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ASSESSMENT OF THE POSSIBILITY OF USING WASTE FROM AGRI-FOOD PROCESSING FOR FERTILIZATION PURPOSES

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Abstract:
In order to assess the possibility of using waste from agri-food processing for fertilization, residues in the form of apple pomace, carrot root, onion husks and dried nettle were selected for the tests. The research material came from food plants located in north-eastern Poland. In selected waste, the pH value, dry matter content, organic matter, nitrogen, phosphorus, potassium and carbon were determined. It was found that apple pomace, carrot root and onion husk were acidic and dried nettle was alkaline. The nitrogen content in the tested waste ranged from 0.61 to 2.29%, phosphorus from 0.07 to 0.55%, and potassium from 0.19 to 3.72%. Based on the results obtained, it was found that the examined post-production residues are characterized by good fertilizer properties. However, it should be remembered that fertilizers or soil improvers must meet a number of requirements and above all, they must be safe for the environment.

Key words: waste, agri-food processing, fertilizing properties.

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INTRODUCTION

In recent years, environmental protection has become a priority, especially in developed and industrialized countries. This is related to the problem of environmental pollution and its degradation caused by large amounts of waste, both municipal and industrial (Ledakowicz and Krzystek, 2005; Kurcz *et al.*, 2016). Therefore, it is important to reduce the share of waste by managing it properly. Organic residues of plant and animal origin are a special type of waste. They are produced throughout the country, on farms, horticultural and livestock farms, sugar factories, distilleries, dairies, cold stores and other plants involved in the production and processing of food. Considering that in eastern Poland, the dominant branches of agri-food processing are the dairy industry, meat, fruit and vegetables, cereals and distillery and brewing production, the share of organic waste from these industries is the largest (GUS, 2019). The amount of waste generated in agriculture, horticulture, hydroponics, fishing, forestry, hunting and food processing in the Podlasie Province in 2018 was 220.6 thousand tons, of which 170.4 thousand tons were recycled (GUS, 2020). According to the literature data (Białecka, 2008; Dołżyńska *et al.*, 2019; Obidziński *et al.*, 2019), waste from the agri-food industry is to a large extent recycled, mainly for agricultural and energy purposes. In addition, in recent years, research is increasingly being undertaken into the possibility of using waste materials in various biotechnological processes for their further development (Kurcz *et al.*, 2016). Waste from agri-food processing is used in various industries: construction, cosmetics and food (Najafi *et al.*, 2009; Liu *et al.*, 2013; Vaickelionis and Valanciene, 2016; Sharma *et al.*, 2019). The use of waste and production residues for other purposes is a part of a closed-loop economy and this has become a priority for zero waste management in recent years (Okonko *et al.*, 2008; Leśkiewicz, 2017; Esposito *et al.*, 2020).

The use of waste from agri-food processing is associated with numerous studies on the quantity and quality of waste. Waste used for fertilizer purposes must have appropriate fertilizer properties and in addition must not be hazardous to the environment (Górecka and Górecki, 2000; Lopes *et al.*, 2011; Brod *et al.*, 2012). Currently, organic waste can be used directly as a fertilizer or as a raw material for compost production (Hargreaves *et al.*, 2008; Pandey *et al.*, 2016; Sharma *et al.*, 2019).

Taking into account that the abundance of soils in Poland in 2015–2018 has low and medium content of assimilable macroelements such as phosphorus, magnesium and potassium, organic waste can be an indisputable source of these components (Unnisa, 2015; Juliastuti *et al.*, 2017; GUS, 2019). Leśkiewicz (2017) states that in the field of processing of agri-food products an important aspect is the need to reduce the waste produced and use it for fertilizer purposes. This is due to the waste and loss of phosphorus in the environment and to water and soil pollution. Therefore, the need to recycle phosphorus, which is of great importance especially in animal feed and fertilizers, plays an important role. Brod *et al.* (2012) emphasize that today's agriculture relies on the use of mineral fertilizers to provide nutrients to crops. However, the world's fossil fuel and phosphate resources, the raw material for mineral fertilizers, are exhausted. Therefore, in order to ensure food security in the future, we will have to reduce our dependence on mineral fertilizers and replace them with another source of nutrients. In summary, waste from agri-food processing plants is a very large resource of humus-forming organic matter and nutrients for plants, and processing of these resources into useful fertilizers restores the soil its due value (Brod *et al.*, 2012; Zakrzewski and Chabelski, 2016; Sharma *et al.*, 2019).

