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OVERVIEW OF BIOMASS ASH USAGE FOR SOIL QUALITY IMPROVEMENT: POTENTIAL BENEFITS AND APPLICATIONS

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Abstract. The degradation of urban soil is caused by pollution, poor land management practices, and soil sealing, all of which lead to lower infiltration, aeration, and permeability. At the same time, there is a substantial increase in biomass power generation, which increases ash generation, posing concerns for waste management and environmental impact. Biomass ash presents an opportunity for an environmentally friendly amendment of soil, as it provides nutrients, stabilises pH, and improves soil structure. The ash is rich in vital nutrients such as calcium, potassium, and phosphorus, which can restore nutrient-stripped soil and counteract soil acidification. The porous nature of ash improves aeration, retention of water, and root growth, especially in sandy and degenerated soil. Pelletisation makes it easier for biomass ash utilisation by reducing airborne dissemination and ensuring nutrient release occurs in a controlled, graduated process. Empirical evidence shows that granulated biomass ash can release its contents of nutrients in a gradual process, hence avoiding surpassing the safety levels of maximum allowable concentrations of heavy metals. With appropriate practices, biomass ash is a valid alternative to fertilisers, improving agricultural output and environmental sustainability and reducing the by-product troubles of biomass power generation.

Keywords: biofuel ash, soil quality improvement, waste.

1. Introduction

Soil quality in urban areas is declining due to human activities, environmental pollution, and poor land management practices. One of the most significant factors in urban soil degradation is soil sealing, a scenario in which native soil surfaces become sealed with impermeable coverings such as buildings, concrete, and asphalt. By closing pores in the ground, such a scenario reduces infiltration, living organism activity, and gas exchange, and reduces soil permeability (Prokop, 2011)

Global electricity generation from biomass has steadily increased over the past two decades. In 2000, biomass-generated electricity was 162 TWh; by 2020, it had more than quadrupled to 685 TWh (World Bioenergy Association, 2022). This growth reflects the rising adoption of biomass as a renewable energy source, which is driven by multiple factors such as technological advancements, policy support, and the global interest in cleaner energy alternatives. The most significant increase occurred between 2010 and 2020, highlighting an accelerating trend in the utilisation of biomass energy. However, behind the growing industry lies an important issue: the growing quantities of biomass ash waste that have the potential to be used as a fertiliser for soil lacking nutrients. According to Lamers et al. (2018), approximately 5–10 % of the mass of biofuel is released back into the environment as ash during combustion.

Biofuel combustion leads to a large amount of ash, which accounts for as much as 60 % of municipal solid waste in developing nations (Karak et al., 2012). The consequent environmental challenges from this high amount of waste are air pollution, landfill overflow, and potential water pollution. Such impacts can be prevented by practising proper management procedures while maintaining sustainable reuse, such as using ash in construction or ash stabilisation with binders.

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2. Soil porosity and water absorbing quality improvement

Porosity in biomass ash renders it highly valuable, as it is the force behind its water-holding capacity and soil interaction. Water-absorbing quality and porosity of the ashes are especially good at enhancing the soil's water-holding capacity, particularly in sandy or eroded soils. By enhancing soil porosity, biomass ash can enhance aeration and root penetration, enhancing plant health (Demeyer et al., 2001). Moreover, its capability to absorb and store water (Figure 1) renders it an extremely beneficial adaptation for deserts and semi-deserts where water conservation is necessary.

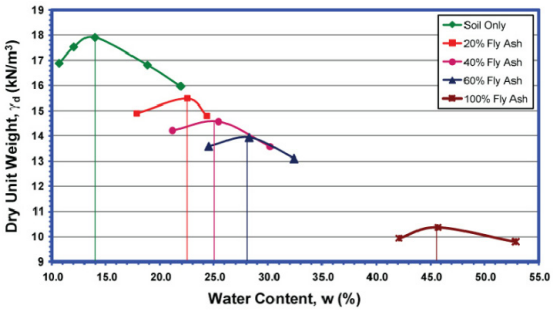


Figure 1. Water retention in soil relation to ash and soil mixture proportions

However, careful handling is needed to prevent such excess porosity from causing excess water retention in clay soils, which would negatively impact root respiration and the uptake of nutrients.

