IMPACT OF ASH OBTAINED AFTER MULTI-CROP PELLET BURNING ON SPRING BARLEY FERTILIZATION

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Abstract. The EU Green Deal envisages a significant reduction in the use of industrial mineral fertilizers in agro-technologies. The use of ash from another fuel made from plant biomass could help not only to utilize combustion residues, but also to optimize the nutrition of cultivated agricultural plants without harming the environment. With this aim, a pot experiment of the effects of multi-crops biomass ash on spring barley sprouts was carried out in January-February 2024 in the greenhouse of the Academy of Agriculture of the Vytautas Magnus University (VMU). Four ash fertilization rates were tested: 1. Unfertilized (N0, comparative-control treatment); 2. Fertilized at a low rate (N1); 3. Fertilized at an average rate (N2); 4. Fertilized at a high rate (N3). Or 200, 1000 and 2000 kg·ha^{-2}, respectively. According to the results of investigations, the average rate of ash fertilization (N2) was the most effective for spring barley sprout growth. The shoot length was about 6 cm higher than in control. Ash fertilization rates had no significant effect on the root development. Fertilization with ash initiated the rise of the concentration of chlorophyll in spring barley leaves significantly by up to 46%. Fertilization with ash usually reduced the amount of dry matter in barley shoots but increased it in their roots.

Key words: *Hordeum vulgare* L., multi-crops ash rates, sprouts, biometry, chlorophyll, dry matter.

Introduction

The increasing use of biomass for biofuels has resulted in large amounts of waste, which are treated as waste. Biomass ash can be applied to soil as a recycling strategy for this waste, contributing to sustainable biomass production [1]. Biomass ash disposal in landfills is not only expensive, but also wastes valuable resources. Biomass ash contains important macro-nutrients and a certain soil liming capacity, so returning ash to the soil contributes to the integration of the biomass-to-energy process [2].

On a global scale, 3 Gt of biomass is used annually for energy production, more than 90 percent of which is used as solid fuel. In this way, about 170 Mt of ash is generated per year. However, the use of biomass can increase to 8 Gt per year, and if all biomass were used, about 1000 Mt of ash would be produced per year [3].

Ash is the non-combustible, inorganic fraction of fuel that remains after complete combustion and contains most of the mineral fraction of biomass [4]. The main elements in biomass ash are calcium (Ca), silicon (Si), magnesium (Mn) and potassium (K), as well as sulphur (S), chlorine (Cl) and phosphorus (P). However, the elemental composition of ash depends on the source of the biomass, which means that the quantity and composition of ash cannot be defined in a generalized way [5]. The concentration of toxic elements in ash is low, which means that ash can be used in agriculture. In addition, biomass ash can enrich the soil with elements such as Zn, Cu and Mn. However, whether the ash can be used in agriculture must be evaluated each time, taking into account the origin of the biomass [6]. Biomass ash fertilization can maintain a sufficient amount of P in the soil. Cruz-Paredes et al. study shows that after examining the effect of ash in the second season after application, no negative effects related to ash application on the plant yield, nutrition, Cd accumulation in plants and mycorrhizae were found. Furthermore, even high amounts of Cd added to the soil with ash did not translocate to the aerial parts of the plants [7].

Barley is among the most important cereals in the world in terms of cultivated areas and production quantities. On average, more than 140 million tons of barley are produced annually on an area of almost 50 million hectares [8; 9]. One of the conditions for the development of agricultural production is quality control. However, the intensive use of fertilizers, especially N, P and K, poses a risk to the environment [10]. Renewable resources are increasingly used in fertilizer production, but the majority of manufactured products are still based on mineral resources and fossil fuels. The European Commission has set a goal to reduce the use of non-renewable resources by 30 percent in the production of fertilizers [11]. Returning ash to the soil can not only reduce the amount of waste to be removed, but also the amount of chemical fertilizers needed by plants [12].

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The aim of this study was to evaluate the effect of ash produced by burning multi-crop biomass pellets on spring barley germination and development.

Materials and methods

A pot experiment of the effects of multi-crop (maize, fibrous hemp and faba bean) biomass ash on spring barley was carried out in January-February 2024 in the greenhouse of the Academy of Agriculture of the Vytautas Magnus University (VMU), according to the following scheme.

Treatments:

1. unfertilized (N0, comparative-control treatment).
2. fertilized at a low rate (N1).
3. fertilized at an average rate (N2).
4. fertilized at a high rate (N3).

The pot experiment was performed with four repetitions. The area of the pot is 0.05 m^2. A substrate with a pH close to neutral was used. The substrate was mixed with soil in a ratio of 1:10. The soil was taken at the VMU Experimental Station. It is a deeper clayey saturated Planosol (*Endohypogleyic-Eutric Planosol – PLe-gln-w*) [13]. Soil pH close to neutral or slightly alkaline, total nitrogen content – up to 0.175 percent, humus – 1.5-1.7 percent, mobile phosphorus – up to 323 $mg \cdot kg^{-1}$, mobile potassium – up to 150 $mg \cdot kg^{-1}$, mobile magnesium – up to 506 $mg \cdot kg^{-1}$.

