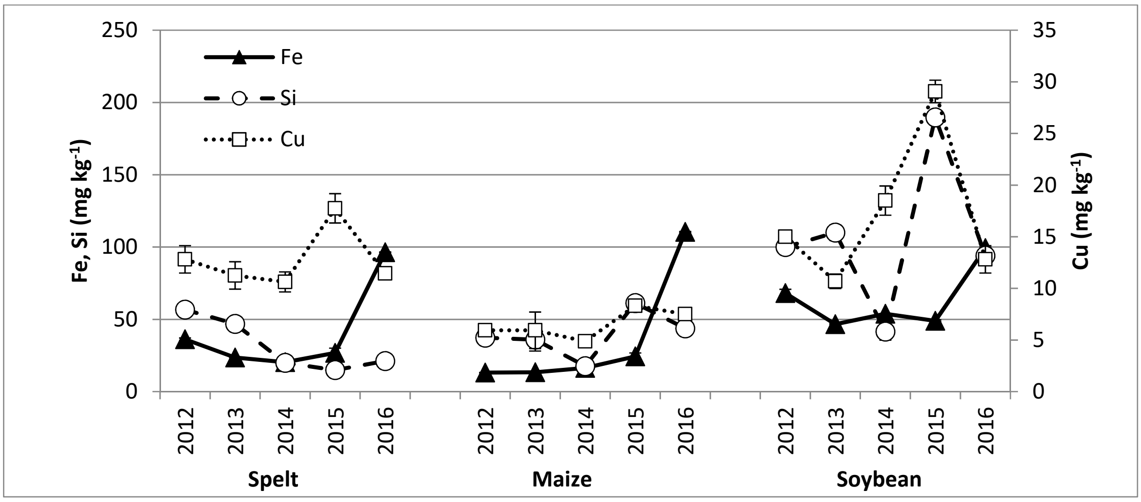

Figure 9. The variation of Fe, Si, and Cu concentration in grain of organically produced spelt, maize, and soybean (bars represent SD values).

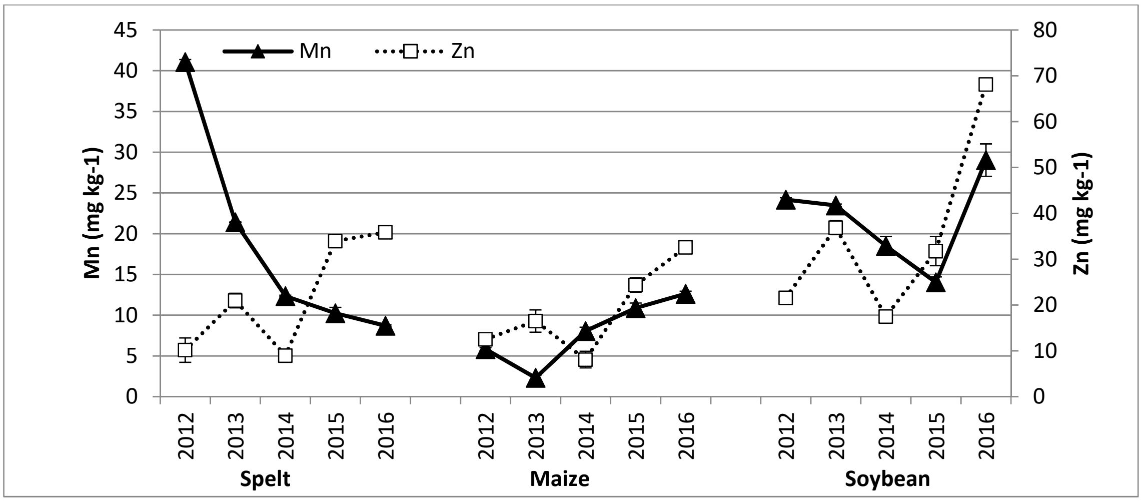

Figure 10. The variation of Mn and Zn concentration in grain of organically produced spelt, maize, and soybean (bars represent SD values).

