Studies on the perspectives of replacing the classic energy plants with Jerusalem artichoke and Sweet Sorghum, analyzing the impact on the conservation of ecosystems

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Abstract. To accurately predict the impact of various species of plants on environment is a very difficult task, because their characteristics and specificities together with the external conditions of climate and fauna lead to very complicated systems that are difficult to analyze. The paper aims to assess two technical plants that may be used for the production of biofuels, namely Jerusalem artichoke and Sweet sorghum in evaluating fuel production efficiency and the possibility of being regarded as a viable solution for ecosystem conservation.

1. Introduction

Conventional thermal power plants using chemical combustion of fossil fuels cause significant contamination of air, water, and soil, generating many toxic substances and greenhouse gases.

The traditional ways of producing power raise concerns related to environmental protection and human health, issues that are not taken into consideration when assessing the total costs of generating energy. According to Zhen et al. (2018), an investment opportunity have to encompass both the costs with processing energy resources and encountering unfavorable environment changes and degraded human welfare [1].

Renewable energy technologies are increasingly competitive, compared with fossil fuels technologies, both in terms of system installation costs and energy production costs. Although switching to alternative energy sources seems to be a hassle-free solution, this approach has proven to be false because, usually occur multiple issues related to poor development of technology, economic problems, and negative influences on the natural ecosystems [2]. Bioenergy production can also cause several negative effects on the environment in terms of excessive consumption and alteration of water quality, greenhouse gas emissions, irreparable damage of biodiversity, changing the properties or even depleting soil resources, or erosions. All these negative effects are usually closely related to the lack of predictability assessments and can have various causes such as: planting new crops without properly analyzing the impact, planting in unsuitable locations and soils, and poor management of farmers. [3]

The main aim of this paper is to assess some technical plants that may be used for replacing the usually used energy crops, our analysis being focused especially on environmental factors.

When analyzing the optimal strategies for using biomass, we should be able to meet the following objectives:
- a large and constantly growing contribution of biomass to the percentage of fuels used for energy production;
- significant reductions in greenhouse gas emissions, and many other environmental benefits;
- improvements in energy security and trade balances, by substituting imported fossil fuels with domestic biomass;
- opportunities related to economic and social development in rural communities;
- reduce waste disposal problems, and making better use of resources

Energy crops refers to the industrial cultivation of annual or perennial plant species, that are designed to produce biomass that will be used to obtain to obtain oils or alcohols. Energy crops are usually divided into three broad categories:

- **Sugar crops**: are plant species characterized by high sugar content. Being rich in starch and sucrose, they are used for producing ethanol.
- **Oil crops**: are plant species with high oil content. This allows them to be used as fuels either in the cogeneration of heat and electricity, directly in automobile engines or transformed into biodiesel by transesterification techniques.
- **Lignocellulosic crops**: are plant species that are producing high quantities of dry matter, and may be planted for several energetic uses such as combustion, pyrolysis, gasification, or biofuels production through complex technologies. These species are rich in cellulose, hemicellulose and lignin.

Energy crops with high energy potentials are very diverse and grow in different families all over the globe, using different parts such as roots, tubercles, stems, branches, leaves, fruits, seeds, or even the whole plant.

There have been extensively analyzed the efficiency of making bioethanol from various plants with high sugar content, and the conclusion was that making ethanol from grains is the worst possible solution, not only because is impacting on food production, but because of the poor energy yield [2]. Considering the total cost with fertilizers, seeds, harvesting, transportation, and treatment, the amount of energy contained in a liter of ethanol is it is not much larger than the quantity required to obtain it from cereals. These analyzes determined us to establish various experimental crops on the degraded lands, and to carry out the agricultural works at a minimum level, even if this implies smaller quantities obtained. In this way we give the affected soils an efficiency (since other crops cannot be planted due to the lack of nutrients and the potential to be flooded), and we create the necessary conditions for the restoration of the soils through an efficient management of the biomass obtained on these soils.

Bioenergy has become increasingly diversified in terms of final uses, since new conversion technologies are being developed in parallel to increase economic viability.

When assessing biomass energy production potential, should be considered the complex relations between the large-scale crops and the other uses of biomass such as food production, water use, biodiversity and climate change.

