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ASSESSMENT OF CHEMICAL COMPOSITION OF BUSHGRASS (*Calamagrostis epigejos* L.) OCCURRING ON FURNACE WASTE AND CARBIDE RESIDUE LIME LANDFILLS. PART 1. CONTENTS OF N, P, K, Ca, Mg AND Na

OCENA SKŁADU CHEMICZNEGO TRZCINNIKA PIASKOWEGO (*Calamagrostis epigejos* L.) WYSTĘPUJĄCEGO NA SKŁADOWISKACH ODPADÓW PALENISKOWYCH I WAPNA POKARBIDOWEGO. CZĘŚĆ 1. ZAWARTOŚĆ N, P, K, Mg, Ca I Na

Abstract: Furnace waste and carbide residue lime landfills are characterized by specific physicochemical properties and may be in some ways arduous for the environment due to among others dusting and element migration. In order to prevent these outcomes reclamation should be conducted, among others by turfing. Wastes deposited on landfills are a rich source of nutrients for plants occurring on incineration ashes and carbide residue lime. Because of rich source of nutrients in incineration ashes and carbide residue lime after suitable treatment these wastes may be also used, for reclamation of other wastes or postindustrial areas. Therefore the investigations aimed at an assessment of macroelement contents in bushgrass occurring on these wastes. The macroelement contents in bushgrass depended on the kind of deposited wastes and ranged widely from 4.84 to 20.89 g N; 0.40–3.00 g P; 2.33–13.35 g K; 0.32–1.97 g Mg; 0.22–11.26 g Ca and 0.02–1.20 g Na $\cdot$ kg^{-1} d.m. Presented investigations aimed among others to assess the contents of these macroelements with respect to fodder. The optimal macroelement contents in pasture sward are: 3.0 g P; 17.0–20.0 g K; 2.0 g Mg; 7.0 g Ca; 1.5–2.5 g Na $\cdot$ kg^{-1} d.m. An assessment of plants collected from the landfills according to this criteria revealed that the contents of phosphoprus, potassium, magnesium and sodium in the analyzed plants did not have optimal values. In case of carbide residue lime, calcium content in plants was above the optimal value, whereas in furnace ashes this macroelement in bushgrass was approximate to the optimal value. Among the investigated elements bigger quantities of nitrogen, phosphorus, sodium and potassium were found in plants collected from furnace ash than from carbide residue lime landfills. Therefore the obtained results point out higher fertiliser value of furnace ashes than carbide residue lime.

Keywords: *Calmagrostis epigejos* L. (bushgrass), landfills, incineration ashes, furnace ashes, carbide residue lime, N, P, K, Mg, Ca, Na

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Furnace waste and carbide residue lime landfills are characterized by specific physicochemical properties and may be in some ways arduous for the environment due to among others dusting and element migration. In order to prevent these outcomes, the Council of the European Union accepted the directive on waste deposition [1]. The overall objective of this document is "to provide for measures, procedures and guidance to prevent or reduce as far as possible negative effects on the environment, in particular the pollution of surface water, groundwater, soil and air, and on the global environment, including the greenhouse effect, as well as any resulting risk to human health, from landfilling of waste, during the whole life-cycle of the landfill". If furnace and carbide lime wastes are not recycled or disposed outside the existing installations and facilities [2], it is suggested that reclamation measures should be conducted on the above mentioned waste landfills among others by means of turfing [3–5]. Wastes deposited on landfills are a rich source of nutrients for plants occurring on incineration ashes and carbide residue lime [6]. Because of rich source of nutrients in incineration ashes and carbide residue lime, after suitable treatment these wastes may be also used, for reclamation of other wastes or postindustrial areas. Therefore the investigations aimed at an assessment of macroelement contents in bushgrass occurring on these wastes.

