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Influence of Agricultural Management Practices on the Soil Properties and Mineral Composition of Potato Tubers with Different Colored Flesh

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Abstract: The objective of the work was to investigate and estimate the effects of conventional, organic, and biodynamic farming systems on biological and agrochemical soil properties and mineral composition of potato tubers with different colored flesh. This study compared the same biological and agrochemical soil quality indicators on samples collected at three sampling times: before potato planting, the middle of the potato season, and before harvesting. In addition, macro- and microelement contents were determined in the tubers. The results showed that the highest soil microbial biomass contents, dehydrogenase activity, and humus contents were found before potato planting in a conventional farming system. However, from potato planting until the end of the growing season, these soil biological indicators significantly decreased in the soil of conventional farming, but significant increases were recorded in organic and biodynamic treatments. The highest contents of all tested nitrogen forms, phosphorus and potassium, were found in the middle of the potato growing season in a conventional farming system. Before harvesting, significant decreases in all studied agrochemical soil quality indicators were observed in all farming systems. The organic and biodynamic potatoes contained significantly more K, P, and Ca than conventional potatoes. In addition, organic samples had significantly higher contents of Mg, Fe, Mn, Zn, and B in comparison to the biodynamic and conventional ones. The cultivar effect on the content of selected minerals in the samples was also observed. Red Emmalie contained more K, N, and B. Salad Blue had the highest contents of Fe, Mn, and Zn in comparison to other studied cultivars.

Keywords: biodynamic; conventional; iron; organic; dehydrogenase; potassium; potatoes; soil

1. Introduction

Lately, one of the world's biggest challenges is to secure adequate food that is safe, healthy, and of high nutritional value for all [1]. In this paper, we will compare three different agricultural management practices: conventional, organic, and biodynamic. In a comparison of farming systems, our goal is to estimate the effect of each cultivation technology on soil and potato quality. According to the literature, the purpose of organic and biodynamic farming is to produce crops without the use of synthetic fertilizers and pesticides, while enhancing soil enzyme activity and biological diversity. Conventional farming uses synthetic fertilizers and pesticides to maximize the yield of potato crops. Therefore, this farming method requires high levels of chemicals and energy input and weakens the ecology of a landscape [2].

In recent years, organically and biodynamically grown food has become increasingly popular. The reasons that drive consumers to buy organic products vary across countries but concerns about personal health and the nutritional value of food generally predominate over concerns about environmental issues [3]. Organic or biodynamic food is in fact produced from raw materials obtained by agricultural farming systems relying on ecological processes, biodiversity, and cycles adapted to local conditions, rather than the use of inputs that have adverse effects on the health of soils, ecosystems, and people. The main features of organic or biodynamic farming are claimed to be sustainability, low-impact cropping methods, use of non-chemical fertilizers, and high-quality production [4]. Nevertheless, an objective and exhaustive assessment of the supposedly higher nutritional value of organic food and the benefits on consumers' health is still missing.

Potato (*Solanum tuberosum*) is the fourth most important food crop worldwide after corn (*Zea mays* L.), rice (*Oryza sativa* L.), and wheat (*Triticum aestivum* L). Potato tubers contain from 1 to 1.2% of minerals, the most important of which are potassium, magnesium, nitrogen, and phosphorus [5]. As well as performing important functions in the human body, minerals are an integral part of many enzymes and play an important role in the regulation of metabolism [6]. Other studies have reported that potato tubers also contain mineral nutrients, such as sodium, manganese, calcium, copper, and iron [7,8]. According to Wroniak [9], potassium is the major mineral in potatoes, followed by phosphorous, calcium, magnesium, iron, and copper. However, the nutrient contents of potatoes, such as macro- and microelements, vary depending on differences in soil mineral content, the interaction between minerals, cultivars, growing conditions, cultivation technologies applied, and processing [10,11].

Therefore, the aim of the study was to investigate and estimate the effects of different agricultural management practices (conventional, organic, and biodynamic) on biological and agrochemical soil properties and mineral composition in potato tubers with colored flesh.

2. Materials and Methods

2.1. Plant Material

Trials included five cultivars of potato (*Solanum tuberosum* L) with different flesh colors: dark purple (Violetta), light purple (Salad Blue), red (Red Emmalie), yellow (Laura), and white (Tornado). All these potato cultivars are early-maturing. Potatoes were grown in 2018–2019 at a farm in the Širvintos district (Lithuania, latitude, 54°54′43″ N; longitude, 25°06′07″ E).

Potatoes were cultivated according to traditional potato production technology in conventional, organic, and biodynamic farming systems. In autumn, the soil was plowed deep. In spring, the field was cultivated twice. The field was furrowed before potato planting. The tubers were planted at the end of April in rows spaced at 70 cm, with 30 cm between the tubers at a depth of about 7 cm. The tubers were harvested at maturity during the first week of September.

In the conventional farming system, a mix of universal complex fertilizers "Blaukorn Novatec" $N_{14}P_7K_{17}$ (800 kg ha^{-1}) were used at planting by inserting 112 kg ha^{-1} of nitrogen, 56 kg ha^{-1} of phosphorus, and 136 kg ha^{-1} of potassium. As well, before the potato germination, the field was sprayed with herbicide (Nufarm MCPA 2.3 L ha^{-1}, active substance MCPA 750 g L^{-1}). Later, the following pesticides were used: at the inflorescence formation and two flowering stages, fungicide (Infinito 1.6 L ha^{-1} (active substances propamocarb hydrochloride 625 g L^{-1} and fluopicolide 62.5 g L^{-1}) and Gloria 2 L ha^{-1} (active substances fenamidone 75 g L^{-1} and propamocarb hydrochloride 375 g L^{-1}), respectively) was sprayed, in combination with insecticide (Mavrik Vita 0.2 L ha^{-1}, active substance tau-fluvalinate 240 g L^{-1}).

