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THE DIDACTIC AND ENVIRONMENTAL FUNCTIONS OF THE COLLECTION OF ENERGY CROPS IN THE TRANSFER TECHNOLOGY CENTER IN KONSTANTYNÓW ŁÓDZKI

Abstract
One of the priorities in the production of renewable energy is the selection of suitable energy crops that can develop in different soil and climate conditions. Expanding knowledge in this area fosters the creation of collections that play an important role in promoting the idea of RES and provide opportunities to get acquainted with a wide assortment of energy crops and technologies for energy conversion and application in phyto-environment technologies. The energy crop collection established in RES TTC presents energy crops that can be cultivated under a variety of environmental conditions and, in addition to their didactic and training functions, play an experimental role.

Key words
environment, collection of energy crops, renewable energy

Introduction

According to the EU directive, the share of energy from renewable sources in the energy balance should amount to at least 20% in the nearest future. It is anticipated that its majority will come from the crop biomass, which will be derived from current agricultural and forestry production, and to a significant extent from plantations of energy crops cultivated on agricultural land. Previous data point to the possibility of growing energy crops on medium-quality soils and fallow or waste lands, where cultivation of edible plants was abandoned, or on lands unsuitable for such production. The problem is new, and therefore the amount of theoretical and practical data on the production of energy crops under certain soil and climate conditions is still insufficient.

The research undertaken indicates that the production of energy biomass on weak and degraded soils and in adverse climatic conditions is possible, provided that appropriate agrotechnics are used, including, but not limited to, biological and enriching agents, and certified sludge from municipal treatment plants that favorably affect plant development of crops and do not pollute the environment. With proper agrotechnics, protection against pests and fertilization, it is possible to provide satisfactory yields of plant biomass under a variety of soil and climate conditions [1-8].

One of the most important tasks in the production of energy crops is the selection of suitable plant species that could thrive in specific soil and environmental conditions of the changing climate, be used in many areas, and produce a large amount of biomass that is easily converted into energy. Particularly useful are those plants that produce high yields of dry biomass, as they can be grown on low quality soils with adverse hydrographic conditions and can also be used for reclamation of degraded post-industrial sites and phytoremediation [5, 6, 8, 3]. The selection of energy crops depends on the agro-technical requirements of the plants, the conditions of the habitat, the possibilities of applying specific harvesting technology and the possibilities of biomass storage, its quality and processing technology, and the economic efficiency of production. In Europe, it is possible to set up energy commodity plantations, the yield potential of which ranges from 10 to 25-30 t of dry mass ha $^{-1}$ year $^{-1}$ and multiple times the yield of cereal and rape straw. To obtain energy biomass, sunflower (*Helianthus annuus*), rape (*Brassica napus* ssp. *Oleifera*), camelina (*Camelina sativa)*, spurge, (*Euphorbia lathyris)*, annual grasses (cereals, sorghum, corn), type C_3 perennial grasses (reed canary grass, reed) and type C_4 perennial grasses (spartina, big bluestem, miscanthus, millet, giant cane), and dicotyledonous perennials (artichoke, topinambour, silphium, Japanese and Sakhalin smartweed, Virginia mallow, lavatera). Among the arboreal plants useful in setting up energy crop plantations are the fast-growing willow, poplar, and eucalyptus [9-11].

So far in Poland, when it comes to energy crops, much attention has been paid to the production of the basket willow, which produces a significant amount of biomass, but its monoculture cultivation on large areas could compromise the biological balance and lead to adverse changes in the agro-ecosystem. In a monoculture cultivation, it is easy to deplete the agro-environment and it is also difficult to protect plants against diseases and pests. There are also fears that global climate change may cause unknown effects on plant, flora, and pest development, which could lead to a reduction in the amount of biomass that is being generated and shake up the entire energy system. For this reason, increased attention has been paid to the problem of increasing biodiversity by expanding the plant biomass assortment to other plant species that would also produce large amounts of biomass on weak soils, be resistant to unfavorable soil and climate conditions, have phytoremediation properties and, if possible, could be used in many fields for other purposes than energy provision, including in the feed, paper, food, medical, or beekeeping industries [5, 8, 12, 13, 4, 14].