Material and methods

The subject of investigations was the substratum of bushgrass (*Calamagrostis epigejos* L.) occurring on furnace waste and carbide residue lime landfills and on their embankments. Material representing "Sedimentation pool 3" with the area of 23 ha was sampled for the analyses. The sedimentation pool comprised three sections: 1) inactive the incineration ash section LŁ, where 20 samples were collected including 10 from the landfill bowl and 10 from the embankment, 2) active incineration ash section, where 10 samples were taken, including 5 from the landfill bowl and 5 from the embankments, 3) lime section – repository of carbide residue lime obtained after acetylene production, where 10 samples represented the landfill bowl and 10 the embankments. A total of 50 samples collected from the depth of 0–20 cm were subjected to physicochemical analysis. In order to determine some physicochemical properties of the analyzed substratum, the following assessments were made using methods commonly applied in agricultural chemistry and soil science [7]: granulometric composition with Boyoucose-Casagrande method modified by Prószyński, soil pH in H_2O and 1 mol KCl $\cdot$ dm^{-3} using potentiometric method, organic carbon using Tiurin method, nitrogen content with Kjeldahl method on Kjeltec System 1026 apparatus (Tecator), the contents of bioavailable phosphorus and potassium using Egner-Riehm method, bioavailable magnesium content using Schachtschabel method, total contents of P, K, Ca, Mg and Na were determined after the sample digestion in HNO_3 and $HClO_4$ (3:2) acids and the contents of these metals soluble in 1 mol $\cdot$ dm^{-3} HCl solution with Rinkis method.

The analysis of plant material comprised determining total nitrogen content using Kjeldahl method and other macroelement content following the material "dry" mineralization. Concentrations of P, K, Ca, Mg and Na in the substratum and in bushgrass were assessed using ICP-AES method on sequential spectroscope Ultrace JY-238. Statistical computations were conducted using Statsoft 7.1. program. Basic statistical parameters were computed: minimum, maximum and medium values and variation coefficient. Correlation coefficients describing the relationship between the element contents in plants and physicochemical properties of the substratum were also computed.

Results

Detailed physical and chemical properties of incineration ashes and carbide residue lime were presented in a previous publication [8]. The granulometric composition of furnace ashes and carbide residue lime may be diversified, which is connected with the method of their transport to the landfill [9]. The analyzed wastes were transported by means of water which has a crucial influence on sedimentation processes in sedimentation pools. Results obtained in the analyses of granulometric composition place the analyzed samples from the bowl of furnace ashes landfill in the ordinary dust category. Also heavy, medium and light silt loams were present on the furnace ash landfills. Mean contents of the silt fraction in furnace crust was 37 %. Beside silt fraction also the share of sand fraction was considerable in the ash crust, its mean content reached 36 %, whereas the floatable particles constituted the remaining 28 % . Granulation of samples collected from the bowl of post carbide lime section was very similar to furnace ashes. The share of sand and silt fractions reached 37 %. A greater share of sand fractions but the smaller of floatable fraction were determined in the samples from the landfill embankments. Beside ordinary dusts also loamy sand presence was determined in the embankments of furnace ash landfills. On the other hand, loam presence was noted in the embankments of carbide residue lime section.

Reaction. The analyzed furnace wastes and carbide lime revealed alkaline reaction. pH value measured in 1 mol · dm^{-3} KCl solution on the furnace ashes depository ranged from 6.77 to 10.69, while in H_2O from 7.50 to 10.52. In the samples collected from the inactive section of ashes (LŁ) pH value was by approximately one unit lower in comparison with the operating section of ash landfill section. It may evidence occurrence of lime leaching processes among others from inactive section an therefore lowered pH value. The reaction of carbide residue lime samples was more alkaline in comparison with the furnace ash landfills; its mean value in 1 mol KCl was 11.24 and in H_2O – 11.52. On the other hand, the reaction of samples collected from the embankments of the analyzed sections was slightly lower in comparison with the landfill bowl.

Organic carbon. The content of organic carbon in the analyzed wastes ranged widely from 1.21 to 168.92 g · kg^{-1} d.m. Mean content of organic carbon in the furnace ashes landfill (60.85 g · kg^{-1} d.m.) was much higher than in the carbide residue lime depository (31.60 g · kg^{-1} d.m.). Much higher content of organic carbon was registered in the embankment of the analyzed landfill than in its bowls.

Biovailable phosphorus, potassium and magnesium. Furnace ashes contained much larger quantities of bioavailable macroelements in comparison with carbide residue lime. Moreover it was found that the embankments of the analyzed landfill sections were far more abundant in bioavailable macroelements. Mean contents of bioavailable phosphorus, potassium and magnesium in furnace ash samples were respectively: 149.3 mg K, 142.80 mg K and 350.35 mg Mg $\cdot$ kg^{-1} d.m. According to limit numbers for soil assessment [10] the contents for bioavailaible P, K and Mg were on very high, high and medium level, respectively. On the other hand, average content of bioavailable phosphorus, potassium and magnesium in the carbide residue lime were: 83.58 mg P; 71.55 mg K and 117.09 mg Mg $\cdot$ kg^{-1} d.m., respectively and in view of phosphorus concentration corresponded to low level, while concerning potassium and magnesium to very low one.