In the organic and biodynamic farming systems, potatoes were grown in accordance with the IFOAMS (International Federation of Organic Agriculture Movements) and Demeter Biodynamic standards, which promote ecologically sustainable farming practices and prohibit synthetic pesticides, synthetic fertilizers, genetically engineered seeds, artificial ingredients, and other inputs that can be used in conventional agriculture and food processing.

In the organic farming system in the spring before the first cultivating, the soil was fertilized with 30 t ha^{-1} of compost. This compost composition was as follows: pH_{KCl}—6.97, available P_2O_5—193.25 mg kg^{-1}, available K_2O—304.80 mg kg^{-1}, and mineral nitrogen (52.73 mg kg^{-1}).

In the biodynamic farming system, the potato crops were fertilized with biodynamic compost (30 t ha^{-1}). Compost also was added in the spring before the first cultivating. This compost composition was as follows: pH_{KCl} 6.83, available P_2O_5 159.108 mg kg^{-1}, available K_2O—263.18 mg kg^{-1}, and mineral nitrogen (51.09 mg kg^{-1}). Two weeks prior to the potato planting, the soil was sprayed with biodynamic preparation 500 at a solution concentration of 1% (200 L ha^{-1}). Potatoes were sprayed with biodynamic preparation 501 at a solution concentration of 0.5% twice—at the bud formation stage (organogenesis stage VIII) and the flowering stage (organogenesis stage IX) (200 L ha^{-1}). The soil and the potato plants were sprayed with tested preparations according to the methods and rules set down for European biodynamic farms [12].

The potatoes were grown after oats (*Avena sativa*), and the oats were grown after clover (*Trifolium*).

The biodynamic preparations (500 and 501) and organic and biodynamic composts were purchased from the Demeter-certified farm in Lithuania. In both organic and biodynamic farming systems, weeds were controlled by mechanical measures. Colorado beetles and their larvae were removed by hand.

In each farming system, the experimental plots were arranged in a randomized design with four replications. The total plot size was 50 m^2 (8 × 6.25 m) and the size of a harvested plot was 32 m^2 (6.60 × 4.85 m); the width of the protection zone was 0.7 m.

The weather conditions during the potato growing seasons in 2018–2019 are given in Table 1.

Table 1. Weather conditions during the potato growing season in 2018–2019 (Vilnius weather station, Lithuania).

Years	Months						Average
	April	May	June	July	August	September	
	Air Temperature, °C						
2018	10.3	17.0	17.3	19.5	19.1	14.6	16.3
2019	9.0	13.3	21.1	17.1	18.0	12.6	15.2
SRC *	7.0	12.8	15.7	18.0	17.1	12.0	13.8
	Rainfall, mm						Sum
2018	42.5	27.3	16.0	107.7	65.4	57.0	316
2019	0.6	28.6	27.5	49.9	100.3	46.6	253.5
SRC	43	57	73	89	75	66	403
	Sunshine, h						Sum
2018	249	365	284	209	278	206	1591
2019	328	233	348	234	263	190	1596
SRC	179	252	246	260	237	154	1328

* SRC—Standard climate normal is the 30-year average from 1981 to 2010.

The weather course during the years of study was diverse. The year 2018 was warmer by 2.5 °C compared with the standard rate of climate, with a deficiency of precipitation in May, June, and August. The year 2019 was characterized by temperatures above the long-term average of 1.4 °C and rainfall in April–September, except August, was below the long-term standard. The sunshine in both years during the potato vegetation period was higher on average at 265 h, compared with the standard rate of climate (Table 1).

2.2. Soil Chemical Analysis

Soil sampling for the evaluation of the soil agrochemical characteristics was carried out in 2018 and 2019. To estimate the effects of farming systems, the soil was sampled three times—before potato planting, at 63 days (the middle of the potato growing season (potato organogenesis stages VIII–IX)), and at 126 days (shortly before harvesting) after the potato planting. In each replication of the treatment, composite soil samples were taken from five different places from the arable layer (0–20 cm depth) using a soil auger. The samples were air-dried, crushed in a porcelain mortar, and sieved with a 2 mm sieve. The agrochemical characteristics of the soil samples were analyzed by the following methods: the available phosphorus (P_2O_5) mg kg^{-1} and available potassium (K_2O) mg kg^{-1} by the Egner-Riehm-Domingo (A-L) method [13]; ammonia nitrogen and nitrogen (the sum of nitrate and nitrite nitrogen concentrations) (mg kg^{-1}) by a flow injection analysis (FIA) spectrometric method using inductively coupled plasma mass spectrometry (ICP-MS, Thermo Finnigan MAT, Germany); mineral nitrogen concentration (mg kg^{-1}), calculated as a sum of nitrogen (nitrate and nitrite) and ammonia nitrogen; soil reaction pH by a potentiometric method, using a pH-meter in 1 N KCl extract [14]; soil activity of dehydrogenase after Tabatabai [15] and Järvan [16] methods [17]; microbial biomass by the chloroform fumigation-extraction method [18]; humus content by the Thurine method.