3. Soil pH improvement

Soil acidification is the predominant soil quality risk, and neutral soil pH is found to be the most ideal pH for plant growth (Pierzynski & Brajendra, 2017). Over time, imbalanced soil conditions may also contribute to broader environmental concerns, such as reduced biodiversity and weakened ecosystem stability. Effective management practices like fertilisation can help preserve soil health and support long-term agricultural productivity.

The observed impacts of ash application on soil acidity are a rise in the potassium (K^+), calcium ($Ca2^+$) and magnesium ($Mg2^+$) ion concentrations, pH and the base saturation of cation exchange capacity. In contrast, there is a reduction in exchangeable acidity (Augusto et al., 2008).

In the study by Saletnik et al. (2018), the pH value of the soil before the experiment (2015) and after the first and second year of cultivation, depending on the fertiliser used. As in the previous experiment, the soil taken from the area on which the field experiment was carried out was characterised by an acidic reaction (pH in 1M KCl - 4.98). The pH value of the soil determined for the control plots (no fertilisation) was 5.13, after both the first and second year of cultivation. There were no statistically significant differences for this variant compared to the results obtained before the experiment. The addition of biochar, ash, and their mixture in the soil influenced the increase in the pH value of the soil to a statistically significant extent when compared to the results obtained in 2015 (in 13 cases out of the 16 analysed). Depending on the type of fertiliser used and its application rate, there was an increase in the study parameter by a value in the range from 0.19 to 1.29 after the first year and from 0.04 to 1.13 after the second year of cultivation when compared to the control group. After the first and second year of cultivation of giant miscanthus, the highest concentrations of hydrogen ions in the soil were determined in the case of fertilisation with ash at an application rate of 4.5 t ha−1. (Saletnik et al., 2018). The results of the study are presented in Figure 2.

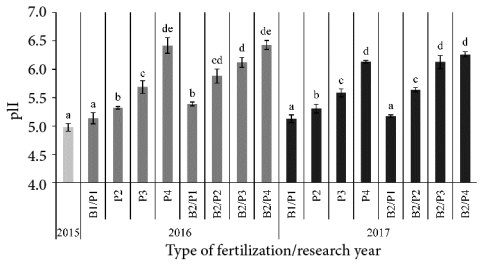


Figure 2. pH value of the soil before the experiment (2015) and after the first and second year of cultivation, depending on the fertiliser used

Where

- B1/P1 (control test—no fertiliser),
- P2 (soil fertilised with ash amount of 1.5 t ha^{-1}),
- P3 (soil fertilised with ash amount of 3.0 t ha^{-1}),
- P4 (soil fertilised with ash amount of 4.5 t ha^{-1}),
- B2/P1 (soil fertilised with biochar amount of 11.5 t ha^{-1}),
- B2/P2 (soil fertilised with biochar and ash amounts of 11.5 and 1.5 t ha^{-1}, respectively),
- B2/P3 (soil fertilised with biochar and ash amounts of 11.5 and 3.0 t ha^{-1}, respectively),
- B2/P4 (soil fertilised with biochar and ash amounts of 11.5 and 4.5 t ha^{-1}, respectively)

According to the study's data, soil fertilised using biomass ash and compounds with the highest concentrations of biomass ash presented the best results in increasing the soil's pH.

Rising pH using biomass ash as a fertiliser would stimulate the growth of soil microbial biomass and increase activity, and therefore increase the biological soil fertility in acidic soils (Bougnon et al., 2011).