Macroelement content in the wastes. Total contents of macroelements in furnace ash and carbide residue lime samples were diversified and ranged from 0.14–9.72 g Mg; 0.37–65.56 g Ca; 0.01–1.63 g K; 0.08–1.96 g Na; 0.07–1.95 g P; 0.06–2.07 g N $\cdot$ kg^{-1} d.m. (Table 1). Author's own research has demonstrated that furnace ashes were more abundant in nitrogen, phosphorus and potassium in comparison with carbide residue lime. Magnesium content in the samples from the analyzed landfills was equalized. Almost ten-fold higher calcium concentrations were found in the landfill carbide residue lime section in comparison with furnace ashes. Carbide residue lime also revealed much higher sodium content.

In Poland amounts of many elements (P, K, Ca, Mg and Na) soluble in 1 mol HCl $\cdot$ dm^{-3} are considered bioavailable, therefore these are forms relatively easily accessible. They are formed mainly of ions present in the soil solution and adsorbed on mineral and organic colloids of arable soils [11, 12]. Solubility of the analyzed macroelements in relation to the total contents ranged from 0.72 to 92.25 % P; 1.30–70.06 % K; 19.75–97.44 % Mg; 20.0–87.49 % Ca and 4.54–99.9 % Na. From among the researched macroelements the highest percent of sodium and the lowest of potassium was extracted. Moreover, in four samples it was determined that 1 mol HCl $\cdot$ dm^{-3} extracted greater amount of sodium than a mixture of nitric(V) and chloric(VII) acids (3:2). The highest variability in extraction of the analyzed macroelements was noted for sodium (V = 132.7 %) and the lowest for magnesium (V = 39.9 %). In his own investigations the Author found that 1 mol HCl $\cdot$ dm^{-3} to a greater degree extracted phosphorus and calcium from furnace ashes and sodium from carbide residue lime. The power of potassium and magnesium extraction by 1 mol HCl $\cdot$ dm^{-3} from the samples of the analyzed landfills was generally unified.

Macroelement contents in bushgrass. The macroelement contents in the researched plant ranged from 4.84 to 20.89 g N; 0.40–3.00 g P; 2.33–13.35 g K; 0.32–1.97 g Mg; 0.22–11.26 g Ca and 0.02–1.20 g Na $\cdot$ kg^{-1} d.m. (Table 1). Presented results point to differences in the contents of the analyzed macroelements in bushgrass present on the analyzed landfills. Considering the studied macroelements larger quantities of nitrogen, phosphorus, sodium and potassium were noted in the plants collected from furnace ash landfills than carbide residue lime. However, mean contents of magnesium in bushgrass growing on furnace ashes and carbide residue lime landfills were equalized. Con-

Table 1

Macroelement contents in plants and samples of wastes from analyzed landfill sections

Parameter	Plant	Total*	Soluble**	Plant	Total*	Soluble**	Plant	Total*	Soluble**
	Mg			Ca			K		
	$[g \cdot kg^{-1}$ d.m.]								
Furnace ash sections									
Minimum	0.32	0.14	0.03	0.22	0.37	0.12	6.21	0.23	0.03
Maximum	1.97	9.23	1.95	8.73	8.69	5.96	13.35	1.63	0.28
Mean	1.26	4.37	1.76	2.84	5.87	4.02	10.09	0.98	0.11
V [%]	45.40	48.67	30.16	85.88	33.04	35.35	16.88	39.84	39.13
Carbide residue lime section									
Minimum	0.48	2.15	0.96	0.33	4.99	3.27	2.33	0.01	0.00
Maximum	1.95	9.72	1.93	11.26	65.56	13.11	8.70	1.63	0.12
Mean	1.25	4.97	1.79	4.08	41.15	10.09	5.70	0.74	0.07
V [%]	39.54	44.03	17.04	88.33	68.76	39.75	31.71	87.98	62.55

Table 1 contd.