2.3. Drying of Potato Samples

4 kg of tubers from each treatment were randomly selected. The whole tubers were washed with tap water, dried, and cut into a thickness of about 10 mm. The potato samples were oven-dried at 60 °C for 12 h and ground with a Grindomix GM 200 mill (Retsch GmbH, Haan, Germany) [19]. The prepared samples were placed in plastic bags and stored in a dry and dark place until analysis.

2.4. Macro and Microelements Analysis in Potato Samples

The quantification of macro- and microelements of the potato samples were determined using standard methods. Nitrogen (N) was established by the Kjeldahl method [20]. Calcium (Ca), phosphorus (P), potassium (K), magnesium (Mg), iron (Fe), zinc (Zn), copper (Cu), boron (B), and manganese (Mn) were established by ICP-AES (inductively coupled plasma atomic emission spectrometry) [21]. The concentrations for N, P, Ca, K, and Mg were expressed in g kg^{-1}DM; the concentrations for Fe, Zn, B, Mn, and Cu in mg kg^{-1} DM.

2.5. Statistical Analysis

All data were statistically processed using a one-way analysis of variance (ANOVA) method from the Statistica software package (Statistica 10; StatSoft, Inc., Tulsa, OK, USA). Data were expressed as arithmetic means. The statistical significance of differences between the means was estimated by Fisher's least significant difference (LSD) test ($p < 0.05$). As no significant effect of the production year was identified for a vast majority of the tested parameters, the data for individual years are not presented in the paper.

3. Results and Discussion

3.1. Soil Quality

3.1.1. Biological Soil Properties

The enzymatic activity of the soils in our experiment was determined by assessing the activity of dehydrogenase systems, which depends on the same factors that influence the abundance of microorganisms and the biomass [22]. Dehydrogenase activities, together with the microbial biomass, give information on the total activity of the microbial community [23]. The highest soil microbial biomass contents and dehydrogenase activity were found before potato planting in the conventional farming system (Table 2.). From potato planting until the end of the growing season these soil indicators significantly increased in the soil of organic (11.37 and 25.20%, respectively) and biodynamic (10.68 and 27.06%, respectively) farming systems. It is likely that composts applied in the organic and biodynamic farming system increased these soil indicators. According to Erhart and Hartl [24], regular compost addition enhances soil fauna and soil microbial biomass and stimulates enzyme activity, leading to increased mineralization of organic matter. However, the use of herbicides and other pesticides in the conventional farming system negatively affected the microbe biomass (−16.67%) and soil dehydrogenase activity (−22.23%). In the conventional treatment, the weeds were controlled by MCPA. It is liable that this herbicide might noxiously affect the bacterial communities because, in the soil of this system, the soil microbial biomass decreased. Our results are similar to the results of other researchers, who have reported on the toxic effect of MCPA on bacteria [25] and soil enzymatic activity [22]. Previous studies revealed the adverse impacts of pesticides on soil microbial biomass [26,27]. In addition, the negative impact of pesticides on soil enzymes such as hydrolases, oxidoreductases, and dehydrogenase activities has been widely reported in the literature [28,29].

Table 2. The biological soil properties in conventional, organic, and biodynamic practices.

Sampling Treatment	Soil Microbial Biomass C μg C g^{-1}	Soil Dehydrogenase Activity μg g^{-1}	Humus %
Conventional farming systems			
Before potato planting	379.50 ± 3.44 a	42.73 ± 3.70 a	2.32 ± 0.07a
Middle of the potato growing season	322.17 ± 8.49 b	32.40 ± 1.70 b	2.16 ± 0.13 ab
Before harvesting	316.23 ± 6.17 b	33.23 ± 1.40 b	2.11 ± 0.02 b
Organic farming systems			
Before potato planting	335.47 ± 15.83 b	32.93 ± 2.57 b	2.07 ± 0.05 b
Middle of the potato growing season	320.27 ± 1.50 b	34.23 ± 3.01 b	2.09 ± 0.06 b
Before harvesting	373.60 ± 6.82 a	41.23 ± 1.53 a	2.30 ± 0.03 a
Biodynamic farming systems			
Before potato planting	224.00± 18.36 b	25.50 ± 3.00 b	1.78 ± 0.08 b
Middle of the potato growing season	231.93 ± 11.51 ab	25.13 ± 1.87 b	1.76 ± 0.04 b
Before harvesting	247.93 ± 11.81 a	32.40 ± 1.66 a	1.90 ± 0.03 a

[1] Different lower-case letters (a, b, c) indicate significant differences between sampling treatment ($p < 0.05$).

A similar tendency was observed with the changes of humus in the soil (Table 2.). Before potato planting, the highest content of humus was determined in the conventional farming system (2.32%) than in the organic (2.07%) and biodynamic (1.78%) farming systems. However, after the harvesting period, the content of humus significantly decreased by 9.05% in the soil of conventional farming, but significant increases were recorded in the organic and biodynamic treatments—11.11 and 6.74%, respectively. The compost used for fertilization on both farms apparently affected this. Zhen et al. [30] also stated that manure compost significantly enhanced soil microbial properties in response to the increase in soil physicochemical properties of soil organic matter and humus.

