Economical and ecological effects of cultivation of basket willow Salix viminalis L.

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Abstract. The aim of the investigations was the assessment of the size of harvest of five energetic basket willow clones at a plantation of the Forest Inspectorate Krzeszowice, the Forest Inspectorate Brodla branch, in the Malopolska voivodeship. The paper presents the effect of yielding of the willow Salix viminalis L., which is characterized by intense weight gain. An economic analysis was conducted for the plantation, the environmental effect was calculated and the social outcome was determined. An environmental impact analysis (EIA) showed, that the biomass combustion process emits far fewer pollutants than coal: 8 times less carbon oxide and 6 times less sulfur dioxide. The environmental effect is significant due to the reduction of pollutant emissions. The willow Salix viminalis L. is a plant, which easily adapts to vegetation on any soil. The plant growing does not require any special agrotechnical treatment. By the establishment and maintenance of willow plantations can contribute to rural development, increase income and reduce unemployment in the country. Farmers are willing to assume willow plantations, if you will guarantee the sale at attractive prices. Europe is looking for alternatives to conventional energy sources, combustion of which releases a greenhouse gas - carbon dioxide.

1. Introduction

Energy Policy of the European Union envisages providing a reliable and environmentally friendly energy supply. In the second half of the twentieth century coal has ceased to be a major source of energy, especially in developed countries [1]. For ecological reasons, it has been replaced by the petroleum and natural gas. Energy, which played a central role in the industry and the economy, is produced mainly in thermal power plants, water, nuclear and wind [2, 3]. Thermal power plants produce over 60% of global heat energy.

Depletion of energy resources and oil crises led the world looking for alternative energy sources. Poland is adapting to these patterns and looking for renewable energy sources [4].

Compared with other countries in the EU, Poland has a large technical potential of biomass energy. Among the energy crops the greatest chance has energetic willow Salix viminalis L.

Willow Salix viminalis

Type of Salix (figure 1) includes over 300 species that occur as trees, shrubs or dwarf shrubs. Willow Salix viminalis L. can grow both on arable land and on grassland. Willow is a plant with no special needs cultivation. It can grow in both areas very dry and poor in nutrients, as well as very humid and fertile. Shrub willow species are used mainly for basket-work, but fast-growing forms are assigned for energy purposes [5].
For many years in Poland there is cultivation of willow for basket-work or honey-yielding aims, thanks to early flowering period. Crops willow *Salix viminalis* L. and *Salix purpurea* L. started about 25 years ago in order to use the energy purpose [6]. These species are characterized by very rapid and large increase in biomass, as well as disease resistance (scab, gangrene of shoots) and harmful insects. The willow growing on a 4-year plantation exhibits 14 times larger growths than the willow which grows at the same time in the natural forest. If cultivations are to become more popular, then in the future it will be possible to partially replenish the wood harvested from the forests [7].

After the first year of growing shoots should be cut at a height of 3 cm above the soil surface, so that has been dormant buds. If the cut bars correspond to the standards, they can be used for new plantings. If we make a harvest every 2 or 3 years, the resulting biomass use for heating purposes and for production of chipboard. After harvesting willow plantations should be intensively fertilized to get faster gains. Operation of the plantation may take up to 30 years. After the liquidation of the plantation, soil should be renovated [8, 9].

For one-time yield they use combine harvester or sheaf-binders. To cut willow stems on small plantations you can use sickle or hand mower blades: exhaust or tractor.

2. Purpose and methods

The task of a research study was to assess the economic, environmental and social benefits of growing willow *Salix viminalis* L. on the example of Forest Inspectorate Brodła (municipality Alwernia), 30 km in the west of Krakow. In an experimental nursery planting of seedlings was carried out in six rows: at 50 cm, a length of 10 meters for each clone. Seedlings distributed at 33 cm.

The goal of study was the choice of clone, whose yield is the largest and the most profitable as well. The study was realized in 2004, 2006, 2011, 2013, 2015. Subject to annual increases its clones following numbers: 1051, 1052, 1054, 1056 and 1059th.

Field experiments lasted from June of one year to June of the following research year. During the study, the height and the thickness (customarily at the level of 1 m) were measured in 50 randomly selected shoots of each of the five clones. The research tools included measuring tape, calliper, and lever scales.

The willow shoots on the surface area of 1 m² were counted. In each of the clones the number of shoots per ten meters was tested. The weight for individual clones was determined for 100 shoots. An estimated one-year yields of individual clones were calculated in megagrams per hectare.