4. Soil fertilisation

Ash that is produced from burning biomass has a very varied chemical composition. There are numerous reasons for this which generally relate to the raw material itself: biomass type, plant species or parts, growth conditions and processes, plant age, fertilisation and dosage of plant protection products, harvest time and methods, transportation and storage conditions, processing methods, and the combustion process itself, including fuel preparation, combustion technology, and combustion conditions plus other technical conditions.

Soil fertilisation with biomass ash is an effective way to enhance soil quality by replenishing essential nutrients. Zając et al. (2018) combusted 35 types of biomass (trees and energy crops) and determined that the major macro elements of the chemical contents of the ash were calcium, potassium, phosphorus, and sulphur. Rich in these elements, biomass ash can improve soil fertility, promote plant growth, and help restore nutrient-depleted soils. Nutrient rates of: 90–135 kg P_2O_5 ha^{-1} (Xu et al., 2023), 30 kg K_2O ha^{-1} (Singh et al., 2011. were found most effective in agriculture, particularly for wheat growth. As for calcium, fertilisation rates of 80 kg/ ha^{-1} proved to be effective for increasing potatoes growth yield (Giletto et al., 2022). Biomass ash contents usually vary, but phosphorus content can be as high as 7% (Kasina et al., 2023), potassium as high as 43.1% (Wang et al., 2014) and calcium as high as 33%. Such valuable nutrients prove biomass ash to be a plausible fertilisation material for agriculture.

However, careful application is necessary to avoid excessive accumulation of heavy metals or nutrient imbalances. When used appropriately, biomass ash serves as a sustainable alternative to chemical fertilizers, supporting both agricultural productivity and environmental conservation.

5. Granulation of biomass ash

The ash is less dense and lighter than the surrounding soil. Because of this, it tends to stay near the top layers of the soil instead of descending. Because of its tiny particle size and lightness, the ash slowly builds up in the top layers over time (Okonta & Kafodya, 2018).

Environmental factors, including wind and water, can carry even the tiniest particles of biofuel ash, enabling them to disperse within the atmosphere. The smallest particles can become wind-suspended from exposed ash deposits and transported over long distances, impacting air quality at the global and local scales. Water also facilitates the suspension and redistribution of ash particles through surface runoff and precipitate ions (Kuppusamy et al., 2015).

One of the best ways to reduce the dispersion of fine biofuel ash particles into the atmosphere is through the granulation process (Figure 3), i.e., the agglomeration of the ash particles with binding materials. By mixing materials and ash, the fine and easily airborne ash particles are converted into more stable granules, and hence, their erodibility by wind and water significantly decreases (Bowden-Green & Briens, 2015). The transformation of the ash from loose dusty powder to consolidated granules improves its handling, storage, and disposal, reducing the possibility of environmental pollution.



Figure 3. Granulation process

One way to insert biomass ash into the soil is to produce pellets. Pelletisation's benefits extend to the ease of application of the larger sizes and reducing the rate at which the nutrients are released. It also alleviates numerous issues with dust management in the field and during transport.

Yliniemi et al. (2016) studied peat-wood ash granulation using the binding agents potassium silicate and sodium aluminate. The study's results contributed to the production of lightweight aggregated material used in civil construction projects or as a constituent in the construction of lightweight concrete.

Several other researchers have explored the granulation of waste byproducts generated from bioenergy production, specifically fly ash and biochar. In their studies, these materials were combined with organic-rich lake sediments to create granulated products. The primary objective of these studies was to promote the sustainable reuse of industrial waste while also investigating the potential application of these granules in agricultural practices (Vincevica-Gaile et al., 2019).