A properly organized energy biomass market should include as many plant species as possible, adapted to specific climatic and soil conditions and local energy needs. Increasing biodiversity will prevent the agro-ecological imbalance and will limit the spread of pests, which migrate easily and are difficult to combat in large areas of agricultural and forestry monocultures [9]**.** According to current literature, under Polish environmental conditions, several dozen species can be cultivated for acquiring energy biomass, but a significant number of them are little known in our country. Of the perennial plants, the most popular species is still the basket willow (*Salix viminalis* L.*)*. There are also high hopes for other perennial species, including poplars *(Populus* sp. L.), Japanese rose (*Rosa multiflora* Thumb.), Virginia mallow (*Sida hermaphrodita* R.) topinambour (*Helianthus tuberosus L.),* silphia *(Silphium perfoliatum*), Sakhalin smartweed (*Reynoutria sachalinensis*), and garden tree-mallow (*Lavatera thuringiaca* L.). There are also high expectations for a large group of monocotyledonous plants including giant miscanthus, switchgrass, prairie cordgrass, corn, sorghum, and other species of cereals and perennial grasses. Plants of these species produce relatively large biomass under a variety of environmental conditions, usually favorably affecting the structure and fertility of the soil, the shape hydrographic conditions, and absorb many substances from the soil, including toxins. Many are resistant to adverse soil and climate conditions and the excess or lack of water. They develop well under variable weather conditions, while willow requires sufficiently fertile soil, abundant fertilization, and adequate groundwater levels [9]. Because of the great interest in the industrial, prosumer, and social energetics in the country, there are collections of energy crops established that are of educational importance and provide opportunities for acquaintance with these species.

Selected types of energy crops included in this collection will be grown in ecological systems in which monocultures of cyanobacteria and chlorophytes will be used in addition to biological agents. The authors' research has shown that the application of these monocultures in seeds, seedlings, and leaves improves plant health and their growth and physiological activity, and reduces the recommended dose of artificial fertilizer, which significantly reduces environmental contamination [7].

The energy crop garden at the Technology Transfer Center in Konstantynów Łódzki

Poland has the largest potential across the EU in the field of energy agriculture (agro-energetics and biomass production) and for the development of a prosumer model where the energy producer is also its consumer. That is why research and implementation work regarding the development of RES in Poland should be carried out in scientific institutions and energy companies. Several million hectares of land lie fallow in all regions of our country. Energy crops could be cultivated on those lands. Soils of the lowest quality should be allocated to this cultivation to eliminate competition with the production of food crops. Thanks to agro-energetics, Poland can produce biogas and biomass in large quantities, which will significantly affect the country's energy security. Renewable energy represents an enormous opportunity for the Polish economy in the long run.

In response to these assumptions, Pro Akademia TTC has created a garden of energy crops for didactic, experimentation and training purposes. The energy crop garden will be of a functional and universal nature. The designed set of plant species will make it attractive and decorative throughout the year, and the paths created around the Pro Akademia TTC are optimal and convenient for driveways and pedestrians taking part in an ecological didactic presentation. An adequate extensive area of the lawn and space for scientific experiments was planned. The developed format of the area is of average fertility with medium permeability and acid reaction. Planting energy crops will allow for testing a wide range of bio-stimulants and soil improvers to improve its structure, biological life, and functionality. The results obtained from the experience will significantly influence the development of research and implementation work in the TTC Pro Akademia, the development of innovative RES technologies, and the development of specialist staff (Fig. 1).

Fig. 1. Land development concept at the RES CTT in Konstantynów Łódzki
Source: [15]

The design concept of the garden at the RES TTC
The designed greenery covers an area of about 2400 m^2, in which there is a small front area of about 200 m^2 and a large part on the rear side of the building with an area of 2200 m^2. The front side is where the main emphasis of the garden is put, where the characteristic elements of free bushes, perennial herbaceous, and grasses against the backdrop of hedges have been utilized. Plants with energy properties have been utilized as well, and a selection of plants resistant to unfavorable habitat and climatic conditions has been carried out. Tibetan cherry plant, with unique red bark coloring, have been planted in strips. Their location accounts for the possibility of creating two corridors connecting adjacent parcels in the future. Attractive yew hedges have been designed in two fragments along the fence.

