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Impact of Integrated and Conventional Plant Production on Selected Soil Parameters in Carrot Production

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Abstract: Currently, the level of efficiency of an effective agricultural production process is determined by how it reduces natural environmental hazards caused by various types of technologies and means of agricultural production. Compared to conventional production, the aim of integrated agricultural cultivation on commercial farms is to maximize yields while minimizing costs resulting from the limited use of chemical and mineral means of production. As a result, the factor determining the level of obtained yield is the soil's richness in nutrients. The purpose of this study was to conduct a comparative analysis of soil richness, depending on the production system appropriate for a given farm. The analysis was conducted for two comparative groups of farms with an integrated and conventional production system. The farms included in the research belonged to two groups of agricultural producers and specialized in carrot production.

Keywords: soil fertility; integrated agricultural production; conventional agricultural production; management

1. Introduction

In an agronomic sense, the agricultural system is defined as a way to manage the space for the production of plant and animal products. The agricultural system also includes the processing of primary products [1,2]. In modern agriculture, there are three basic management systems [3,4]: conventional, ecological, and integrated. The basis for this distinction is the extent of dependence of agriculture on the industrial means of production, mainly mineral fertilizers and pesticides, and the degree of their impact on the natural environment [5]. Conventional production is a management method aimed at maximizing profits. It is based on increasing the use of means of production and minimizing the number of agrotechnical operations in order to maximize profits [6,7]. Integrated agriculture is a form of alternative farming, which is based on harmonizing the premises of conventional agriculture with elements of biological plant protection in order to increase the safety of food products.

This form of agriculture treats the farm as an agricultural ecosystem (agro-ecosystem). Its main goal is to maintain a high level of agricultural production, while protecting the population of beneficial organisms that inhabit the ecosystem and preventing soil degradation. The integrated production (IP) of plants is a more restrictive system, in terms of both environmental protection and product safety. To ensure compliance with the principles of IP, quantitative and qualitative restrictions on the use of pesticides, as well as quantitative and technological restrictions related to the use of fertilizers, are introduced. Restrictions related to the use of agrochemicals require more precise application that takes into account a wide range of agrotechnical, climatic, and habitat factors. This requires greater knowledge and experience of producers [8–10]. Due to the smaller number of restrictions related to fertilization and protection, conventional agriculture is a greater burden on the natural environment and is therefore much less effective in achieving ecological goals. However, it should be noted that in both integrated and conventional agriculture, production capacities are not yet fully utilized. Similarly, in both systems, there are opportunities to better achieve environmental goals [11,12].

Created in 2001, the European Initiative for the Sustainable Development of Agriculture (EISA) was developed to promote and defend consistent principles of integrated production in the European Union. One of the first tasks of this organization was to create the Common Codex of Integrated Farming. The document, which presented EISA's policy in terms of integrated agriculture, was published in 2006 and reviewed in 2012. FAO (Food and Agriculture Organization) used the latter version to determine sustainable practices in agriculture [13]. The state of research on implementations of integrated agriculture systems in many Western European countries is advanced [14]. Research by Dutch scientists shows that an integrated farm can achieve income at 94% of the income of a conventional farm. In Germany, where the average area of an integrated farm in Germany is approx. 17 ha [15], the implementation of an integrated system is carried out by, e.g., the Institute for Plant Protection in Stuttgart. In Poland, the integrated production system is currently regulated by the provisions of art. 5 of the Act on Plant Protection of 18 December 2003 (Journal of Laws [Dz. U.] of 2008 No. 133, item 849, as amended) and the Regulation of the Minister of Agriculture and Rural Development of 16 December 2010 on integrated production (Journal of Laws [Dz. U.] of 2010 No. 256, item 1722, as amended). Since 14 June 2007, due to the decision of the Minister of Agriculture and Rural Development, integrated production, as understood by art. 5, par. 1 of the Act on Plant Protection, has been recognized as a national food quality system. Detailed guidelines for the production technology of each plant species are included in methodologies developed by the Main Inspectorate of Plant Health and Seed Inspection. A producer wishing to join the integrated production system is obliged to continue agricultural production based on the methodologies approved by the Chief Inspector of Plant Health and Seed Inspection. Each methodology contains practical information about the planting, care, and harvesting of the crop. At the request of the plant producer, a certificate of integrated production is issued by the regional inspector consistent with the place of cultivation, along with an integrated production trademark signed with the producer's number.

