[1.]Laurențiu VLĂDUȚOIU, [1.]Iulian DUMITRU, [1.]Valentin VLADUT, [1.]Alexandru IONESCU, [1.]Gabriel NAE, [1.]Florin NENCIU, [1.]Costin MIRCEA, [1.]Iulian VOICEA, [1.]Marius OPRESCU, [1.]Andreea–Iulia GRIGORE, [1.]Nicoleta VANGHELE

# CONSIDERATIONS REGARDING EXISTING TECHNOLOGIES FOR PRODUCING BIOCHAR

[1.]National Institute of Research – Development for Machines and Installations Designed to Agriculture and Food Industry – INMA Bucharest, ROMANIA

**Abstract:** Biochar is a form of charcoal produced (generally) by burning biomass at high temperatures in the absence of air, in a process called pyrolysis. This substance has the potential to have a positive impact on the environment. The positive impact on the environment is manifested through the improvement of soil fertility, reduction of greenhouse gas emissions, improvement of water quality, and reduction of dependence on fossil fuels. The presence of biochar in the germination bed of plants provides an improvement in the soil's water retention capacity, which can lead to an increase in crop yields. However, the use of biochar must be carefully managed to prevent unwanted side effects and to maximize its benefits.
**Keywords:** biochar, biomass, pyrolysis, soil fertility

## INTRODUCTION

Biochar is a material obtained by burning biomass at high temperatures in an oxygen–limited environment. This process is called pyrolysis and has been used for thousands of years by various cultures around the world to improve soils and reduce waste. Modern biochar, as a sustainable solution for agriculture and the environment, began to be more intensively researched in the 1990s. During this time, research was conducted to evaluate biochar's potential to improve soil quality and reduce greenhouse gas emissions (*Nenciu et al. 2022*). Since then, interest in biochar has grown, and research and technology development for its production continue to progress. Today, biochar is used as an ecological and sustainable alternative to chemical fertilizers and is used in various applications, such as soil improvement, energy production, and carbon capture from the atmosphere. There are several modern technologies used today around the world for producing biochar, including slow pyrolysis, fast pyrolysis, hydrothermal, hydrothermal oxidation, gasification, etc. Slow pyrolysis is a thermal transformation process of biomass that occurs at relatively low temperatures (between 300 and 500 degrees Celsius) in the absence or with a very small amount of oxygen. This method of pyrolysis is different from fast pyrolysis, which occurs at higher temperatures, with reduced vapor content, and shorter exposure time to temperature. During slow pyrolysis, the biomass is slowly heated, and the organic matter is gradually decomposed into a mixture of gases, biochar, and liquids (mainly pyroligneous acid and tar) (*Oprescu et al. 2023; Nenciu et al. 2022*). These products can be subsequently separated and used in a variety of applications, such as energy production, biofertilizer production, and soil improvement. Slow pyrolysis can be performed using various types of reactors, such as ovens, retorts, or pipe networks. This method of pyrolysis is considered less efficient than fast pyrolysis, as it requires more time to produce smaller quantities of products, but it can be an efficient solution for producing high–quality biochar.

Fast pyrolysis is a thermal conversion process of biomass that takes place at high temperatures (between 500 and 800 degrees Celsius), in an environment with a low amount of oxygen or no oxygen. This process is carried out in a relatively short time, usually in a few seconds or minutes, and can produce a variety of valuable products such as biochar, bio–oils, and syngas. During fast pyrolysis, the biomass is rapidly heated to high temperatures, leading to the thermal decomposition of the material into a mixture of gases, biochar, and bio–oils. The resulting gaseous products can be used as an energy source to power the pyrolysis process or can be further processed to produce other valuable products such as hydrogen or methane. Biochar produced through fast pyrolysis can be used in various applications, such as soil improvement or the production of activated carbon. Fast pyrolysis is considered an efficient method for converting biomass into a variety of valuable products, and the development of fast pyrolysis technologies has played an important role in promoting the use of renewable resources and reducing greenhouse gas emissions.

Gasification is a technology that involves heating biomass to high temperatures in an oxygen–reduced environment, which allows the production of a mixture of syngas that can be used in various applications, such as the production of electricity or synthetic fuels. Hydrothermal oxidation technology produces biochar by treating biomass in a water and oxygen environment at high temperatures and pressures. This allows the production of biochar with a porous structure and high–water retention capacity, which can be used in various applications, such as soil improvement. Hydrothermal technology treats biomass in a supercritical water environment at high temperatures and pressures, allowing the production of biochar with a porous structure and high–water retention capacity, which can be used in various applications, including soil improvement.