In each study (5 experiments), the objective was to evaluate the yield of eight clones of the willow *Salix viminalis* L. and choose the best yielding clones (with the highest annual growth rate in weight).

In 2013, an additional objective of the experiment was established: to evaluate the yielding potential of selected clones after application of sewage sludge. Seedlings of the two clones with the highest shoot thickness were selected for experimental research: 1056, 1059. They were watered with sewage sludge to observe the growth of biomass. Sewage sludge was taken from the Municipal Sewage Treatment Plant in Krzeszowice. The parameters of the sewage sludge used in the experiment indicated the possibility of using them in agriculture (table 1) [10]. Sediments were introduced to soil by injection, by
directly injecting 0.5 dm³ of sediment under each seedling. After one year the willow shoot thickness was measured at a level of 1 meter [7, 11].

Table 1. Parameters of digested and dewatered sludge with the comparison of the maximum allowed sludge values for agricultural use (own study based on data from [10]).

| Selected parameter                  | Unit             | Value on day | Maximum value permitted to be used in agriculture |
|-------------------------------------|------------------|--------------|-----------------------------------------------|
| pH                                  |                  | 7.06         | -                                             |
| Dry mass                            | %                | 19.01        | -                                             |
| Organic substance                   | % dry mass       | 53.5         | -                                             |
| Phosphorus                          | % d.m.           | 2.73         | -                                             |
| Calcium (Ca)                        | % d.m.           | 4.7          | -                                             |
| Magnesium (Mg)                      | % d.m.           | 0.65         | -                                             |
| Content of ammonium nitrogen        | % d.m.           | 0.96         | -                                             |
| Content of nitrogen                 | % d.m.           | 4.71         | -                                             |
| Cadmium (Cd)                        | mg/kg d.m.       | 3.36         | 20                                            |
| Copper (Cu)                         | mg/kg d.m.       | 136.4        | 1000                                          |
| Nickel (Ni)                         | mg/kg d.m.       | 15           | 300                                           |
| Lead (Pb)                           | mg/kg d.m.       | 51.4         | 750                                           |
| Zinc (Zn)                           | mg/kg d.m.       | 1103.7       | 2500                                          |
| Mercury (Hg)                        | mg/kg d.m.       | 0.79         | 16                                            |
| Chrome (Cr)                         | mg/kg d.m.       | 24.5         | 500                                           |
| Pathogenic bacteria Salmonella      | colony-forming unit/kg sludge | lack | lack |
| Number of live eggs of intestinal parasites Ascaris, Toxocara, Trichuris | number/kg dry mass | 0 | 0 |

3. Research results and discussion
In each field experiment (except for 2004), the measurements showed the largest increases in the weight of the seedlings of clones 1056 and 1059 (figure 2). To establish an energy plantation, the seedlings of the best growing clone 1056 should be picked.

Figure 2. Weight of 100 shoots of the studied willow clones in individual years (own study).
The willow exhibits high demand for water. The precipitation in the year of 2011 was significant, so higher yields were observed in the clones in question. The mean annual air temperatures in the research years did not differ significantly from the multivariate average (figure 3, 4).

![Figure 3. Illustration of changes in the sum of annual precipitation [mm] in Malopolska in individual years of research (own study).](image1)

![Figure 4. Illustration of changes in the sum of average annual air temperature in Malopolska [°C] in individual years of research (own study).](image2)

The ecological effect is the reduction of pollutant emissions by replacing conventional fuel with alternative fuel, i.e. with energy crop willow chips. A one-hectare plantation of clone 1056 of the energy-crop willow will provide about 19 Mg of dry wood mass with a calorific value of 19.5 GJ/Mg, i.e. 374 GJ of energy. Taking into account the 70% efficiency of combustion, 262 GJ of energy are obtained. The energy equivalent weight of coal is 14.5 Mg. The calorific value of fossil fuel, in this case black coal from the “Piekary” Mining Plant, is 26 MJ/kg, the ash content is 4% and the sulphur content is 0.5%. 90% dedusting efficiency was assumed.
During combustion of 14.5 Mg of coal, 28.8 Mg CO₂, 648 kg CO, 115.2 kg SO₂, 14.4 kg NOₓ, and 10.8 kg of dust are generated. During combustion of the energy-crop willow, 76.8 kg CO, 19.2 kg SO₂, 19.2 kg NOₓ, 38.4 kg of dust are released into the atmosphere. Replacing black coal with energetically equivalent amounts of energy-crop willow chips lets one avoid emission of a very large amount of pollutants into the atmosphere: 96 kg of sulphur dioxide, 571.2 kg of carbon monoxide and 28,800 kg of carbon dioxide, which means that 100% of carbon dioxide (except spending fossil fuel for willow cultivation and for agricultural machine), 88.15% carbon monoxide and 83.33% sulphur dioxide are prevented from emission. During wood combustion, much more dust is produced than when burning coal – the difference is 27.6 kg. This dust can be used as a wholesome fertiliser.