In turn, in the area in the immediate vicinity of the parking lot there is a collection of grasses, including the decorative small reed and staghorn sumac. There are also birch *(Betula utilis 'Doorenbos'),* Scots pine, and black pine trees. All species and varieties, in total more than 80, have been deliberately chosen for size, color, strength, habitat needs, disease resistance, and frost resistance [15]. An essential part of the work in the energy crop garden will be the systematic maintenance, which primarily includes fertilization, irrigation, trimming shoots, weeding, mulching, protection against pests, and frost. All these works will be carried out as part of the testing of new, ecological plant protection products.

The characteristics of selected plant species useful for energy biomass production

Basket willow (*Salix viminalis*)

The Basket willow (*Salix viminalis*) is referred to as the "fast rotation tree", thanks to the rapid growth and the ability of efficient vegetative propagation through seedlings. In Poland, the acreage of this species will grow rapidly due to ease of cultivation, access to new and more efficient varieties, the introduction of new biomass energy harvesting techniques, and the lower cost of producing 1 GJ of energy compared to fossil fuels. The reaction of the soil intended for cultivating the willow should be within the pH range of 5.5-6.5. It should not be too low, because at pH below 5.5 there are disturbances in growth. Willow is a water-loving plant and it develops most effectively on the outskirts of watercourses and wetlands. Its cultivation can lead to the drying of the land and therefore it is a threat to the current water deficit in Poland. Thanks to the superior ability to accumulate harmful substances and their degradation, it can be planted in the form of protective belts around industrial facilities, landfills, and along communication routes. Thanks to its massive roots penetrating the deep layers of the soil, the high and rapid regeneration capacity of the aboveground parts and the large amount of biomass produced, the willow is used in phyto-extraction and serves as a raw material for energy production.

The basket willow grows up to 8 m in height, and in favorable environmental conditions it grows up to 10 times faster than the pine and the spruce [16]. Almost all types of land can be used for the cultivation of the willow. A high biomass yield (from 12 to 15 tons ha^{-1} $year^{-1}$) is obtained on arable land of the III and IV bonitation, with a reaction of pH 5.5– 7.5. It may also grow on class V soils, provided that the soil is moist in the growing season, properly fertilized, and not boggy [17]. When cultivated on weak soils, it requires proper fertilization and adequate soil moisture, as drought can reduce yield by as much as 50%. [1, 18, 2, 3, 8, 4, 6,12]. Willow cultivated on degraded soils should be cultivated in ecological systems, where biological agents and *in vitro* monocultures of cyanobacteria and chlorophytes are used. The application of these monocultures in seeds, seedlings, and leaves has a beneficial effect on plant health and accelerates their growth by increasing their physiological activity [13, 5, 7]. The use of these monocultures reduces the recommended amount of artificial fertilizer that degrades the environment (Photo 1).

Properly maintained plantations are suitable for at least 15-20 years of use, with the possibility of repeated obtainment of wood biomass in the amount of 10-15 tons DM $ha^{-1}year^{-1}$ in a one- to five-year cycle. The biomass harvested in autumn or winter is characterized by high humidity (50-60%), which requires proper storage and drying. The energy value of one ton of dry biomass is 4.5 MWh, as is the calorific value of low-quality pulverized coal or 500 liters of fuel oil [19]. After burning, the amount of ash is about 1% of the biomass, whereas in the case of inferior grades of coal the content is up to 20%. Basket willow can also be the raw material produce biomethanol. The most useful clones in the national conditions are *Salix viminalis* 082, *Salix viminalis* var. Gigantea, *Salix viminalis* 052, *Salix viminalis* 051 and *Salix viminalis* 'Piaskówka', the yield of fresh biomass of biennial plants can be 74.13; 60.30; 70.30; 59.98 and 52.34 tons/ha, respectively [17, 20, 21, 22].