In our country, there are several biochar producers, both for use in agriculture and other fields. Generally, biochar production in our country focuses on local biomass such as wood, straw, or agricultural residues. There are also research projects exploring the use of biochar in various fields, such as combating climate change, soil improvement, and energy production. In recent years, interest in the use of biochar in Romania has grown due to its potential benefits for agriculture and the environment, as well as the increasing global demand for sustainable and environmentally friendly products. There are several companies that produce biochar production technologies. Here are a few examples:

In the world, among the companies that produce biochar production technologies, we can list:

- Earth Systems – produces biochar production technologies based on pyrolysis with gasification, using various biomass sources.
- Advanced BioRefinery Inc. – produces biochar production technologies based on pyrolysis with gasification, with a production capacity of up to 100 tons of biochar per day.
- Carbofex – produces biochar production technologies based on pyrolysis with a production capacity of up to 10 tons of biochar per day.
- Agri–Tech Producers LLC – produces biochar production technologies based on pyrolysis with gasification, using various biomass sources, with a production capacity of up to 500 tons of biochar per year.
- Biochar Solutions Inc. – produces biochar production technologies based on pyrolysis with a production capacity of up to 2 tons of biochar per day. It is important to note that the benefits of biochar depend on several factors, and its application must be done properly and in accordance with the recommended specifications for each type of crop and soil.

## MATERIALS AND METHODS

In general, woody or agricultural biomass is treated at high temperatures. This process results in the rapid concentration of elemental carbon and the disappearance of the fibrous structure, improving its grinding capacity. In order to maximize the efficiency of the pyrolysis process, the combustion gases are cooled in the heat exchanger. Figure 1 shows a variant of the process of pyrolyzing vegetable matter.

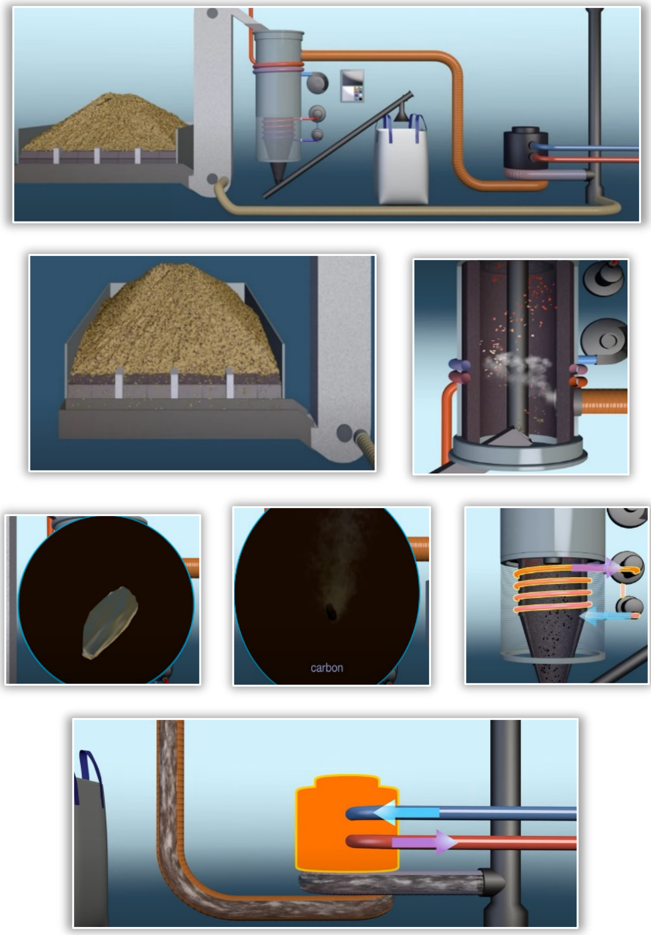


Figure 1 – a), b), c), d), e), f), g) The process of biomass pyrolysis (www.youtube.com/watch?v=3K1zWAYDvMA)
b) Raw material (biomass); c) Biochar production; d) Evaporation of moisture; e) The carbonization processes; f) The cooling processes; g) Generating heat

The Pyreg PX technology represents a compact, decentralized carbonization option that can be easily integrated into existing infrastructure. Biomass or sludge is not incinerated, but rather gently degassed and then carbonized at temperatures between 500 and 750°C – in a process with limited oxygen. It is an efficient, durable and profitable technology.

