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Review article

Agri-energy Crops for Biogas Production Regimes

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Abstract

The most significant challenges posed to agriculture are connecting multiple segments in a sustainable way that includes resource and energy efficiency as well as environmental protection through the rational use of limited resources. One way is to use field crop biomass as a feedstock for biogas production in the process of anaerobic digestion. Codigestion of manure and energy crops biomass reduces the impact on the environment primarily through reducing greenhouse gas emissions during the entire life cycle of the plant. Energy crops should meet the basic conditions: efficient conversion of solar energy in the process of photosynthesis that allows high yields, low requirements for nutrients and water due to a well-developed root system, low requirements for agronomic measures, low cost of establishing and maintaining plantations. The main factors that determine the biogas yields are the type and variety of crops, harvest time, method of storage and pretreatment before AD conversion and nutrient content. The most used field crops are maize (silage, grain), sorghum (fodder and sveet) due to their high potential for methane production and mature technologies. Lignocellulosic biomass of field residues of field crops or originating from purpose-grown perennial crops such as switchgrass, miscanthus, reed canary grass, Napier grass has significant environmental advantages but also technological limitations (pre-treatment is necessary). The success and future potential for the role of biogas technologies in integrated infrastructures providing bioenergy, biomethane for static and mobile applications, bio-CO2, and even play a key role in the circular economy by recycling nutrients back into the land through the use of digestate which is by-product as soil amendment in energy crops production chan.

Keywords: anaerobic digestion, bioeconomy, biomass, sustainability.

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INTRODUCTION

The main interest driver in renewable energy sources is climate change, which is recognized as a major threat to the further development of human civilization and its survival. Therefore, a large number of researchers are engaged in the development and improvement of technologies for the use of RES (Renewable Energy Sources) in all sectors. The results of this research should contribute to the realization of SDGs, especially goal 7 - available renewable energy, but also goals 9-industry, innovation and infrastructure, 10 - reducing inequality, 13- climate action and 15-life on land. Energy crops biomass, such as RES, is specific because, unlike others for which technologies, it involves reducing the impact on the environment primarily through reducing greenhouse gas emissions during the entire life cycle of the plant, biomass uses CO_2 from the atmosphere for photosynthesis so that its use makes it easier to achieve carbon neutrality. In addition, agro-energy crops contribute to increasing soil fertility by increasing its carbon content and can be grown on marginal and contaminated soils, thus achieving two advantages: avoiding competition with food production on fertile agricultural land, and remediation of degraded locations.

Biomass energy of agro-energy crops can be converted by thermochemical and biochemical processes, whereby biochemically they show greater sustainability over longer periods of time. Anaerobic digestion (AD) is one of the most promising technologies for biomass energy conversion. As raw materials in the production of biogas are using different types of bomas that contains a high proportion of moisture and organic matter - cellulose, hemicellulose, proteins and fats: manure, food waste and food processing, slaughterhouse and farm waste, waste from the dairy industry, fruit and vegetables, sewage sludge. The energy production potential of raw materials varies depending on the type, level of processing / pretreatment and concentration of biodegradable material. As these types of waste do not have a high enough potential for sustainable biogas production, either due to low energy content or limited availability of materials, it is necessary to use agro-energy crops. If these crops are grown near a biogas plant, have high biomass and energy yields per unit area of land and low production costs that can be reduced by using digestate, a by-product of the AD process, as soil amendment, environmental sustainability and economic viability can be expected.

The aim of this research is to rewiev literature regards to energy-crop utilization for biogas production from aspect of sustainable agriculture.

AGRICULTURE

Today, the most significant challenges posed to agriculture are connecting multiple segments in a sustainable way that includes resource and energy efficiency as well as environmental protection through the rational use of limited resources.

Agriculture is recognized as a significant emitter of greenhouse gases, 11% of global GHG emissions (FAO 2020), so intensive research is being conducted on the use of renewable energy sources in agriculture in order to increase environmental sustainability (Turkmen, 2020).

