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Chemical composition of chicory root ash (*Cichorium intybus* L.) depending on the yield level

Abstract. The world practice of growing chicory root is ineffective for Ukrainian phenotypic forms of varieties, since the weight and shape of the root crop, and the accumulation of ash elements in the plant, differ from modern forms. The purpose of the study was to establish the features of accumulation of the main ash macro- and microelements in the root crop and leaf mass of chicory of the Umanskyi-99 variety, considering the different background of mineral nutrition, the size of root crops, and yield levels. The study was conducted on the premises of the Khmelnytskyi state agricultural experimental station of the Podillia Institute of Feed Research and Agriculture of the National Academy of Sciences of Ukraine. The leaf mass (petioles and leaf blade) and root crops were combusted, and then the content of potassium, phosphorus, calcium, magnesium, sodium, and a complex of meso- and microelements (Ba, Si, Fe, Mn, Al, Cu, B, Cr, Zn, Co) was determined in the ash using a spectrograph, or using standardised methods. The content of the studied trace elements in leaves, roots, and petioles ranged from 1×10^{-4} up to 1×10^{-2}%. The specific removal of nutrients to form 8.1 t/ha of root dry matter and the corresponding amount of by-products was 216.6 kg/ha of nitrogen, 79.6 kg/ha of phosphorus, 277.9 kg/ha of potassium, 92.7 kg/ha of calcium, 88 kg/ha of magnesium, and 109.3 kg/ha of sodium. A significant part of macronutrients accumulated in the leaf mass, so about 60-84% of the removed elements were returned to the soil. It is established that the chemical composition of ash of different-sized and different-yielding root crops differs. The content of phosphorus and potassium in root crops at an average yield level is the lowest among the samples under study, and at a high yield, it significantly exceeds low-yielding ones. Therefore, for optimal removal of nutrients when growing chicory root crops, a fertiliser system should be developed to obtain commercial roots at the level of average yield, which would reduce the specific removal of phosphorus and potassium. The practical significance of the results obtained is to highlight the features of the removal of the main macronutrients by chicory root plants, which is the basis for developing an effective fertiliser system for a high planned yield and choosing a strategy for using by-products (leaf mass) as a source of immobilised nitrogen, phosphorus, and potassium

Keywords: combustion of vegetative organs, different quality of root crops, spectrogram, nitrogen forms

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INTRODUCTION

Chicory root is a promising technical crop with a high yield potential and undemanding cultivation technology. The advantage of chicory root crops is the presence in their composition of a polymer carbohydrate – inulin, which consists of glucose residues and belongs to dietary fibre by its nutritional value [1-3]. From a technological standpoint, inulin does not require chemical hydrolysis to start alcoholic fermentation in yeast culture, so the cost of producing alcohol from chicory is 1.2-1.5 times less compared to starch [4; 5]. The content of inulin in chicory roots is 42-76 g/100 g of dry matter [6] and varies depending on the growing conditions, technology elements, root size, and fertiliser system [7].

The development of root crop yields closely depends on the chemical composition of the product and the availability of nutrients in the soil. In contrast to sugar beet, the ratio of leaf and root fractions in the plant can vary significantly [8], so it is necessary to determine the content and gross removal of the main macro-, meso-, and microelements by root crops and the leaf mass of chicory, to establish the dependence of this removal between the yield and economic characteristics of the roots (size).

Chicory growing conditions have a decisive influence on the content of macro- and mesoelements in individual plant organs. G.L. Lenz *et al.* [9] indicated that the concentration of phosphorus and potassium in the leaves varied depending on the shape of the substrate and the time of cultivation, i.e., low photoperiodicity. Overall, they noted that the phosphorus content of chicory leaves ranged from 1.5 to 2.2 g/kg of crude weight, and potassium – from 41 to 76 g/kg of crude weight. However, the results obtained are not entirely representative, since the phenology of the studied varieties in terms of size and structure of root vegetables does not correspond to those grown in Ukraine. In aquaponics conditions, the water content of tissues is high, and the dry matter content is low (at the level of 7-8%), so in the field, the availability of individual elements and their assimilation in the aboveground part may vary.

