Silphium perfoliatum

Subjects: Agriculture, Dairy & Animal Science
Contributor: Dumitru Peni

Silphium perfoliatum L. is a perennial crop native to North America that has been the subject of increased scientific interest in recent years, especially in Europe. It is drought and frost-resistant, which makes it suitable for cultivation in Europe on marginal lands that are not used for growing other crops.

Keywords: energy expenses ; biogas ; biomass yield

1. Introduction

Since climate change is caused mainly due to the wide use of fossil fuels, it is necessary to mitigate their impact and prevent their depletion. Under these conditions, it is very important to replace fossil fuels with renewable energy sources (RES), to stop the increase in greenhouse gases in the atmosphere [1] and reduce pollution caused by burning fossil fuels. Researchers are trying to identify different biomass sources that are acceptable for production, cheap, easy to grow and offer high yields that will be suitable for the commonly used conversion technologies. Moreover, there is a need to adapt some of the possible biomass sources to specific climatic conditions of some regions or try to use local sources. Anaerobic digestion can be seen as the most attractive renewable energy pathway to convert organic material into green fuel [2]. These complex processes provide several additional environmental benefits, since digestate from biogas production can be used as a biofertilizer and its utilization can reduce the amount of fertilizers needed [1][3].

Biomass is considered to be an organic, non-fossil material of biological origin, such as manure, wastewater sludge, food and organic waste, municipal organic waste, animal waste, agricultural residues, and forest and industrial wood waste. The biological wastes are classified as a renewable energy resource due to the possibility of the incorporation of solar energy [4][5].

Perennial crops are seen as a promising feedstock for renewable energy technologies [5][6], including biogas production, due to the large amount of biomass that can be obtained from a relatively small area compared to annual crops. Moreover, perennial crops offer other benefits for biodiversity and the environment [7][8][9][10].

The *Silphium perfoliatum* (cup plant) is considered a promising alternative substrate for biogas production [11][12] that could replace the current use of maize silage [13][14][15]. It is characterized by low production costs and can be grown on less productive or polluted soil [16]. The crop is resistant to winter frost and summer drought and is less dependent on atmospheric precipitation [17]. Moreover, in Central Europe, it is not very susceptible to pests and diseases that affect biomass productivity or yield [11][18]. Existing pests are unlikely to limit the production of seeds or biomass of *Silphium perfoliatum* [19]. In the USA, there have been cases reported of plantation damage caused by larvae, birds and mammals (moths, turkey and deer) [20]. In this case, damage was caused by natural biodiversity factors, which are beyond human control and can occur in every country. Silphium was studied in different countries, for different purposes: as a potential forage crop in New Zealand [21], Ukraine [22], USA [23][24] and Romania [25]; and as a forage crop in Belarus [26], Chile [27], China [28] and Russia [29][30][31][32][33]. In Austria [12], Czech Republic [15] and Poland [34][35], biomass has been investigated for biogas production. It is also being studied for future possible use in Kazakhstan as a forage crop [36]. Another use of *Silphium perfoliatum* was proposed as a raw material for particleboards that can successfully replace wood and reduce wood shortages [37], which is important for industrial applications. Seeds of *Silphium* L. species, including *S. perfoliatum*, *S. integrifolium* and *S. trifoliatum*, were studied by using different parameters for different purposes [35]. *Silphium perfoliatum* was also cultivated as an ornamental plant [25] with high nectar productivity [38][39][40][41].