Biogas production is important for farms, where it allows the use of residues from livestock production - most often the most solid and liquid manure as well as harvest residues from crop production (Battini et al. 2014), as well as on the regional level when produced biogas is placed on the distribution network for natural gas or, more often, biogas energy is converted to electricity and heat in a cogeneration plant (Lansche and Müller, 2012). Electricity is sold through the distribution network, usually at a discounted price. Thermal energy is used on the farm itself or in the immediate vicinity to heat greenhouses, hothouses, fishponds, dryers and more.

Manure is more convenient to use, as a substrate for AD, than directly as fertilizer because it contains significant concentrations of nutrients and pathogens (Neshat et al., 2017). Direct application in the field can cause groundwater and soil pollution. By using manure as a raw material for AD the negative impact on the environment is reduced; emissions of carbon dioxide, methane and nitrogen oxides; reduction of waste, odors; destruction of pathogens (especially when AD works in thermophilic conditions). On the other hand, the use of only animal manure in AD also has disadvantages, and the most significant is the low ratio of carbon to nitrogen (C / N) (Neshat et al., 2017). Although manure has been identified as the basic substrate for biogas plants especially in countries with intensive livestock production (Franco et al., 2019), which causes a low yield of biogas (10 ÷ 20 m^3/t of fresh manure), pre-treatment methods, co-digestion with other biodegradable organic substrates or a combination of both should be applied. Energy crops that were mainly used as raw material in the production of biogas through AD pose a threat to their use for food in contrast to abundant amounts of lignocellulosic biomass residues from field production that have the appropriate biochemical potential of methane (BPM).

ENERGY CROPS

The biomass of bioenergy crops is actually the only one that is carbon neutral because these crops absorb CO_2 from the atmosphere and increase its concentration in the soil. The production of biofuels based on energy crops shows positive impacts on the environment, both through intensive photosynthesis, and through the reduction of greenhouse gas emissions and the reduction of soil erosion. These crops can be efficiently grown on marginal or contaminated soils where they also perform the function of phytoremediation of soil that is contaminated with heavy metals, hydrocarbons or complex organic pollutants (Xiang et al., 2020). Bioenergy crops are classified into four generations:

I – first generation contains starch or sugar and should be used primarily for human consumption (corn, sorghum, rapeseed, and sugarcane).

II – second generation contains lignocellulose crops (switchgrass, miscanthus, alfalfa, reed canary grass, Napier grass) as well as woody fast-growing species (most often willows and poplars);

III- third generation includes boreal species, species that are characterized by a particularly efficient way of photosynthesis - crassulacean acid metabolism (CAM), microalgae, halophytes from the genera Acacia, Eucalyptus, Casuarina, Melaleuca, Prosopis, Rhizophora and Tamarix;

IV- fourth generation includes energy crops with special properties - mostly genetically modified organisms (Yadav et al., 2019)

Recently, a review of biogas production concerning energy crops and plant processing raw materials (Kulichkova et al., 2020). As woody types of energy crops are not suitable for AD due to their high lignin content, primarily herbaceous species will be considered here. Energy crops should meet the basic conditions: efficient conversion of solar energy in the process of photosynthesis that allows high yields, low requirements for nutrients and water due to a well-developed root system, low requirements for agronomic measures, low cost of establishing and maintaining plantations. The main factors that determine the biogas yields are the type and variety of crops, harvest time, method of storage and pretreatment before AD conversion and nutrient content. Therefore, energy crops that are suitable in one country do not have to be in every other. Research in northern Bulgaria (Zlateva and Dimitrov 2021) indicates that crop residues make up about 44% of potential raw materials for biogas production, with the highest lower thermal power (about 27.11 MJ/kg) compared to Livestock breeding waste, Waste water and Seaweed.

Maize (*Zea mays*)

The use of maize silage is the most common for several reasons: biogas potential and yields are among the highest (Tab. 1), this crop is widespread and developed agrotechnics for its production which is well known to farmers and uses existing agricultural machinery. Foreign processing technology in the AD process is mature (Chulz et al., 2018; Amon et al., 2007 a; Meyer-Aurich et al., 2016). Even plants that are built with the aim of processing waste (solid or liquid) use maize in energy cohesion (Amon et al., 2007 b; Ormeceida et al., 2018). However, maize production in industrial farming requires the application of agrotechnical measures that are very energy demanding (Herrmman 2013), which calls into question the energy efficiency of the entire biogas production process (Oleszek1 and Matyka 2020). To achieve satisfactory yields, it is necessary to use significant doses of industrial fertilizers, which further jeopardizes the sustainability of the process from the aspect of nitrogen and phosphorus management (Ning et al., 2012).