The PYREG process is suitable for a wide range of carbonaceous inputs. Examples include: manure, dry waste, cereal waste, husks, silage waste, abattoir waste, hay, straw, wood chips, green waste, fruit kernels, nut shells, grape marc, rice straw, rice husks, cotton stalks and sawdust (*Tong et al. 2021; Wang et al. 2021; Xiong et al. 2021*), rubber, used tires, storm damage, wear parts, textiles/cotton, waste wood, paper, cardboard, paint residue, and sewage sludge (*Buss 2021; Zhang et al. 2021, Mircea et al. 2021*) and many others. The PYREG process allows for such precise control of carbonization parameters; hence, carbon products can be produced in different grades of quality, ensuring that raw materials such as phosphorus can be easily recycled. At the same time, organic–based pollutants (such as solvents and microplastics) are virtually eliminated, and mineral–based pollutants are filtered out at temperatures of up to 1000°C in the combustion chamber. It is efficient, environmentally friendly, and without harmful secondary products, as shown in Figure 2. (https://pyreg.com/our–technology/)

The Pyreg PX technology is an innovative slow pyrolysis technology for converting biomass into biochar and other valuable products, developed by the German company Pyreg GmbH. This technology is based on a multi–chamber reaction system that allows for the efficient processing of biomass in an oxygen–deficient environment. The process starts by heating the biomass to a certain temperature in a first chamber with reduced air. Then, the material is transported to a second chamber with no air, where the actual pyrolysis takes place. In this chamber, the biomass is subjected to higher temperatures and longer exposure times, leading to the production of biochar and other secondary products such as bio–oils and bio–gases. The Pyreg PX system is a closed system, which means that there are no polluting emissions to the environment. Additionally, the technology is designed to use the heat generated by the pyrolysis process to heat the next biomass to be processed, thus reducing external energy consumption and operating costs. The Pyreg PX technology is considered an environmentally friendly and sustainable solution for converting biomass into biochar and other valuable products, as well as for reducing greenhouse gas emissions and dependence on fossil fuels.

Figure 2 – Installation using Pyreg PX technology (https://pyreg.com/our–technology/)

Biochar –animal feed additive | Biochar – soil amendment | Biochar – filler additive

Figure 3 – a), b), c) Different types of biochar (https://pyreg.com/going–circular/biochar/)

Biochar can be used as additives for animal feed, soil additives, and filler additives as shown in figure 3 a), b), c). In addition to being used as an animal feed additive, biochar is also used as bedding, for treating manure, or as an additive for compost (*Lu H. et al. 2021; Shan G. et al. 2021; Yin Y.et al. 2021, Nenciu et al. 2023*). Biochar improves animal health, reduces unpleasant odors, optimizes fertilizer quality, and reduces the loss of harmful nutrients for the climate and the environment. Among the advantages are: increased vitality, feed efficiency, food intake, and weight gain; strengthening of the immune system and a decrease in the mortality rate; improved milk quality in cows due to improved udder health; reduction of diarrhea and hoof and foot diseases; increased egg production and egg quality in poultry; improved meat quality; significant increase in milk ingredients; improved stable hygiene and reduced odor pollution; enormous reduction in the smell of liquid excrement; and reduction in costs for medicines and veterinary doctors (https://pyreg.com/going–circular/biochar/).

In figure 4, a schematic representation of a Pireg technology–based process is presented. The energy generated by the carbonization of waste is utilized for the continuous operation of the system.