The aim of this research was to assess the soil properties on farms using integrated crop production and on conventional farms.

2. Materials and Methods

2.1. Material

The research objects were two producer groups, varying in terms of the available land resources, direction of production, and the number of members. The main grouping factor was the type of production, i.e., integrated production (22 farms) and conventional production (8 farms). On conventional farms, fertilization was carried out without reference to actual nutritional needs under given agrotechnical and environmental conditions. Therefore, the amounts of biogen introduced into the soil were much higher than the nutritional needs of plants. Plant nutrient balance was not maintained on conventional farms.

The soil sampling scheme included taking 20 primary samples per pooled sample, with one pooled sample per max. 4 ha. The weight of a single sample was approx. 0.5 kg.

2.2. Analytical Methods

Within the assumed objective, in 2016, tests were carried out on 22 farms producing in accordance with the IP standard (Integrated Plant Production) and on eight conventional farms carrying out intensive production with no certified quality management system. All integrated farms were subject to the control of a certification body and were certified based on inspections. The examined farms were located in the Małopolskie (22) and Śląskie (8) provinces and their area ranged from 30 to 90 ha. A soil sample from the 0–20 cm layer was collected from each farm, in accordance with the PN-R-04031:1997 standard at the end of the growing season. The collected soil samples were dried and sieved with a 1 mm mesh sieve. Next, their parameters determining the greatest agricultural usefulness, including the pH, organic carbon content, assimilable forms of phosphorus, potassium, calcium, and magnesium, were designated. The content of assimilable forms of phosphorus and potassium was determined by the Egner Riehm method. The content of the remaining macro- and micronutrients was determined by atomic emission spectrometry (ICP-OES), following prior extraction with acetic acid at a concentration of $0.03 \text{ mol}\cdot\text{dm}^{-3}$. Soil pH was determined using the potentiometric method, in a KCl suspension at $1 \text{ mol}\cdot\text{dm}^{-3}$.

3. Results and Discussion

Carrot (*Daucus carota* L.) is a two-year plant belonging to the celery family (*Apiaceae*), formerly umbellifers (*Umbelliferae*). Carrots are characterized by a high capacity for an excessive accumulation of heavy metals, especially cadmium and lead [16,17]. For this reason, the soil with the lowest content of these elements should be selected for the cultivation of this plant. Growing carrots in the first year after fertilizing with manure is not recommended as it fosters an increased accumulation of nitrates, resulting in distorted and forking roots, which significantly worsen the quality of the produce. In rational pest management, the plant should not be cultivated in monoculture, as well as following other umbelliferous plants [18].

Phosphorus is the basic fertilizer macronutrient that must be delivered to agroecosystems. Intensification of plant production has led to a high demand for this element. As a consequence, the plants' ability to nourish with this element through the soil's ecosystem has become impaired. Phosphorus is taken in the form of phosphoric acid (V) ions. In the plant cell, the element is a component of nucleotides, phospholipids, and adenosine triphosphate (ATP), the latter of which plays a fundamental role as an energy carrier in the plant cell. It participates in the activation of enzymes by their phosphorylation or dephosphorylation. The availability of phosphorus in the initial stage of plant development affects the proper development of roots and thus results in drought and nutrient deficiency resistance. The deficiency of this macronutrient negatively affects the growth and development of plants, which leads to reduced crops and the deterioration of their quality, both sensory and technological. Very often, growth inhibition of lateral shoots is observed. Purple spots appear on the leaves, which, over time, become deformed and dry. The plant blooms; however, it does not bear fruit. Fertilization with phosphorus is carried out based on the soil's content of this element, or when its deficiency in the plant is observed. Phosphorus is a macronutrient, which is very often deficient in agriculturally used soils. The reason for the low content of phosphorus is due, on the one hand, to the insufficient level of fertilization with this element, and on the other hand, to processes related to the chemisorption of this element [11]. Therefore, in addition to application of the phosphate fertilizer itself, the management of the fertilization process includes the control and maintenance of soil properties at an optimum level. The most important parameters affecting the availability of phosphorus for plants are the soil's pH and its content of organic matter [19–21]. Phosphorus is best absorbed by plants at a soil pH of 6–7. In a strongly acidic environment, phosphorus is rebound by combining with aluminum, iron, and manganese cations. On the other hand, at a very high pH, calcium