Table 1. Gross crop yield and bigas potential of different crops.

Crop	Crop yield tFM/ha	Biogas Yield Nm^3/(tVS)	Methane content (%)
Sugar beet	40-70	730-770	53
Fodder beet	80-120	750-800	53
Maize	40-60	560-650	52
Corn cob mix	10-15	660-680	53
Wheat	30-50	650-700	54
Sorghum	40-80	520-580	55
Grass	22-31	530-600	54
Red clower	17-25	530-620	56
Sunflower	31-42	420-540	55
Wheat grain	6-10	700-750	53
Rye grain	4-7	560-780	53

Source: Weiland, 2010

The quality of produced biogas depends on the quality of maize at all stages of production. Although the greatest impact is in the initial phase when maize grows in a field where the location, climate and variety of maize can be distinguished (Fig. 1.). Agrotechnical measures applied during growth as well as the selection of the optimal harvest time enable optimal biogas yields. In the following phases, the technology of biomass conservation and the addition of additives have a positive effect on the methane yield. In the next stage, the energy of the biological substrates is transformed into biogas where conditions in the digester such as pH, temperature or the presence of inhibitors and the nutritional composition of the biomass determine the methane yield. In the last phase, biogas and digestate were obtained (Amon et al., 2007 a).

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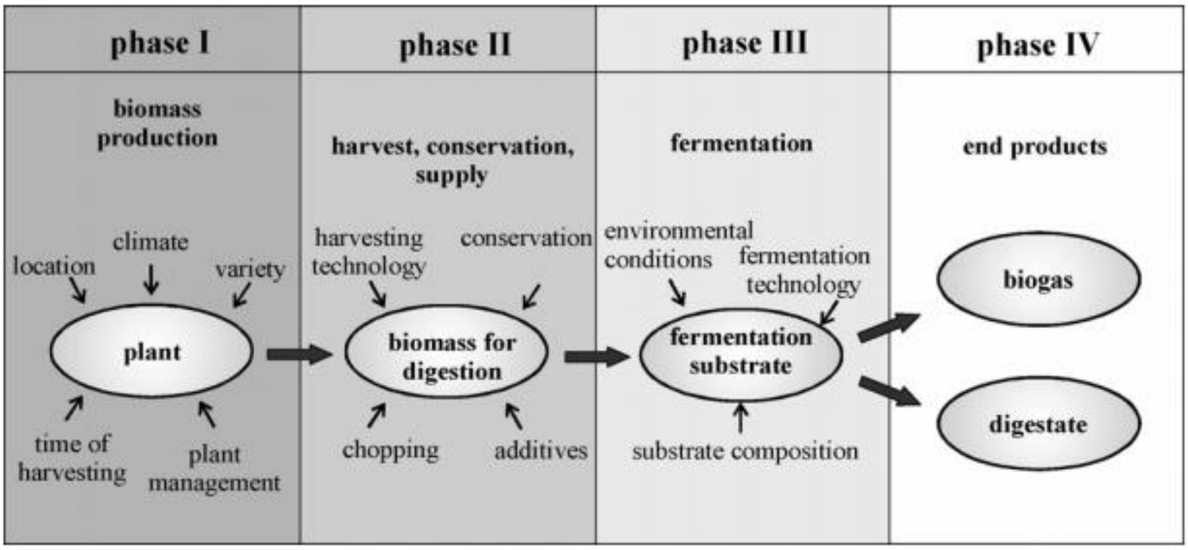

Figure 1. Influences on biogas production from maize along the production process

Source: Amon et al. 2007 b

Other energy crops

The potential for the production of biogas (and methane) of annual crops (Tab. 1.) indicate that some other crops also have a potential that is close to maize and are therefore recommended for cultivation. It should be borne in mind that different parts of the plant are used as raw material for AD, which have different chemical composition on which the potential of biogas depends, so it is difficult to interpret the literature data. Some of these parts are actually classified as crop residues (corn, soybeans, sunflowers stalks …) but can be also used in animal nutrition. On the other hand, perennial crops show several advantages over annuals: protection of soil from erosion, nutrient leaching and depletion of organic matter (Barbanti et al., 2014). Their biomass is less biodegradable, which can be overcome by harvesting optimization and pretreatment.