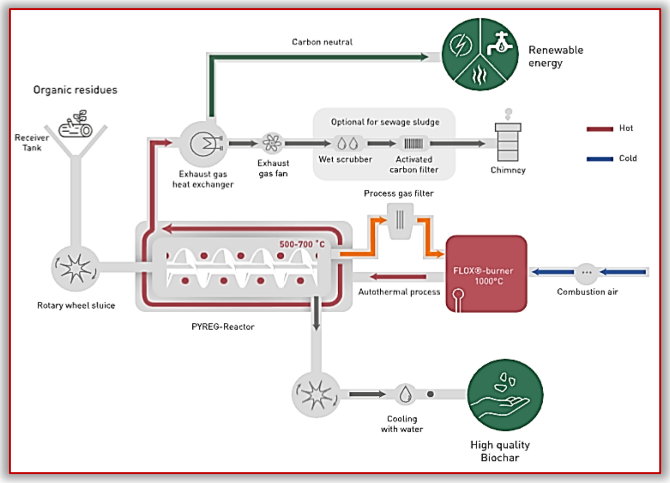


Figure 4 – The technological process of an installation (Pyreg processes (https://pyreg.com/our–technology/)

## RESULTS

The advantages of biochar used as a soil amendment can be: An intact humus layer stores nutrients and water, as well as large amounts of $CO_2$, a greenhouse gas. Biochar facilitates this process. With a surface area of 200–500 m² per gram and high porosity, biochar can absorb up to five times its weight in water and nutrients. "Green carbon" remains stable during decomposition and does not decay. As a result, farmers can improve soil quality with biochar, save money on fertilizers; nitrate loads in soil and groundwater are considerably reduced; soil acidification is reduced; humus accumulation is increased; excellent capacity to store nutrients and water; plants resist extreme weather conditions, such as weeks of drought–induced stress and subsequent irrigation is significantly improved; biochar can significantly improve biogas yield; it improves the stress resistance of urban trees.

The possible uses of biochar (pyrolytic biomass carbon) are extremely varied. It also has numerous positive effects when used in industrial processes. In the cement industry, biochar can be used as an additive/replacement, as well as in the production of construction materials. Last but not least, biochar is beneficial because it replaces fossil fuels and thus improves the $CO_2$ footprint (https://pyreg.com/going–circular/biochar/)

Biochar has been rediscovered in recent years as a natural soil ameliorant. Nutrient–poor soil has been enriched with a composted or fermented mixture of plant residues, manure, as well as charcoal from hearths. However, biochar is not a fertilizer if used alone. It is highly porous. Biochar acts like a sponge that can absorb up to five times its weight. It stores water and nutrients and allows microorganisms to establish themselves in its pores. This property is also described by the absorption capacity (AC). It depends on both the pyrolyzed biomass and the pyrolysis conditions of the carbonization process, (Hagemann N. et al. 2017; Inyang MI. et al. 2015; Woolf D. et al. 2021).

Biochar must first be "activated," which means it needs to be enriched with nutrients and soil organisms, for example, during composting. If pure biochar is introduced into the soil, it withdraws water and dissolved substances in it from the surrounding environment and thus has the exact opposite effect, (https://pyreg.com/going–circular/biochar/).

In Figure 5, we have the size of the biochar market in the United States, the analysis report of the share and trends by technology (pyrolysis, gasification), by application (agriculture, animal feed, health and beauty products), by state, and forecasts by segment, 2021–2028. The size of the biochar market in the United States was estimated at USD 125.3 million in 2020 and is expected to expand at a compound annual growth rate (CAGR) of 16.8% from 2021 to 2028. This is attributed to the growing demand for the product to improve crop yields.

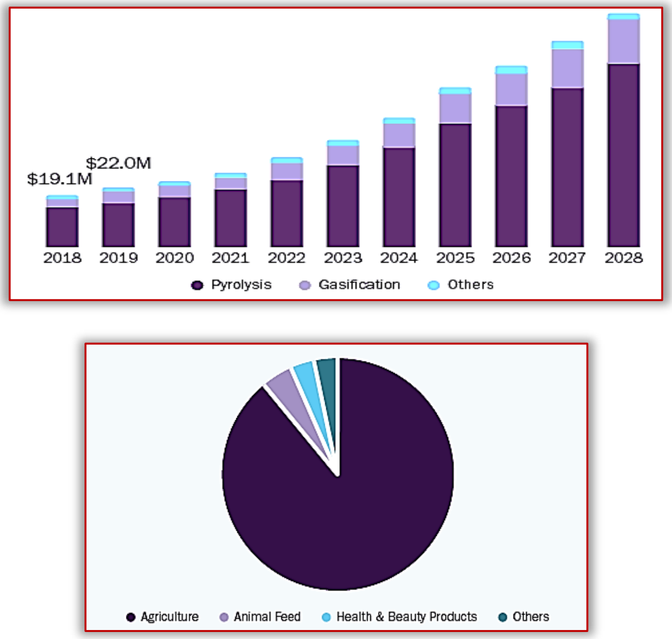


Figure 5 – Situatia si prognoza biochar SUA 2018– 2028 (https://www.grandviewresearch.com/industry–analysis/us–biochar–market)

Since the primary feedstock is woody biomass, it is anticipated that the US Forest Service will have an increased interest in providing feedstock to local biochar producers. Trees and vegetation destroyed due to natural causes as well as fires can be used for the production of biochar.