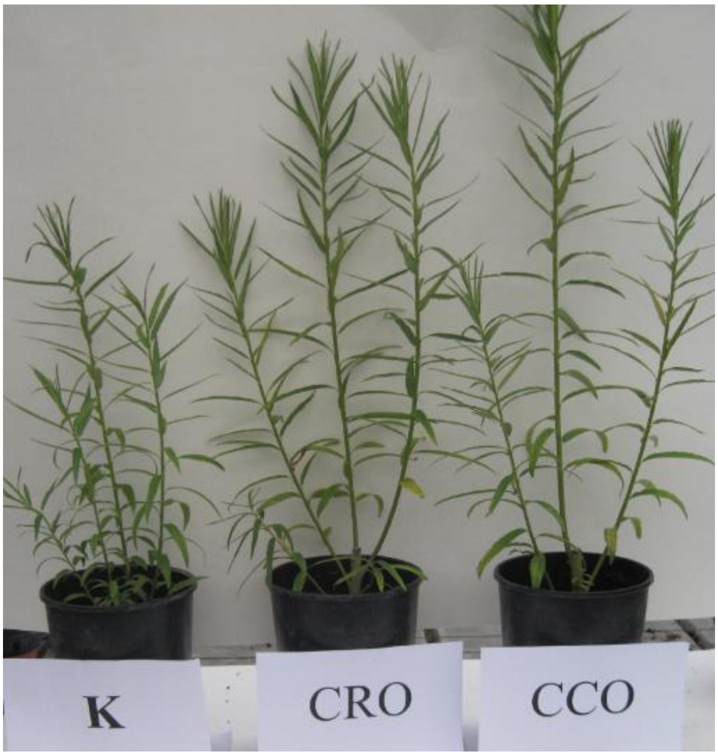

Photo 1. Basket willow sprinkled with sonificated (CRO) and unsonificated monocultures of *Chlorella* sp.
Author: M. Grzesik.

Poplar (*Populus* sp.)
Poplar is a diclinous and anemophilous plant, requiring a sunny location and relatively high soil moisture, although the individual species and crossbreeds exhibit some variation in this respect. It reproduces florally from seeds and vegetatively from seedlings. The poplar is a fast-growing tree in Polish environmental conditions and has similar utility value and soil and water requirements as the willow. It can be grown on almost all land and achieves large biomass gains on V-class soil with a peat and sandy subbase. The annual shoot growth rates range from 2.5 to 3 m, while the biomass growth of a single tree can be about 3-3.5 kg. The biomass yield of the poplar depends on many soil-climatic and agro-technical factors, and on the number of plants per area unit. 700-2000 ha $^{-1}$ plants are often planted on commodity poplar plantations, the biomass of which is harvested in a 4-6 year cycle and the annual yield is 6-12 t dry mass ha $^{-1}$. With a large plantation, 6500 trees ha^{-1}, the annual yield of biomass can amount to about 23 tons with a moisture content of 50%, or about 17 tons of wood ha^{-1} year^{-1} with a water content of 25%. By contrast, with the increase of the plantation up to 10,000 trees ha $^{-1}$, one can obtain about 22.5 tons of wood with a water content of about 25%. The biomass yield of the poplar tree depends on climatic conditions, soil type, species and clone, crop rotation, plantation age, fertilization level, and other agro-technical treatments. High yield poplar plantations should be planted on fertile soils with appropriate air-water relations. On the other hand, sandy soils of low bonitation classes are not suitable for this kind of cultivation. Soil reaction (pH) should be 6.0-7.5, and the optimum groundwater level should be 0.5-2 m. In Italy, the poplar clone of the *poplar populations species*, in bi-annual rotation, yielded 11.7 t of dry mass ha-^{1}year^{-1}. On the other hand, the elongation of crop rotation to a three and four-year period resulted in a significant increase of its yield, to 15.0 and 18.4 t dry matter ha-^{1}year^{-1}, respectively. The highest yield of biomass is produced by the poplar under the environmental conditions in river valleys and water bodies. Most often biomass is obtained in a four- to seven-year and ten- to twelve-year cycle in the case of aspen.

In Poland, it is recommended to cultivate a fast-growing cross between Swedish Aspen and American Aspen, which is suitable for cultivation on hydrated waste land and degraded land [9, 10]. Another crossbreed recommended for plantings in energy plantations is the canadensis 'Robusta' cultivated in Poland, which in the short term produces biomass comparable to the willow and is resistant to diseases. Trees are cut down every 3 to 4 years [23, 24, 18]. The planting material comprises cuttings approximately 20 cm long that are obtained from mother plantations in the winter period, from one-year or two-year old shoots. From 5.5 to 6.6 thousand cuttings are most commonly planted per 1 ha.