Parameter	Plant	Total	Soluble	Plant	Total	Soluble	Plant	Total	Soluble
	Na			P			N		
	[g · kg^{-1} d.m.]								
Furnace ash sections									
Minimum	0.02	0.08	0.01	1.26	0.07	0.04	6.12	0.06	—
Maximum	1.20	1.34	0.32	3.00	1.57	1.22	20.89	2.07	—
Mean	0.19	0.67	0.08	2.02	1.01	0.72	11.74	0.81	
V [%]	140.67	38.17	98.20	22.72	35.10	37.03	40.22	56.02	—
Carbide residue lime section									
Minimum	0.02	0.17	0.05	0.40	0.09	0.00	4.84	0.16	—
Maxmum	0.12	1.96	1.49	2.52	1.95	1.34	15.62	0.73	—
Mean	0.05	0.66	0.25	1.49	0.88	0.49	8.56	0.38	
V [%]	50.14	66.19	139.35	40.34	75.95	110.70	31.28	39.90	—

* Total content in wastes; ** content of forms soluble in 1 mol HCl · dm^{-3} in wastes.

siderably higher contents of calcium were assessed in bushgrass present in the carbide residue lime landfill section in comparison with the plants occurring on ashes. The analysis of chemical composition revealed that the plants absorbed the greatest amounts of nitrogen, than potassium, calcium, phosphorus and the smallest amounts of sodium.

The optimal macroelement contents in pasture sward are: 3.0 g P; 17.0–20.0 g K; 7.0 g Ca; 2.0 g Mg; 1.5–2.5 g Na · kg^{-1} d.m. [13]. An assessment of the plants taken from the landfills according to this criterion shows that contents of phosphorus, potassium, magnesium and sodium in the collected plants do not correspond to the optimal values. In case of carbide residue lime calcium content in plants was over the optimal value, whereas in furnace ashes of the inactive section this macroelement concentration in bushgrass approximated the optimal value.

Correlation coefficients. Occurrence of statistically significant relationships between macroelement contents in bushgrass and their amounts in the wastes and its physicochemical composition was determined by computing simple correlation coefficients at significance level $p = 0.001$ (Tables 2 and 3). In the presented research a statistically significant correlation was established between the contents of Mg, Ca, K, Na and P in plants and the total and soluble form contents of these elements in ashes and carbide residue lime (Table 2). Mg concentration in bushgrass growing in ash landfill sections was strongly correlated with the total contents of Mg and Ca in the ashes and calcium content in the plant. On the other hand, calcium content in the plant was positively correlated also with K content in the plant and with total Mg content in ashes. Also significant relationships were determined between K content in bushgrass and total content of calcium in ashes. The content of 1 mol HCl · dm^{-3} soluble Na in ashes most strongly affected this element content in bushgrass.

Mg content in bushgrass occurring on carbide residue lime was significantly correlated with Ca content in this plant. Total content of calcium in the acetylene production waste (carbide residue lime) was determined by this element solubility in 1 mol HCl · dm^{-3} but negatively correlated with the total and soluble calcium content, as well as positively correlated with K content in this waste.

Table 3 shows correlation relationships between the macroelement content in plants and wastes and physicochemical properties of the wastes. C and K contents in bushgrass growing in the ash landfill sections were most strongly affected by bioavailable magnesium, whereas sodium contents in bushgrass was determined by the reaction. Nitrogen content in bushgrass present on the ashes was negatively correlated with sand content but positively correlated with coarse grained clay, reaction and organic carbon. However, Ca content in bushgrass growing in the carbide residue lime landfill section was most strongly affected by sand and colloidal clay, whereas phosphorus content was affected by the substratum pH.

Values of simple correlation coefficients compiled in Table 3 point to a most significant relationship between total contents of Mg and Ca in incineration ashes and bioavailable magnesium content. The content of total and 1 mol HCl · dm^{-3} soluble Na in furnace ashes was most determined by the presence of colloidal clay and the substratum pH. On the other hand the total and 1 mol HCl · dm^{-3} soluble P content in

Table 2

Simple (linear) correlation coefficients (r) between macroelement content in plant and wastes

Specification		Plant	Total*	Plant	Total*	Soluble**	Total*	Soluble**	Plant	Total*	Total*
		Mg		Ca			K		Na		P
Quarters incineration ash (N = 30)											
Total*	Mg	0.70									
Plant	Mg	0.75	0.62								
Total*	Ca	0.63	0.85								
Soluble**	Ca		0.68								
Plant	K			0.81							
Total*	K				–0.61						
Soluble**	Na								0.73		
Soluble**	P									0.60	0.91
Quarters lime carbide (N = 20)											
Plant	Ca	0.85									
Soluble**	Ca				0.94						
Total*	K				–0.98	–0.90					
Soluble**	K				–0.81	–0.70	0.85				
Plant	K						0.76				
Total*	P				–0.93	–0.80	0.93	0.82			
Soluble**	P				–0.96	–0.84	0.94	0.80			0.98

r significant at: $p = 0.001$; * total content in wastes; ** content of soluble forms in 1 mol HCl $\cdot$ dm^{-3} in wastes.