3.3. Interdependence between Soil Properties and Status of Mineral Nutrients in Soil and Grain of Spelt, Maize, and Soybean

A significant correlation was observed between SOM content in the soil and GY of spelt and soybean (Table S1). Spelt GY and protein content also positively correlated with K and Ca content in the soil, while GY negatively correlated with N, P, Mg, Cu, and Si content in the soil and protein content negatively correlated with P, Mg, Fe, and Si. In maize, GY correlated positively with Ca and negatively with Zn content in the soil, while protein content was positively related to the K, Ca, and Mn content in the soil, as well as negatively with the P content in the soil. Considering soybean, increased GY was positively related to the Fe content in the soil and negatively to Cu, Zn, and Si. Nevertheless, the protein content in grain correlated positively with Ca and Mn and negatively with Mg and Fe.

SOM content in soil positively affected Cu accumulation in spelt grain, K and Cu concentration in maize grain, and P, Mg, Fe, Zn, and Si content in soybean grain (Table S2). Negative correlations were observed between SOM and Mn and Si concentrations in spelt grain, between SOM and P, Mg, Fe, and Zn concentrations in maize grain, as well as between SOM and K concentrations in soybean grain. Positive correlations between N content in soil and P, Ca, Mg, Fe, and Cu concentrations in spelt grain were present, as well as between N from the soil and K and Cu concentrations in maize grain and between soil N and Mn concentrations in soybean grain. Negative correlations between N in the soil and K and Mn concentrations in spelt grain were present, as well as between N in the soil and K and Cu concentrations in maize grain, and between N in the soil and Cu concentrations in soybean grain.

When the correlation between each examined element in the soil and grain was considered (Table S3), a positive dependence on P, Mg, Zn, and Si status was observable in soybean and maize and a negative dependence on K status in maize. Moreover, we observed a positive correlation between Fe status in the soil and maize grain, Mn status in soybean, as well as Cu and Si status in spelt, while a negative correlation between the soil and grain Mn status was present in maize.

PCA indicated that the first axis contributed 65.5% to the total variability, the second totaled 19.4%, and the third axis showed 12.7%. P, Mg, Cu, and Zn significantly and positively correlated with the PC1 axis, while N, Ca, and Mn correlated negatively; K and Si correlated significantly and positively with PC2 and Fe with PC3. According to the results revealed in Figure 11, high variability in the content of N, Ca, and Mn was present in the soil under all three crops, including Fe content varying, to a lesser extent, in the soil under soybean. Nevertheless, the Mg concentration varied highly in spelt and maize grain, with less variability present in N (protein) content in spelt grain, as well as the Fe concentration in maize grain. K and Si were more prone to variability, and to a lesser extent, K, Cu, Si, and Zn in soybean grain.