Taking into account the above, the aim of the study was to assess the fertilizer properties and to determine selected physical and chemical parameters of waste from agri-food processing. Organic waste such as apple pomace, onion husks, carrot root, dried nettle, from food and herbal plants located in north-eastern Poland were selected for the research.

MATERIAL AND METHODS

In order to assess the fertilizing properties of waste from the agri-food industry, residues from fruit and vegetable processing and the herbal industry were selected. The Waste came from plants located in the Podlasie Voivodeship, where the dominant branches of the agri-food industry are milk, meat, fruit and vegetable processing plants. The specificity of the production in this region is determined by the typically agricultural nature of the voivodeship, where the agricultural area in 2018 was 1,072.7 thousand hectares. About 86% of the area of farms consists of the arable land, while forests and forest land occupy 10% only. The most common agricultural crops are cereals, legumes and potatoes. On the other hand, among vegetable crops, the largest area in 2019 was that of cabbage, cauliflower, onions and carrots. Among the fruit crops, apples are dominant (GUS 2019, 2020). Therefore, based on this they were selected for testing waste derived from processing of fruit and vegetables.

However, when describing soil conditions in the Podlasie Voivodeship, it can be concluded that the soils are over-acidified, not very rich in nutrients and have the lowest average agricultural usefulness in Poland, so the consumption of mineral fertilizers in 2018 was 124 kg/ha (GUS, 2019). Therefore, the tested waste may be a source of nutrients for plants grown in the Podlasie Voivodeship.

Taking the above into account, apple pomace, onion husks, carrot root and dried nettle were selected for the research. The apple pomace was a mixture of seeds, seed nests and peels. The carrot root is the remains and cuttings from the production line for the production of frozen food. The onion husk is the so-called "dry husk" coming from peeling the onion by hand. The dried nettles are the remains of the herbal plant, producing among other herbal teas of nettle.

Table 1. Methodology of laboratory tests.

Parameter	Method	Research equipment
dry matter	drying and weighing	Moisture analyzer RADWAG MAC 210
organic matter	weight (loss on ignition)	Muffle furnace SNOL
pH	potentiometric	IQ Scientific ISFET Handheld pH meter
potassium (K)	spectrophotometry	The BWB XP Flame Photometer
nitrogen (N)	Kjeldahl method	Analyzer Vapodest Vap50 Gerhard
phosphorus (P)	spectrophotometry	Spectrophotometer UV-1800 Shimadzu
carbon (C)	catalytic oxidation by combustion	Carbon analyzer (TOC-L) Shimadzu

Selected waste was subjected to physical and chemical tests. The pH, dry matter, organic matter, nitrogen, phosphorus, potassium and carbon were determined in properly prepared samples (Table 1).

Selected tests were performed in five repetitions. Before the average pH value was calculated, the obtained results were converted to hydrogen concentration, from which the average value was calculated, then converted to the average pH value. The ANOVA variance analysis with Tukey's *post hoc* test was used to determine the differences between the mean values using Statistica 13.

RESULTS

Based on the conducted research, the selected wastes from agri-food processing were found to be characterized by different values of the determined fertilization indices (Table 2).