Some companies are also experimenting with using the product in other application areas as it is called a safe and environmentally friendly product. For example, Biochar Supreme has developed a stormwater treatment method using biochar (https://www.grandviewresearch.com)

The global biochar market was valued at USD 1,448.6 million in 2018 and is projected to grow at a CAGR of 9.1% from 2019 to 2026. Biochar, in the past few years, has gained significant attention in the agricultural sector globally. Due to its physical and chemical properties, biochar has been described as a major driver for climate change mitigation and sustainable agriculture, figure 6. Waste generation from agriculture and related industries provides a potential feedstock for biochar production. By converting residual biomass from farms and food processing industries into biochar, it provides a solution to achieve long–term carbon sequestration and also other beneficial effects on soils and environmental properties.

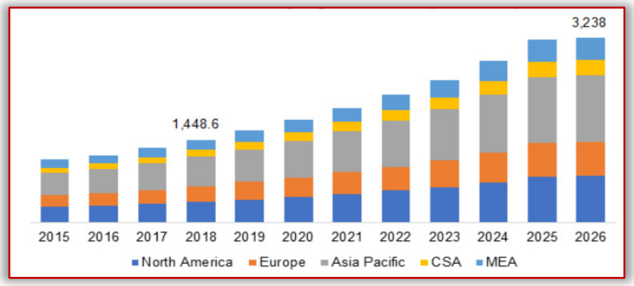


Figure 6 – Situation and forecast of biochar in the USA 2018–2028. (https://www.polarismarketresearch.com/industry–analysis/biochar–market)

Production of biochar from organic waste and its role in improving biomass production by enhancing soil fertility and remediation of contaminants is anticipated to be a crucial factor driving its demand during the forecast period. The technology segment is further divided into gasification, pyrolysis, and other production processes. The application segment has expanded greatly in agriculture (including animal husbandry), general farming (organic farming, inorganic farming), and others. Slow pyrolysis is the most conventional process used for biochar production. The gasification process is among the most widely used in the current scenario of the industry and is expected to be the fastest–growing segment during the forecast period. Asia Pacific was the largest regional industry in 2018. China is the leading biochar producer in the region, followed by India. Southeast Asian countries such as Vietnam, Philippines, Malaysia, etc. are some of the other developing markets in the region and are expected to experience significant growth in product usage over the next six years (https://www.polarismarketresearch.com/industry–analysis/biochar–market).

Biochar application in the field can be done through various methods, depending on the crop, soil, type of biochar, and available resources. Among the most common options for applying biochar in the field are: manual application, using agricultural machinery, application in a mixture with compost or fertilizers, and solution form. Manual application of biochar is done around plant roots or spread evenly on the soil surface, and then incorporated with a cultivator plow. This method is more suitable for small areas and is often used in households. For larger areas, biochar can be applied with the help of agricultural machinery, such as machines for administering organic fertilizers. These distribute biochar uniformly, quickly, and efficiently over the entire soil surface.

Biochar can be mixed with compost or organic fertilizers, such as manure or vegetable residues, and then distributed on the soil surface. This method brings good soil quality improvement and can provide nutrients for plants. Another way to distribute biochar can be by mixing it with water and then applying this mixture as a solution on the soil surface or directly to plant roots. This method can be used especially for crops in pots or in greenhouses, where the solution can also be applied with an irrigation system.

It is important to consider the soil characteristics and crop requirements, as well as the manufacturer's specifications when deciding on the optimal method of biochar application in the field. It is also important to apply appropriate amounts of biochar to avoid negative effects on soil and plants.