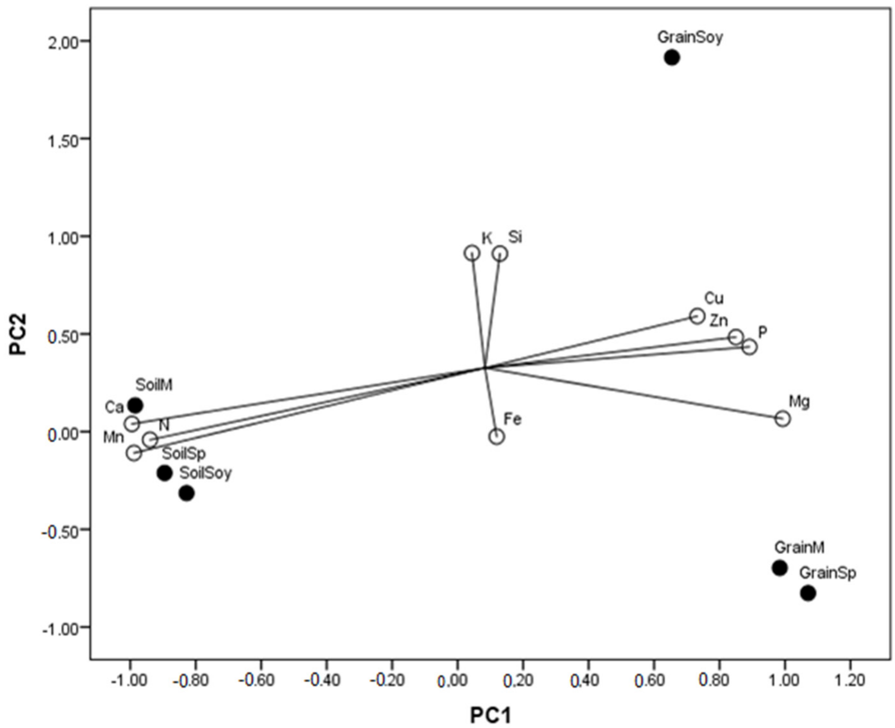

Figure 11. *Cont.*

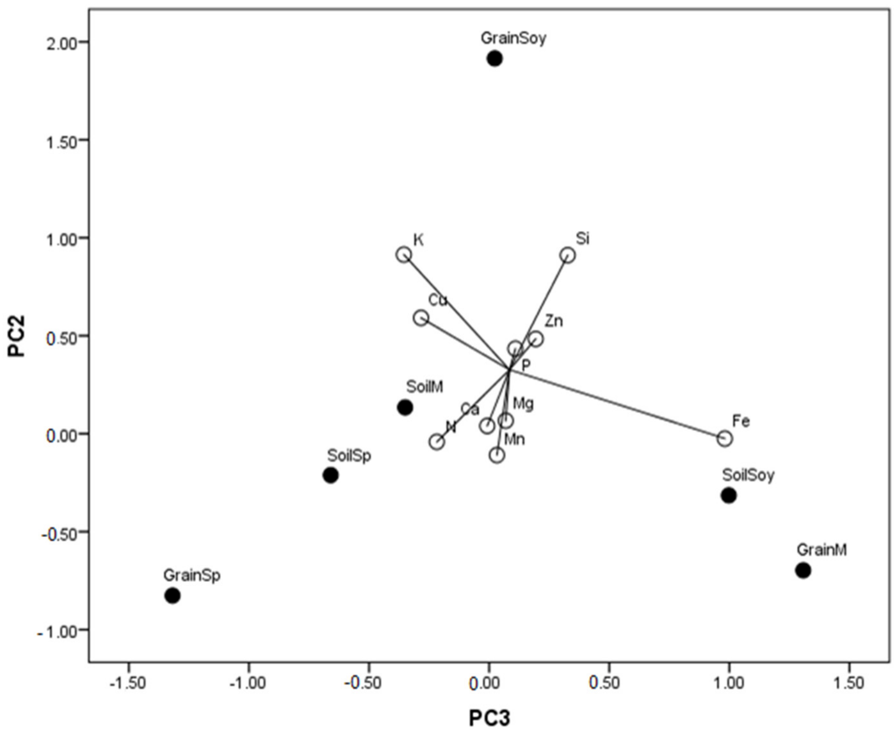

Figure 11. Principal Component Analysis (PCA) for N, P, K, Ca, Mg, Fe, Cu, Mn, Zn and Si concentration in soil under spelt (SoilSp), maize (SoilM), and soybean (SoilSoy), as well as the grain of spelt (GrainSp), maize (GrainM), and soybean (GrainSoy).

4. Discussion

Low-input systems, including organic agricultural systems, are low-yield, and at the same time, they are more resilient, providing various benefits through increased crop quality without pesticide residues [1]. Low yields, together with low inputs, may indicate environmental devastation, diversity reduction in the long term, calling into question the rationality of this production. The lack of information on the impact of low-input, organic systems on soil and crop quality tends to additionally contribute to their unpopularity in practice. The objective of this research is to provide information about soil fertility and crop quality over 5 years, implying minimal environmental impact through crop rotation and a low quantity of organic fertilizers in dry-farm conditions.