From among the analyzed waste, only dried nettle was slightly alkaline, while the rest were acidic. The lowest pH value was found in apple pomace (Fig. 1). Research by Ülger *et al.* (2018) also showed that the apple pomace is acidic, the value of which depends on the variety of apples. Given the pH of apple pomace, direct application to the soil should be avoided. Before using them as a fertilising product, they should be subjected to other processes, e.g. composting with the addition of other organic waste (Jiang *et al.*, 2014; Zhou *et al.*, 2017; Krasowska and Kowczyk-Sadowy, 2018). Due to the fact that soils in Poland are acidic (Filipek and Skowrońska, 2013), the pH of the applied fertilizers or soil improvers should be taken into account to prevent excessive acidification of the soil.

Comparing the average content of dry matter in selected wastes, statistically significant differences were found

Table 2. Descriptive statistics of selected physicochemical properties of the tasted agri-food processing waste.

Waste		pH	Dry matter content	Organic matter content	N	P	K	C
			[%]					
Apple pomace	**Average**	**4.03**	**24.05**	**97.23**	**0.61**	**0.07**	**0.19**	**6.99**
	Min	3.73	21.84	96.28	0.39	0.06	0.13	5.99
	Max	4.25	25.84	98.13	0.89	0.08	0.27	8.26
	SD	0.21	1.92	0.79	0.19	0.007	0.06	0.91
Carrot root	**Average**	**5.42**	**12.72**	**95.83**	**0.64**	**0.38**	**2.83**	**9.77**
	Min	5.34	12.18	94.69	0.43	0.32	2.39	9.37
	Max	5.53	13.06	96.72	0.77	0.48	3.13	10.12
	SD	0.07	0.38	0.84	0.13	0.06	0.30	0.29
Dried nettle	**Average**	**7.99**	**91.85**	**79.71**	**2.29**	**0.55**	**3.72**	**32.06**
	Min	7.91	91.33	78.24	1.21	0.44	3.29	29.18
	Max	8.12	92.25	81.32	2.93	0.67	4.28	33.8
	SD	0.08	0.38	1.14	0.74	0.09	0.37	1.83
Onion husks	**Average**	**4.48**	**75.91**	**96.23**	**1.7**	**0.21**	**1.48**	**28.92**
	Min	4.43	72.14	94.26	1.1	0.15	1.36	21.18
	Max	4.52	78.16	97.24	2.2	0.29	1.58	39.00
	SD	0.03	2.34	1.19	0.45	0.05	0.08	7.09

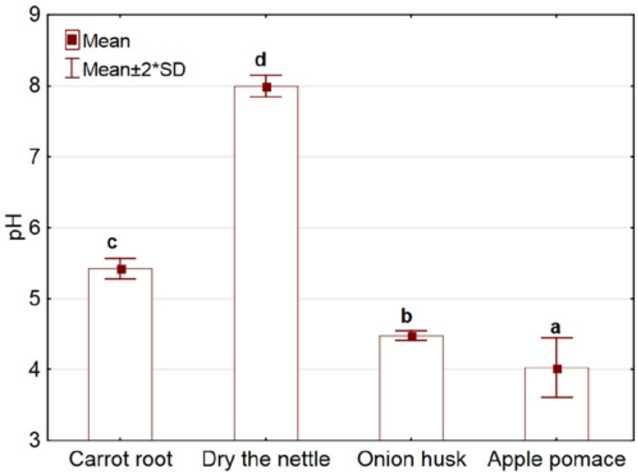

Fig. 1. The pH value of tested wastes from agro-food processing; a, b, c, d – the same letters in the columns next to the mean values denote the absence of statistically significant differences compared by Tukey's test α <0.05.