Among the advantages of using biochar, we can enumerate:

- Increased soil fertility through the use of biochar as a soil amendment, improving soil structure, water retention capacity, and nutrient release. It can help prevent soil erosion and improve agricultural production.
- Reduction of greenhouse gas emissions by using biochar to capture carbon from biomass and retain it in the soil for long periods of time, thus reducing greenhouse gas emissions and contributing to the fight against climate change.
- It can also be used to improve water quality by filtering contaminants and toxic substances from water, as well as reducing nutrient levels from excess chemical fertilizers and fertilizers in soils.

- Biochar can be used as an alternative source of energy, replacing fossil fuels in heat and electricity production. This can reduce dependence on fossil fuels and reduce greenhouse gas emissions.
- Reduced use of chemical fertilizers, as biochar has a high nutrient retention capacity, it can reduce the need for chemical fertilizers in agriculture, which can lead to a reduction in costs and their negative impact on the environment.
- The use of biochar can lead to increased crop yields, due to the improvement of soil fertility and its capacity to retain water and nutrients

## CONCLUSIONS

All of these technologies are used worldwide and continue to be developed and improved to produce high–quality biochar and enhance sustainability and environmental protection. In general, using biochar in agriculture can bring numerous benefits to soil, crops, and the environment. However, it is important to consider the specific characteristics of the soil and crops, as well as the methods of biochar production and application, in order to maximize the benefits and minimize the risks associated with its use. Currently, the use of biochar in agriculture is growing globally, being used in diverse geographic areas and for a wide range of crops.

**Acknowledgement**

This work was supported by a grant of the Romanian Ministry of Research, Innovation and Digitization, project code PN–III–P2–2.1–PTE–2021–0306, contract no. 87PTE/21.06.2022 and through Program 1 – Development of the national research–development system, Subprogram 1.2 – Institutional performance – Projects for financing excellence in RDI, Contract no.1PFE/30.12.2021.