phosphate precipitates. In line with the principles of the development of sustainable agriculture, primary production management should aim not only at the intensification of production, but also at the quality of yield, as well as at reducing the negative impact of agriculture on individual elements of the environment [22,23]. The proper management of phosphorus in agroecosystems is associated with maintaining an adequate amount of assimilable forms of this element in the soil. Both a too high and too low content of the element in the soil is unfavorable for plants and the environment. Carrot is not a plant with a high demand for phosphorus. The optimum content of phosphorus in soils intended for carrot cultivation varies between 40 and 60 mg P·dcm⁻³ [18]. According to the methodology of integrated carrot production, the level of phosphate fertilization at average soil fertility should amount to about 60–80 kg of P₂O₅·ha⁻¹.

The average phosphorus content in the studied soils from integrated carrot farms was 118.0 mg·kg⁻¹, ranging from 47.87 to 275.2 mg·kg⁻¹. In the soils of farms producing carrots using the conventional method, an average of 29.5 mg·kg⁻¹ more of this element was found, i.e., 147.5 mg·kg⁻¹. No low or very low phosphorus content was found in the soil samples collected from carrot producing farms. In the group of farms with integrated carrot production implemented, an average phosphorus content was observed in 18% of soil samples, whereas in 23% of cases, the content of this element was found at a high level. Approx. 60% of the studied soils contained bioavailable phosphorus compounds at a very high level. In the group of conventional vegetable farms, a high content of phosphorus was found in only one case. On the other hand, the remaining soils contained a very high amount of this element. From the point of view of the rationalization of phosphorus management, it is not beneficial to maintain very high concentrations of this element in the soil. The phosphorus not used by plants undergoes immobilization processes, and as a result of erosion, it enriches aquatic ecosystems, leading to the intensification of eutrophication processes. In addition, very high levels of phosphorus in the soil can lead to a reduced absorption of certain micronutrients, for example, zinc. According to the methodology of integrated carrot production, for carrot cultivation, the optimal content of assimilable phosphorus in the soil should be between 40 and 60 mg·dcm⁻³ [18], which gives approximately 30–75 mg·kg⁻¹. At higher contents of this element, fertilization with phosphorus should be limited. The results of our own research indicate that on approx. 60% of farms carrying out integrated carrot production, and on all conventional farms studied, the content of available phosphorus forms was higher than recommended in the integrated carrot production methodology. On the other hand, in conventional farms, these quantities were much higher (Table 1).

Table 1. Content of available forms of phosphorus in the soils of the studied farms (mg·kg⁻¹).

	Min.	Average	Max.	Median	Standard Deviation
Integrated vegetable farms	47.87	118.0	275.2	116.2	69
Conventional vegetable farms	134.6	147.5	174.5	151.4	13.4

Potassium belongs to the group of macronutrients. One of its most important functions in plants is the regulation of water management and maintenance of cellular turgor. As an activator of many enzymes, it is responsible for regulatory functions and is involved in the synthesis of both simple and complex proteins and sugars. This element has an active part in the transport of nitrate (NO₃⁻) and phosphate (PO₄³⁻) ions, as well as assimilates. It increases plant resistance to frost, diseases, and pests. Potassium is responsible for the proper growth of apple fruits, as well as their color and firmness. A good supply of this element strengthens plants' resistance to drought. Over 50% of agricultural land is characterized by a potassium deficit [24–26], which is why rational fertilization with this element plays a strategic role in the development of modern agriculture. According to the principles of integrated carrot production, the optimal content of potassium in the soil should be 120–150 mg·dm³. The number of doses of fertilization with this element should be determined on the basis of a chemical analysis of the soil. However, when the analysis shows that the potassium content

is equal to or higher than the optimal content, then it is reasonable to reduce the level of fertilization with this element, or in the case of a very high content, to discontinue fertilization altogether in a given year [24]. With a potassium content below optimal, the element should be supplemented with doses higher than that required by the plants. For a fruiting orchard, the level of fertilization should amount to 50–80 kg $K_2O \cdot ha^{-1}$ [18]. The greatest demand for this nutrient occurs in the period of setting of the fruit and its intensive growth. Later, potassium takes part in retarding the growth of tree shoots and entering winter dormancy.