Japanese rose (*Rosa multiflora* Thunb.)
The Japanese rose plant is a tall, expansive and widely growing shrub with a diameter of 4 m and shoots of 4-6 m in length. The plant produces a deep root system of up to 1.4 m and is resistant to drought, whereas biomass growth is greater on soil that maintains moisture well. A well-developed root system, penetrating deep into the soil profile, contributes to the increase in permeation. In addition, it has a positive effect on the productivity of adjacent crops, especially during drought, causing an increase in soil retention of adjacent soils. The Japanese rose has significant reclamation properties, it weakens water and wind erosion, and prevents excessive soil drying. It is also resistant to diseases. In Poland, it grows in the wild and it is resistant to low temperatures, resistant to drought, grows strongly on sludge, and its biomass yield is 15-20 t ha^{-1} with a hardness comparable to beech wood [23-25]. Plantations of the JART crossbreed variety, having no spikes and strongly regenerating, can be established on sands and poor sandy soils of class V and VI. The Japanese rose biomass can be briquetted, burned or gasified. The advantage of cultivating the Japanese roses is the annual harvest of biomass, starting from the year in which the plantation was established. This plant also has phytoremediation properties and can therefore be used for planting on coal dumps, landfills, gravel sites, post-flotation sludge and chemical waste disposal sites, along transport routes and in areas contaminated with sulfur, heavy metals and salts. The reproductive material is seedlings with a length of 20-25 cm, which are planted vertically in the ground.

Virginia mallow (*Sida hermaphrodita*)
The Virginia mallow is one of the prospective plants that, like willow, can be used for energy purposes. It is suitable for cultivation in the climate of Poland on all types of soils, land laying fallow, weak and degraded land, sewage sludge and municipal sludge landfills and sandy soil of the V bonitation class, provided they are sufficiently humidified. It also grows, albeit much worse, in landfills of unprocessed sludge from municipal treatment plants [26], and based on the results of the research of the authors of this publication, it grows very well on poor soils, enriched with processed, ecological municipal treatment plant sludge [6]. The deep root system, capable of penetrating deeper substrate layers, makes this plant resistant to periodic drought and capable of accumulating toxic compounds. The Virginia mallow is a species resistant to many chemical pollutants of the soil. The possibility of using Virginia mallow biomass obtained from chemically degraded areas for energy purposes indicates the great importance and value of this crop in Poland [4, 14]. It can also be used for reclamation of degraded areas. Slightly less leafy or stem forms are more useful for combustion, while more leafy forms are more suitable for biogas production. The plant also has other uses, including as hemp or as an herb. It plays a role honey production, and can be grown for feed and serve as a raw material in the cellulose and paper industry or as a substrate to produce mushrooms. The mallow plantation can be used for 15 to 20 years. Under favorable conditions, the winter harvest of plant mass is 20 to 25 tons ha^{-1}, and its harvesting humidity ranges between 20 and 25%. Because of this, it can be burned immediately after the harvest, without drying, which lowers the energy costs. The calorific value of the mallow stems is 14.5 MJ kg^{-1}. The relatively high ash content of 14.7 to 16.6% of the dry matter is a problem.

As shown by the results of the research, the cultivation of the mallow on polluted soils is possible in an ecological system. The use of biological agents, the Bio-Algeen S 90 preparation and monocultures of cyanobacteria and chlorophytes has a favorable impact on plant health, it accelerates their growth, and increases their physiological activity. This treatment reduces the amount of the recommended dose of artificial fertilizers that contaminates the environment (Photo 2).

The Virginia mallow reproduces using seeds that germinate unevenly and in a low percentage. Seed conditioning, which is an ecological treatment, accelerates germination and increases the rate of emergent seedlings [9, 27]. The alternative is vegetative propagation through seedlings from root sections, division of the underground part of the plant, herbaceous seedlings from above shoots, and *in vitro* seedlings. Between ten and twenty thousand plants are usually grown on 1 ha.