The ash content of chicory roots varies depending on the moisture content. Samples obtained and described by G. Jan [10] contained 58% moisture, and the content of other components in terms of dry weight was 8.12% ash and 27.3% raw fibres. According to the results of other studies [3; 11], chicory roots with a moisture content of 75-76% contain 4.25-4.45% raw ash in terms of dry weight and about 30% insoluble dietary fibre. The ash content in the dry matter of the roots reached 10.9% in samples containing 87.6% moisture [12], that is, the ash content of the dry matter decreases with the accumulation of dry matter during the growing season.

The total ash content in the leaf samples obtained [10; 13] ranged from 15.1-18.7% of the dry weight, with a tendency to increase with the ageing of these organs. The ash content in the raw mass in the leaves ranges from 1.65-2.14%, depending on the conditions of the year and the time of harvest [14]. With an average ash content of 1.78 g/100 g of leaves, almost a third was occupied by potassium (699 mg/100 g), high sodium (75.9 mg/100 g), calcium (100 mg/100 g), and magnesium (25.5 mg/100 g). The phosphorus content of chicory leaves is relatively low compared to other members of the *Asteraceae* family and is only 47 mg/100 g of raw weight [15].

Chicory roots can contain up to 7.3% ash [16], which includes a variety of minerals, including calcium, magnesium, and sodium, and the content of these compounds exceeds many herbaceous plants [17], which makes chicory tops a valuable animal feed. However, chicory can accumulate a significant part of heavy metals in the leaves, for example, the concentration of chromium, aluminium, cadmium, nickel, and cobalt [18], can exceed the limit standards, and the use of such products in food is not allowed. The content of calcium and magnesium in chicory leaves is 6-17 g/kg and 1.4-2.2 g/kg of raw mass, but due to the high digestibility of silicon (more than 4% by weight of ash) and trace elements, chicory leaves can only be consumed from products grown on substrates without an excess of heavy metals [9; 19].

Global studies of the chemical composition of chicory are based on local forms and varieties, so they are not always representative. Modern varieties of chicory root are characterised by an increase in the proportion of roots in the total biomass of the plant, so the content of macro- and microelements observed in wild plants no longer corresponds to cultivated forms for obtaining roots. Since the chemical composition of roots and leaves is closely correlated with the removal of these nutrients, the study of the chemical composition of plants of programmed parameters allows optimising the cultivation technology, especially in terms of developing a fertiliser system.

The purpose of the study was to investigate changes in the chemical composition of chicory root plants in various organs (root crops, leaves, petioles) depending on the yield and fractional composition of root crops.

MATERIALS AND METHODS

The initial material for assessing the chemical composition of chicory was obtained during 2014-2016 when growing the Umanskyi-99 chicory root variety on the premises of the Khmelnytskyi state agricultural experimental station of the Podillia Institute of Feed Research and Agriculture of the National Academy of Sciences of Ukraine. The soil of the experimental site was podzolised chernozem, large-dusty-medium-loam low-humus. The thickness of the humus horizon was 110-120 cm, the humus content was 2.2-2.8% (according to Tyurin). The supply of soil with nutrients was average: 0.157-0.169% of total nitrogen (according to Keldal), 16.5 mg of mobile phosphorus per 100 g of soil, and 11.5 mg of exchange potassium per 100 g of soil. The content of mobile forms of macronutrients and humus was established annually in the laboratory of the Khmelnytskyi branch of the Institute of Soil Protection of Ukraine in accordance with DSTU 4289:2004 [20].

The total amount of precipitation during the growing season (April-September) in 2014 was 773.1 mm (283.2 mm more than the long-term value), in 2015 – 510.1 mm, and in 2016 – 529.9 mm. The average temperature of the growing season in 2014 was 17.7°C (+2.7% of the long-term), in 2015 – 18.7°C (+3.7°C), and in 2016 – 17.9°C. According to weather conditions, all years were characterised by warm weather and high precipitation, which is sufficient to form high yields of chicory, so the weather was not a limiting factor.