Vegetative containers were filled with a mixture of substrate and soil. Then, 7 g of ammonium sulfate nitrate (N26) or 140 $g \cdot m^{-2}$ was mixed into the topsoil layer of 5 cm depth in each pot. Also the intended amount of ash is mixed in: N1 – 1 g, N2 – 5 g, N3 – 10 g per pot. These amounted to 20, 100 and 200 $g \cdot m^{-2}$, respectively. The ash used for the experiment was obtained by burning biofuel pellets made from the biomass of maize, fibrous hemp and faba bean grown in the same field. Pots prepared for the experiment with concentrated ammonium sulfate nitrate fertilizers and different ash rates can be seen in Figure 1.

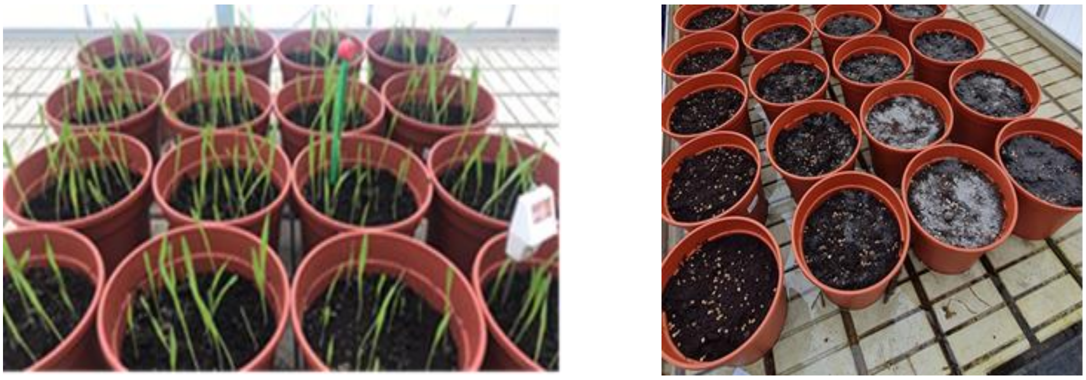

Fig. 1. **Fertilization experiment of spring barley using different rates of ash**

The elemental composition of the ash used for the experiment, obtained after burning the pellets produced of multi-crop plant biomass, is given in Table 1.

Table 1

Elemental composition of multi-crop biomass ash

Chemical element	Content	Chemical element	Content
Ca	123449.73 ± 6.22	Al	3741.99 ± 12.44
Cd	< 0.51	K	236102.69 ± 16.36
Cu	81.80 ± 10.16	Na	9383.18 ± 12.04
Fe	4512.95 ± 10.02	P	27063.62 ± 5.82
Mg	34676.88 ± 12.22	Si	276629.95 ± 5.68
Pb	< 1.20	Cl	2.98 ± 0.10
Zn	265.02 ± 5.71	S	1.36 ± 0.07

Note: The amount of Cl and S is given in percent, all other elements in $mg \cdot kg^{-1}$.

As it can be seen from Table 1, the dominant elements in the ash obtained from burning of the multi-crop biomass are Si, K, Ca, Mg and P. As indicated by Zelazny and Jarosinski, although Si dioxide does not belong to the group of macro or micronutrients, it significantly contributes to increasing the resistance of plants to fungal diseases [14]. The amounts of heavy metals Cd, Pb and Zn do not exceed the norms.

After adding fertilizer, the soil was slightly compressed, and seeds were placed on its surface – 20 seeds per pot. The seeds were inserted at a depth of 3 cm. The environmental conditions in the greenhouse were controlled. Air temperature – 18-20 ºC, relative humidity – 50-60 percent. Lighting time – up to 12 hours.

Dry matter content of sprouts in percent was determined by drying the samples at a temperature of 105ºC in a drying oven (Memmert, Germany) to constant mass (LST ISO 751:2000). For biomass determination, 10 germinated grains or seeds together with sprouts and roots were weighed. The seedling height and root length were also determined. The average plant height and root length (cm) were determined by measuring the plants in each experimental pot. The leaf chlorophyll concentration was measured with a chlorophyll meter MC-100 (Apogee Instruments). It measured the chlorophyll concentration from red (653 nm) to short infrared (931 nm) wavelengths. At least 10 leaves of each plant species were measured.

The data were statistically evaluated using the computer program ANOVA [15]. Differences between the averages of treatments marked with different letters (a, b, c, …) are significant, $P < 0.05$. The calculations were carried out at the Vytautas Magnus University Agriculture Academy.

Results and discussion

Biometry of sprouts. In our pot experiment we measured the height of shoots and length of roots 4 times. At the beginning of the experiment, we found the negative significant impact of the high ash fertilization rate (N3) on the height of barley shoots (Table 2). However, during further observations, it turned out that the most favorable was the use of the average ash rate (N2). This rate was the best of all further vegetative period.