Photo 2. The Virginia mallow plants sprayed with the Bio-Algeen S90 (BO) preparation, and sonificated (CRO) and unsonificated (CCO) *Chlorella* sp. (chlorophyte) monocultures. Author: M. Grzesik.

The Jerusalem artichoke (topinambour; *Helianthus tuberosus*)
The Jerusalem artichoke is an interesting energy crop with a very high production potential, used to produce large quantities of biomass (the above ground part) and biofuels (the bulbs). The height of the crop is determined primarily by the genotype of the plant, but also by the fertility of the soil. The plants bloom from August to November. The biomass yield can reach as much as 110 t/ha, including 75.6 t/ha of green mass and 32.4 t/ha of bulbs [16]. In most production conditions in Poland, one hectare can produce 12 to 36 tons of bulbs and 10 to 15 tons of dry stem and leaf mass. Jerusalem artichoke bulbs have a high nutritional and dietary value. Due to the presence of inulin, they are used to make treatments for diabetics, and they are becoming an alternative to potatoes in the French diet. They can also be used to produce bioethanol or biogas, and as feed for farm animals or game. The above ground part, apart from direct combustion, can be used to produce briquettes and pellets and as a substrate for growing mushrooms. Biogas can also be produced from fresh or pickled shoots.

The Jerusalem artichoke grows well and produces a large biomass in a wide range of environmental conditions. It grows best on medium compacted, airy, and sufficiently moist soils that are rich in nutrients. It can also be grown on low quality soils that are fertilized with treated waste water [9, 16, 4, 14]. The Jerusalem artichoke can be used to reclaim soil contaminated with phosphorus and chlorine-organic pesticides. It also demonstrates the ability to accumulate heavy metals Pb < Cu < Ni < Zn, and in particular Cd. During testing of suitability for phytoremediation of sewage sludge, it was found that the Jerusalem artichoke accumulates much larger amounts of Mn than the willow and the Virginia mallow, and slightly higher amounts of Co and Cd than the mallow [26]. The propagation material is bulbs.

Sylphia, the cup plant (*Silphium perfoliatum*)
Sylphia is a dicotyledonous perennial plant of the *Asteraceae* family, which also includes the Jerusalem artichoke and the sunflower. It blooms from July to September and is resistant to diseases, pests and low temperatures (even below -25°C) and is therefore suitable for growing under the diverse soil and climatic conditions of Poland. It is also characterized by low soil requirements and can be recommended as a pioneer plant for the rehabilitation of degraded land. The utility and physico-technical values are given in Table 1. Its energy plantations are set up in late autumn (X-XI), sowing seeds directly to the ground. After about three or four years, the plantation can yield 100 tons of biomass ha^{-1}, or approximately 15 to 19 tons of dry mass ha^{-1}. Sylphia is used as a valuable feed and medicinal plant because its leaves, inflorescences and rhizomes contain a large amount of saponin compounds, and it is used in the production of honey. Its honey yield is 550 $kg \cdot ha^{-1}$ [28] and its pollen yield is 200 to 300 $kg \cdot ha^{-1}$ [9, 11, 29, 30, 31].

Table 1. Sylphia's utility and physico-technical values [31]

Dry matter yield [t·ha-1] (estimated value)	14
Shoot height [m]	2.4
Length of shoot sides [mm]	11.2 x 12.4
Specific density [kg · m-3] at 17% humidity	210
Calorific value [MJ·kg-1] at 13% humidity	15.23
Heat of combustion [MJ·kg-1]	17.3
Ash content [%]	3.4

Japanese smartweed (*Reynoutria japonica*) **and Sakhalin** smartweed (*R. sachalinensis*)
The smartweeds are rapidly growing plants producing shoots up to 6 m in height. In Polish conditions, smartweeds start vegetation in April or May and finish with the first frosts. They blossom in the first decade of September, as one of the latest blooming plants in the country, and are valuable honey plants. Energy plantation yields from one planting for about 25 years. The annual yield of dry biomass is 10 to 40 tons ha^{-1}, depending on the soil and climatic conditions. Shoot drying occurs in the late autumn, and biomass harvesting takes place in the winter months. The shoots contain 32-36% of water and do not require drying before combustion or preparing for gasification. The problem is the rapid depletion of the soil by the plantation of the smartweed in the absence of fertilization. These species are easily spread by the seeding of rapidly ripening and drooping seeds, or through the growth of long (5-6 m) navelworts. This results in the formation of dense clusters of these plants that are difficult to eradicate [18].