3.1.2. Agrochemical Soil Properties

Chemical soil properties showed mixed patterns (Table 3). Before planting, the contents of nitrogen compounds such as nitrogen (nitrate + nitrite) and mineral nitrogen were similar for all farming systems: 40.64 and 45.89 mg kg^{-1}, 41.00 and 43.67 mg kg^{-1}, 35.76 and 41.44 mg kg^{-1} for the intensive, biodynamic, and organic systems, respectively (Table 3). In the middle of potato vegetation significant increases in all nitrogen forms were observed only in the conventional (nitrogen (nitrate + nitrite) by 113.93%, ammonia nitrogen by 84.38%, and mineral nitrogen by 110.55%) and biodynamic (nitrogen (nitrate + nitrite) by 21.44%, ammonia nitrogen by 41.57%, and mineral nitrogen by 22.67%) farms. However, in the organic farm, significant decreases in all nitrogen forms were found. It is likely that synthetic fertilizers used in the intensive farming system greatly increased the contents of all nitrogen forms. From the middle of potato vegetation until the end of the growing season, the contents of these nutrients in the intensive and biodynamic farming systems' soils were decreasing. In the organic farm, the highest content of mineral compounds in the soil occurred before the potato planting, which also declined dynamically until the end of potato vegetation.

Table 3. The agrochemical soil properties in conventional, organic, and biodynamic practices.

Sampling Treatment	Nitrogen Forms			Available P_2O_5	Available K_2O	pH
	Nitrogen (Nitrate + Nitrite)	Ammonia Nitrogen	Mineral Nitrogen			
	mg kg^{-1}					
Conventional farming systems						
Before potato planting	40.64 ± 2.78 b	5.25 ± 0.42 b	45.89 ± 1.73 b	140.04 ± 1.02 b	272.81 ± 16.02 b	5.39 ± 0.02 b
Middle of the potato growing season	86.94 ± 2.00 a	9.68 ± 0.69 a	96.62 ± 3.68 a	280.75 ± 0.34 a	375.98 ± 9.05 a	5.47 ±0.03 a
Before harvesting	15.11 ± 0.20 c	2.49 ± 0.24 c	17.60 ± 1.27 c	146.80 ± 0.34 b	174.73 ± 15.25 c	5.47 ± 0.04 a
Organic farming systems						
Before potato planting	35.76 ± 2.23 a	5.68 ± 0.22 a	41.44 ± 3.60 a	172.51 ± 7.68 a	188.75 ± 2.97 a	5.39 ± 0.03 b
Middle of the potato growing season	18.70 ± 1.25 b	3.87 ± 0.50 b	22.57 ± 0.62 b	155.80 ± 3.20 b	176.73± 5.94 b	5.55 ± 0.01 a
Before harvesting	10.49 ± 1.50 c	2.63 ± 0.10 c	13.12 ± 0.80 c	140.04 ± 5.41 c	181.74 ± 3.91 b	5.51 ± 0.04a
Biodynamic farming systems						
Before potato planting	41.00 ± 3.86 b	2.67 ± 0.18 b	43.67 ± 3.00 b	176.57 ± 2.54 b	181.74 ± 5.13 c	5.20 ± 0.05 c
Middle of the potato growing season	49.79 ± 3.12 a	3.78 ± 0.20 a	53.57 ± 4.98 a	184.04 ± 3.33 a	279.82 ± 7.97 a	5.79 ± 0.01 a
Before harvesting	6.17 ± 1.66 c	1.90 ± 0.41 c	8.07 ± 1.10 c	154.25 ± 4. 99 c	202.76 ± 4.13 b	5.47 ± 0.02 b

[1] Different lower-case letters (a, b, c) indicate significant differences between sampling treatment ($p < 0.05$).

Before planting, the highest concentration of available P_2O_5 was in the biodynamic and organic farming soils, while the highest concentration of available K_2O was in the conventional farming soil. In the middle of potato vegetation, significant increases in these elements were observed in the conventional (P_2O_5 by 100.48%, K_2O by 37.81%) and biodynamic (P_2O_5 by 4.23%, K_2O by 53.97%) soils. The highest concentration of P_2O_5 in the conventional farming system indicates that fertilizer application significantly increased the soil phosphorus concentration. From the middle of the potato vegetation period until the end of the growing season, concentrations of P_2O_5 and K_2O significantly decreased in the soil of conventional (47.71 and 53.53%, respectively), biodynamic (16.19 and 27.54%, respectively), and organic (only phosphorus by 10.11%) farming systems.

Soil pH values varied between 5.39 and 5.47 for the conventional farming system, 5.39 and 5.55 for the organic farming system, and 5.20 and 5.79 for the biodynamic one (Table 3). In all the farms, the lowest values of soil pH were before the potato planting, which significantly increased until the end of potato vegetation.

3.2. Potato Tuber Quality

The recent research results confirm that higher contents of bioactive compounds, such as polyphenols and carotenoids, were in tubers from organic and biodynamic farming systems than from the conventional system [31,32]. However, there is a lack of information in the literature about the impact of the different farming systems (conventional, organic, and biodynamic) on the content of some elements in the potato tubers with colored flesh.

The contents of macroelements under the three farming systems are reported in Table 4. K was present in the highest content and varied from 22.89 to 25.49 g kg^{-1} DM, depending on farming systems. The organic potato contained significantly more K in comparison with the conventional potato.

However, the K content showed no significant difference between the conventional and biodynamic treatments. The cultivar effect on the K content also was found. Red Emmalie cultivar contained significantly more K in comparison with other studied cultivars.

Statistical analyses showed that the differences in the content of N between the samples from conventional, organic, and biodynamic farming systems were not statistically significant. However, the cultivar effect on the content of this element was observed. The highest content of N was estimated for Red Emmalie, followed by the Salad Blue, Tornado, and Violetta cultivars at 20.15, 19.47, 19.34, and 19.07 g kg^{-1} DM, respectively. These values were not significantly different at $p < 0.05$. On the whole, the Laura cultivar exhibited the lowest N content among all of the studied samples.