2. Economic Aspects and Energy Efficiency of Biomass Production

Economic factors are very important in the use of *Silphium perfoliatum* as a feedstock for energy and other purposes. Since this plant is tolerant of unfavorable environmental conditions, it offers high biomass yields and the possibility of being planted on poor quality soils where other crops would be unprofitable. However, due to the high price of seedlings and the very high establishment costs for the farmers, *Silphium perfoliatum* cultivation is low and limited to small scale and trial plantations [42]. It was estimated that to be able to obtain reasonable yields, seed processing is necessary, which costs 1,700 Euro per hectare. This operation is considered to be time- and cost-consuming due to the different and unequal seed size and maturity. The seed amount required per hectare is 2.5 kg, whose market price is approximatively 680 Euro kg^{-1}. Thus, the cultivation by seedlings can be replaced with sowing. To obtain a high yield level, sowing 1 ha with *Silphium perfoliatum* seeds is estimated to cost about 3,150 Euro. This cost is estimated to be around 60% of the total costs of maintaining a plantation. If the plantation is used for ten years, these costs are divided to this period and total around 400 Euro per hectare per year. Of course, this cost may decrease if the plantation is operated for longer periods, such as 15 years (290 Euro per hectare per year) [43]. The cost of using *Silphium perfoliatum* as a feedstock for biogas production was discussed by Gerstberger et al. [44]. It was estimated that, together with additional compensation, the costs are almost the same as for maize crops [44]. Moreover, compared with maize fields, *Silphium perfoliatum* fields facilitate water infiltration and nutrient circulation [45] and are well-suited for the diversification of bioenergy farming landscapes [44][46]. *Silphium perfoliatum* may contribute to reducing the need for nitrogen fertilizers since its well-developed root system stops the leaching of nutrients from the soil. Thus, in subsequent years of growing, this plant may reduce the amount of fertilizers and prevent the contamination of waters with nitrogen due to reduced erosion [45]. To further reduce the costs, in some cases it was proposed to sow different crops, including forage crop [26][32] between plant rows for the first year of growing, when the *Silphium perfoliatum* biomass yields are significantly lower than in the following years [45].

Another important issue is the energy efficiency of *Silphium perfoliatum* biomass production. The goal is to obtain much higher energy output than energy input level in the biomass production of this species. The energy input depends on the production technology used. The amount of applied mineral fertilizers, mainly nitrogen fertilizers, is of particular importance. In studies conducted in Lithuania [47], the energy input for the cultivation of this species without mineral fertilization was 7.4 GJ ha^{-1} (Table 1). The use of liming and nitrogen fertilization increased these inputs up to 28 GJ ha^{-1}, depending on the variant and the amount of fertilizers used. It must be stressed that the applied fertilization also increased the energy accumulated in biomass from 187.6 to 361.9 GJ ha^{-1} both with and without the highest fertilization doses, respectively. Therefore, the energy gain from biomass harvested at the end of September was high and ranged from 180.2 to 333.9 GJ ha^{-1}, respectively. However, the energy ratio of *Silphium perfoliatum* biomass production was the highest (25.3) without fertilization, although this index was only 12.9 in the variant with the highest fertilization dose [47].

Table 1. Energy-efficiency indicators of *Silphium perfoliatum* for different types and rates of fertilization, harvested at the end of September; based on Šiaudinis et al. [47].

Fertilization Rate	Energy Input (GJ ha^{-1})	Energy Accumulated in Biomass (GJ ha^{-1})	Energy Gain (GJ ha^{-1})	Energy Ratio
N0 (not limed)	**7.4**	**187.6**	**180.2**	**25.3**
N120 (not limed)	**17.2**	**299.4**	**282.2**	**17.4**
N0 + 0.5 liming rate	**12.8**	**267.1**	**254.3**	**20.9**
N120 + 0.5 liming rate	**22.6**	**290.5**	**267.9**	**12.9**
N0 + 1.0 liming rate	**18.2**	**332.6**	**314.4**	**18.3**
N120 + 1.0 liming rate	**28.0**	**361.9**	**333.9**	**12.9**

N—nitrogen; 0.5 liming rate (3.0 Mg ha^{-1} $CaCO_3$); 1.0 liming rate (6.0 Mg ha^{-1} $CaCO_3$).

3. Conclusions

It is necessary to investigate the possibility of cultivating Silphium on marginal and degraded soils, after extensive agriculture, that cannot be used for other crop plantations. In addition, long-term cultivation of *Silphium perfoliatum* will contribute to improving the soil quality, controlling erosion, improving water infiltration, enriching soil mineral compounds and enhancing biodiversity, especially regarding honeybees and other pollinators.

However, more studies are needed on the costs of maintaining a Silphium plantation for future possible large-scale implementation. It is well-known that cultivation by sowing rather than by seedlings can considerably reduce the cost of a *Silphium perfoliatum* plantation. It is very important to improve growing characteristics to obtain sufficient biomass yields to enable the replacement of a maize crop by *Silphium perfoliatum* for biogas production. Although the reviewed studies show that the use of fertilizers can improve biomass yields, these operations can generate other costs which reduce energy efficiency. Therefore, further long-term research is needed to evaluate the use of Silphium biomass in comparison with other substrates, taking into account the full cultivation cycle and economic, environmental and energy efficiency. The results of such studies would help to determine whether *Silphium perfoliatum* is competitive to other crops and which ecosystem services are the most important and the most reliable.