Table 3

Simple (linear) correlation coefficients (r) between macroelement content in plant and substratum, and some its properties

Specification	Total*	Plant	Total*	Substr.**	Plant	Total*	Substr.**	Plant	Substr.**	Plant	Total*	Substr.**	Plant	Total*
	Mg	Ca			K			Na		P			N	
Quarters incineration ash (N = 30)														
Sand													–0.70	
Coarse silt clay													0.69	
Fine silt clay											0.63	0.68		
Colloidal clay									0.66					
pH_{KCl}								0.65	0.69				0.78	
pH_{H_2O}									0.67				0,65	0.63
Org. C													0.62	
Available P											0.60	0.69		
Available K							0.94							
Available Mg	0.70	0.64	0.60		0.69								0.66	

Table 3 contd.

Specification	Mg	Ca			K			Na		P			N	
	Total*	Plant	Total*	Substr.**	Plant	Total*	Substr.**	Plant	Substr.**	Plant	Total*	Substr.**	Plant	Total*
Quarters lime carbide (N = 20)														
Sand		–0.79												
Coarse silt clay														
Fine silt clay														
Colloidal clay		0.85												
pH_{KCl}			0.91	0.83		–0.90	–0.90			–0.83	–0.85	–0.87		
pH_{H_2O}			0.89	0.82		–0.88	–0.88			–0.80	–0.84	–0.85		
Available P			–0.95	–0.98		0.91					0.83	0.88		
Available K			–0.80	–0.80		0.82	0.91							
Available Mg			–0.91	–0.82		0.93	0.82				0.89	0.89		

r significant at: $p = 0.001$; * total content in wastes; ** content of soluble forms in 1 mol HCl · dm^{-3} in wastes.

the ashes depended on fine-grained silt clay and bioavailable phosphorus content. Total content of nitrogen in the ashes depended on the substratum pH.

In case of carbide residue lime the total and soluble Ca and K contents in this waste were determined by the reaction and the contents of bioavailable macroelements. The total and 1 mol HCl $\cdot$ dm^{-3} soluble P content in carbide residue lime were most strongly influenced by the reaction and the contents of bioavailable phosphorus and magnesium.

Because of many directions of changes occurring in the deposited wastes, their systematic control may be used for the proper assessment of the state of the natural environment.

Discussion

Granulometric composition and particularly considerable content of silt particles may be considered as an advantageous factor from the perspective of application for reclamation of other wastes or postindustrial areas. Moreover, a big share of the finest-grained fractions in these wastes favours processes of dusting, which poses a hazard to the environment, therefore a necessity of turfing to secure these areas [14]. Research conducted by Meller et al [15] corroborate the presented investigations, that fresh furnace ashes, which were subjected to washing processes to a smaller degree, are more alkaline than ashes deposited for a longer period of time. Higher pH value than in carbide residue lime was also corroborated by investigations conducted by Kac-Kacas and Drzas [16]. Depending on the kind of coal, incineration ashes contain diversified amounts on non-burned coal, which has swelling properties and therefore contributes to loosening the ash crust [6]. Higher contents of organic carbon in landfills and embankments of furnace wastes are explained by expanding vegetation [17]. High contents of bioavailable macroelement forms in ashes were also found by Meller et al [15] and Kac-Kacas and Drzas [16].

Mean content of nitrogen in mineral soils ranges from 0.2 to 4.0 g $\cdot$ kg^{-1} d.m. [18]. Nitrogen content in furnace ashes comparable to mineral soil concentrations have been explained by the amount of non-burned organic coal [17]. On the other hand, the total range of macroelement contents in mineral soils of Poland is: 0.1–2.0 g P; 3.0–21.0 g K; 0.2–8.0 g Mg; 0.5–49 g Ca; 1.00–10.0 g Na $\cdot$ kg^{-1} d.m. [19]. Total contents of phosphorus, magnesium and sodium in the samples from the analyzed landfills generally did not differ from these elements contents in arable soils. Potassium and sodium contents in furnace ashes and carbide residue lime were much lower in comparison with mineral soils. The tested ashes and particularly carbide residue lime were abundant in calcium, which was not registered in mineral soils [19]. The obtained results show that higher contents of macroelements in furnace ashes point to them as a macroelement source for plants [17]. Moreover, the analyzed furnace ashes, due to a source of macroelements may constitute a substrate for preparing ash-sludge mixtures for environmental management of post-industrial areas [20]. Identification of the properties of incineration ashes and carbide residue lime will make possible a selection of proper and efficient reclamation procedures [21].