To obtain different-quality root crops, a one-factor field experiment was laid: factor A – the norm of mineral fertilisers: without fertilisers (Control), $N_{40}P_{60}K_{80}$, $N_{80}P_{120}K_{160}$, $N_{120}P_{140}K_{180}$, $N_{160}P_{180}K_{220}$. Model chicory variety – Umanskyi-99. The technology of growing chicory root is typical for the forest-steppe zone of Ukraine, with the exception of the factors under study. Its predecessor was winter wheat. After harvesting the predecessor, stubble was shelled with a Husker LDG-10 disk to a depth of 5-6 cm. Phosphorous (double superphosphate, 43% P_2O_5) and potash fertilisers (potash salt, 60% K_2O) was fully applied in autumn for ploughing. Ploughing was carried out in the first ten days of September of each research year to a depth of 25-27 cm. In spring, when the soil moisture reached below 60% of the pre-irrigation humidity, early spring harrowing was carried out to a depth of 4-6 cm, and on the day of sowing, pre-sowing cultivation was carried out to a depth of 2-4 cm. Nitrogen fertilisers (ammonium nitrate, 34.4% N) were applied in full for pre-sowing cultivation according to the research scheme. Sowing was carried out to a depth of 1-1.5 with SZF-3600-T seed drill at a soil temperature in a layer of 0-5 cm at the level of +5...+7°C (April 15, 2014, April 22, 2015, and April 18, 2016). Drained seeds of the Umanskyi-99 variety were sown in a quantitative norm of 250 thousand germinating seeds per hectare with a row spacing of 45 cm. Plant protection products were not used on chicory crops. The area of the accounting experimental plot was 25 m^2, total area – 35 m^2.

Samples of root crops and the aboveground part were taken diagonally across the experimental plot. Plant samples were taken during the technical ripeness phase of root crops with a viable leaf mass. The mass of the total sample for laboratory tests was: small root crops – not less than 1 kg; large ones – not less than 3 kg.

Chemical quality indicators of root crops and leaves were determined in fresh samples in accordance with generally accepted standard methods: dry matter content – on RPL 3M refractometer according to DSTU 8402:2015 [21]; protein nitrogen according to Bartstein [22], total nitrogen according to Kendal [22]; potassium by flame photometer according to Ginzburg [22]; phosphorus by colorimetric method, other chemical elements by spectral analysis. The content of phosphorus, potassium, calcium, magnesium, and sodium in dry ash (excluding nitrogen) was determined using a spectrograph.

The alkalinity of ash (expressed in mg 0.1H of hydrochloric acid) was determined by titration of ash contained in 100 g of dry matter to neutralise alkaline elements.

Comparison of averages and determination of the materiality of the difference was carried out using the Student's t-test at the level of 95% significance.

RESULTS AND DISCUSSION

The chemical composition of chicory root in the phase of technical ripeness of root crops allows assessing the effectiveness of the fertiliser system and its contribution to crop development. The content of individual nutrients in products is the result of a complex influence of growing conditions, individual elements of the technology, and fertiliser system. Weather conditions and the chemical composition of the soil of the experimental site affect the chemical composition of individual plant organs, so there may be a certain difference between products grown in different conditions.

The content of individual chemical elements in plants of the Umanskyi-99 variety varied depending on the organ (Table 1). The content of phosphorus and potassium in the raw ash of the chicory leaf blade significantly exceeded the indicators of root crops (76% more phosphorus and 33.3% more potassium). The phosphorus content in the leaf blade reached 3.8% of the total mass of raw ash, while in root crops and cuttings, its content was significantly lower – 2.15 and 1.5%, respectively. The potassium content in the raw ash of the leaf blade reached 20%, and in the petioles – 17.0%, while the root crop contained 15%, which is explained by its role as a transport element, so in the zones of active formations of dry matter (petioles and leaves) during this period it will always be less. The content of calcium (Ca) in the raw ash of root crops and petioles did not differ significantly (4.5-5.6%), and it increased significantly in the leaf blade (8.8%). A similar situation was repeated with magnesium, but the gross content was on average 40-50% less than that of calcium. The highest silicon content of chicory was in root crops – 5.1% by weight of raw ash, then in the leaves its content was slightly less – 4.0%, but this element in the petioles was twice less. The sodium content in root crops was several times less than in petioles or leaves.

Table 1. Chemical composition of raw ash of conditioned chicory plants of the Umanskyi-99 variety, % (average for 2014-2016)

Chemical element	Plant organ		
	Root crop	Leaf blade	Petioles
P	2.15[b]	3.8[a]	1.5[b]
K	15.0[b]	20.0[a]	17[ab]
Ca	4.5[a]	8.8[b]	5.6[a]
Mg	2.5[a]	5.6[b]	2.3[a]
Ba	0.03	0.05	0.01
Si	5.1[a]	4.0[a]	2.5[b]
Na	1.5[a]	4.4[b]	5.5[b]
Fe	0.1	0.5	0.3
Mn	0.04	0.05	0.03
Al	0.1	0.01	5×10^{-3}
Cu	5×10^{-4}	3×10^{-3}	1×10^{-3}
B*	3×10^{-3}	5×10^{-3}	3×10^{-3}
Cr*	2×10^{-3}	2×10^{-3}	2×10^{-3}
Zn*	4×10^{-4}	8×10^{-4}	1×10^{-4}
Co*	1×10^{-3}	2×10^{-3}	1×10^{-3}