References

1. Paolini, V.; Petracchini, F.; Segreto, M.; Tomassetti, L.; Naja, N.; Cecinato, A. Environmental impact of biogas: A short review of current knowledge. J. Environ. Sci. Health Part A 2018, 53, 899–906.
2. Appels, L.; Baeyens, J.; Degreve, J.; Dewil, R. Principles and potential of the anaerobic digestion of waste-activated sludge. Prog. Energy Combust. Sci. 2008, 34, 755–781.
3. Herrmann, A. Biogas production from maize: Current state, challenges and prospects. 2. Agronomic and environmental aspects. Bioenergy Res. 2013, 6, 372–387.
4. Wu, X.; McLaren, J.; Madl, R.; Wang, D. Biofuels from Lignocellulosic Biomass. In Sustainable Biotechnology: Sources of Renewable Energy; Singh, O.V., Harvey, S.P., Eds.; Springer: Dordrecht, The Netherlands, 2010; pp. 19–41.
5. Stolarski, M.J.; Krzyzaniak, M.; Snieg, M.; Slominska, E.; Piórkowski, M.; Filipkowski, R. Thermophysical and chemical properties of perennial energy crops depending on harvest period. Int. Agrophysics 2014, 28, 201–211.
6. Romanowska-Duda, Z.; Grzesik, M.; Pszczółkowski, W.; Piotrowski, K.; Pszczółkowska, A. The didactic and environmental functions of the collection of energy crops in the transfer technology center in Konstantynów Łódzki. Acta Innov. 2014, 13, 37–48.
7. Van Tassel, D.L.; Albrecht, K.A.; Bever, J.D.; Boe, A.A.; Brandvain, Y.; Crews, T.E.; Gansberger, M.; Gerstberger, P.; González-Paleo, L.; Hulke, B.S. Accelerating Silphium domestication: An opportunity to develop new crop ideotypes and breeding strategies informed by multiple disciplines. Crop Sci. 2017, 57, 1274–1284.
8. Landis, D.A.; Gratton, C.; Jackson, R.D.; Gross, K.L.; Duncan, D.S.; Liang, C.; Meehan, T.D.; Robertson, B.A.; Schmidt, T.M.; Stahlheber, K.A. Biomass and biofuel crop effects on biodiversity and ecosystem services in the North Central US. Biomass Bioenergy 2018, 114, 18–29.
9. Langhammer, M.; Grimm, V. Mitigating bioenergy-driven biodiversity decline: A modelling approach with the European brown hare. Ecol. Model. 2020, 416, 108914.
10. Fiedler, A.K.; Landis, D.A. Attractiveness of Michigan native plants to arthropod natural enemies and herbivores. Environ. Entomol. 2007, 36, 751–765.
11. Gansberger, M.; Montgomery, L.F.R.; Liebhard, P. Botanical characteristics, crop management and potential of Silphium perfoliatum L. as a renewable resource for biogas production: A review. Ind. Crop. Prod. 2015, 63, 362–372.
12. Gansberger, M.; Stüger, H.-P.; Weinhappel, M.; Moder, K.; Liebhard, P.; von Gehren, P.; Mayr, J.; Ratzenböck, A. Germination characteristic of Silphium perfoliatum L. seeds. Bodenkult. J. Land Manag. Food Environ. 2017, 68, 73–79.
13. Schoo, B.; Kage, H.; Schittenhelm, S. Radiation use efficiency, chemical composition, and methane yield of biogas crops under rainfed and irrigated conditions. Eur. J. Agron. 2017, 87, 8–18.
14. Mast, B.; Lemmer, A.; Oechsner, H.; Reinhardt-Hanisch, A.; Claupein, W.; Graeff-Hönninger, S. Methane yield potential of novel perennial biogas crops influenced by harvest date. Ind. Crop. Prod. 2014, 58, 194–203.
15. Ustak, S.; Munoz, J. Cup-plant potential for biogas production compared to reference maize in relation to the balance needs of nutrients and some microelements for their cultivation. J. Environ. Manag. 2018, 228, 260–266.
16. Zhang, X.; Xia, H.; Li, Z.; Zhuang, P.; Gao, B. Potential of four forage grasses in remediation of Cd and Zn contaminated soils. Bioresour. Technol. 2010, 101, 2063–2066.
17. Jasinskas, A.; Simonavičiūtė, R.; Šiaudinis, G.; Liaudanskienė, I.; Antanaitis, Š.; Arak, M.; Olt, J. The assessment of common mugwort (Artemisia vulgaris L.) and cup plant (Silphium perfoliatum L.) productivity and technological preparation for solid biofuel. Zemdirb. Agric. 2014, 101, 19–26.
18. Stolarski, M.J.; Śnieg, M.; Krzyżaniak, M.; Tworkowski, J.; Szczukowski, S. Short rotation coppices, grasses and other herbaceous crops: Productivity and yield energy value versus 26 genotypes. Biomass Bioenergy 2018, 119, 109–120.
19. Reinert, S.; Hulke, B.S.; Prasifka, J.R. Pest potential of Neotephritis finalis (Loew) on Silphium integrifolium Michx., Silphium perfoliatum L., and interspecific hybrids. Agron. J. 2020, 112, 1462–1465.