Grasses
Of the many thousands of species of grasses that occur in the world, 200 species of 56 alliances occur in Poland. The represented species are characterized by considerable variability of morphological, anatomical, and biological characteristics. In addition to cereal grasses, fodder grass, as a feed for animals, and lawn grass for lawns, pitches and park grounds, ornamental plants for their decorative leaves and inflorescences, used in phytoremediation and rehabilitation of degraded areas, and as raw materials for energy purposes are highly valued in the country.

Grasses, as plants that are widely used in the economy, which form almost any environment and easily adapt to local conditions, are most suited to the development of all areas and can be used simultaneously for the economy. Unlike other permanent plantings (willow, shrubs, or trees), the land under the grasses can easily be converted into agricultural lands. Grasses have a more favorable impact on the structure of the soil, prevent erosion, shape hydrographic conditions, strongly absorb substances, fertilize the soil and are beneficial for the flora and the fauna. Thanks to their seed production, they practically plant themselves, there are no major problems with their renovation, and the cost of sowing fields and maintenance of crops are much lower than in the case of trees and shrubs. Cultivation of grasses ensures plant renewability, reduces CO_2 in the environment, has a beneficial impact on the landscape, minimizes maintenance costs of the ecosystem, contributes to the decentralization of economic structures, increases autonomous energy supply, increases farmers' incomes, and has a beneficial impact on the environment. Grown around draining ditches, reservoirs, rivers, toxic contamination sites, they provide a large mass that can be used as energy material and plant substrate.

Grass plantations established in ecological niches can be used to prevent the eutrophication of waters and cyanobacteria frog spits by creating a natural filter. For phytoremedia and energetic purposes, the following species are useful: reed grass (*Calamagrostis arundinacea*), purple small-reed (*Calamagrostis canescens*), wood small-reed (*Calamagrostis epigeios*), tall fescue (*Festuca arundinacea*), giant miscanthus (*Miscanthus sinensis giganteus*), Amur silver-grass (*Miscanthus sacchariflorus*), English ryegrass (*Lolium perenne*), reed canary grass (*Phalaris arundinacea*), common reed (*Phragmites communis*), and Kentucky bluegrass (*Poa pratensis*).

The cost of obtaining energy from grasses using existing equipment, like for straw, is lower than for coal and natural gas. Obtaining energy from grasses is more environmentally friendly and less polluting. Some grass species make better use of CO_2, and their biomass gain from $1m^2$ per day is 30 to 60 grams, while in crop plants it is smaller and amounts to 20 to 40 grams. At the same time, grass consumes less than half the water (150-350 g) to produce a gram of mass compared to cereals (300-800 g). Grass cultivation ensures plant renewal, has a positive impact on the landscape, lowers the cost of maintaining the ecosystem, improves ecological balance, and enables large amounts of biomass to be obtained for energy purposes. The condition for obtaining these effects is the selection of the appropriate species and varieties for the objectives of the cultivation and soil conditions, the refinement of seeding material to enable rapid germination of the kernels and the growth of plants under unfavorable conditions, and the use of effective cultivation methods in a variety of conditions [24, 32]. Among the large number of energy grass species, maize, giant miscanthus, switchgrass and common reed deserve a special mention.

Corn (*zea mays*)
Corn is a commonly grown grain crop. The yield of green mass is 50 to 60 tons ha^{-1}, but the dry matter yield can reach 45 tons h $^{-1}$, including the yield of about 30 tons of stems, 11 tons of grain, 3 to 5 tons of rachis, which should put this plant among the most useful in the energetics industry with its high plant mass and low humidity. The energy value is close to the value of cereals (approximately 17-18 MJ kg of dry mass^{-1}). Corn plants are of the photosynthetic C4 type and this is an important element in energetics. Corn is grown from seed sowing on fertile, warm, airy soils, the quality of which could be improved using suitable bio-stimulants and fertilization with refined sludge from municipal treatment plants [6]. Corn is starting to find a good use in bioenergy production due to its high biomass yield, favorable climatic conditions and the ability to obtain energy from it through burning, gasifying or production of biofuels. As with willow and Virginia mallow, also the corn grown on contaminated soils can be treated with the Bio-Algeen S 90 preparation in an organic system and with non-toxic monocultures of cyanobacteria and chlorophytes, which have a positive effect on plant health and accelerate their growth (Photo 3).