For this present study, two technical plants were selected for analysis, namely Jerusalem artichoke and Sweet sorghum, considering the fact that they can be planted in difficult soils, withstand difficult conditions of temperature and humidity, have good resistance to diseases and pests and do not require expensive agricultural work.

All crops were established on low-nutrient soils that were easily floodable, crops have not been irrigated or treated against pests and weeds and only basic agricultural work was applied when establishing the culture and on harvesting. For comparison, in parallel with these crops there were established cultures on fertile soils, which benefited from all agricultural works.

Technologies for production of cellulosic ethanol are more competitive every year in terms of fuel production costs, however the technology cannot be applied on a global scale because the transformation processes are still difficult to perform. The recent advances in transgenic plants, pretreatment technologies, and fermentation have greatly reduced the process intensity, but there are still numerous problems with the transport of raw materials, the high complexity of the processes, and the technological variations depending on the type of material.
To accurately predict the impact of various invasive species of plants is a very difficult task despite intensive research during the past years, because their characteristics and specificities together with the external conditions of climate and fauna lead to very complicated systems that are difficult to analyze.

The plants begin to be associated to the category of invaders from the moment they establish a new range in which they proliferate, spread, and persist to the detriment of the environment [4]. The main reason that allow to immigrant plant species to prosper is correlated either to the disappearing of their native predators and parasites, or in the case of established agricultural crops, through the intervention of farmers with agricultural works and treatments. All the anthropic activity with the role of eliminating local weeds in order to increase productivity yields might produce human-caused disturbance of local plant communities leading to the proliferation of new invasive plants.

In order for an invasiveness assessment study to be effective, long term evaluations are needed, because failing to address in a proper matter could generate long term problems such as loss of agricultural, forestry, and fishery resources. It is very helpful to create some predictions to quantify long term effects of specific plants, especially since preventive actions are less expensive than measures to correct some imbalances already created.

The establishment of agricultural crops with highly invasive potential can generate some environmental issues, therefore it is essential to identify effective methods and models to reduce the risk of endangering native vegetation and plant species. The risk posed by the introduction of invasive plants has been intensively studied by researchers [4-7]. Although some plant species have been introduced to protect the environment, such as some tree species that stop soil degradation and landslides and increase soil nutritional quality, have been found some negative effects in the medium and long term, due to the resource-use pressure on the local ecosystem. Richardson et al., 2004 notifies that some of the plants introduced with the role of protecting the environment may have adverse effects if they acquire in time an invasive character.

Given that the consequences of a biological invasion are extremely costly, some prediction models are created for high-risk species, allowing farmers to differentiate between different crops. Predictions, however, involve some challenges, because differentiating the characteristics that define these two groups of species they are conditioned by a very large series of parameters related to local characteristics.

Some of the prediction models, such as the one made by Pheloung et al. [8, 9], have proved extremely valuable and they have been integrated into national policies, quantifying plant invasion risk and allowing a decision to be made whether to reject, accept or further evaluate possible invasive species.

The introduction of agroforestry plantations on degraded lands in order to diversify biodiversity or for carbon sequestration to reduce greenhouse effects are trends that can negatively affect ecosystems. Therefore, the development of powerful predictive risk assessment tools must be considered even in environments considered resistant to invasion, because it is possible to witness an increase in the number of invasive plants [10-13].

**Experimental**

Finding sources of low cost fermentable sugars coming from low-energy intensive crop that does not compete for food, can utilize low-grade agricultural soils and can grow without special treatment requirements led us to cultivation of Jerusalem artichoke.

Although the plant's body can also be a source of energy production either by pelletizing and incineration or thermo-chemical decomposition of cellulose and hemicellulose into sugars, in this article we will exclusively perform the processes related to ethanol production from juice produced from stems (sorghum) and tubers (Jerusalem artichoke).

Given that the high complexity of technological production flows has in the past led to decades of delays in the implementation of the objectives set to replacing fossil fuels with organic ones, we proposed in this study to evaluate only basic transformation techniques, which can be put into practice even by farmers without raising special difficulties.
Jerusalem artichoke (Helianthus tuberosus), is an herbaceous perennial plant that has a high productivity of tubers rich in inulin, which is a fructan polymer [14]. These inulins can be broken down into fructose and glucose for conversion into ethanol by fermentation.