The experiment was established in dry-farm conditions, meaning that soil and crops were significantly prone to seasonal influences [25,26]. From this standpoint, the heavy rainfall during May and July 2014 mainly affected grain composition, reducing thereby protein content, as well as the concentration of Mg, Fe, Si, and Zn. The importance of soybean (legume crop) residues as a significant N source was noticeable in the relatively higher average soil N (4.16%) prior to maize sowing, consequently promoting the realization of the higher grain yield [27], especially when supported by a greater amount of precipitation by the maize, asit was in 2014. Together with the impact of precipitation, fertilizer application contributed to a greater degree of GY stability. Irrespective of the fact that soybean is able to increase soil N status, in this research, greater SOM was present after spelt, i.e., prior to soybean sowing, indicating that the rotation system plays an important role not just in nutrient availability but also in SOM preservation [10]. Prolonged effects of organic fertilizers, cover crops, and rotation results in an increase in SOM, microbial biomass, and available nutrients in the soil in general [6]. Since soil N status is an important factor for overall plant growth, yield, and protein accumulation in grain [28], N could additionally affect the absorption and accumulation of other elements, such as P, Ca, Mg, Fe, and Cu in spelt grain, P, Mg, Fe, and Cu in maize grain, as well as Mn in soybean crops, particularly under limited conditions. Nevertheless, a higher N level in the soil negatively affected K absorption and accumulation in spelt and maize grain, as well as Cu accumulation in maize and soybean grain. Wozniak [29] revealed that lower N doses that are correspondingly used in low-input systems, which could positively affect the accumulation of P, K, Ca, Fe, and Zn in wheat grain, in relation to high N doses.

Organic farming includes the application of organic fertilizers and other various practices that enhance the SOM level and, particularly, microbial abundance and activity [9]. Thus, increased microbial biomass (microbial C and N) and enzymatic activity in the soil contribute to the increased availability of mineral nutrients. The SOM level is an important factor that could enhance the availability and absorption of some elements by crops. Therefore, it could contribute to greater Cu accumulation in spelt grain, P, Mg, Fe, Zn, and Si in soybean grain, and K and Cu in maize grain, as it was observed in this research. At the same time, a greater SOM level could suppress the availability and accumulation of some elements, such as P, Mg, Fe, and Zn in maize grain, as well as K in soybean grain. In regard to the results established by Houx [12], that rotation did not influence the availability of many soil nutrients, in this experiment, such a situation could be observed in the content of Ca, Mg, Mn, Zn, and Si. Sharma et al. [14] claim that preceding and/or cover crops can alter the content and availability of mineral nutrients, such as Zn, B, Fe, and Mn, in the topsoil, without a significant influence on Ca and Mg availability. Nevertheless, in this trial, N, P, K, Fe, and Cu are generally affected by the preceding crop (maize and soybean, primarily), including significant variability in N, Ca, and Mn content in the grain of all three crops. On average, soybean increased the N level in the soil and also contributed to increased K and Cu levels, while maize increased the N and P content and spelt increased the Fe content in the soil, supporting the statement that under conditions of limited water and nutrient availability, such as dry-farming organic production, crop rotation design could have a huge impact on nutrient availability and uptake by subsequent crops [20].

When macro-elements, such as P and K, were considered, their status in the soil was dependent on the year, meaning that after maize, higher P amounts were preserved on average, while after soybean, greater K availability to the next crop in the sequence was enabled. Accordingly, Łukowiak et al. [17] and Almaz et al. [30] found that oilseed rape as a preceding crop in rotation, as well as the incorporation of soybean and soybean + maize residues, could promote the of nutrients, thus serving as a partial replacement for mineral fertilizers, without losses of yield and grain quality. The same authors indicated that cropping sequences are a primary factor that determines P use efficiency, crop yield, and its stability. It is also important to underline that the lowest P content in soil (on average and across all experimental seasons) was present prior to soybean crop establishment, in regard to spelt and maize. Nevertheless, soybean grain was the highest in P, on average. The results achieved for wheat and soybean [16,18] prove that some crops are tolerant to long-term low P content in the soil, as well as the fact that maize–soybean rotation is important not just for enhanced P absorption, but also for elements such as Fe and B.