The results show that organic and biodynamic potatoes contained significantly more *P* in comparison with the conventional. In this study, no essential differences were found between the five cultivars: the cultivar Red Emmalie accumulated the most *P* (2.66 g kg^{-1} DM), while the least *P* was determined in tubers of the cultivar Tornado (2.54 g kg^{-1} DM).

Ca content was significantly higher in organic (0.43 g kg^{-1} DM) than in conventional (0.37 g kg^{-1} DM) potatoes. Violetta had the highest concentration of Ca with 0.52 g kg^{-1} DM, and Red Emmalie had the second highest concentration of Ca with 0.44 g kg^{-1} DM.

The analysis of variance showed that Mg content in potatoes depends on the farming type and the cultivar. Organically grown tubers accumulated higher Mg contents (1.53 g kg^{-1} DM) than conventionally (1.12 g kg^{-1} DM) and biodynamically (1.15 g kg^{-1} DM) grown tubers. Laura cultivar showed the highest content of Mg at 1.62 g kg^{-1} DM. The Salad Blue and Tornado tubers showed the lowest contents (1.10 and 1.17 g kg^{-1} DM, respectively) with no significant difference between them.

The content of microelements under the three farming systems is reported in Table 5. Five minerals, Fe, Zn, B, Mn, and Cu were quantified in potato tubers. As indicated by the presented results, potato tubers from the organic production were characterized by a significantly higher content of microelements in comparison with the conventional and biodynamical farming systems. The contents of Fe, Mn, Zn, and B were significantly higher in the organic farming system. However, these element contents showed no significant difference between the conventional and biodynamic treatments. It was found that the biodynamic potato tuber was characterized by a significantly higher Cu content (4.43 mg kg^{-1} DM) compared with the organic (2.96 mg kg^{-1} DM) and conventional (3.04 mg kg^{-1} DM) farming systems.

Genetic factors significantly contributed to the content of all tested microelements. Of all the microelements evaluated, Fe was detected at a higher concentration in potato tubers. This element content of potato cultivars ranged from 50.97 to 141.13 mg kg^{-1} DM (Table 5). Salad Blue showed the highest Fe content, while Laura showed the lowest contents of this element. The contents of microelements Cu and Zn were similar in all cultivars, independent of the production system. Salad Blue, Violetta, and Tornado tubers showed the highest Mn contents (11.12, 9.30, and 9.27 mg kg^{-1} DM, respectively) with no significant difference between them. Red Emmalie showed the highest B content, followed by Violetta and Salad Blue, while Tornado and Laura showed the lowest content of this element.

Table 4. The content of macroelements (g kg^{-1} DM) in potato tubers from conventional, organic, and biodynamic practices.

Macro-Elements	Farming systems			Cultivars				
	Conventional Potato	Organic Potato	Biodynamic Potato	Red Emmalie	Violetta	Salad Blue	Tornado	Laura
N	19.31 ± 0.60 a	19.70 ± 0.20 a	18.77 ± 0.27 a	20.15 ± 0.89 a	19.07 ± 1.60 ab	19.47 ± 1.50 ab	19.34 ± 1.75 ab	18.28 ± 1.65 b
P	2.40 ±0.04 b	2.73 ± 0.14 a	2.65 ± 0.06 a	2.64 ± 0.38 a	2.66 ± 0.19 a	2.56 ± 0.14 a	2.54± 0.21 a	2.56 ± 0.41 a
K	22.89 ± 0.45 b	25.49 ± 0.67 a	24.06 ± 0.73 ab	27.61 ± 2.19 a	24.61± 1.73 b	21.64 ± 1.52 c	23.10 ± 1.81 bc	23.77 ± 1.79 bc
Ca	0.37 ± 0.02 b	0.43 ± 0.02 a	0.42 ± 0.05 ab	0.44 ± 0.09 b	0.52 ± 0.02 a	0.38 ± 0.04 bc	0.35 ± 0.06 c	0.35 ± 0.09 c
Mg	1.12 ± 0.08 b	1.53 ± 0.05 a	1.24 ± 0.09 b	1.39 ± 0.23 ab	1.20 ± 0.18 ab	1.10 ± 0.06 b	1.17 ± 0.08 b	1.62 ± 0.23 a

[1] Different lower-case letters (a, b, c) indicate significant differences between farming systems and cultivars ($p < 0.05$).

Table 5. The content of microelements (mg kg^{-1} DM) in potato tubers from conventional, organic, and biodynamic practices.