Sewage sludge can be used to fertilise the plantation – its properties can improve the yield (table 2) [9].

**Table 2.** Calculation results of average thickness of clone shoots 1056 and 1059 in 2013 and increments of plant thickness and weight in a year (own study).

| Clones           | Clone no. | Average thickness [mm] | Average thickness growth [%] | Weight of 100 shoots [kg] |
|------------------|-----------|------------------------|-----------------------------|--------------------------|
| Without fertilising | 1056     | 12.1                   | 7.1                         | 27.85                    |
|                  | 1059     | 10.8                   | 6.9                         | 22.6                     |
| Sewage sludge fertilising | 1056     | 12.5                   | 10.6                        | 29.5                     |
|                  | 1059     | 11.2                   | 10.0                        | 23.4                     |

The willow can be used to protect the natural environment, among others, to create protective zones along transport routes [12] and for reclamation of post-industrial areas. The willow *Salix viminalis* L. is characterised by phytoremediation [13]. Within 15 years the plantation can clean the soil of toxic metals that accumulate in the roots, so they do not penetrate the combustion products [14].

The economic analysis is about balancing the costs and benefits of the planned investment. Financial expenditures required to establish a one-hectare energy-crop willow plantation will amount to about 1730 euro. The costs include: soil quality analysis, machine use, herbicide, and fertilizers, remuneration [15].

The purchase of seedlings covers 40% of the costs of establishing a plantation [16] (it was assumed that the purchase comprises seedlings of very good quality, for 690 euro in total). The costs of establishing, maintaining and eliminating the plantation within 25 years amount to 12,470 euro. Expenditures are spread over the entire period of the plantation existence and amount to 28 euro/year. The revenue over the period of 25 years is 17,450 euro. The financial analysis of energy-crop willow cultivation showed that a one-hectare plantation, harvested every 3 years, yields a hypothetical annual profit of 202 euro [17]. The profitability ratio, expressed by the degree of cost cover with the value of production is satisfactory, i.e. 140%.

Cultivation of the energy-crop willow fulfils important social functions: it can serve as a model plantation presenting a new solution and demonstrate that agriculture is a source of alternative energy [18, 19], raise environmental awareness, activate local communities to create new values in the labour market and services.

A plantation on a small area of 0.5 hectares provides fuel for the medium-sized farm (about 10 hectares) throughout the year, increases farmers' incomes and contributes to reducing rural unemployment. A new product in the form of chips, briquettes and pellets is introduced into the market. Thanks to the establishment of the plantation it is possible to use land set aside and polluted by the industry as well as excluded from the production of food raw materials.

The educational function of the plantation is to make it accessible to interested persons: farmers, entrepreneurs, students.
4. Conclusions
The obtained results of the research allowed us to draw the following conclusions:

- Of the five studied clones of the willow *Salix viminalis* L. (1051, 1052, 1054, 1056, 1059) scion 1056 exhibited the best growth rates, with the largest shoot thickness growth and the highest average height.
- By establishing a one-hectare plantation of the willow *Salix* and using it for energy purposes, it is possible to prevent the emission of significant amounts of pollution generated by the combustion of an energy equivalent of black coal. The ecological effect is measurable.
- A one-hectare plantation of energy-crop willow (clone 1056) allows for a measurable annual revenue of PLN 844.
- The use of sewage sludge for fertilisation has significantly increased the growth of shoot thickness of clones 1056 and 1059. In comparison to unfertilised shoots, the growth rate was 30% higher.
- An important measure to improve the situation in rural areas is the development of different forms of agricultural entrepreneurship, providing opportunities for alternative employment for part of the population. Farmers with low-productivity soils can use it for growing willow because it does not require a lot of labour, has low energy consumption, low fertiliser and pesticide demand, offers high productivity and the ability to use standard machines.

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