In Germany, the suitability of various energy crops as raw materials for biogas production during 8 years and at 8 localities was examined. With an emphasis on biomass productivity, and the profitability of its production maize yielded 14.22-25.12 t/ha depending on the locality and proved to be the most efficient bioenergy crop in Central Europe. Other crops such as winter triticale (whole plant) had a yield of 6.71 to 15.17 t/ha and a mixture of perennial forage grasses 7.51 to 19.44 t/ha, which makes them also favorable raw materials for biogas production (Straus et al., 2019).

Wheat straw, as a harvest residue, can be used as a raw material in biogas power plants. It is recommended that wheat be grown in crop rotation with maize, grain used for food and straw (which is actually lignocellulosic bimass) in the AD process. In Banat (Republic of Serbia) the performance of wheat straw was examined and it was established that the biogas yield depends on the genotype (variety) and climate conditions. Biomass yields up to 3.85 t/ha and biogas yields up to 388.93 m^3/ha were confirmed (Rakašćan et al., 2020). In order to be used for sustainable production, wheat straw must undergo an appropriate pre-treatment process (mechanical, steam explosion or alkaline treatment) where mechanical processing is more economically viable but the biogas yield is lower. The reason for this is that chemical and thermal treatment require high investments to provide high pressure or long retention times (Andersen et al., 2020).

In the AD process uses two varieties of ***Sorghum***: fodder and sweet. The productivity of biogas produced from sorghum silage significantly depends on the genotype, climatic conditions and soil type (Thomas et al., 2017). Comparative studies of energy efficiency of maize, sorghum and canary grass silage on lands of different fertility in Poland, with the application of three doses of nitrogen fertilizer, show that only a small effect of increasing nitrogen dose on yield as a function of soil quality, 50 t/ha for maize, 70 t/ha for sorghum I 40 t/ha for canary grass, all on fertile land. The highest biogas yield per ha is for maize 15,595 m^3 ha/y on fertile land, for sorghum 115 m^3/t_{GM}, for canary grass 125 m^3/t_{GM}, where the methane content in biogas produced from maize and sorghum was significantly higher than canary grass. From energy calculations, the authors conclude that the application of lower doses of nitrogen fertilizer is the key to increasing energy efficiency (Krzystek et al., 2020). The problem of sustainability caused by the application of high doses of nitrogen mineral fertilizer can be overcome by using digestate as a by-product of the AD process as an amendment to the soil that partially or completely replaces mineral fertilizer (Pstorelli et al., 2021). The influence of digestate on the productive properties of fodder sorghum grown on fertile and degraded land in Vojvodina, Republic of Serbia, during three-year period was performed (Rakašćan et al., 2021). Digestate in the amount of 50 t/ha significantly increased the yield of fodder sorghum biomass in all variants of the field experiment, with a greater effect on calcic gleysol compared to chernozem. The highest biomass yield is 41.74 t_{DM} /ha on chernozem, with digestate application the biogas yield is 157.05 Nm^3/t_{DM} (9582 Nm^3/ha).

Other field crops can also be used for the production of biogas with a focus on crop residues, which requires technological improvements, and in the process is most often used biomass codigestion with other forms of biomass (sewage sludge, residues from the meat and milk industry, manure of various origins) with satisfactory energy and environmental efficiency (Sukhesh and Rao 2018). Growing leguminous crops contributes to the quality of the soil (Vasileva and Vasilev 2020) so it is often used in crop rotation with other agro-energy crops, primarily maize. Comparing biodegradability and biogas yield based on organic matter and fresh biomass, it can be seen that legumes and their mixtures have a lower degree of biodegradability compared to cereals and thus lower biogas yield compared to fresh biomass but similar biomethane yield calculated on organic matter (Straus et al., 2019).