The experimental procedure involved setting up two Jerusalem artichoke crops, one on fertile soil benefiting from all agricultural works, and the second on difficult and floodable soil. The crop established on difficult soil have been harvested only in the first year, while in the 2nd and 3rd years after the establishment of the culture many tubers remained in the soil, being very small and difficult to harvest, therefore planting was no longer needed. In this way we were able to simulate the behavior of the plant when it grows in the wild environment, without being helped by anthropogenic activities.

In addition to the potential for producing ethanol for both the crop established on fertile soil and the crop established on difficult land, we also researched the effect that Jerusalem artichoke culture has on the ecosystem. Interactions with the ecosystem can be either positive, considering the potential to provide food to local fauna or negative by the invasive tendencies, suffocating local plants. Figure 1 is suggestive for the plant grown from bulbs left in the soil, in the 3rd year after planting.

![Figure 1. Jerusalem artichoke crop which grew without being planted, from the tubers that remained in the soil](image1)

It can be seen that Jerusalem artichoke plant is not much affected by the soil type even if it is low in nutrients, managing to adapt and thrive in difficult soils.

However, the unirrigated land and the high density of plants per square meter made the size of the tubers to remain very small. Even though the number of tubers developed per square meter in the unfavorable conditions crop is higher, the total productivity was much lower.

As exemplified in figure 2, several crop parameters were analyzed such as the number of plants per square meter, plant sizes, the number of tubers harvested per square meter, and the number of inflorescences.

![Figure 2. Evaluation of the development parameters of Jerusalem artichoke plants on less fertile soils](image2)
Depending on the number of tubers found per square meter, we could determine the productivity of the two Jerusalem artichoke crops, being able to make a comparison between them. Twenty plots of 1 square meter from both crops were analyzed to determine the mass of tubers, and the minimum and maximum results are shown in figure 3. It was found that the average quantity of tubers grown in unfavorable conditions was much lower compared to the crop grown in optimal conditions with around 40%. Figure 3 contains both the minimum and maximum values for a better highlighting of the difference.

![Figure 3](image_url)

**Figure 3.** Comparative analysis of the mass of tubers produced both in favorable planting conditions and in unfavorable planting conditions (minimums and maximums recorded for each category)

The large differences between the dimensions of the tubers obtained in the two cultures can be observed in figure 4, below. The size of the tubers was actually the element that made the difference in mass between the two crops.

![Figure 4](image_url)

**Figure 4.** Differences between the dimensions of the tubers obtained in the two cultures favorable planting conditions first picture) and in unfavorable planting conditions (second picture)

Another very important factor is the production of biomass, consisting especially of plant stems. Although there are some technologies that manage to transform the gross mass of plants into sugars, then into alcohol, we did not intend to address this issue, because we aimed to evaluate technologies that are easy to implement for obtaining biofuels.

The vegetable mass of plants might be also used as fuel in other ways, being transformed throw several thermal processes (combustion, pyrolysis, and hydrogenation). However, given that our study is based on the impact of these technical plants on the ecosystem, we will consider the plant mass only to assess the amount of carbon dioxide sequestered by the crop. For this, all the mass of
plants will be chopped and integrated into the soil, in this way contributing to the improvement of soil qualities.

In figure 5 we can see that the crops established on disadvantaged soils had a very close vegetal mass as compared to the culture established on favorable soils. Although on favorable land the plants were more vigorous and taller, on the other crop many plants have grown, close to each other, recovering mass through the large number of plants.

![Figure 5](image)

**Figure 5.** Comparative analysis between plant mass of stems for favorable conditions versus unfavorable conditions

Regarding the size of the plants, significant differences were found. As can be seen in Figure 6, in the case of crops planted on fertile soils, the plants were generally tall, the vast majority being in the height ranges of 150-200 cm and 200-300 cm, while in the case of field crops grown in unfavorable conditions, due to the large number of plants and drought the vast majority of plants were in the range of 50-100 cm.