Seasonal fluctuations in the content of analyzed nutrients resulted in the highest differences achieved in N content in the soil prior to maize sowing, P content before spelt and maize, resulting in enhanced P accumulation in the grain of maize and spelt. Significant variability was also present in the Si and Fe content in the soil before soybean sowing. High variability in the accumulation of mineral elements by spelt in semi-arid conditions of the Mediterranean region has been suggested [31]. Accordingly, spelt is able to acquire and accumulate higher amounts of essential elements, such as Fe and Zn, without significant GY variations [31,32]. Mn and Zn content in the soil also varied significantly under all three crops, with higher values in drier seasons. Nevertheless, positive correlations between Mn and Zn concentrations in grain and status in the soil before soybean establishment exist. When the relationship between the nutrient level in soil and their accumulation in grain was considered, it is important to underline that N, Ca, and Mn were reversely connected to P, Mg, Cu, and Zn and that their level varied highly in soil, indicating that not just meteorological factors, but also rotation plays an important role in their potential status and availability. Irrespective of the relatively high Mg content and availability from the soil, significant variations in the Mg concentration were mainly noted in spelt and maize grain, indicating the prominent impact of meteorological factors on its accumulation in the grain of these two crops. A similar trend, but to a lesser degree, was observed for the Fe concentration in maize grain. Besides, variability in Mn and Zn concentrations in spelt and maize grain was mainly induced by the impact of the season and previous crop, according to the results of Dragicevic et al. [15], who underlined the important effect of cover crop residues, as well as the season, on the status of Mg, Fe, Zn, and Mn in sweet maize kernel grown in a low-input system. Poaceae crops, such as spelt and maize, tend to accumulate higher concentrations of P, K, Mg, Cu, Mn, Zn, and Si on average. Such results could indicate a positive connection and possibly beneficial role of Si in the improved efficiency of use of K and Zn [33,34]. Houx et al. [12] observed a significant impact of the soybean–maize rotation on Cu and Mn status in soybean grain, while seasonal influence expressed a lower impact.

Optimal mineral nutrition supports crop growth and yield potential, including mineral accumulation in the grain. Thus, the correlation between SOM, nutrient status in the soil and GY, and protein concentration in the grain indicated that increased Ca content in the soil was followed by increased values of GY and protein in the grain of all three crops (particularly in maize). Similar results were obtained using liming as ameliorative practice [35]. While Mahmood et al. [36] emphasized the advantage of N, P, and K for GY increase of conventionally produced maize, in this research, increased N and P levels in the soil correlated negatively with spelt and maize GY, but to a lesser extent. It seems that fertilization with micronutrients is more important for the increase in GY and protein content, which was proven with an experiment on barley yield [37]. Furthermore, organic farming contributes to increased protein content, as well as protein quality, as has been found in chickpea grain [4]. Therefore, in this research, particular importance was given to an increased Mn level in the soil that could support protein accumulation in grain. Irrespective of the fact that N plays an important role in protein accumulation in grain, it seems that K has a larger impact through its role in various physiological processes in photosynthesis and water usage, thus providing a proper environment for greater GY and protein accumulation [36,38], but only in spelt grain.

Generally, the present trend of the reduction of GY and protein concentration in the grains of all three crops could seemingly qualify dry-farm organic production as a worthless agricultural system. However, the increased concentration of mineral elements, such as P, Ca, Mg, Fe, Zn, and Mn in maize grain, over time, suggests evidence of the greater ability of crops under this farming system to employ all accessible ecosystem services to enhance nutrient availability and absorption. Irrespective of the fact that spelt is a small grain crop, under the present agro-climatic conditions, it achieved the highest average GY among all three crops, evidencing its high adaptability and tolerance to stressful conditions [31]. Soybean grain was the richest in the majority of examined nutrients. The influence of the season and rotation is significant for GY variability. Correspondingly, cover crops with greater biomass and legumes are able to increase GY and the concentration of essential elements in sweet maize grain [15]. The lesser variability in maize GY across seasons could be connected to the positive impact of soybean, as a preceding crop, enriching the soil with nutrients to a greater degree. This means that the use of legumes in the rotation, particularly when they are combined with organic fertilizers, could have a huge impact on yield stability [13,19], enabling savings in fertilizers by their partial replacements, such as those acquired in the maize + soybean rotation in conventional production [28].

