Abstract

Rapid economic development since the late 18th century, including in agriculture, has led to a sharp increase in the concentration of greenhouse gases (GHG) in the atmosphere, such as methane (CH_4) and carbon dioxide (CO_2), resulting in progressive global warming. Agriculture is responsible for 10-12% of total anthropogenic greenhouse gas emissions, including nearly half of global methane emissions. Furthermore, carbon dioxide, as one of the most important greenhouse gases, also comes largely from agricultural production. Annual global CO_2 emissions from changes in land use are estimated at around 1.3 Gt C. This accounts for nearly half of the carbon that is globally deposited annually on land, i.e., 3 Gt C.

Intensifying climate changes, together with the intensification of agriculture, lead to soil degradation. This affects the decline in the productivity of agricultural fields, however, degradation manifests itself initially in the deterioration of the structure and physicochemical properties of the soil, as well as in a decrease in biodiversity and microbiological activity. In the long run, this leads to the impoverishment of entire ecosystems and problems with food supply.

Progressive degradation of soils and intensifying climate changes mean that solutions are being sought more and more intensively to stop or delay these unfavourable phenomena. The increase in plant production has also led to a significant accumulation of post-harvest residues and plant waste from the processing industry, hence a serious challenge is the rational management of the growing amounts of waste biomass. The production of biochar and the enrichment of soils with biochar may prove to be a solution that can meet the challenges facing agriculture today, i.e. protection of soils against degradation, reduction of emissions and increased absorption of greenhouse gases from agriculture, as well as rational management of waste biomass.

In this doctoral dissertation, the multifaceted application potential of selected biochars as a material for improving the properties and methanotrophic activity of Haplic Luvisol was determined. The aim of this work was to characterise biochars produced from waste biomass (wood offcuts, sunflower husks, raspberry stems and potato stems), including its physicochemical properties and the potential of biochars to absorb methane from the atmosphere, in addition to a multi-faceted assessment of the role and usefulness of selected biochars in reducing greenhouse gas emissions from Haplic Luvisol.

The research material consisted of biochar samples, produced in the pyrolysis process from selected types of waste biomass, i.e. wood offcuts, sunflower husks, as well as raspberry stems and potato stems, which are a new biomass for this type of application. The research material in the subsequent stages of the work was lessive soil (Haplic Luvisol), taken from experimental plots kept fallow, on which biochar from wood offcus was applied in doses of 10, 20 and 30 Mg ha^{-1}, as well as biochar from sunflower husks, used in a wide range of doses from 1 to 100 Mg ha^{-1}.

Planned physicochemical analyses of the test material were performed, i.e. measurement of pH, redox potential (Eh), determination of soil organic carbon (SOC), dissolved organic carbon (DOC), nitrate nitrogen (NO_3-N) and water holding capacity (WHC). Biochar samples and soil samples taken from the plots with the addition of biochar were incubated under two moisture conditions (corresponding to 60% and 100% WHC) at 25 ℃, with the addition of 1% CH_4 (v/v). At that time, regular measurements of the composition of the gas atmosphere in the prepared samples were carried out using a gas chromatograph. DNA was also isolated from selected variants of the experiment and next generation sequencing (NGS) was performed. The analysis made it possible to characterise the community of microorganisms inhabiting the tested soil and better understand the changes that occur in the soil microbiota as a result of the application of biochar to the soil.

The research showed that the type of biomass from which the biochar was produced (feedstock) and the moisture content of the biochar strongly determined its ability to absorb CH_4. In addition, at both of the tested moisture levels, biochar from potato stems (shaws) showed the highest rate of CH_4 absorption, which indicates the high usefulness of the new biochar as a CH_4 sorbent, and the innovation and practicality of this solution was reflected in the patent achievement.

In addition to testing the biochars themselves, their global warming mitigation potential when added to soil was also assessed. The experiment in which poor lessive soil was enriched with biochar from wood offcuts made it possible to assess the impact of selected doses of biochar on the soil environment, taking into account the time aspect of biochar in the soil. It was proven that the addition of biochar at a dose of 30 Mg ha^{-1} increased, among others, pH and water retention in the soil, increased the number and biodiversity of methanotrophic communities, led to an increase in the share of methanotrophic bacteria of the genus *Methylocystis*, and consequently permanently improved the methanotrophic activity of lessive soil. Another important point was that the initially observed increase in CO_2 emissions was not sustained five years after biochar addition to the soil.

The effects of using biochar from sunflower husks in doses of 1, 5, 10, 20, 30, 40, 50, 60, 80, 100 Mg ha^{-1}, presented in subsequent studies, also confirmed the multidimensional benefits of this treatment. Haplic Luvisol enriched with sunflower husk biochar at doses $\geq$ 40 Mg ha^{-1} in soil with a moisture content corresponding to 60% WHC, and $\geq$ 20 Mg ha^{-1} in water-saturated soil (100% WHC), was characterised by increased CH_4 oxidation capacity compared to the control. While the addition of biochar from wood offcuts enriched methanotrophic communities with bacteria of the genus *Methylocystis,* high doses (60, 80, 100 Mg ha^{-1}) of sunflower husks biochar led to a significant increase in the share of methanotrophs of the genus *Methylobacter*. The results of the conducted experiments confirm the positive role of the tested biochars in shaping the soil environment and stimulating the methanotrophic activity of lessive soil.

Although the introduction of biochar into the soil has a very long history, in our part of the world this treatment has so far remained mainly in the field of research. These studies are justified, because taking into account the durability of biochar and the potential duration of its impact, it is particularly important to know the long-term impact of this additive on the soil environment. The presented doctoral thesis, showing various aspects of the operation of biochars (made both from widely available and only recently tested, niche biomass), provides information helpful when considering the use of biochar in soil enrichment, and may also contribute to the dissemination of this procedure.

Keywords: lessive soil (Haplic Luvisol), biochar, greenhouse effect, methanotrophy, *Methylocystis*, *Methylobacter*