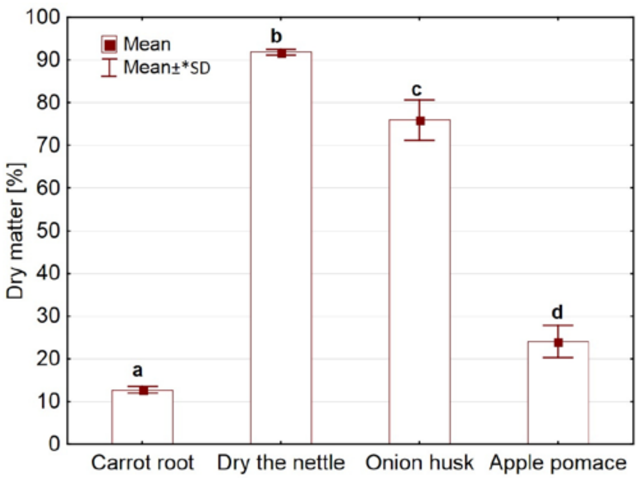

Fig. 2. Dry matter content [%] in the analyzed wastes from agri-food processing; a, b, c, d – the same letters in the columns next to the mean values denote the absence of statistically significant differences compared by Tukey's test α <0.05.

(Fig. 2). However, dried nettle was characterized by more than 90% of dry matter. Such a high content of dry matter results from the production process of nettle teas produced from dried nettle leaves. This has implications for the storage of these post-production residues. On the other hand, onion husk also had a high dry matter content. According to Dach and Niżewski (2008), two types of onion husk are produced in typical processing plants: from manual peeling, with high dry matter content (up to 75%), hereinafter referred to as "dry husk", and during machine peeling, with relatively low dry matter content (usually in the range of 12–25%). Carrot root and apple pomace were raw post-production waste and therefore had low dry matter content. A study by Wichrowska and Żary-Sikorska (2015) found that wet apple pomace contained approximately 32% dry matter, while dried pomace can contain over 92%. In contrast, based on a study by Sikora *et al*. (2009), the dry matter content of carrot roots can range from 10.51 to 11.28 mg·100g^{-1}f.m. depending on variety and crop. Considering the use of these wastes, it should be remembered that untreated wastes with low dry matter content spoil quickly and may be a source of microbiological contamination. Furthermore, prolonged storage of such waste in a fresh state changes its physico-chemical composition. Leading to a decrease in their value and usefulness, they should be therefore managed as soon as they are obtained. Drying of pomace in the mother plant in a closed technological cycle seems to be a suitable method (Gullon *et al*., 2007; Tarko *et al*., 2012).

An analysis of organic matter content was also conducted and based on Tukey's test, no statistically significant differences were found between the average organic matter content of apple pomace, onion husk and carrot root (Fig. 3). The organic matter content of these wastes ranged from about 96 to 97%. The lowest organic matter content was found in the samples of dried nettle. This indicator affects soil fertility and determines, among others, its ability to retain and release macro and micro elements into the soil solution. It counteracts negative changes in pH and

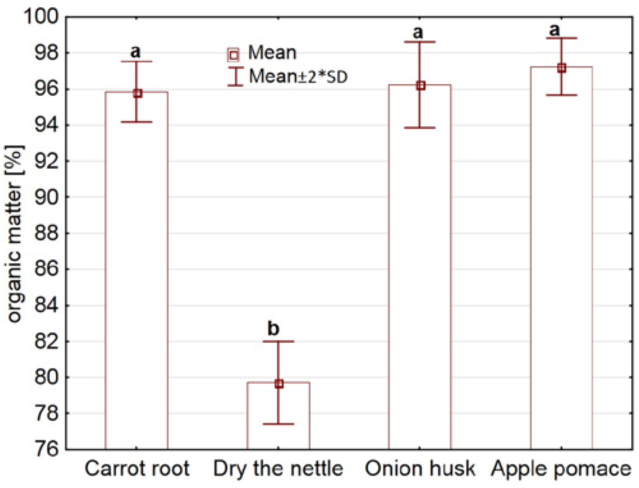

Fig. 3. Organic substance content [%] in the analyzed wastes from agri-food processing; a, b, c, d – the same letters in the columns next to the mean values denote the absence of statistically significant differences compared by Tukey's test α <0.05.