Table 2

Impact of ash rates on the height of spring barley shoots (cm)

Treatments/Date	17 01 2024	24 01 2024	31 01 2024	12 02 2024
N0	23.8	31.3	31.5	31.9
N1	22.6	31.0	33.2	34.4
N2	24.6	36.8***	36.6***	37.8*
N3	19.1***	31.4	35.6**	31.6

Note: Unfertilized (N0), comparative-control treatment, fertilized at a low rate (N1), fertilized at an average rate (N2), fertilized at a high rate (N3); * – significant differences at the 95% probability level, ** – significant differences at the 99% probability level, *** – significant differences at the 99.9% probability level.

The impact of ash rates on the length of barley roots was not so common (Table 3), however, the previously mentioned N2 treatment was also usually the most favored.

Table 3

Impact of ash rates on the length of spring barley roots (cm)

Treatments/Date	17 01 2024	24 01 2024	31 01 2024	12 02 2024
N0	6.2	10.4	10.2	14.0
N1	5.8	9.1	9.7	11.7
N2	6.6	10.5	12.6*	14.0
N3	6.2	9.5	11.0	13.5

Notes as in Table 2.

Sprout development and productivity indices. At the beginning of the experiment, in N3 pots with higher ash rate, the chlorophyll concentration in the barley leaves was significantly the lowest one (Table 4). During the next 7 days and further vegetative period, the situation changed cardinally. The highest concentration was observed in treatments with average and high ash rates (N2-N3). At the end of the experiment, all treatments with incorporated ash were significantly better than the control without ash.

Table 4

Impact of ash rates on the chlorophyll concentration in spring barley leaves (μmol·m^{-2})

Treatments/Date	17 01 2024	24 01 2024	31 01 2024	12 02 2024
N0	5.6	4.2	5.7	8.2
N1	6.3	4.1	5.9	13.4**
N2	4.8	5.9	7.3	13.8***
N3	2.4*	6.1	8.6	15.1***

Notes as in Table 2.

The effect of ash rates on dry matter content of barley shoots was not consistent, however, it can be concluded that N1 and N2 ash rates tended to reduce the amount of dry matter in the roots (Table 5). It was the highest in unfertilized (N0) and high rate (N3) fertilized pots.

Table 5

Impact of ash rates on the percentage of dry matter in barley shoots

Treatments/Date	17 01 2024	24 01 2024	31 01 2024	12 02 2024
N0	8.1	7.7	7.9	7.9
N1	8.7*	7.8	7.7***	7.5**
N2	8.2	7.0*	7.6***	7.5**
N3	9.8***	7.2	7.9	7.9

Notes as in Table 2.

The percentage of dry matter in the barley roots was similar as at the beginning of the experiment (Table 6).

Table 6

Impact of ash rates on the percentage of dry matter in barley roots

Treatments/Date	17 01 2024	24 01 2024	31 01 2024	12 02 2024
N0	30.6	19.6	17.8	15.6
N1	38.0	31.8***	15.8*	18.0
N2	38.4	17.7	15.6*	15.8
N3	36.2	15.2**	16.1*	18.5

Notes as in Table 2.

During the next observations, it constantly changed, but at the end of the experiment, the balance was established in favor of the N3 treatment. The amount of dry matter in the barley roots of this treatment was the highest, although not significantly.

Research by other authors shows that ash obtained by burning biomass is an innovative alternative to mineral fertilizers. Pycia et al. investigated that fertilization of barley with ash from the combustion of woody biomass had an effect on the starch properties of spring barley [16]. Bunevičienė et al. study showed that fertilization with wood biomass ash had an effect on the yield increase of spring wheat and spring barley [17]. Pastuszczak et al. showed that the biological, physical and chemical properties of the soil are improved by treating the soil with ash formed after biomass burning. Fertilization at the rate of 400 and 500 kg K2O per ha had the greatest positive effect on the number of the bacterial community, as well as on the physical and chemical properties of the soil [18].

Conclusions

1. The average rate (100 g·m^{-2}) of ash fertilization (N2) was the most favorable for spring barley sprout growth, but ash fertilization had no significant effect on root development.
2. As the rate of ash fertilization increased, the concentration of chlorophyll in spring barley leaves also increased significantly (from 13.4 to 15.1 µmol·m $^{-2}$).
3. In the course of long-term observations, it was found that it was most favorable to use the average ash rate (N2 – 5 g) for plant fertilization, as this indicator was the best during the entire subsequent

vegetation period. Fertilization with ash usually reduced the amount of dry matter in barley shoots but increased it in their roots.

Author contributions

Conceptualization, K.R. and A.S.; methodology, A.J., R.P., M.P. and K.R.; software, K.R. and A.S.; formal analysis, A.J., R.P., K.R. and A.S.; investigation, R.P., M.P., K.R. and A.S.; data curation, R.P., K.R. and A.S.; writing – original draft preparation, R.P., M.P., K.R. and A.S.; writing – review and editing, A.J., R.P. and K.R.; visualization, R.P. and K.R.; project administration, A.J., R.P. and K.R.; funding acquisition, A.J. and R.P. All authors have read and agreed to the published version of the manuscript.

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