Micro-Elements	Farming Systems			Cultivars				
	Conventional Potato	Organic Potato	Biodynamic Potato	Red Emmalie	Violetta	Salad Blue	Tornado	Laura
Fe	57.50 ±1.84 c [1]	127.68 ± 8.10 a	98.26 ± 4.71 b	84.13 ± 14.83 b	101.93 ± 16.30 b	141.13 ± 16.20 a	94.24 ± 14.88 b	50.97 ± 8.57 c
Cu	3.04 ± 0.20 b	2.96 ± 0.20 b	4.43 ± 0.24 a	3.03 ± 0.73 a	3.55 ± 1.24 a	3.62 ± 0.56 a	3.92 ± 1.13 a	3.27 ± 0.42 a
Mn	7.50 ± 0.80 b	11.02 ± 0.80 a	8.39 ± 0.63 b	7.42 ± 1.36 b	9.30 ± 1.45 ab	11.12 ± 2.93 a	9.27 ± 1.89 ab	7.73 ± 1.12 b
Zn	14.42 ± 0.40 b	15.80 ± 0.10 a	14.76 ± 0.35 b	15.77 ± 0.44 a	14.50 ± 1.75 a	15.83 ± 0.77 a	14.57 ± 2.13 a	14.30 ± 2.05 a
B	4.89 ± 0.52 b	6.22 ± 0.55 a	3.78 ± 0.46 b	6.28 ± 0.73 a	5.57 ± 1.27 ab	5.27 ± 1.57 ab	4.37 ± 0.97 bc	3.33 ± 0.55 c

[1] Different lower-case letters (a, b, c) indicate significant differences between farming systems and cultivars ($p < 0.05$).

Numerous studies have confirmed that farming methods have an effect on macro- and microelement contents of crops, but the effects are not the same for all elements. Our studies agree with the findings of Wszelaki et al. [33] who reported that K, P, Mg, S, and Cu contents were higher in organic than in conventional tubers. In the study of Griffiths et al. [34], organic potatoes had more Cu and Mg, less Fe and Na, and the same concentration of Ca, K, and Zn as conventional potatoes. Similar results were demonstrated by Warman and Havard [35], who reported that the contents of P, Ca, and Mg were higher in organically fertilized potato plots than in conventional ones. In studies done by other researchers, P and K were higher in organic potatoes than in conventional ones [36]. Kumpulainen [37] found that organically grown potatoes and carrots had higher K and Na contents, while conventionally grown ones had higher N content. In Poland, in a recent study conducted by Wierzbowska et al. [38], organically grown potatoes had a higher content of B (8.6–8.9 mg kg^{-1}) and Cu (2.8–3.1 mg kg^{-1}), and a lower content of Fe (47.0–47.1 mg kg^{-1}), Mn (6.0–6.4 mg kg^{-1}), and Zn (11.9–12.2 mg kg^{-1}) than potatoes grown in conventional systems. Gąsiorowska et al. [39] reported that potatoes cultivated in the integrated production system contained more Cu, Mg, and Zn, whereas organic tubers had more Fe and B.

According to some authors, soil that has been managed organically has more microorganisms [40,41]. These microorganisms produce many compounds that help plants, including substances that combine with soil minerals and make them more available to plant roots [42]. The presence of these microorganisms at least partially explains the trend that shows a higher mineral content in organic food crops. Also, several studies found that some element concentrations in vegetables decreased under higher treatments of N fertilizer [43,44]. However, the effect of N fertilizers on the mineral content of vegetables is variable depending on the doses applied, the nutrient analyzed, the species under study, and the organ to be consumed [45].

4. Conclusions

The results of our studies show that the highest soil microbial biomass contents, dehydrogenase activity, and humus contents were found before potato planting in the conventional farming system. However, after the harvesting period, these soil biological indicators significantly decreased in the soil of conventional farming, but significant increases were recorded in the organic and biodynamic treatments. The highest contents of all tested nitrogen forms, phosphorus and potassium, were found in the middle of the potato growing season in the conventional farming system. Before harvesting, significant decreases in all studied agrochemical soil quality indicators were observed in all farming systems.

Mineral composition in potatoes depends on the farming type and the cultivar. The organic and biodynamic potatoes appeared to be richer in mineral elements such as K, P, and Ca in comparison with the conventional ones. In addition, organic samples contained significantly more Mg, Fe, Mn, Zn, and B than biodynamic and conventional potatoes. Therefore, this study confirms that the farming systems may have a significant impact on the mineral composition of potato tubers. The organic and biodynamic potatoes appeared to be richer in macro- and microelements. Comparing the cultivars, it was found that Red Emmalie contained more K, N, P, and B. Salad Blue had the highest contents of Fe, Mn, and Zn in comparison with other studied cultivars.

However, more long-term studies are needed to better understand the impact of different agricultural management practices on the biological and agrochemical soil properties and mineral composition of potato tubers.