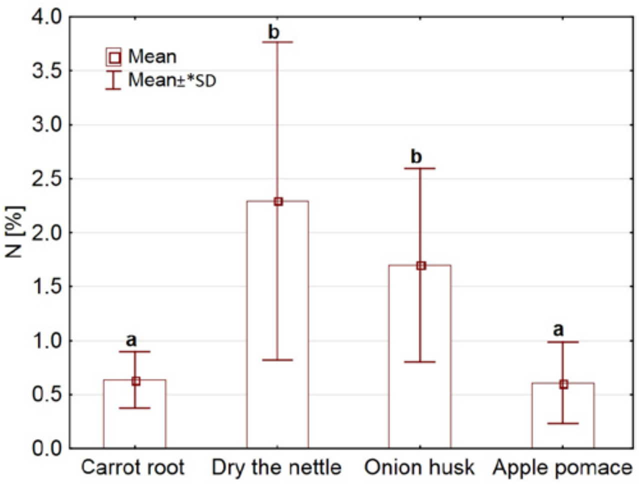

Fig. 4. The content of nitrogen N [%] in the analyzed wastes from agri-food processing; a, b, c, d – the same letters in the columns next to the mean values denote the absence of statistically significant differences compared by Tukey's test α <0.05.

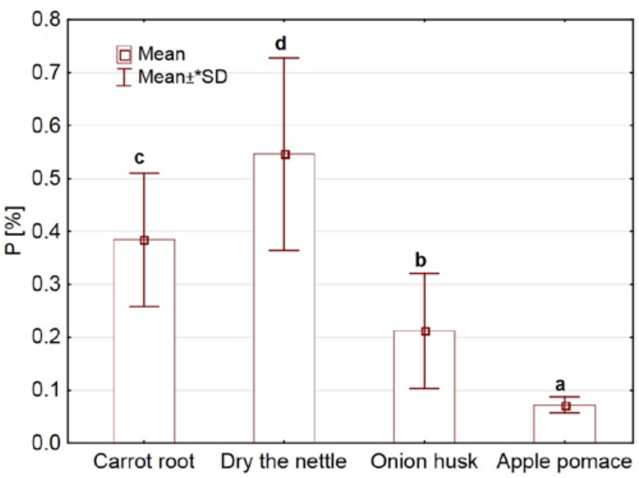

Fig. 5. The content of phosphorus P [%]in the analyzed wastes from agri-food processing; a, b, c, d – the same letters in the columns next to the mean values denote the absence of statistically significant differences compared by Tukey's test α <0.05.

affects the soil ability to retain and store water (Gonet and Markiewicz, 2007; Singh *et al*., 2011; Singh *et al*., 2012).

The content of fertilizer indicators, i.e. nitrogen, phosphorus and potassium (N, P, K) was differentiated. Dried nettle was characterized by the highest content of all analyzed components, while apple pomace by the lowest. The content of nitrogen in the studied samples was differentiated and based on the average values, two groups were distinguished (nettle – onion husk and carrot root – apple pomace), for which no statistically significant differences were found (Fig. 4). Statistically significant differences were found for the mean phosphorus and potassium contents of the tested wastes (Figs 5 and 6).

Waste from agri-food processing is characterized by a diversified composition. Based on the study of Juliastuti *et al*. (2017), the corn and banana peel residues used for compost production were found to contain less N, P, K than the studied wastes. The contents of these components in the corn and banana compost mixture were N – 0.57%, P – 0.18% and K – 0.09%, respectively. Unnisa (2015) conducted a study on the quality of fertilizer from food waste from restaurants and hotels. From this study, a liquid organic fertilizer was obtained with the following composition: N – 1.15%, P – 0.308% snd K – 0.7%. In contrast, Jeng *et al*. (2006) indicate a significant proportion of these elements in a bone meal (N – 8%, P – 5%) and report that this waste can be a source of nitrogen and phosphorus fertilizer used to fertilize cereals and grasses.