Soybean silage is as well a suitable substrate for biogas production. Ikanović et al., (2020) examined the influence of soybean genotype and ecological conditions on plant height, number of pods, absolute mass, volume mass, grain yield and biogas. It has been shown that after seed harvest, about 5 t/ha of vegetative biomass residues, consisting of stem and leaves, and enables the biogas production of about 574.33 m^3/ha, which is in accordance with the results of Milanović et al., 2020 reporting that soybean, cultivar Favorit 368 m^3/ha. Soybean productivity significantly depends on genetic and ecological factors, and they ecologically condition the expression of genetic potentials, so it is necessary to examine their interaction in each specific case, and the development of its own genotypes is of the great importance for the state (Popović et al., 2015). Therefore, crop development and biogas yield of three soybean genotypes developed in the Republic of Serbia - Favorit, Dukat and Laura, on chernozem in Banat (Republic of Serbia) were investigated. The average three-year biogas yield was 529.44 m^3/t in a positive very significant correlation with grain yield and a positive significant correlation with 1000 grain weight, plant height and precipitation. Genotype, year, and interaction of test factors (G x Y) had a statistically significant effect on biogas yield (Popović et al., 2020).

CONCLUSION

Although a number of relatively mature technologies are used in biogas production, there is still a need to improve them in terms of economic, energy and economic sustainability through technologies that are used to process a very wide range of raw materials into a range of the bioproducts. The potential is expected to triple by the year 2030 in the EU, compared to year 2020, using biodegradable waste and residues from agriculture and many industrial processes, as well as aquatic biomass. Case studies are used to illustrate the success and future potential for the role of biogas technologies in integrated infrastructures providing bioenergy, biomethane for static and mobile applications, energy storage, balancing growing and solar power grids, greening the natural gas grid, bio-CO_2 recovery and Power - to-X, and even play a key role in the circular economy by recycling nutrients back into the land.

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REFERENCES

Amon, T., Amon, B., Kryvoruchko, V., Machmüller, A., Hopfner-Sixt, K., Bodiroza, V., Hrbek, R., Friedel, J., Pötsch, E. & Wagentristl, H. (2007a). Methane production through anaerobic digestion of various energy crops grown in sustainable crop rotations. *Bioresour. Technol.*, 98, 3204–3212. doi: 10.1016/j.biortech.2006.07.007

Amon, T., Amon, B., Kryvoruchko, V., Zollitsch, V., Mayer, K.& Gruber, L. (2007b). Biogas production from maize and dairy cattle manure—Influence of biomass composition on the methane yield. *Agriculture, Ecosystems and Environment*, 118, 173–182.

Andersen, L.F., Parsin, S.,Lüdtke, O. & Kaltschmitt, M. (2020). Biogas production from straw—the challenge feedstock pretreatment. *Biomass Conv. Bioref.*,. https://doi.org/10.1007/s13399-020-00740-y

Barbanti, L., Di Girolamo, G., Grigatti, M., Bertin, L.& Ciavatta, C. (2014). Anaerobic digestion of annual and multi-annual biomass crops. *Ind. Crop. Prod*., 56, 137–144. https://doi.org/10.1016/j.indcrop.2014.03. 002

Battini, F., Agostini, A., Boulamanti, A.K., Giuntoli, J. & Amaducci, S. (2014). Mitigating the environmental impacts of milk production via anaerobic digestion of manure: Case study of a dairy farm in the Po Valley. *Sci. Total Environ*., 481, 196–208.

Schulz , V., Munz, S., Stolzenburg , K., Jens Hartung , Weisenburger , S., Mastel , K., Möller, K., Claupein, V. & Graeff-Hönninger, S. (2018). Biomass and Biogas Yield of Maize (*Zea mays* L.) Grown under Artificial Shading. *Agriculture*, 8(11), 178. doi:10.3390/agriculture8110178FAO. The Contribution of Agriculture to Greenhouse Gas Emissions; FAO: Rome, Italy, 2020

Franco, M., Hurme, T., Winquist, E. & Rinne, M. (2019). Grass silage for biorefinery—A meta-analysis of silage factors affecting liquid–solid separation. *Grass and Forage Science*, 74 (2), 218-230. doi10.1111/gfs.12421,