![Figure 6](image)

**Figure 6.** Plant height analysis for Jerusalem artichoke crops

**Controlling local weeds**

In addition, all the other types of weeds found in the crop were counted to see the ability of the crop to eliminate competing plants. The culture have proven to be extremely effective in controlling local weeds (only 1-4% of other plants have been identified in the Jerusalem artichoke crop). A disadvantage, however, is that establishing other crops after Jerusalem artichoke is extremely difficult, because there are many small tubers remaining in the soil after harvesting.

One beneficial issue envisaging the ecosystem is that the Jerusalem artichoke culture has a high potential for honey production. The culture offers benefits to the ecosystem, being a honey
producing plant, especially because insects have the opportunity to collect nectar in the late autumn when there are not many plants in the vegetation.

In terms of alcohol production, Jerusalem artichoke has a lower potential than other similar plants (such as potatoes), because inulin is the main carbohydrate contained and is more difficult to break down into sugars under normal conditions. Although we have obtained amounts close to those specified in the literature, using an enzyme called inulinase, this can still generate problems to the production of biofuels. From a qualitative point of view, there were no differences between the tubers harvested from the two crops, however as was specified above on the crop with fertile soil and performed agricultural works, a much higher mass of tubers per hectare was obtained.

**Sweet sorghum** (Sorghum Saccharatum) juice is rich in fermentative sugar and is a favorable alcoholic fermentation material, therefore it can be a good alternative crop for ethanol production especially since it is not as a demanding culture as conventional biofuel crops. It is a plant very resistant to disease, wide adaptive, and has very good biological productivity conferring to sorghum a high energy balance, as compared to other competing crops.

The working method was similar as in the previous case, evaluating two crops, one cultivated in fertile land and optimal conditions for agricultural works, and one on difficult land. Then for each of the cultures the potential of bioethanol production and the impact on the ecosystem were evaluated.

**Figure 7.** Establishment of sorghum crops, in order to evaluate the development of crops on soils with different properties and the potential for the production of bioethanol from the juice obtained by squeezing the stems

**Potential for alcohol production**
The sorghum plant have been harvested using specific threshing equipment, then was washed and left for 10 minutes to remove the water excess. After removing leaves and panicles, the stems passed through a squeezing equipment extracting the juice from the plant (Fig. 8). The extraction equipment has an increased efficiency, managing to extract over 300-500 kg of raw material in one hour, depending on the plants that are being processed.

**Fig. 8.** Processing the Sorghum Saccharatum, to extract the juice that has high sugar content, using the extraction equipment designed by INMA Bucharest
The evaluation of the alcoholic potential was performed by refractometric analysis, the Brix degrees indicating the amount of sugars present in the sorghum juice.

One of the problems encountered on sorghum crops is the highly time dependence of the amount of sugars found in stems. Harvesting period is therefore a key point in the management of this technical crop.

Figure 9 shows the variation of sugar levels in June-November in a sorghum crop. It can be seen that in this case the Brix index registered a steep increase in August, followed by a decrease after the plant reached maturity.

![Figure 9. Variation of sugar levels in June-November in a sorghum crop](image)

Particular attention is also paid to the very rapid degradation of the juice after extraction. It tends to oxidize and lose its potential to produce alcohol. To avoid the rapid degradation of the juice and to optimize the fermentation process, our experiments aimed at creating a mixture of fruit waste and sorghum juice.

The process creates a symbiosis because sorghum juice benefits from apple fermentations, and apples replace the amount of water needed for fermentation with sorghum juice, thus considerably increasing the fermentation efficiency.

![Figure 10. Create recipes from apple waste and sorghum juice to optimize the fermentation and distillation processes](image)
Table 1 shows an example of how the concentrations of sugars in apple waste and sorghum juice varied in one of the experiments performed.