Conclusions

1. Conducted analysis of granulometric composition showed silt granulation of incineration ashes and silt and loam granulation of carbide residue lime. The reaction of furnace ashes was neutral or alkaline, whereas carbide residue lime revealed exclusively alkaline reaction.

2. Much lower mean content of organic carbon and bioavailable macroelements were registered in carbide residue lime landfill in comparison with furnace ash repository.

3. Total contents of phosphorus, potassium and nitrogen in the analyzed samples of furnace ashes were much higher than in carbide residue lime samples. On the other hand calcium content in carbide residue lime landfill section was almost ten-fold higher in comparison with the analyzed ashes. Carbide residue lime was also more sodium abundant.

4. Higher contents of phosphorus, potassium, sodium and nitrogen were noted in bushgrass growing on furnace ash landfill in comparison with carbide residue lime. An opposite relationship was found for calcium, ie higher content in bushgrass occurring in carbide residue lime section.

5. According to fodder value criteria, the contents of phosphorus, potassium, magnesium and sodium in bushgrass did not correspond to optimal values.

6. Investigated furnace ashes and carbide residue lime were characterized by satisfactory physical and chemical properties allowing for their application for reclamation measured in the areas, mainly destined for non-agricultural purposes.

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OCENA SKŁADU CHEMICZNEGO TRZCINNIKA PIASKOWEGO WYSTĘPUJĄCEGO NA SKŁADOWISKACH ODPADÓW PALENISKOWYCH I WAPNA POKARBIDOWEGO CZĘŚĆ 1. ZAWARTOŚĆ N, P, K, Ca, Mg I Na

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Abstrakt: Składowiska odpadów paleniskowych i wapna pokarbidowego charakteryzują się specyficznymi właściwościami fizykochemicznymi i mogą stwarzać określone uciążliwości dla otoczenia, do których można zaliczyć m.in. pylenie i migrację pierwiastków. Aby zapobiec tym skutkom, należy przeprowadzić zabiegi rekultywacyjne między innymi poprzez zadarnienie. Zdeponowane odpady na składowiskach stanowią bogate źródło składników pokarmowych dla roślin występujących na podłożach z popiołów paleniskowych i wapna pokarbidowego. Ze względu na bogate źródło składników pokarmowych w popiołach paleniskowych i wapnie pokarbidowym odpady te można także wykorzystać, po odpowiednim przetworzeniu, do rekultywacji terenów poprzemysłowych. Stąd celem badań była ocena zawartości makroskładników w trzcinniku piaskowym występującym na tych odpadach.

Zawartość makroelementów w trzcinniku piaskowym zależała od rodzaju składowanych odpadów i wahała się w szerokim zakresie: 4,84–20,89 g N; 0,40–3,00 g P; 2,33–13,35 g K; 0,32–1,97 g Mg; 0,22–11,26 g Ca; 0,02–1,20 g Na $\cdot$ kg^{-1} s.m. W niniejszych badaniach podjęto między innymi ocenę zawartości tych makroskładników według kryteriów jakości paszowej. Optymalna zawartość makroelementów w runi pastwiskowej wynosi: 3,0 g P; 17,0–20,0 g K; 2,0 g Mg; 7,0 g Ca; 1,5–2,5 g Na $\cdot$ kg^{-1} s.m. Oceniając rośliny pobrane ze składowisk według tego kryterium stwierdzono, że zawartość fosforu, potasu, magnezu i sodu w badanej roślinności nie odpowiadała wartościom optymalnym. W przypadku wapna pokarbidowego zawartość wapnia w roślinach była większa od wartości optymalnej, natomiast w popiołach paleniskowych zawartość tego makroelementu w trzcinniku była zbliżona do wartości optymalnej. Spośród badanych makroelementów większe ilości azotu, fosforu, sodu, potasu stwierdzono w roślinach zebranych ze składowisk popiołów paleniskowych aniżeli wapna pokarbidowego. Stąd uzyskane wyniki wskazują na większą wartość nawozową popiołów paleniskowych niż wapna pokarbidowego.

Słowa kluczowe: trzcinnik piaskowy (*Calmagrostis epigejos* L.), składowiska, popioły paleniskowe, wapno pokarbidowe, N, P, K, Ca, Mg, Na