Note: indexes [a, b, c] horizontally indicate the presence/absence of a significant difference between the options according to the Student's criterion. The same letters indicate that there is no difference between the options. It is used only fo r macronutrients P, K, Ca, Mg, Si, Na. *The content of Cu, B, Cr, Co is set with an accuracy of 1×10^{-3}, and Zn to 1×10^{-4}

The content of trace elements in the chicory plant also varied depending on the location. Consequently, the iron content in root crops was 5 times lower than in the leaf blade and 3 times lower than in petioles, and the manganese content in different organs varied by 0.01% (from 0.03% in the ash of petioles to 0.05% in the root crop). Most aluminium accumulated in root crops – 0.1%, while it was 10 times less in leaves (0.01%), and 20 times less in petioles. The content of boron (B), copper (Cu), and zinc (Zn) in the leaf blade in some cases was more than 2 times higher than their accumulation in petioles and root crops, while the concentration of chromium and cobalt in various organs of chicory plants did not vary significantly.

The accumulation of macronutrients in the root crop and leaf mass during the growing season has a close direct correlation with the removal of nutrients, so it can characterise the effectiveness of the applied fertiliser system. The content of the main macro- and mesoelements in chicory plants when forming a yield of 13.3 t/ha of dry biomass (8.1 t/ha of dry root mass and 5.2 t/ha of dry leaf mass) is shown in Table 2.

Table 2. Mineral content in chicory plants of the Umanskyi-99 variety (average for 2014-2016)

Mineral substance	Root vegetable				Leaf mass				Total biomass content, kg/ha
	Spectrogram indicators	Element content in dry ash, %	Element content in dry mass, %	Content in root crops, kg/ha	Spectrogram indicators	Element content in dry ash, %	Element content in dry mass, %	Leaf content, kg/ha	
Nitrogen (N)	–	–	1.07	86.9	–	–	2.49	129.7	216.6
Phosphorus (P)	4	9.2	0.39	31.4	2.5	5.7	0.92	48.2	79.6
Potassium (K)	18	21.7	0.91	74.1	20	24.1	3.90	203.8	277.9
Calcium (Ca)	4.5	6.3	0.27	21.6	6	8.4	1.36	71.1	92.7
Magnesium (Mg)	2.5	4.1	0.17	14	6	10	1.42	74.0	88.0
Sodium (Na)	5	10.7	0.45	36.6	4	8.6	1.39	72.7	109.3

It was found that root crops in dry ash contained the most potassium – 21.7%, which in terms of dry matter was 0.91%. The potassium content in the leaf mass was 24.1% by weight of dry ash and 3.9% by dry weight. In the absolute removal of potassium as a food element, chicory crops accumulated 277.9 kg/ha of this element during the growing season – 74.1 kg in root crops and 203.8 kg in leaves.

The phosphorus content in the dry ash of root crops was 9.2%, and in the dry mass, respectively, 0.39%, so the total accumulation of this element was 31.4 kg/ha in the roots. In total, 48.2 kg/ha of phosphorus accumulated in the leaf mass, while the content in dry ash and dry mass was 5.7 and 0.92%, respectively. In total, during the growing season, chicory plants removed 79.6 kg/ha of phosphorus from the field, but 48.2 kg/ha (60.6%) of this element was returned together with the leaf mass, so the total need for this element for growth and development during the growing season can be met with a small amount of phosphorous fertilisers in an easily accessible form with a high content of the element of nutrition in the soil.

Since nitrogen does not belong to ash elements, its content was determined only from the dry mass by alternative methods. It was found that the dry weight of root crops contained 1.07% of nitrogen, and in total 86.9 kg/ha of nitrogen was accumulated, and in the leaf mass respectively 2.49% and 129.7 kg/ha. In general, chicory crops produced 216.6 kg/ha of nitrogen during the growing season, of which 86.9 kg/ha was irrevocable, so this should be considered when developing a fertiliser system for the next crop.