20. Boe, A.; Albrecht, K.A.; Johnson, P.J.; Wu, J. Biomass Production of Cup Plant (Silphium perfoliatum L.) in Response to Variation in Plant Population Density in the North Central USA. Am. J. Plant Sci. 2019, 10, 904–910.

21. Douglas, J.A.; Follett, J.M.; Halliday, I.R.; Hughes, J.W.; Parr, C.R. Silphium: Preliminary research on a possible new fo rage crop for New Zealand. Proc. Agron. Soc. N. Z. 1987, 17, 51–53.

22. Rakhmetov, D.B.; Vergun, O.M.; Stadnichuk, N.O.; Shymanska, O.V.; Rakhmetova, S.O.; Fishchenko, V.V. Biochemical study of plant raw material of Silphium L. SPP. in M.M. Gryshko National Botanical Garden of the NAS of Ukraine. Plant Introd. 2019, 83, 80–86.

23. Han, K.J.; Albrecht, K.A.; Mertens, D.R.; Kim, D.A. Comparison of in vitro digestion kinetics of cup-plant and alfalfa. Asi an-Australas. J. Anim. Sci. 2000, 13, 641–644.

24. Han, K.J.; Albrecht, K.A.; Muck, R.E.; Kim, D.A. Moisture effect on fermentation characteristics of cup-plant silage. Asia n-Australas. J. Anim. Sci. 2000, 13, 636–640.

25. Puia, I.; Szabo, A.T. Experimental cultivation of a new forage species-Silphium perfoliatum L.-in the Agrobotanical Gard en from Cluj-Napoca. Not. Bot. Horti Agrobot. Cluj-Napoca 1985, 15, 15–20.

26. Pastukhova, M.A.; Sheliuto, B.V. Возделывание сильфии пронзеннолистной под покровом сельскохозяйственных культур [Cultivation of Silphium perfoaliatum under agricultural crops cover]. Bull. Belarus. State Agric. Acad. 2019, 3, 83–87.

27. Pichard, G. Management, production, and nutritional characteristics of cup-plant (Silphium perfoliatum) in temperate cli mates of southern Chile. Cienc. Investig. Agrar. 2012, 39, 61–77.

28. Guoyan, P.; Ouyang, Z.; Qunying, L.; Qiang, Y.; Jishun, W. Water consumption of seven forage cultivars under different climatic conditions in the North China plain. J. Resour. Ecol. 2011, 2, 74–82.

29. Gimbatov, A.S.; Alimirzaeva, G.A. Optimization of technology for the cultivation of new feed crops in the irrigated conditi ons of the lowland zone of Dagestan. Probl. Dev. Agric. Ind. Apk Reg. 2011, 5, 8–11.

30. Zaynullina, K.S.; Ruban, G.A.; Mikhovich, J.E.; Portnyagina, N.V.; Potapov, A.A.; Punegov, V.V.; Fomina, M.G. Prospect s of introduction in culture in the North some resource plants (Komi Republic). Bull. Samara Sci. Cent. Russ. Acad. Sci. 2015, 17, 121–126.

31. Novichikhin, A.M.; Piscareva, L.A. The study of elements of the cultivation technology of Silphium Perfoliatum. Symb. S ci. 2016, 10, 38–41.

32. Semerenko, M.V.; Chupina, M.P.; Stepanov, A.F. The influence of compacting crops on the productivity of perfoliate syl phs. Bull. Omsk State Agric. Univ. 2016, 2, 61–65.