5. Conclusions

In a semi-arid climate, under dry-farming conditions, a low-input organic production system exhibited an important impact on the soil characteristics, as well as on GY and grain composition. Significant variations were governed by the fluctuations in meteorological conditions. SOM, and in particular, residual N, enhanced the absorption and accumulation of P, Ca, Mg, Fe, and Cu in spelt grain, P, Mg, Fe and Cu in maize grain, as well as Mn in soybean grain. Spelt achieved the highest average yield among all three crops, while soybean grain was the richest in the majority of examined nutrients. The slight variability of maize GY could be related to the soybean as a previous crop. Soil characteristics, such as SOM and the status of mineral nutrients (particularly N), could affect the accumulation of essential nutrients in the grain of all three crops, while the preceding crop could define the elemental composition of the grain. Thus, maize contributed to greater P preservation, while soybean to greater K preservation and availability to the next crop in sequence.

The beneficial role of Si in improved use efficiency of K and Zn was proven, particularly when soybean grain was considered. The important role in the achievement of GY and increased protein level in the grains is played by soil Ca content, but mainly in maize.

The novelty of this research was reflected in the soil–crop crosstalk, as an important strategy for macro- and micro-nutrient management in the soil and grain of organically produced spelt, maize, and soybean. Though a reduction in GY and protein concentration in grain was present over time, it was established that a low-input system under dry-farming conditions supports better nutrient availability and accumulation in grain, under the semi-arid agro-ecological conditions of central Serbia. It was shown that a maize–spelt–soybean rotation is effective at enhancing the availability of nutrients from the soil, thus increasing their accumulation in grain and improving the nutrient density of organically produced crops. Soil fertility was also enhanced, so the benefits are multi-level: The low impact on the environment, enhanced crop quality and farmers' incomes, the health benefits of the consumption of organically produced food, as well as societal benefits, through reduced malnutrition and improved health.

Future perspectives could aim for the inclusion of catch crops and bio-fertilizers, which could additionally support soil fertility, and increase GY sustainability and quality.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture12050702/s1, Table S1: The correlation (Pearson's correlation coefficients) between organic matter (SOM), N, P, K, Ca, Mg, Fe, Cu, Mn, Zn, and Si in soil and grain yield (GY) and protein content in grain of spelt, maze and soybean; Table S2: The correlation (Pearson's correlation coefficients) between organic matter (SOM) and N content in soil and concentration of P, K, Ca, Mg, Fe, Cu, Mn, Zn, and Si in grain of spelt, maze and soybean; Table S3: The correlation (Pearson's correlation coefficients) between concentrations of P, K, Ca, Mg, Fe, Cu, Mn, Zn, and Si in soil and grain of spelt, maze and soybean.

Author Contributions: Conceptualization: V.D. and M.S. (Milena Simić); methodology: V.D. and M.S. (Milena Simić); statistical analysis: V.D. and M.B.; validation: V.D., M.S. (Milovan Stoiljkovic), M.B. and M.S.D.; chemical analysis: V.D., M.B. and M.S. (Milovan Stoiljkovic); investigation: V.D., M.B., M.S. (Milena Simić) and M.T. (Marijenka Tabaković); writing—original draft preparation: V.D. and M.B.; visualization: V.D., M.S. (Milena Simić) and M.T. (Marijenka Tabaković); resources: M.S. (Milena Simić) and M.T. (Miodrag Tolimir); supervision: M.S. (Milena Simić); project administration: M.S. (Milena Simić); data curation: M.B., M.T. (Marijenka Tabaković) and M.S.D.; writing—review andediting: M.B., M.S. (Milena Simić) and M.S.D.; funding acquisition: M.S. (Milena Simić), M.T. (Miodrag Tolimir) and M.S. (Milovan Stoiljkovic). All authors have read and agreed to the published version of the manuscript.

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