According to the methodology of integrated carrot production, the optimal content of assimilable phosphorus in the soil for carrot cultivation should be between 120 and 150 $mg \cdot dcm^{-3}$ [18], which gives approx. 80–100 $mg \cdot kg^{-1}$. The results of our own research show that on 18% of farms carrying out integrated carrot production, and on all conventional farms, the content of assimilable forms of potassium in soil was much higher than recommended by the methodology (Table 2).

Table 2. Content of assimilable forms of potassium in the soils of the studied farms ($mg \cdot kg^{-1}$).

	Min.	Average	Max.	Median	Standard Deviation
Integrated vegetable farms	48.35	57.9	148.6	52.10	31.32
Conventional vegetable farms	86.2	100.9	248.3	109.6	74.80

Boron is a common element worldwide; however, in agroecosystems, its deficit is observed more and more often [27]. It is most common in the form of boric acid and belongs to the group of micronutrients essential for living organisms [28]. Plants collect boron from the soil through the root system, in the form of anion $H_2BO_3^-$ or in the form of undissociated boric acid molecules (H_2BO_3). Only a part of this element is fully available to plants; usually no more than 5%–6% of the total boron content in the soil, and sometimes even less than 1%. Carrot is very sensitive to the deficiency of some micronutrients, especially boron. The deficiency of this element is most often observed in alkaline soils. The effect of the boron deficit is the stunting of the plant growth cone and the appearance of black spots on carrot roots after washing.

The average content of available boron forms in soil on integrated carrot farms was 2.960 $mg \cdot kg^{-1}$, whereas on conventional farms, it was 1.70 $mg \cdot kg^{-1}$. Soil analysis carried out on integrated fruit farms demonstrated that the average content of available boron was 0.70 $mg \cdot kg^{-1}$, while for conventional production farms, this value fluctuated at 0.66 $mg \cdot kg^{-1}$. The boron contents indicated the possibility of a deficit of this element in the agroecosystem [29].

Calcium plays a very important role in the production of vegetables and fruits. As a nutrient that is not very mobile in the plant, it is absorbed into fruits and vegetables in small quantities, causing a need for its urgent replenishment [30]. For this reason, even a high content of calcium in the soil may not provide a sufficient level of plant nutrition. Therefore, foliar feeding of the apple tree is a necessary element of integrated production, and is an integral part of the full fertilization program. Symptoms of calcium deficiency on vegetative parts of plants are rare, appearing in the form of brightening apical leaves with yellow spots. With a deficit of calcium, apples are small and tend to crack and cork. They are sensitive to sunburn. Regardless of the use of calcium in apple cultivation, its optimal content in soil is a prerequisite for cultivating fruit plants. It improves the soil structure and prevents it from crusting, regulates its pH, and supports soil microbes by accelerating the distribution of organic matter and facilitating the development of the root system. According to the methodology of integrated carrot production, the optimum level of this component in the soil is 1000–2000 $mg \cdot dm^{-3}$ [18], which amounts to approx. 666–1333 $Ca \cdot mg \cdot kg^{-1}$ of soil. The available amount of this element in the soil on farms carrying out integrated carrot production was 1095 $mg \cdot kg^{-1}$ on average, whereas for farms from the conventional group, the average amount of available calcium forms in the soil was 255.9 $mg \cdot kg^{-1}$ (Table 3). An appropriate content of calcium in carrot increases the strength of cell walls, making the roots less susceptible to cracking.

Table 3. Calcium content in the tested soil samples ($\text{mg}\cdot\text{kg}^{-1}$).

	Min.	Average	Max.	Median	Standard Deviation
Integrated vegetable farms	416.4	1095	2119	768.4	536
Conventional vegetable farms	174.6	255.9	474.1	204.4	300.8

Copper plays an important role in plant organisms, impacting the regulation of cellular metabolism [29]. This element controls the transport of electrons in the process of photosynthesis, takes an active part in nitrogen transformations and in the synthesis of proteins and vitamin C, and binds and neutralizes free radicals. Plants require small amounts of copper for proper development. In the majority of soils in Poland, there are shortages of copper. On average, the largest amount of assimilable forms of copper was recorded in the soil from vegetable farms with an integrated production profile ($0.54 \text{ mg}\cdot\text{kg}^{-1}$). Soils collected from vegetable and conventional farms contained $0.39 \text{ mg Cu}\cdot\text{kg}^{-1}$ on average (Table 4).