Herrmann, A. (2013). Biogas production from maize: Current state, challenges and prospects. 2. Agronomic and environmental aspects. *Bioenergy Res*., 6, 372–387.https://doi.org/10.2298/GENSR2003055P

Hutňan, M. (2016). Maize Silage as Substrate for Biogas Production. In Advances in Silage Production and Utilization, EDs T.De Silva and M. Santos, eBook (PDF) ISBN: 978-953-51-4151-8, DOI: 10.5772/64378

Ikanović, J., Popović,V., Rakaščan, N., Janković, S., Živanović, Lj., Kolarić, Lj., Mladenović Glamočlija, M. & Dražić,G. (2020). Genotype and Environment Effect of Soybean Production and Biogas. GEA (Geo Eco-Eco Agro) International Conference, 28-31 May 2020, Montenegro - Book of Proceedings, 280-288, in Advances in Silage Production and Utilization, 173- 196, Edited by Thiago Da Silva, Intech Open, ISBN: 978-953-51-4151-8. DOI: 10.5772/64378

Krzystek, L., Wajszczuk, K.,Pazera, A., Matyka, M, Slezak, R. & Ledakowicz, S.(2020). The Infuence of Plant Cultivation Conditions on Biogas Production: Energy Efciency, *Waste and Biomass Valorization,* 11,513–523. https://doi.org/10.1007/s12649-019-00668-z

Kulichkova, G., Ivanova, T., Köttner, M., Volodko, O., Spivak, S., Tsygankov, S. Blume, Y., Zlateva, P.& Dimitrov, R. (2021). An analysis of the potential use of waste materials for biogas plant development. OP Conf. Ser.: *Mater. Sci. Eng.* 1031 012012

Lansche, J. & Müller, J. (2012). Life cycle assessment of energy generation of biogas fed combined heat and power plants: Environmental impact of different agricultural substrates. *Eng. Life Sci*., 12, 313–320.

Meyer-Aurich, A.,Lochmann, Y., Klauss, H., & Prochnow, A. (2016).Comparative Advantage of Maize- and Grass-Silage Based Feedstock for Biogas Production with Respect to Greenhouse Gas Mitigation. *Sustainability*, 8, 617. doi:10.3390/su8070617

Milanović, T., Popović, V., Vučković, S., Popović, S., Rakaščan, N. & Petković Z. (2020): Analysis of soybean production and biogas yield to improve eco-marketing and circular economy.*Economics of Agriculture,* Belgrade, 67 (1): 50-60.

Neshat, S. A., Mohammadi, M., Najafpour, G. D. & Lahijani, P. (2017). Anaerobic co-digestion of animal manures and lignocellulosic residues as a potent approach for sustainable biogas production, Renewable and Sustainable Energy Reviews, 79, 308-322. doi.org/10.1016/j.rser.2017.05.137

Ning, T., Zheng, Y., Han, H., Jiang, G., & Li, Z. (2012). Nitrogen uptake, biomass yield and quality of intercropped spring-and summer-sown maize at different nitrogen levels in the North China Plain. *Biomass Bioenergy,* 47,91–98. https://doi.org/10.1016/j.biombioe.2012.09. 059

Oleszek, M.& Matyka, M. (2020). Energy Use Efficiency of Biogas Production Depended on Energy Crops, Nitrogen Fertilization Level, and Cutting System. *BioEnergy Research*, 13 (4) https://doi.org/10.1007/s12155-020-10147-2

Ormaechea, P., Castrillon, L., SuÃrez, B., Megido, L., FernÃ¡ndez, Y., Negral, L., MaraÃ±on, E.& RodrÃguez-Iglesias, J. (2018). Enhancement of biogas production from cattle manure pretreated and/or co-digested at pilot-plant scale. Characterization by SEM. *Renewable Energy*, 12610.1016/j.renene.2018.04.022

Pastorelli, R., Valboa, G., Lagomarsino, A., Fabiani, A., Simoncini, S.; Zaghi, M. &Vignozzi, N. (2021). Recycling Biogas Digestate from Energy Crops: Effects on Soil Properties and Crop Productivity. *Appl. Sci.* 11, 750. https://doi.org/10.3390/app11020750

Popovic, V., Vidic, M., Vuckovic, S., Drazic, G., Ikanovic, J., Djekic, V. &Filipovic, V. (2015). Determining genetic potential and quality components of NS soybean cultivars under different agroecological conditions.*Romanian Agriculture Research*, 32,35-45.