The removal of mesoelements of calcium (Ca) and magnesium (Mg) was 92.7 and 88 kg/ha during the growing season, but their localisation depended on the plant organ because a significant proportion (77% and 84%) of these elements were contained in the leaf mass, and with the main products (root) a small part was removed, so it is not necessary to purposefully apply fertilisers to compensate for them. The calcium content in root crops was 6.3% by weight of dry ash and 0.27% of dry matter, and during the growing season, 21.6 kg/ha was removed. At the same time, the leaf mass contained 8.4% calcium by weight of dry ash and 1.36% by total dry weight, and the removal reached 71.1 kg/ha.

The magnesium content in root crops was less than calcium – 4.1% by weight of dry ash and 0.17% by dry weight, respectively, only 14 kg/ha of magnesium is required for the development of 8.1 t/ha of dry biomass of root crops. The content of magnesium in the leaf mass significantly exceeded its concentration in root crops – 10% by weight of dry ash and 1.42% in dry mass, so for the development of the planned level of yield of leaf mass, 74 kg/ha of magnesium is needed, which is 84% of the total need for this element for the plant during the growing season.

Sodium plays an important physiological role in plants, so it is absorbed from the soil and accumulates in the roots in an average ratio of 1:2 relative to potassium. The Na concentration in root crops reached 10.7% of dry ash and 0.45% of the dry weight of the plant, and 36.6 kg/ha accumulated in root crops. The ash of the leaf mass contained 8.6% sodium, which corresponded to 1.39% of the dry weight of the plant, and during the growing season 72.7 kg/ha of this element was carried out with leaves (in total, the plant – 109.3 kg/ha).

The removal of the main nutrients with the main products (root) from the field ranged from 16% for magnesium to 40% for nitrogen and phosphorus, but for the effective development and accumulation of dry matter in chicory, a large amount of available nutrients (216.6 kg/ha of nitrogen, 79.6 kg/ha of phosphorus and 277.9 kg/ha of potassium) is necessary, which are returned to the soil after harvesting.

The chemical composition of root crops and leaves of chicory of the Umanskyi-99 variety was different, since the ratio of different groups of chemicals (proteins, fats, carbohydrates, ash substances) is different. The root crop in chicory performs a storage role – assimilation of carbohydrates, in particular inulin, while the ash content, in this case, decreased by 3.8 times compared to the leaves (Table 3).

Table 3. Composition of raw ash of the Umanskyi-99 chicory variety, % per dry matter (average for 2014-2016)

Plant organs	Raw ash	Cl	Ca	Na	Mg	Fe
Root crops	3.9	0.2	2.13	0.4	0.26	0.04
Leaves	14.9	1.26	3.9	2.1	1.7	0.08

In leaves, as organs of active assimilation of dry substances, the content of ash elements is high, and the concentration of individual elements (Mg, Fe) is increased, because they are part of the photosynthetic apparatus of the plant. The content of raw ash in the leaves was 14.9%, which is almost 4 times higher than its content in root vegetables, while the concentration of calcium (Ca) and iron (Fe) was only doubled. The concentration of chlorine and sodium in various organs of chicory plants is proportional to the content of raw ash, and the content of magnesium in the leaves was 71% higher than the indicator of roots in terms of a unit of raw ash. Chicory roots are the main product in the cultivation of this crop, so the content of macro- and mesoelements in them is an important characteristic for determining the optimal need of plants for fertilisers at different yield levels. The content of crude ash in dry chicory biomass depended on the level of yield (Table 4), but an inverse correlation was observed between yield and ash content, since the increase in biomass is mainly conditioned by the accumulation of carbohydrates (inulin) in cambial tissue, and ash elements are localised in meristems that do not grow intensively.

Table 4. Chemical composition of Umansky-99 chicory root crops depending on different yield levels (average 2014-2016)

Yield, t/ha	Content, % per dry matter						
	Raw ash	N	P	K	Ca	Mg	Na
Low (15-25)	4.05[a]	1.29[a]	0.408[a]	0.381[a]	1.03[a]	0.245[a]	0.197[a]
Average (30-35)	3.97[a]	1.18[ab]	0.349[b]	0.358[a]	1.37[b]	0.230[a]	0.275[b]
High (40 or more)	3.57[b]	1.10[b]	0.475[c]	0.44[b]	1.42[b]	0.225[a]	0.291[b]

Note: indexes a, b, c vertically indicate the presence/absence of a significant difference between the options according to the Student's criterion. The same letters indicate that there is no difference between the options