In the study done by Buneviciene et al. (2020b), the LKD (lime kiln dust) and BA (biomass ash) were weighed and mixed (Figure 4) well using a specially designed ribbon blade mixer. The blended raw materials were then added to the drum. In the course of agitation, a small amount of water (around 12%) was added to the dry materials until tiny aggregates started to form a paste. The formed paste was further granulated using a disc pelletiser. It consisted of an internal disc rotated at approximately 20 revolutions per minute in a plane tilted

at 60 degrees. The disc was circular, measuring 72 centimetres (cm) in diameter with raised edges of 8 cm. Following the granulation process, the pellets produced were subjected to a drying time of 24 hours at room temperature in a laboratory fume hood.

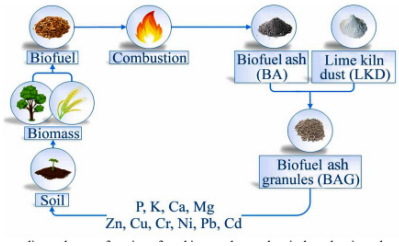


Figure 4. Potential nutrient recycling and reuse from biomass thermochemical combustion ash

Produced pellets were inserted into the soil, and changes in soil nutrient composition were observed for two years (Figure 5).

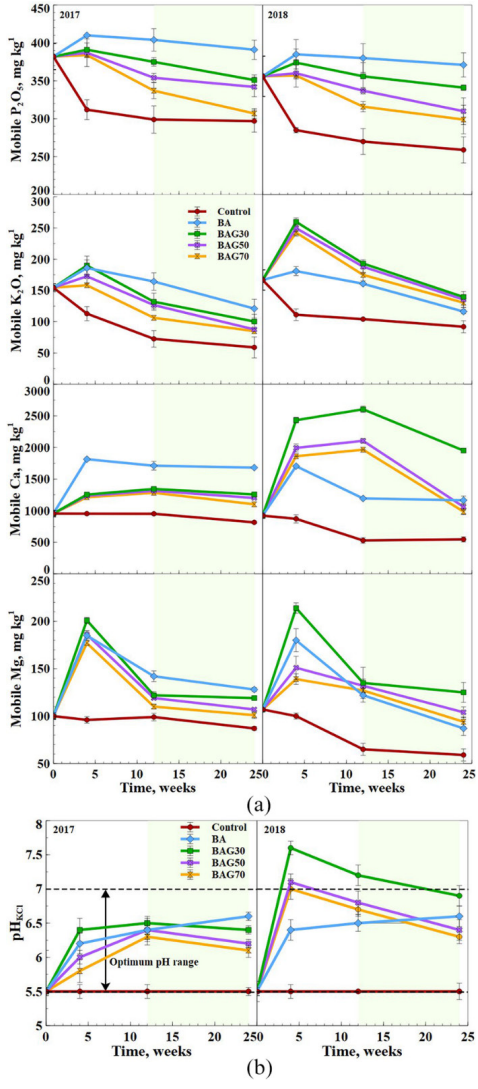


Figure 5. Soil nutrient concentration changes after the implementation of biomass ash granules, 2017–2018

The study measured nutrient release patterns from BA and BAG (biomass ash in granules) in soil over two years, recording changes in mobile P_2O_5, K_2O, Ca, and Mg at different intervals. Nutrient concentrations peaked within 4 weeks of application, followed by a decline, especially for Mg. After crop harvesting at 12 weeks, the decrease slowed, with BA and BAG maintaining higher P_2O_5 and K_2O levels compared to the control. In 2017, BA showed the highest nutrient release, while in 2018, higher precipitation enhanced Ca release from BAG due to its composition and larger particle size.

Heavy metal and micronutrient levels (Pb, Cd, Cr, Zn, Cu, Ni) increased slightly but remained within regulatory limits, with Zn and Cu notably rising due to their presence in ash. Heavy metal diffusion was minimal due to low solubility; most elements remained in the topsoil. In general, BA resulted in a linear increase in these elements.

5. Conclusions

The growing utilisation of biomass as a renewable energy source has resulted in a significant amount of biomass ash, which is both ecologically challenging and potentially valuable. Prospective application of biomass ash as a soil amendment presents an eco-friendly option, especially for degraded urban soils. By increasing soil water-holding capacity and porosity, biomass ash can provide better aeration, root penetration, and plant growth, particularly beneficial in semi-arid and arid regions.