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References

1. Hunter, D.; Fanzo, J. Agricultural Biodiversity, Diverse Diets and Improving Nutrition. In *Diversifying Food and Diet: Using Agricultural Biodiversity to Improve Nutrition and Health*; Franzo, J., Hunter, D., Borelli, T., Mattei, F., Eds.; Issues in Agricultural Biodiversity: Earthscan, UK, 2013; pp. 1–13.
2. Gomiero, T.; Pimentel, D.; Paoletti, M.G. Environmental impact of different agricultural management practices: Conventional vs. organic agriculture. *Crit. Rev. Plant Sci.* **2011**, *30*, 95–124. [CrossRef]
3. Smith-Spangler, C.; Brandeau, M.L.; Hunter, G.E.; Bavinger, J.C.; Pearson, M.; Eschbach, P.J.; Sundaram, V.; Liu, H.; Schirmer, P.; Stave, C.; et al. Are organic foods safer or healthier than conventional alternatives? A systematic review. *Ann. Intern. Med.* **2012**, *157*, 348–366. [CrossRef] [PubMed]
4. Herencia, J.F.; García-Galavís, P.A.; Dorado, J.A.R.; Maqueda, C. Comparison of nutritional quality of the crops grown in an organic and conventional fertilized soil. *Sci. Hortic.* **2011**, *129*, 882–888. [CrossRef]
5. Gugala, M.; Zarzecka, K.; Mystkowska, J. Potato tuber content of magnesium and calcium depending on control methods. *J. Elem.* **2012**, 247–254. [CrossRef]
6. White, P.J.; Broadley, M.R. Biofortification of crops with seven mineral elements often lacking in human diets–iron, zinc, copper, calcium, magnesium, selenium and iodine. *New Phytol.* **2009**, *182*, 49–84. [CrossRef] [PubMed]
7. Allaga, J.; Horvath, S.; Szuts, G. Effect of large doses of nitrogen and potassium fertilizers on the crude protein content and amino acid composition of potato. *Acta Agron Hung.* **1999**, *47*, 277–286.
8. Ukom, A.N.; Ojimelukwe, P.C.; Alamu, E.O. All trans-cis β-carotene content of selected sweet potato (Ipomea batatas (L) Lam) varieties as influenced by different levels of nitrogen fertilizer application. *Afr. J. Foo Sci.* **2011**, *5*, 131–137.
9. Wroniak, J. Nutritional values of edible potato (Walory zywieniowe ziemniaka jadalnego). *Ziemn. Pol.* **2006**, *2*, 17–20.
10. Hamouz, K.; Lachman, J.; Dvorak, P.; Hejtmankova, K.; Cepl, J. Antioxidant activity in yellow and purple-fleshed potatoes cultivated in different climatic conditions. *Zesz. Probl. Postep. Nauk Rol.* **2008**, *530*, 241–247.
11. Rosen, C.J.; Kelling, K.A.; Stark, J.C.; Porter, G.A. Optimizing phosphorus fertilizer management in potato production. *Am. J. Potato Res.* **2014**, *91*, 145–160. [CrossRef]
12. Biodynamic Association Certification. *Demeter and Organic Production Standards for the Use of Demeter and Related Trademarks*; Biodynamic Association: Stroud, UK, 2012; pp. 1–79.
13. Oreshkin, N. Extraction of mobile forms of phosphorus and potassium by the Egner–Riehm–Domingo method. *Agrokhimiia* **1980**, *8*, 135–138.
14. Lithuanian Organization for Standardization. LST ISO 10390:2005; *Soil Quality. Determination of pH*; Lithuanian Organization for Standardization: Vilnius, Lithuania, 2005.
15. Tabatabai, M.A. Soil Enzymes. In *Methods of Soil Analysis, Part 2*; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; American Society of Agronomy, Soil Science Society of America: Madison, WI, USA, 1982; pp. 903–947.
16. Järvan, M.; Edesi, L.; Adamson, A.; Võsa, T. Soil microbial communities and dehydrogenase activity depending on farming systems. *Plant Soil Env.* **2014**, *60*, 459–463. [CrossRef]
17. International Organization for Standardization. ISO/FDIS 23753-2; *Soil Quality. Determination of Dehydrogenase Activity in Soils, Part 2: Method using Iodotetrazolium Chloride (INT)*; International Organization for Standardization: Geneva, Switzerland, 2005.
18. International Organization for Standardization. ISO 14240-2:1997; *Soil Quality. Determination of Soil Microbial Biomass, Part 2: Fumigation-Extraction Method*; International Organization for Standardization: Geneva, Switzerland, 1997.
19. Vaitkevičienė, N. A comparative study on proximate and mineral composition of coloured potato peel and flesh. *J. Sci. Food Agric.* **2019**, *99*, 6227–6233. [CrossRef] [PubMed]
20. Lithuanian Organization for Standardization. LST EN 5983-1:2005; *Animal Feeding Stuffs. Determination of Nitrogen Content and Calculation of Crude Protein Content, Part 1: Kjeldahl Method*; Lithuanian Organization for Standardization: Vilnius, Lithuania, 2005.