The content of raw ash in chicory root crops did not differ significantly at low and medium yields (4.05% and 3.97%, respectively), but it significantly decreased by 0.40-0.48% according to the Student's criterion with a yield of more than 40 t/ha. The nitrogen content also decreased with increasing yields, gradually and without significant differences between adjacent groups, however, the difference between low- and high-yield root crops was significant (1.29 and 1.10%, respectively). The phosphorus content in root crops at a low yield was 0.408%, at an average significantly decreased (up to 0.349%), and at a high significantly increased – 0.475%, a similar effect was observed with potassium, so it can be assumed that at a high yield (due to high rates of mineral fertilisers) there is an additional accumulation of these macronutrients without an equivalent physiological role, that is, ballast. With an average (30-35 t/ha) and a high level of yield (40 t/ha or more), the content of calcium and sodium did not differ significantly, and with a low level of yield, their content was significantly lower according to the Student's criterion and amounted to 1.03% and 0.197% in terms of dry matter, respectively. The magnesium content in root crops ranged from 0.225% with a yield of 40 t/ha of root crops and more to 0.245% in variants with a low yield level (15-25 t/ha), but statistically, these indicators did not differ according to the Student's criterion, because the average error exceeded the difference between the values.

When growing chicory root crops under the same conditions, random differentiation of root crop development occurs, so small, average, and large root crops are formed. The size and weight of such root crops in each individual case were different depending on the average yield level and the year of research. Average root crops included typical root crops weighing 100-250 g (depending on the conditions of the year and yield), small ones included root crops that differed from the average fraction by more than 50% by weight, and large ones – those that exceeded 100%. The content of macronutrients and their oxides in the ash of these root crops varies depending on their size (Table 5).

Table 5. Composition of raw ash in different groups of chicory root crops grown under the same conditions, % by dry weight (average for 2014-2016)

Chemical compound	Gradation of root crops by size		
	Large	Average	Small
P_2O_5	1.46[a]	1.30[b]	1.21[b]
Na_2O	0.30[a]	0.06[b]	0.06[b]
$K_2O + Na_2O$	1.77[a]	1.46[b]	1.27[c]
Ca	0.21[a]	0.24[ab]	0.27[b]
MgO	0.31[a]	0.32[a]	0.32[a]
Ca + MgO	0.52[a]	0.56[ab]	0.59[b]
F_2O_3	0.23[a]	0.21[a]	0.20[a]
MnO	0.009[a]	0.01[a]	0.041[b]
Cl	0.24[a]	0.18[a]	0.10[b]
SO_2	0.24[a]	0.26[a]	0.26[a]
Raw ash	27.1[a]	28.6[a]	37.2[b]

Note: indexes [a, b, c] horizontally indicate the presence/absence of a significant difference between the options according to the Student's criterion. The same letters indicate that there is no difference between the options

Content of P_2O_5 in the raw ash of large root crops was significantly higher (1.46%) than in average and small ones. Na_2O concentration in large root crops was 5 times higher (0.3%) than in average and small ones (0.06%).

Since potassium and sodium ($K_2O + Na_2O$) are absorbed by the plant at the same time and have a similar physiological role, then their sum indicates the growth efficiency of each individual plant. In large root crops, the sum of these compounds was 1.77%, while in average-sized crops – 1.46%, and in small ones – 1.27%. A higher amount of these compounds in medium-sized root crops than in small ones indicates a greater accumulation of potassium at the same sodium level, therefore, it is potassium among these substances that has a determining effect on the size of the root crop.

The concentration of calcium in large root crops was significantly lower (0.21%) than in small ones (0.27%), which may be conditioned by the concentration of cytosolic-free calcium $[Ca^{2+}]_{cyt}$, which is a signal complex of the plant's stress state. At the same time, a small relative difference (28.5%) indicates that the main reason for the increase in calcium concentration in the plant is the overall increase in raw ash in small root crops compared to large ones, and not a stress factor, which is generally consistent with the results obtained by K.A. Wilkins [23]. Calcium in the soil promotes the absorption of Mg^{2+} ions, however, it does not lead to the accumulation of surpluses, which is observed in the experiment, since the MgO content is almost independent of the size of the root crop, and the difference is statistically insignificant. The nature of this phenomenon is the high mobility of magnesium in the plant organism and its localisation in the conducting vessels [24], so the stability of the concentration of this element in ash is evidence of homeostasis, while a significant difference (more than 25%) indicates the manifestation of stress and magnesium deficiency [25]. As a consequence of this indicator, it can be argued that the differentiation of root crop size is not conditioned by abiotic stress, which affects the growth of the root system and magnesium absorption [26].