**Table 1.** Theoretical evaluation of the amount of bioethanol produced from apple waste and sorghum juice.

| Probe | Sorghum | Apple juice |
|-------|---------|-------------|
| 1     | 12.4    | 12.1        |
| 2     | 12.2    | 11.7        |
| 3     | 12.4    | 12.3        |
| 4     | 11.7    | 12.4        |
| 5     | 12.1    | 11.5        |
| 6     | 12.7    | 11.3        |
| 7     | 11.9    | 11.5        |
| 8     | 12.4    | 12.4        |
| 9     | 11.7    | 12.5        |
| 10    | 12.1    | 12.4        |

**Controlling local weeds**

The Sorghum plants have proven to be extremely effective in controlling local weeds (2-5% of other plants have been identified in the Sorghum crop).

**Invasive behavior of the plant**

Establishment of other crops after Sorghum culture is not as difficult compared to other technical crops (Jerusalem Artichoke or Miscanthus), the plant not having a pronounced invasive characteristic.
5. Centralization of indicators which determine energy crops to be regarded as a solution of ecosystem conservation and improvement

Table 2 Centralizing table of the evaluations indicators for the two technical plants

| Indicator                                      | Jerusalem artichokes | Sweet sorghum  |
|------------------------------------------------|----------------------|----------------|
| High potential to produce bioethanol           | High potential in tubers | High potential from the juice obtained by squeezing the stems |
| Possible problems in alcohol production        | Inulin is difficult to break down into sugars | The juice has a fast degradation time |
| Adaptability on difficult terrain              | High adaptability    | High adaptability |
| Drought resistant                              | High resistance     | High resistance |
| Pest resistance                                | High resistance     | High resistance |
| Vegetable mass production on difficult lands   | High production      | High production |
| Carbon sequestration                           | High                 | High           |
| Potential invazivitate                         | High                 | Medium         |
| Potential controlling local weeds              | High                 | High           |
| Ecosystem benefits                             | High nectar production | High pollen production |
| Problems planting on difficult terrain         | Small amount of tubers obtained per hectare | Weaker development of plant mass |

Conclusions:
Second-generation biofuels could decrease petroleum dependence, although they could not entirely replace it, due to the limited amount of usable land and available biomass considering the very high consumption trends. Renewable resources must all develop simultaneously and become more efficient so that dependence on fossil fuels to decrease in the medium term.

The evaluation of Jerusalem artichokes crops showed a good growth of the plants in difficult conditions and in less fertile soils, even though the culture was not irrigated, the humidity being regulated only by rain. The mass of plants in the less fertile land was maintained at values close to the values obtained on fertile lands, however tuber productivity was very low due to soil compaction and the large number of plants that naturally grew per square meter.

Although Jerusalem artichokes crops has a good ethanol production potential, the process is complicated requiring the conversion of inulin (carbohydrate) into sugars for fermentation.

-The plants have proven to be extremely effective in controlling local weeds (1-4% of other plants have been identified in the J.A. crop). It might be a good solution for processing plants, but it cannot be easily implemented at farm level.

Establishing other crops on less fertile soils after Jerusalem artichokes it is extremely difficult, because there are many small tubers remaining in the soil after harvesting, which will germinate next year.

The culture Jerusalem artichokes crops offers important benefits to the ecosystem, being a honey producing plant, especially because insects have the opportunity to collect nectar in the late autumn when there are not many plants in the vegetation.

From a qualitative point of view, (after distilling the tuber mass) the two cultures did not show major differences regarding the potential for alcohol production, so the quality of the tubers was similar in the two cultures (of course neglecting the difference in productivity per hectare).

Sweet sorghum (Sorghum Saccharatum) is a plant very resistant to disease, wide adaptive, and has very good biological productivity conferring to sorghum a high energy balance, as compared to other competing crops.
One of the problems encountered on sorghum crops is the highly time dependence of the amount of sugars found in stems. Harvesting period is therefore a key point in the management of this technical crop.

The juice has a rapid degradation after extraction, tending to oxidize and lose its potential to produce alcohol.

The Sorghum plants have proven to be extremely effective in controlling local weeds but is not as difficult compared to other technical crops for the invasive behavior.

The study allowed us to realize a centralization of the indicators that show that the analyzed technical plants have a potential for remediation and conservation of the ecosystem, however, research is needed to produce alcohol from biomass, and not just from tubers (Jerusalem artichokes) and juice extracted by pressing the stems (Sorghum). In this way the process would prove much more economically viable.

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