21. Lithuanian Organization for Standardization. LST EN 15510:2017; *Animal Feeding Stuffs: Methods of Sampling and Analysis. Determination of Calcium, Sodium, Phosphorus, Magnesium, Potassium, Iron, Zinc, Copper, Manganese, Cobalt, Molybdenum and Lead by ICP-AES*; Lithuanian Organization for Standardization: Vilnius, Lithuania, 2017.
22. Wolinska, A.; Stepniewska, Z. Dehydrogenase activity in the soil environment. In *Dehydrogenases*; Canuto, R.A., Ed.; Intech: Rijeka, Croatia, 2012; pp. 183–210.
23. Natal-da-Luz, T.; Lee, I.; Verweij, R.A.; Morais, P.V.; Van Velzen, M.J.M.; Sousa, J.P.; Van Gestel, C.A.M. Influence of earthworm activity on microbial communities related with the degradation of persistent pollutants. *Environ. Toxicol. Chem.* **2012**, *31*, 794–803. [CrossRef]
24. Erhart, E.; Hartl, W. Compost use in Organic Farming. In *Genetic Engineering, Biofertilization, Soil Quality and Organic Farming*; Lichtfouse, E., Ed.; Springer: Dordrecht, The Netherlands, 2010; Volume 4, pp. 311–345.
25. Schellenberger, S.; Drake, H.L.; Kolb, S. Impairment of cellulose- and cellobiose-degrading soil Bacteria by two acidic herbicides. *Fems. Microbiol. Lett.* **2012**, *327*, 60–65. [CrossRef]
26. Pampulha, M.E.; Oliveira, A. Impact of an herbicide combination of bromoxynil and prosulfuron on soil microorganisms. *Curr. Microbiol.* **2006**, *53*, 238–243. [CrossRef]
27. Zhou, Y.; Liu, W.; Ye, H. Effects of pesticides metolachlor and S-metolachlor on soil microorganisms in aquisols. II. Soil respiration. *J. Appl. Ecol.* **2006**, *17*, 1305–1309.
28. Menon, P.; Gopal, M.; Parsad, R. Effects of chlorpyrifos and quinalphos on dehydrogenase activities and reduction of Fe3+ in the soils of two semi-arid fields of tropical India. *Agric. Ecosyst. Environ.* **2005**, *108*, 73–83. [CrossRef]
29. Monkiedje, A.; Spiteller, M. Effects of the phenylamide fungicides, mefenoxam and metalaxyl, on the biological properties of sandy loam and sandy clay soils. *Biol. Fertil. Soils* **2002**, *35*, 393–398. [CrossRef]
30. Zhen, Z.; Liu, H.; Wang, N.; Guo, L.; Meng, J.; Ding, N.; Wu, G.; Jiang, G. Effects of manure compost application on soil microbial community diversity and soil microenvironments in a temperate cropland in china. *PLoS ONE* **2014**, *9*, 1–12. [CrossRef]
31. Vaitkevičienė, N.; Kulaitienė, J.; Jarienė, E.; Levickienė, D.; Danillčenko, H.; Średnicka-Tober, D.; Rembiałkowska, E.; Hallmann, E. Characterization of bioactive compounds in colored potato (*Solanum Tuberosum* L.) cultivars grown with conventional, organic, and biodynamic methods. *Sustainability* **2020**, *12*, 2701.
32. Kazimierczak, R.; Średnicka-Tober, D.; Hallmann, E.; Kopczyńska, K.; Zarzyńska, K. The impact of organic vs. conventional agricultural practices on selected quality features of eight potato cultivars. *Agronomy* **2019**, *9*, 799. [CrossRef]
33. Wszelaki, A.L.; Delwiche, J.F.; Walker, S.D.; Liggett, R.E.; Scheerens, J.C.; Kleinhenz, M.D. Sensory quality and mineral and glycoalkaloid concentrations in organically and conventionally grown redskin potatoes (*Solanum tuberosum*). *J. Sci. Food Agric.* **2005**, *85*, 720–726. [CrossRef]
34. Griffiths, A.M.; Cook, D.M.; Eggett, D.L.; Christensen, M.J. A retail market study of organic and conventional potatoes (*Solanum tuberosum*): Mineral content and nutritional implications. *Int. J. Food Sci. Nutr.* **2012**, *63*, 393–401. [CrossRef]
35. Warman, P.R.; Havard, K.A. Yield, vitamin and mineral contents of organically and conventionally grown potatoes and sweet corn. *Agric. Ecosyst. Env.* **1998**, *68*, 207–216. [CrossRef]
36. Woese, K.; Lange, D.; Boess, C.; Boegl, K.W. A comparison of organically and conventionally grown foods-results of a review of the relevant literature. *J. Sci. Food Agric.* **1997**, *74*, 281–293. [CrossRef]
37. Kumpulainen, J. Nutritional and Toxicological Quality Comparison Between Organic and Conventionally Grown Foodstuffs. In Proceedings of the International Fertilizer Society, Lisbon, Portugal, 5 March 2001; pp. 17–19.
38. Wierzbowska, J.; Rychcik, B.; Światły, A. The effect of different production systems on the content of micronutrients and trade elements in potato tubers. *Acta Agr. Scand. B S P.* **2018**, *68*, 701–708.
39. Gąsiorowska, B.; Płaza, A.; Rzążewska, E.; Cybulska, A.; Górski, R. The potato tuber content of microelements as affected by organic fertilisation and production system. *Environ. Monit. Assess.* **2018**, *190*, 522. [CrossRef]
40. Chaudhry, V.; Rehman, A.; Mishra, A.; Chauhan, P.S.; Nautiyal, C.S. Changes in bacterial community structure of agricultural land due to long-term organic and chemical amendments. *Microb. Ecol.* **2012**, *64*, 450–460. [CrossRef]

41. Hartmann, M.; Frey, B.; Mayer, J.; Mader, P.; Widmer, F. Distinct soil microbial diversity under long-term organic and conventional farming. *ISME J.* **2015**, *9*, 1177–1194. [CrossRef]
42. Stevenson, F.J.; Ardakani, M.S. Organic Matter Reactions Involving Micronutrients in Soils. In *Micronutrients in Agriculture*; Mortvedt, J.J., Giordano, P.M., Lindsay, W.I., Eds.; Soil Science Society of America: Madison, WI, USA, 1972; pp. 79–114.
43. Cserni, I.; Peto, J.B.; Huvely, A.; Nemeth, T.; Vegh, K.R. Nitrogen, phosphorous, potassium, acid, sugar and vitamin c content in tomato grown in different soil types and under different nitrogen doses. *Cereal Res. Commun.* **2008**, *36*, 1415–1418.
44. Malvi, U.R. Interaction of micronutrients with major nutrients with special reference to potassium. *Karnataka J. Agric. Sci.* **2011**, *24*, 106–109.
45. Martinez-Ballesta, M.C.; Dominguez-Perles, R.; Moreno, D.A.; Muries, B.; Alcaraz-Lopez, C.; Bastias, E.; Garcia-Viguera, C.; Carvajal, M. Minerals in plant food: Effect of agricultural practices and role in human health. A review. *Agron. Sustain. Dev.* **2010**, *30*, 295–309. [CrossRef]