Table 4. Copper content in the tested soil samples ($\text{mg}\cdot\text{kg}^{-1}$).

	Min.	Average	Max.	Median	Standard Deviation
Integrated vegetable farms	0.25	0.54	1.60	0.50	0.32
Conventional vegetable farms	0.23	0.39	0.73	0.35	0.20

The iron content in the soils of Poland is very diverse, ranging from 0.8% to 1.8% [31]. As a rule, heavy soils contain much more of this element than sandy soils. The physiological functions of this metal in plants are related to the activation of oxidation-reduction reactions associated with many metabolic processes, such as respiration, photosynthesis, or the transformation of nitrogen compounds. The symptom of iron deficiency in plants is iron chlorosis of leaves, which first appears on the youngest leaves. The most important causes of iron deficiency in agroecosystems include intensive cultivation, large temperature fluctuations in the growing season, and intensive exposure. The iron content varies considerably in the individual organs. Its concentration in plant tissues ranges from 50 to 300 ppm [32]. The iron is taken up by plants in the ionic form of Fe^{2+} and the form of chelates. In the case of this micronutrient, its deficiencies are most often associated with soil properties. At a pH level above 6, and with the presence of large quantities of other macro- and micronutrients, the ability of its assimilation by plants may be limited. The average content of available forms of iron in the soil (Table 5) on the farms producing carrots using the integrated method was $0.750 \text{ mg}\cdot\text{kg}^{-1}$, while on conventional farms, the average was $1.330 \text{ mg}\cdot\text{kg}^{-1}$.

Table 5. Iron content in the tested soil samples ($\text{mg}\cdot\text{kg}^{-1}$).

	Min.	Average	Max.	Median	Standard Deviation
Integrated vegetable farms	0.28	0.75	1.65	0.67	0.42
Conventional vegetable farms	0.73	1.33	2.43	1.01	0.49

Most Polish soils are characterized by a low magnesium content [33,34]. The reason for the deteriorating deficit of this element in the soils is their acidification and low content of organic matter [35,36]. Magnesium is an element that is easily washed into deeper soil layers. It is estimated that its annual leaching oscillates between 10 and $40 \text{ kg MgO}\cdot\text{ha}^{-1}$ [37]. Magnesium is taken up by plants in accordance with its osmotic concentration, i.e., passive movement from the soil water. A high content of dissolved magnesium in the soil water allows it to be better absorbed by the roots. In order

to prevent soil degradation and to ensure the supply of this element to plants, its content in soil should be maintained at the level of 60 to 80 mg·dm³, i.e., approx. 40–53 mg·kg⁻¹ [18]. Magnesium is the basic ingredient of chlorophyll. It determines the course of photosynthesis and energy transformations taking place in the plant, as well as the synthesis of proteins, carbohydrates, and fats. Magnesium is an activator of many enzymes. It plays an important role in the construction of cell walls, and thus increases the resistance of plants to diseases. Magnesium deficiency is most often observed in young trees, as chlorosis and necrosis between the main nerves of the leaves, or yellow-purple spots on the lamina. Magnesium deficiency accelerates the generative development of plants and early maturing of fruits. In addition, plants are less resistant to low temperatures. The average magnesium content in the soils in which the carrots were grown in the integrated system was 33.63 mg·kg⁻¹ (Table 6). On conventional farms, however, a slightly smaller amount of this element was found, i.e., 31.90 mg·kg⁻¹.

Table 6. Magnesium content in the tested soil samples (mg·kg⁻¹).

	Min.	Average	Max.	Median	Standard Deviation
Integrated vegetable farms	20.85	33.63	36.95	32.07	3.30
Conventional vegetable farms	29.56	31.90	36.15	3.02	2.05