33. Chupina, M.P.; Stepanov, A.F. The application of Silphium perfoliatum in the system of green and raw material conveyor s. Agric. Sci. J. Omsk 2017, 4, 92–97.

34. Kowalski, R. Analysis of lipophilic fraction from leaves, inflorescences and rhizomes of Silphium perfoliatum L. Acta So c. Bot. Pol. 2005, 74, 5–10.

35. Kowalski, R.; Wierciński, J. Evaluation of chemical composition of some Silphium L. species seeds as alternative foodst uff raw materials. Pol. J. Food Nutr. Sci. 2004, 13, 349–354.

36. Danilov, K.P. The effect of the method and sowing rate on the yield of Silphium perfoliatum. News Orenbg. State Agrar. Univ. 2013, 4, 37–39.

37. Klímek, P.; Meinlschmidt, P.; Wimmer, R.; Plinke, B.; Schirp, A. Using sunflower (Helianthus annuus L.), topinambour (Helianthus tuberosus L.) and cup-plant (Silphium perfoliatum L.) stalks as alternative raw materials for particleboards. I nd. Crop. Prod. 2016, 92, 157–164.

38. Pastukhova, M.A. The place of Silphium perfoliatum in the nectariferous conveyor in the conditions of the south-west of Belarus. Bull. Belarus. State Agric. Acad. 2019, 3, 88–92.

39. Mueller, A.L.; Berger, C.A.; Schittenhelm, S.; Stever-Schoo, B.; Dauber, J. Water availability affects nectar sugar produc tion and insect visitation of the cup plant Silphium perfoliatum L. (Asteraceae). J. Agron. Crop Sci. 2020, 206, 529–537.

40. Mueller, A.L.; Biertümpfel, A.; Friedritz, L.; Power, E.F.; Wright, G.A.; Dauber, J. Floral resources provided by the new e nergy crop, Silphium perfoliatum L. (Asteraceae). J. Apic. Res. 2020, 59, 232–245.

41. Savin, A.P.; Gudimova, N.A. The influence of mineral fertilizers on the nectar, forage and seed productivity sylphs stand ardized. Современные проблемы пчеловодства и апитерапии: монография/под, Рыбное: ФГБНУ «ФНЦ пчеловод ства. In Modern Problem of Beekeeping and Apitherapy; Brandorf, A.Z., Lebedev, V.I., Kharitonova, M.N., Savina, A.P., Savushkina, L.N., Lizunova, A.S., Eds.; Publisher: Rybnoe, Russia, 2019; pp. 186–191.

42. Trölenberg, S.D.; Kruse, M.; Jonitz, A. Improvement of the seed quality in the Streaky Silphie (Silphium perfoliatum L.). In Nachhaltigkeitsindikatoren für die Landwirtschaft: Bestimmung und Eignung, VDLUFA-Schriftenreihe. Presented at t

he 124th VDLUFA-Kongress; VDLUFA-Verlag: Darmstadt, Germany, 2012; pp. 926–933.

43. Biertümpfel, A.; Conrad, M. (Eds.) Joint Project: Increase of the Performance Potential and the Competitiveness of the Streaky Silphie as an Energy Plant through Breeding and Optimization of the Cultivation Method: Subproject 2: Optimization of the Cultivation Method and Provision of Selection Material; Abschlussbericht; Project no. 99.05; FKZ; no.: 2201 2809; Friedrich-Schiller-Universität Jena: Jena, Germany, 2014.
44. Gerstberger, P.; Asen, F.; Hartmann, C. Economy and ecology of cup plant (Silphium perfoliatum L.) compared with silage maize. J. Kult. 2016, 68, 372–377.
45. Grunwald, D.; Panten, K.; Schwarz, A.; Bischoff, W.A.; Schittenhelm, S. Comparison of maize, permanent cup plant and a perennial grass mixture with regard to soil and water protection. GCB Bioenergy 2020, 12, 694–705.
46. Schorpp, Q.; Schrader, S. Earthworm functional groups respond to the perennial energy cropping system of the cup plant (Silphium perfoliatum L.). Biomass Bioenergy 2016, 87, 61–68.
47. Šiaudinis, G.; Jasinskas, A.; Šlepetienė, A.; Karčauskienė, D. The evaluation of biomass and energy productivity of common mugwort (Artemisia vulgaris L.) and cup plant (Silphium perfoliatum L.) in Albeluvisol. Agriculture 2012, 99, 357–362.