Comparing the content of fertilizer components in selected organic wastes with manure and chicken dung it was found that carrot root, dried nettle and onion husk contained more nitrogen, phosphorus and potassium than manure, which according to Górecka and Górecki (2000) is characterized by the following composition: N – 0.48%, P – 0.18% and K – 0.61%. In addition, this waste contained more potassium than chicken dung with the composition of N – 1.92%, P – 1.42% and K – 0.92%.

Considering the fertilizing properties, the carbon content of the studied wastes is important because this component forms the basis of humus-forming compounds in the soil after fertilization. According to Mazur and Mazur (2015), cattle manure has a carbon content of 8 to 9%, green waste compost about 10% and wheat straw 32 to 38%. On the other hand, the carbon content of the studied wastes was the highest in the case of dried nettle (about 32%) and the lowest in apple pomace (about 7%). No statistically significant differences were found for the mean values of two groups: in dried nettle and onion hulls and in carrot root and apple pomace (Fig. 7).

When analyzing the fertilizer properties of organic wastes, it is important to note that nitrogen from organic fertilizers is released gradually during the mineralization of organic matter, with the dynamics of this process depending on the carbon/nitrogen ratio of the fertilizer (Rutkowska, 2014; Swangjang, 2015). In the case of the analyzed samples, the ratio of carbon to nitrogen (C:N) ranged from 11.5:1 for apple pomace to 17:1 for onion husk. This relationship is also important from the point of view of the

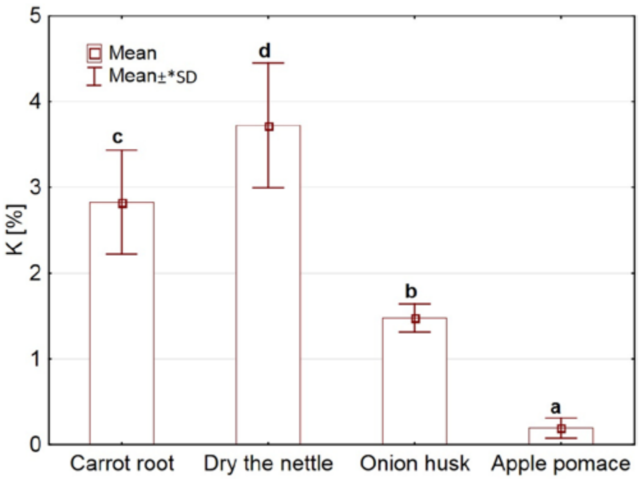

Fig. 6. The content of potassium K [%]in the analyzed wastes from agri-food processing; a, b, c, d – the same letters in the columns next to the mean values denote the absence of statistically significant differences compared by Tukey's test α <0.05.

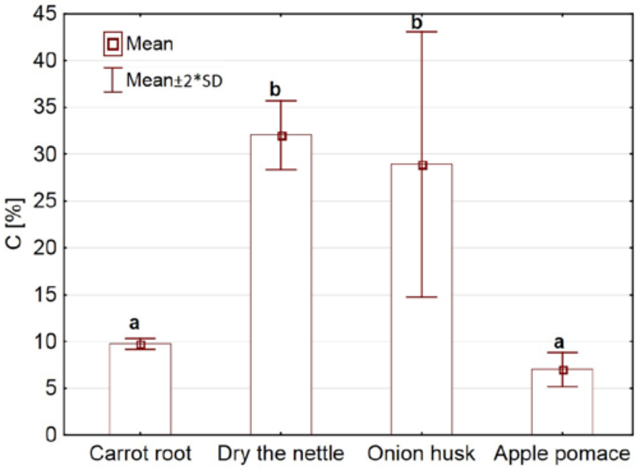

Fig. 7. The content of carbon C [%] in the analyzed wastes from agri-food processing; a, b, c, d – the same letters in the columns next to the mean values denote the absence of statistically significant differences compared by Tukey's test α <0.05.