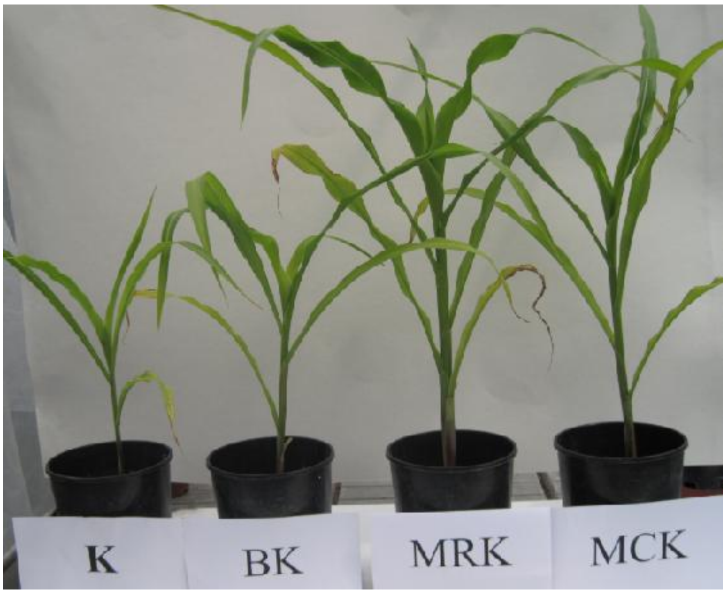

Photo 3. Corn obtained from kernels conditioned in Bio-Algeen S90 (BK) and in sonificated (MRK) and unsonificated (MCC) monocultures of *Microcystis aeruginosa* (cyanobacteria).
Author: M. Grzesik.

Giant miscanthus (*Miscanthus* x *giganteus*)
The giant miscanthus is a crossbreed created by a cross between the Chinese silver grass and the Amur silvergrass. It is a magnificent meadow grass with a very deep, strong root system reaching up to 2.5 m deep in the ground and an above-ground part growing to a height of 200 to 350 cm. The calorific value of the miscanthus is 19.25 MJ kg of dry mass $^{-1}$. It is characterized by rapid growth, high yield of biomass (6-30 t ha^{-1} depending on the cultivation conditions) and relatively high resistance to low temperatures of older plants. Under the conditions present in our country it does not produce seeds and it only reproduces vegetatively. Miscanthus biomass is harvested in February or March. These plants can be cultivated for 10 to 12 years in one field, with the best yields during the first 8 to 9 years of the plantation [10,16].

Switchgrass (*Panicum virgatum*)
Switchgrass is a monocotyledonous energy crop that is little known in Poland, while in the USA and Western Europe intensive work is being carried out on its wide application in energy crops. According to current information, it is suitable for cultivation in our climate. The yield of dry matter at harvest is very high and amounts to

16-22 tons per ha^{-1} and the energy yield is 17-18.4 MJ kg^{-1}. It multiplies through seeds, 3 to 11 kg ha^{-1} of which are planted at a depth of 0.6 to 1.3 cm when starting a plantation. Seeds germinate in about 50%. Switchgrass grows well on soils with a pH reaction of 4.9 to 7.6. The seedlings develop best at 20 to 25°C, while the plants can even survive a temperature of -30°C. Plantation life may be up to ten years. They belong to the photosynthetic type C4.

Common reed (*Phragmites australis*)
In natural conditions, the common reed is a perennial that reaches a height of up to 4 m. It has very long rhizomes and navelworts. It mostly multiplies vegetatively. It is a cosmopolitan species with a wide ecological amplitude, growing on both acid and alkaline soils and on sands and peat. It is quite tolerant of over-drying and flooding. It is characterized by its high capacity to collect water and excrete it in the form of water vapor. The expanded root system increases the surface area where microorganisms develop. The intense growth of the reed means a significant increase in biomass production and an intensification of the mineralization processes.

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