Manganese is a micronutrient that is essential for the life of plants as it contributes to the processes of nitrogen absorption and protein synthesis, vitamin C synthesis, respiration, and photosynthesis. Manganese deficiency leads to excessive iron uptake by plants. The range of manganese content in the soil varies from 20 to 5000 mg·kg⁻¹ and it occurs in several forms of mineral and organic compounds [37]. The absorption of manganese for plants is strongly correlated with the pH of the soil. Acidic soil promotes solubility of this element. In most cases, acidic soils demonstrate no need for manganese fertilization. Symptoms of manganese deficiency are similar to those of iron deficiency; however, yellowing of leaves starts from the margin of the lamina and develops in a V-shaped direction towards the midrib. In the case of an iron deficit, all veins remain green, while with manganese deficiency, the final vein segments discolor. Most often, manganese deficiency is observed in older leaves. In the case of apple trees, the symptoms of manganese chlorosis occur on long and short shoots. The fruits are small and not very juicy and they quickly lose the green color of the skin. In the case of carrot cultivation, manganese is not as important an element as in the cultivation of apple trees. However, the deficiency of manganese in carrot causes retarded growth, and thus a reduction in yield [38].

The average content of assimilable manganese in the soil recorded for samples from conventional vegetable farms was 41.02 mg·kg⁻¹, while in the integrated production group, it was 33.66 mg·kg⁻¹ (Table 7).

Table 7. Manganese content in the tested soil samples (mg·kg⁻¹).

	Min.	Average	Max.	Median	Standard Deviation
Integrated vegetable farms	5.20	33.56	87.60	29.90	80.0
Conventional vegetable farms	10.95	41.02	97.83	37.54	66.0

Zinc and its compounds are characterized by a good solubility. Its best solubility occurs in acidic and slightly acidic soils [39]. Organic matter and soil minerals bind zinc ions present in the soil. On Polish farms, zinc is an element often overlooked in the process of fertilization, because farmers believe this element has little impact on the yield increase [40,41].

The results of the conducted research indicate that the average content of available zinc forms in the studied soil samples on conventional vegetable farms was $0.710 \text{ mg}\cdot\text{kg}^{-1}$ (Table 8), while in soils from integrated farms, this value fluctuated at $0.580 \text{ mg}\cdot\text{kg}^{-1}$.

Table 8. Zinc content in the tested soil samples ($\text{mg}\cdot\text{kg}^{-1}$).

	Min.	Average	Max.	Median	Standard Deviation
Integrated vegetable farms	0.10	0.58	1.85	0.52	0.41
Conventional vegetable farms	0.20	0.71	1.78	0.56	0.65

Zinc deficiency in agroecosystem plants is often observed at a very high level of phosphorus fertilization, which has been pointed out by many researchers who studying this problem [42]. On the studied farms, the results of our own research indicate a too high level of phosphorus fertilization, inconsistent with the plants' demand. This may lead to an insufficient supply of zinc, especially under intense production conditions.

pH is one of the most important soil parameters, determining its fertility. It is influenced by external and internal factors determined by the applied production techniques. External factors include the type of parent rock, acid rain, and the leaching of alkaline cations, whilst internal factors are fertilization and liming treatments [19]. The pH measured in the aqueous soil suspension indicates the active acidity created by the hydrogen ions found in the soil solution, while the pH measured in the potassium chloride suspension (KCl) also takes into account the acid ions associated with the sorption complex [43].

This parameter determines the conditions of plant growth and development, as well as the direction and speed of biological and physicochemical processes in the soil [43–45]. It is the basic factor affecting the uptake of nutrients by plants, as well as the transformation of nitrogen and phosphorus compounds in the soil. The optimal pH of mineral soil for carrot cultivation is within the range of pH 6–7 [18]. The results of our own research (Table 9) indicate that the soil pH on 27% of farms producing carrot with the integrated methodology was below the optimal values. As a result, on some farms, the necessity of soil liming was identified, while on others, liming was only recommended. Almost 90% of conventional farms also had soil pH below optimal values, thus the need for liming was identified. Only one farm in this group was characterized by a soil with a pH level optimal for carrot production.

The basic element that significantly impacts the formation of soil properties is organic matter consisting of carbohydrates, proteins, fats, and humus. Hummus is part of the organic matter that impacts soil fertility, and is characteristic for each soil [46,47]. The content of organic matter in the soil depends on, e.g., the climate, terrain, parent rock, and water conditions prevailing in the area. In addition, the amount and type of organic matter in the soil are impacted by anthropogenic factors such as indirect or direct human influence on the environment, as well as its flora and fauna. The classification of soils according to the content of humus in soil is presented in Table 10.