use of selected waste for composting purposes. The formation of mixtures involved in this process depends largely on the C:N ratio. According to the literature for the composting process, the optimum C:N ratio is about 30:1, so in order to obtain the optimum it is necessary to know the carbon and nitrogen content of the organic materials used as ingredients to produce compost (Shilev *et al*., 2006). According to Shilev *et al*. (2006) the organic fraction of municipal waste has the C:N value of about 12, sewage sludge 6, vegetable scraps 20, leaves 34–85, and sawdust 150. Considering the above, the use of the studied agro-food processing waste for composting purposes would require the addition of a higher carbon content feedstock to equalize the C:N ratio.

Based on the obtained results, the tested organic waste (apple pomace, onion husks, carrot root, dried nettle) from agri-food processing are characterized by good fertilizing properties. In the analyzed samples the nitrogen content ranged from 0.61 to 2.29%, phosphorus from 0.07 to 0.55% and potassium from 0.19 to 3.72%. At the same time, the dried nettle contained the highest amount of the examined elements and the aqueous solution was alkaline. Therefore, nettle drought has good fertilizing properties and when used to fertilize a soil, it will not cause its acidification. However, the fertilizers or soil improvers must meet a number of requirements and above all, they must be physically, chemically and biologically safe for the environment. Examples are apple pomace or carrot root, which contain a small amount of dry matter, so may be perishable and may therefore be a source of microbial contamination. In addition, organic waste should be neutralized or managed immediately after its production, because stored fresh may be subject to changes in physical and chemical properties, which in turn may lead to a reduction in its value and usefulness.

RECAPITULATION

Considering that the food sector in Poland has undergone major transformations in recent decades and that Poland has become an important exporter of food among the European Union countries, this has a huge impact on the amount of organic waste generated. Therefore, their use for fertilization may contribute to the improvement of the quality of the environment and is part of the issues of the circular economy.

Recycling organic waste as fertilizer has several advantages waste management, since it reduces dependence of inorganic fertilizers, and reduces the processing and storage of waste. The use of organic waste, including apple pomace, onion husks, carrot roots and dried nettle, directly on farmland or through composting provides nutrients to the soil and by increasing the proportion of soil organic matter and nutrients, it improves its structure and influences pH of a soil.

The management of organic residues for fertilizer purposes is important due to the content of fertilizer nutrients in soils in Poland. Data from the Statistics Poland (GUS, 2019) indicate that the abundance of bioavailable macronutrients such as phosphorus, magnesium, potassium in Polish soils in 2015–2018 is low to medium. Therefore, organic waste can be an undeniable source of these nutrients. Considering that the world resources of fossil fuels and phosphate rock, the raw material for mineral fertilizers are being depleted, it is necessary to replace them with another source of nutrients to ensure food security in the future. This deficit can be met by waste from agro-food processing plants, which is a very large resource of humus-forming organic matter and nutrients for plants.

A return of waste to agricultural land by using it as fertilizing products is a systemic approach that requires further research, because a significant part of organic waste is still unused and its components are lost, especially in north-eastern Poland, where the dominant branches of agri-food processing are the dairy industry, meat, fruit and vegetable processing.

CONCLUSIONS

Based on the conducted research, the following conclusions were obtained:

1. Among the studied agri-food wastes, apple pomace and onion hulls had the lowest pH value, therefore their direct application to soil may lead to soil acidification.

2. The dry matter of dried nettle had the best fertilizing properties because of the highest content of nitrogen, phosphorus and potassium.

3. Taking into account the content of organic matter in the analyzed waste, dried nettle was characterized by the lowest content of about 80%, and the remaining waste contained over 95% of organic matter.

4. The most favourable ratio of carbon to nitrogen was recorded in the case of onion husk (17:1), which influences the dynamics of organic matter decomposition.

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