The content of F_2O_3 almost does not differ depending on the size, and the maximum difference between the indicators did not exceed 0.03% (0.23% for large root crops and 0.20-0.21% for average and small ones). The concentration of MnO, on the contrary, increases with a decrease in the root crop – small root crops contain 4 times more of it than small and average-sized ones. The chlorine content in large root crops is 0.24%, slightly decreases in average ones (0.18%), and significantly less accumulates in small ones (0.1%). The sulphur content does not depend on the size of the root crop and was generally stable in the Umanskyi-99 variety – 0.24-0.26%.

In general, the content of raw ash was 27.1% in large root crops, and when the size of the root crop was reduced to small, it increased to 37.2%, since the main factor in increasing the root size is the accumulation of carbohydrates (inulin), so there is an inverse correlation between these indicators. Small root vegetables contain short-chain inulin molecules in their composition and generally form fewer carbohydrates, so the total ash content increases [27].

It was previously established that chicory of the Umanskyi-99 variety contains an average of 1.07% nitrogen in the dry mass of root crops and 2.49% nitrogen in the leaves (Table 2), but from a standpoint of production, it is important to know the efficiency of using this nitrogen. Nitrogen can be found in plants in two main forms – protein (a component of protein, amino acids, and polypeptides) and soluble (nitrates, ammonium form) [28]. The protein form is responsible for the quality and feed value of products, while the soluble form indicates the efficiency of nitrogen assimilation from the soil. The high content of soluble nitrogen in root crops of various sizes during the technical ripeness phase can be an indicator of the effectiveness of fertiliser application [29].

The total nitrogen content in the crude vegetative mass ranged from 0.44 to 0.50% (Table 6). In average and small root crops of low-yielding crops, the total nitrogen content was the lowest – 0.44%, which may indicate trophic problems, and in small root crops from high-yielding crops, this indicator approached the value of large root crops, which is evidence of a deviation in root development for morphological reasons [30]. Protein nitrogen in root crops is part of cells, while soluble nitrogen is a signal of an inefficient fertiliser system, since its excess in late phases of development does not affect the yield level [31].

Table 6. Nitrogen content and alkalinity of raw ash in chicory of the Umanskyi-99 variety, depending on the intensity of root crop growth (average 2014-2016)

Root crop group	Vegetative mass				Root crops			
	Nitrogen content in the crude mass, %			Ash alkalinity	Nitrogen content in the crude mass, %			Ash alkalinity
	Total	Protein	Soluble		Total	Protein	Soluble	
Large	0.50^{a}	0.31^{a}	0.19^{ab}	318	0.44^{a}	0.12^{a}	0.32^{a}	51
Average	0.44^{b}	0.28^{ab}	0.16^{b}	289	0.41^{ab}	0.13^{a}	0.28^{ab}	47
Small high-yielding plants	0.49^{a}	0.27^{abc}	0.22^{a}	298	0.42^{ab}	0.12^{a}	0.30^{ab}	72
Small low-yielding plants	0.44^{b}	0.23^{c}	0.21^{a}	273	0.39^{b}	0.13^{a}	0.26^{b}	57

Note: indexes $^{a, b, c}$ vertically indicate the presence/absence of a significant difference between the options according to the Student's criterion. The same letters indicate that there is no difference between the options

The highest value of protein nitrogen content was found in the leaves of large root crops (0.31%), and in average and small high-yielding crops it decreased to 0.28 and 0.27%, respectively, which is within the measurement error. Small low-yielding root crops contained 0.23%, which is significantly less than in average and large ones, but not significantly compared to small high-yielding ones. The content of soluble nitrogen in average-sized root crops is the lowest – 0.16%, while in other groups of root crops it is significantly higher – 0.19-0.22%.

Chicory roots contain on average 11.1% less total nitrogen than the vegetative mass, but its content, depending on the size of the root, varied within narrower limits – 0.39-0.44%. The highest value of total nitrogen was found in large root crops (0.44%), and in small low-yielding crops it significantly decreased (0.39%), while in other groups it had an intermediate value and did not significantly differ from other indicators. The content of protein nitrogen in root crops almost did not vary and amounted to 0.12-0.13%, and with soluble nitrogen, the situation with total nitrogen (0.26-0.32%) was repeated.