Popović, V., Vučković, S., Jovović, J., Rakašćan, N., Kostić, M., Ljubičić, N., Mladenović-Glamočlija, M. & Ikanović, J. (2020). Genotype by year interaction effects on soybean morpho-productive traits and biogas production. *Genetika*, 52(3), 1055-1073.

Rakašćan, N., Popović, V., Ikanović, J., Janković, S., Dražić, G., Lakić, Ž. & Živanović, Lj. (2020). Wheat Straw in the Function of Obtaining Animal Feed and Biofuel. *EC Veterinary Science*, 5(12), 21-29.

Rakašćan, N., Drazić, G., Popović, V., Milovanović, J., Zivanović, Lj., Aćimić Remikovic, M., Milanovic, T., Ikanovic, J. (2021). Effect of digestate from anaerobic digestion on Sorghum bicolor L. production and circular economy. *Not Bot Horti Agrobo,* 49(1),12270

https://www.notulaebotanicae.ro/index.php/nbha/article/view/12270Strauß, C., Herrmann, C., Weiser, C., Kornatz, P., Heiermann, M., Aurbacher, J., Müller, J. & Vetter, A. (2019). Can Energy Cropping for Biogas Production Diversify Crop Rotations? Findings from a Multi-Site Experiment in Germany. *Bioenerg. Res.*, 12, 123–136. https://doi.org/10.1007/s12155-019-9960-5

Sukhesh, M. J. & Rao, P.W. (2018). Anaerobic digestion of crop residues: Technological developments and environmental impact in the Indian context. *Biocatalysis and Agricultural Biotechnology*, 513–528. https://doi.org/10.1016/j.bcab.2018.08.007

Thomas, H.L., Pot, D., Latrille, E., Trouche, G., Bonnal, L., Bastianelli, D. & Carrère, H. (2019). Sorghum Biomethane Potential Varies with the Genotype and the Cultivation Site. *Waste Biomass Valor.* 10, 783–788. https://doi.org/10.1007/s12649-017-0099-3

Turkmen, B.A. (2020). Renewable Energy Applications for Sustainable Agricultural Systems . *International Journal of Innovative Approaches in Agricultural Research*, 4(4), 497-504. doi: 10.29329/ijiaar.2020.320.11

Vasileva, V. & Vasilev, E. (2020). Agronomic characterization and the possibility for potential use of subterranean clover (Trifolium subterraneum L.) In the forage production in Bulgaria. *Pak. J. Bot.*, 52(2), 565-568. DOI: http://dx.doi.org/10.30848/PJB2020-2(26)

Weiland, P. (2010). Biogas production: current state and perspectives. *Appl Microbiol Biotechnol*, 85, 849–860. DOI 10.1007/s00253-009-2246-7

Xiang, C., Tian, D., Wang, W., Shen, F., Zhao, G., Ni, X., Zhang, Y., Yang, G. & Zeng, Y. (2020). Fates of Heavy Metals in Anaerobically Digesting the Stover of Grain Sorghum Harvested from Heavy Metal-Contaminated Farmland. *Waste and Biomass Valorization*, 11, 1239–1250. https://doi.org/10.1007/s12649-018-0455-y

Yadav, P., Priyanka P., Kumar D., Yadav A.& Yadav K. (2019). Bioenergy Crops: Recent Advances and Future Outlook. In: Rastegari A., Yadav A., Gupta A. (eds) Prospects of Renewable Bioprocessing in Future Energy Systems. Biofuel and Biorefinery Technologies, vol 10. Springer, Cham. https://doi.org/10.1007/978-3-030-14463-0_12

Zlateva, P. & Dimitrov, R. (2021). An analysis of the potential use of waste materials for biogas plant development. *IOP Conf. Series: Materials Science and Engineering*, 1031, 012012, doi:10.1088/1757-899X/1031/1/012012