In addition, inherent properties of biomass ash play critical roles in compensating for soil acidity. Studies have shown that applying biomass ash at the rate of 4,5 t/ha can increase soil pH by up to 1,3, which helps boost microbial life, and improve soil fertility. Studies indicated that the incorporation of biomass ash increases concentration of essential macronutrients in soil, such as potassium (100 mg/kg increase), calcium (700 mg/kg increase), phosphorus (110 mg increase), and magnesium (80 mg/kg) in soil even two years after application and thus promoted the growth of plants and rejuvenated nutrient-poor soil. Despite this, extra attention is essential when using biomass ash as a fertiliser to prevent excessive heavy metal concentration and ensure soil equilibrium.

Granulation methods, especially pelletisation, have been recognised as viable means of stabilising biomass ash to achieve maximum benefits while reducing environmental hazards. Studies have proved that the granulation of biomass ash with lime kiln dust (LKD) and a disc pelletiser produced stable pellets that enhanced soil nutrient retention and avoided the environmental hazard of ash dispersion. Such granulated biomass ash

provided a slow release of nutrients over time, enhancing long-term soil fertility and minimising the leaching of heavy metals into the environment.

To sum up, biomass ash is both a feasible and an environmentally friendly substitute for chemical fertiliser, which boosts soil fertility and ensures environmental sustainability. Through proper controls, handling, and advancement in the use of ash, bioenergy production byproducts can meaningfully contribute to sustainable soil management and land restoration initiatives.

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BIOMASĖS PELENŲ NAUDOJIMO DIRVOŽEMIO KOKYBEI GERINTI APŽVALGA: GALIMI PRIVALUMAI IR TAIKYMO GALIMYBĖS

N. EIGELIS, S. VASAREVIČIUS

Santrauka. Dirvožemio kokybė blogėja dėl žmogaus veiklos, ypač dėl didėjančio užterštumo, netinkamos priežiūros ir dirvožemio uždengimo įvairiomis dangomis. Tokie pokyčiai mažina infiltraciją, biologinį aktyvumą ir dirvožemio pralaidumą. Tuo pat metu, spartus biomasės energijos gamybos augimas lėmė didesnį susidarančių biomasės pelenų kiekį, keldamas susirūpinimą dėl atliekų apdorojimo ir poveikio

aplinkai. Tačiau biomasės pelenai gali būti tvarus sprendimas dirvožemio kokybei gerinti. Biomasės pelenai, kuriuose gausu pagrindinių maistinių medžiagų, tokių kaip kalcis, kalis ir fosforas, gali papildyti dirvožemį, kuriame šių maistinių medžiagų trūksta, taip pat sušvelninti dirvožemio rūgštėjimą. Dėl savo porėtos struktūros biomasės pelenai pagerina dirvožemio aeraciją, vandens sulaikymą ir šaknų įsiskverbimą, ypač smėlinguose ir degradavusiuose dirvožemiuose. Tokie metodai kaip granuliavimas pagerina biokuro pelenų panaudojimą, nes sumažina galimą sklaidą ore pelenams išdžiūvus ir tiekia lėtą maistinių medžiagų išsiskyrimą. Tyrimai parodė, kad tinkamai apdorotos pelenų granulės gali palaipsniui atiduoti maistines medžiagas, neviršydamos leistinų sunkiųjų metalų koncentracijos ribų. Gerai tvarkomi biomasės pelenai yra perspektyvus cheminių trąšų pakaitalas, didinantis žemės ūkio produktyvumą ir aplinkos tvarumą, taip pat mažinantis biomasės energijos šalutinių produktų problemas.

Raktiniai žodžiai: dirvožemio kokybės gerinimas, biokuro pelenai, atliekos.