**References**

[1] Buss W. (2021). Pyrolysis solves the issue of organic contaminants in sewage sludge while retaining carbon—making the case for sewage sludge treatment via pyrolysis. ACS Sustain Chem Eng 9:10048–10053
[2] Inyang M.I, Gao B, Yao Y, Xue Y, Zimmerman A, Mosa A, Pullammanappallil P, Ok YS, Cao X (2015) A review of biochar as a low–cost adsorbent for aqueous heavy metal removal. Crit Rev Env Sci Tec 46:406–433
[3] Hagemann N, Joseph S, Schmidt HP, Kammann CI, Harter J, Borch T, Young RB, Varga K, Taherymoosavi S, Elliott KW, McKenna A, Albu M, Mayrhofer C, Obst M et al (2017) Organic coating on biochar explains its nutrient retention and stimulation of soil fertility. Nat Commun 8:1089
[4] Lu H., Chen XH, Mo. C.H., Huang Y.H., He M.Y., Li Y.W., Feng N.X., Katsoyiannis A, Cai QY (2021) Occurrence and dissipation mechanism of organic pollutants during the composting of sewage sludge: a critical review. Bioresour Technol 328:124847
[5] Mircea, C.; Nenciu, F.; Vlăduţ, V.; Voicu, G.; Cujbescu, D.; Gageanu, I.; Voicea, I. (2020). Increasing the performance of cylindrical separators for cereal cleaning, by using an inner helical coil. INMATEH Agric. Eng., 62, 249–258.
[6] Nenciu F., Fatu V., Arsenoaia V., Persu C., Voicea I., Vladut N–.V., Matache MG, Gageanu I, Marin E, Biris S–S, et al. (2023). Bioactive Compounds Extraction Using a Hybrid Ultrasound and High–Pressure Technology for Sustainable Farming Systems. Agriculture. 13(4):899
[7] Nenciu, F.; Paraschiv, M.; Kuncser, R.; Stan, C.; Cocarta, D.; Vladut, V.N. (2022). High–Grade Chemicals and Biofuels Produced from Marginal Lands Using an Integrated Approach of Alcoholic Fermentation and Pyrolysis of Sweet Sorghum Biomass Residues. Sustainability 14, 402
[8] Nenciu F., Voicea I., Cocarta D.M., Vladut V.N., Matache M.G., Arsenoaia V.–N. (2022). "Zero–Waste" Food Production System Supporting the Synergic Interaction between Aquaculture and Horticulture. Sustainability, 14(20):13396
[9] Nenciu F., Stanciulescu I, Vlad H, Gabur A., Turcu O.L., Apostol T., Vladut V.N., Cocarta D.M., Stan C. (2022). Decentralized Processing Performance of Fruit and Vegetable Waste Discarded from Retail, Using an Automated Thermophilic Composting Technology. Sustainability. 14(5):2835
[10] Oprescu M.R., Biris S–S., Nenciu F. (2023). Novel Furrow Diking Equipment–Design Aimed at Increasing Water Consumption Efficiency in Vineyards. Sustainability. 15(4):2861
[11] Shan G., Li W, Gao Y., Tan W., Xi B. (2021). Additives for reducing nitrogen loss during composting: a review. J Clean Prod 307:127308
[12] Tong S., Zhang S., Yin H., Wang J., Chen M. (2021). Study on co–hydrothermal treatment combined with pyrolysis of rice straw/sewage sludge: biochar properties and heavy metals behavior. J Anal Appl Pyrol 155:105074
[13] Vlăduţ, N.–V.; Ungureanu, N.; Biriş, S.–Ş.; Voicea, I.; Nenciu, F.; Găgeanu, I.; Cujbescu, D.; Popa, L.–D.; Boruz, S.; Matei, G.; et al. (2023). Research on the Identification of Some Optimal Threshing and Separation Regimes in the Axial Flow Apparatus. Agriculture 13, 838
[14] Wang X., Chang V.W., Li Z., Chen Z., Wang Y. (2021). Co–pyrolysis of sewage sludge and organic fractions of municipal solid waste: synergistic effects on biochar properties and the environmental risk of heavy metals. J Hazard Mater 412:125200
[15] Wang Z., Shen R., Ji S., Xie L., Zhang H. (2021). Effects of biochar derived from sewage sludge and sewage sludge/cotton stalks on the immobilization and phytoavailability of Pb, Cu, and Zn in sandy loam soil. J Hazard Mater 419:126468
[16] Wang Z., Tian Q., Guo J., Wu R., Zhu H., Zhang H. (2021). Co–pyrolysis of sewage sludge/cotton stalks with K2CO3 for biochar production: improved biochar porosity and reduced heavy metal leaching. Waste Manag 135:199–207
[17] Woolf D., Lehmann J., Ogle S., Kishimoto–Mo AW, McConkey B, Baldock J (2021). Greenhouse gas inventory model for biochar additions to soil. Environ Sci Technol 55:14795–14805
[18] Xiong Q., Wu X., Lv H., Liu S., Hou H., Wu X. (2021). Influence of rice husk addition on phosphorus fractions and heavy metals risk of biochar derived from sewage sludge. Chemosphere 280:130566
[19] Yin Y., Yang C, Li M, Zheng Y, Ge C, Gu J, Li H, Duan M, Wang X, Chen R (2021). Research progress and prospects for using biochar to mitigate greenhouse gas emissions during composting: a review. Sci Total Environ 798:149294
[20] Zhang X., Xie H., Liu X., Kong D., Zhang S., Wang C. (2021). A novel green substrate made by sludge digestate and its biochar: plant growth and greenhouse emission. Sci Total Environ 797:149194
[21] *** www.youtube.com/watch?v=3K1zWAYDvMA
[22] *** https://www.polarismarketresearch.com/industry–analysis/biochar–market
[23] *** https://www.grandviewresearch.com/industry–analysis/us–biochar–market
[24] *** https://pyreg.com/our–technology/

**Note**: This paper was presented at ISB–INMA TEH' 2023 – International Symposium on Technologies and Technical Systems in Agriculture, Food Industry and Environment, organized by University "POLITEHNICA" of Bucuresti, Faculty of Biotechnical Systems Engineering, National Institute for Research–Development of Machines and Installations designed for Agriculture and Food Industry (INMA Bucuresti), National Research & Development Institute for Food Bioresources (IBA Bucuresti), University of Agronomic Sciences and Veterinary Medicine of Bucuresti (UASVMB), Research–Development Institute for Plant Protection – (ICDPP Bucuresti), Research and Development Institute for Processing and Marketing of the Horticultural Products (HORTING), Hydraulics and Pneumatics Research Institute (INOE 2000 IHP) and Romanian Agricultural Mechanical Engineers Society (SIMAR), in Bucuresti, ROMANIA, in 5–6 October, 2023.