The results of tests for humus content in the soils of vegetable and fruit farms indicate large differences between them (Table 11). In the group of integrated vegetable farms, 13.6% of the samples were classified as humus-deficient, 63.6% were low-humus soils, and 22.7% were medium-humus soils. In the above group of farms, there was not a single farm with humus soil. On conventional farms, no humus-deficient soil samples were identified: 62.5% of samples were low-humus soils, 25% were medium-humus soils, and 12.5% were humus soils.

Table 9. Liming demand of individual farms.

	Type of Soil	Reaction	
		pH	Liming
Farms producing carrots in the integrated system			
1	III	4.24	necessary
2	III	6.66	unnecessary
3	III	6.3	unnecessary
4	IV	4.89	necessary
5	III	6.85	unnecessary
6	III	5.21	necessary
7	III	6.65	unnecessary
8	III	6.94	unnecessary
9	III	7.63	unnecessary
10	III	6.4	unnecessary
11	IV	7.05	unnecessary
12	III	5.14	necessary
13	III	6.54	unnecessary
14	IV	6.94	unnecessary
15	IV	6.33	unnecessary
16	III	6.75	unnecessary
17	IV	7.06	unnecessary
18	IV	6.92	unnecessary
19	IV	5.28	necessary
20	III	6.68	unnecessary
21	IV	4.69	necessary
22	III	6.94	unnecessary
Farms producing carrots in the conventional system			
1	III	5.65	necessary
2	III	4.89	necessary
3	IV	4.92	necessary
4	III	6.93	unnecessary
5	III	5.16	necessary
6	III	4.85	necessary
7	IV	4.99	necessary
8	III	4.8	necessary

Table 10. Soil classification according to the content of humus in the soil [48].

Humus-Deficient Soils	less than 1%
Soils with Low Humus Level	1.0%–2.0%
Soils with Medium Humus Level	2.1%–3.0%
Humus Soils	above 3.0%

Table 11. The content of humus in the soils of vegetable farms, based on the obtained test results.

	Farms Producing Carrots in the Integrated System	Farms Producing Carrots in the Conventional System
Humus-deficient soils <1%	3 farms (13.6%)	-
Soils with low humus level 1.0%–2.0%	14 farms (63.6%)	5 farms (62.5%)
Soils with medium humus level 2.1%–3.0%	5 farms (22.7%)	2 farms (25%)
Humus soils (3.0%)	-	1 farm (12.5%)

Research carried out in recent years has shown a decrease in humus content in Polish soils [46]. This is related to the disturbance of hydrographic conditions and intensive soil use. Low levels of humus in Polish soils, as well as risks associated with mineralization, can cause large emissions of carbon dioxide from soils [1,46]. The mechanism that allows humus depletion to be counteracted is the development of agri-environmental programs, under which farmers receive subsidies for the cultivation of after and intercrops improving the balance of organic matter in the soils of their farms.

4. Conclusions

The following conclusions can be drawn from this study:

1. The rational management of plant nutrients and maintenance of appropriate soil parameters are strategic elements of the quality management system in plant production;
2. The results of our own research indicate that on approx. 60% of farms carrying out integrated carrot production, and on all conventional farms studied, the content of available phosphorus forms was higher than recommended in the integrated carrot production methodology. On the other hand, on conventional farms, these quantities were much higher (Table 1);
3. One of the goals of integrated production is to improve soil properties. In the majority of both integrated and conventional farms, balanced fertilization was not implemented due to irrational fertilization with potassium. The result of such a management strategy may negatively impact both the soil and economic efficiency of production [11,14,31,49]. The calcium content in the tested soil samples varied significantly within the compared production systems. Unfavorable values, i.e., below 1000 (mg·kg⁻¹), were observed on farms with the conventional production system;
4. The results of our own research indicate a very small variability in the amount of available forms of iron in individual samples within the research groups. The value of the coefficient of variation in the group of vegetable farms carrying out production in accordance with the principles of integrated and conventional agriculture was 56% and 36%, respectively;
5. The results of the conducted research indicate that on each of the studied farms, both the integrated and conventional group, the soil had a magnesium deficit. A too low magnesium content in the soil can cause plant metabolism disorders;
6. Comparative analysis indicates an insufficient effectiveness of the integrated production system in terms of soil resource management. However, compared to conventional farms, soil resource management on integrated farms follows the concept of sustainable agriculture more closely. The implementation of obligatory consulting on practical aspects of fertilization should impact optimization of the production process.

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