CONCLUSIONS

The size of root crops and the level of chicory yield affected the chemical composition of root and leaf ash. The mineral composition and removal of nutrients by chicory root plants in root plants and leaves differed from each other. Nutrient content of root crops in raw mass P_2O_5 was 9.2%, while in leaves – 5.7%; K_2O – 21.7%, in leaves – 24.1%. According to the chemical composition of the chicory root plant and the intensity of its growth and high yield, a direct relationship was found with the yield of 15-25 t/ha, the content of raw ash was 4.05%, and with an increase in yield to 40-45 t/ha and above – 3.57%. The specific removal of 8.1 t/ha of dry matter of the main product and its corresponding by-products was 216.6 kg/ha of nitrogen, 79.6 kg/ha of phosphorus, 277.9 kg/ha of potassium, 92.7 kg/ha of calcium, 88 kg/ha of magnesium, and 109.3 kg/ha of sodium. Irretrievable losses of food elements during the export of the main products amounted to 86.9 kg/ha of nitrogen, 31.4 kg/ha of phosphorus, and 74.1 kg/ha of potassium, so this should be considered to compensate for the next crop. Chicory accumulates a high concentration of ash elements in the leaf mass during the growing season, so an appropriate level of available nutrients should be provided for the generation of a high yield of root crops.

A promising area of further research is to investigate the features of accumulation of macro- and microelements by chicory plants, considering the differentiated basal and foliar application of fertilisers. The use of chicory for energy purposes allows growing raw materials on lands contaminated with heavy metals, so a wide geography of research on the chemical composition of root crops and other parts of the plant would expand the understanding of trophic mechanisms of ash element accumulation.

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Хімічний склад золи рослин цикорію коренеплідного (*Cichorium intybus* L.) залежно від рівня врожайності

Анотація. Світова практика вирощування цикорію коренеплідного неефективна для українських фенотипових форм сортів, оскільки маса та форма коренеплоду, а також накопичення зольних елементів у рослині відмінне від сучасних форм. Мета роботи полягала у встановленні особливостей накопичення основних зольних макро- та мікроелементів у коренеплоді та листкові масі цикорію коренеплідного сорту Уманський-99 з врахуванням різного фону мінерального живлення, розміру коренеплодів та рівнів урожайності. Дослідження було проведене в умовах Хмельницької державної сільськогосподарської дослідної станції інституту кормів та сільського господарства Поділля НААН України. Листкова маса (черешки та листкова пластинка) та коренеплоди попередньо озолювалися, а потім в золі визначався вміст калію, фосфору, кальцію, магнію, натрію та комплексу мезо- і мікроелементів (Ba, Si, Fe, Mn, Al, Cu, B, Cr, Zn, Co) за допомогою спектрографа, або з застосуванням стандартизованих методів. Вміст досліджуваних мікроелементів у листках, коренях та черешках становив в межах від 1×10^{-4} до 1×10^{-2} %. Питомий виніс елементів живлення для формування 8,1 т/га сухої речовини коренів та відповідної кількості побічної продукції становив 216,6 кг/га азоту, 79,6 кг/га фосфору, 277,9 кг/га калію, 92,7 кг/га кальцію, 88 кг/га магнію та 109,3 кг/га натрію. Значна частина макроелементів акумулювалася у листковій масі, тому близько 60-84 % винесених елементів поверталося в ґрунт при заробляннi листкової маси. Встановлено, що хімічний склад золи різнорозмірних та різноурожайних коренеплодів різниться. Вміст фосфору та калію у коренеплодах за середнього рівня врожайності найнижчий серед досліджених проб, а при високій врожайності суттєво перевищує низьковрожайні. Отже, для оптимального виносу елементів живлення при вирощуванні цикорію коренеплідного для отримання товарних коренів слід розробляти систему удобрення на рівень середньої врожайності, що дозволить зменшити питомий винос фосфору та калію. Практична цінність отриманих результатів полягає висвітленні особливостей виносу основних макроелементів рослинами цикорію коренеплідного, що є основою для розробки ефективної системи удобрення на високу планову урожайність та вибору стратегії використання побічної продукції (листкової маси), як джерела іммобілізованих азоту, фосфору та калію

Ключові слова: озолення вегетативних органів, різноякісність коренеплодів, спектрограма, форми азоту