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ASSUMPTIONS OF RENEWABLE ENERGY SOURCES TECHNOLOGY TRANSFER CENTER'S PROGRAM OF RESEARCH IN THE FIELD OF ENERGY CROP PROCESSING

Abstract
The development of biomass-based renewable energy requires a broad range of research aimed at developing effective agrotechnologies that address a wide assortment of energy crops that can be grown in a country. The aim of this article is to present the most important directions of research on improving agrotechnology of biomass production and its processing based on the species of energy crops collected in the garden collection of the RES Technology Transfer Center.

Key words
RES Technology Transfer Center, energy crops, seed processing, agrotechnics, phytoremediation, bioindication, torrefaction

Introduction

The use of renewable energy sources (RES) in Poland is seen primarily as a measure to reduce environmental burden and increase energy security in the country. This is especially important since around 90% of the Polish power industry is based on coal, highlight the need to diversify the sources of electricity production. The development of renewable energetics should be based primarily on the potential for distributed generation in the national power engineering system, which contributes to the reduction of energy transmission losses and thus significantly improves energy security and reduces greenhouse gas emissions. The development of the energy sector should consider Poland's commitment to ensuring an adequate share of RES energy in total energy consumption and respecting environmental principles, and at the same time should not have negative effects on the economy, including national food security [1-4].

The development of the prosumer power industry requires the results of research and the implementation of the technologies developed as a result, which fully comply with the recommendations of the Act on RES. Research results should take into account a number of factors, including biomass production for distributed power engineering on marginal soils, the availability of diverse acreage, intensification of plant development after organic fertilization using certified organic waste (reducing the risk of their storage and environmental discomfort), biostimulation of plants with the use of biological agents and soil improvers, and the torrefaction of biomass to improve its calorific value and heat conversion. These research topics, which should be the constituents of the strategic program, will stimulate the rational use of biomass and production of energy and fuels in rural areas, respecting the criteria of sustainable development. It is essential for prosumer production of biomass to implement a recycling technology for the ashes obtained from biomass combustion and their use as fertilizers, which would solve the problem of their utilization and storage and natural use in fertilizing the energy, consumer, ornamental and energy crops of different agro-ecosystems. In biomass production, too little attention is paid to the adaptation of new cultivation systems such as plow-free cultivation, and the rebuilding and biostimulation of the development of flora and fauna in the soil, which has a very large and often undervalued influence on plant growth and development. The biological activity of farmland can contribute to the increase of yields and production efficiency in a variety of agro-ecosystems. It is also important to implement modern technologies to improve the planting value of propagation material through organic methods, which largely determines the efficiency of biomass production and yielding, as well as the greater use of bioindicational assessment of the environment to predict high yielding crops under certain conditions. There are few studies in this area, and most of the current data concern the optimization of energy crops cultivation on soils that are relatively good and suitable to produce consumer plants [5-11].

The optimization of biomass production of plants is necessary to improve the balance and profitability of RES energy recovery, as well as to reduce the costs of logistics, storage, and incineration of this fuel [1, 3]. In view of the limited data on the adaptation of these factors in small-scale prosumer production, the aim of this paper is to indicate the selected conditions and scope of experience to be considered in the production and processing of energy biomass. These issues will be the subject of research conducted at the RES Technology Transfer Center based on the collection of energy crop species.

Development and adaptation of modern energy crop agrotechnologies in specific agrosystems

In Poland, the use of plant biomass has a great advantage over other renewable energy technologies, due to its ability to be produced on a large acreage of marginal (weak) soils, excluded from food production. There is a wide area where it is possible to improve environmental performance and energy efficiency using modern agrotechnology and, in the later stage, subjecting the raw material to carbonation (high temperature drying of plant matter in reactors), with synchronized bioindication of environmental monitoring to protect natural resources (Fig. 1). Producing the required biomass potential on soils of very low quality, without the use of developed, high-performance agrotechnologies, will be very difficult. Plants in these unfavorable conditions yield very poorly and their production uses large amounts of toxic fertilizers, which is unprofitable and additionally has a negative impact on the environment [4, 12-14].

Fig. 1. Bioindication test of the water used in ecological cultivation of plants using the *Spirodela oligorrhiza* bioindicator
Author: Z. Romanowska-Duda

Development of methods to improve the planting value of the propagation material

The efficiency of cultivation is decisively influenced by the planting value of the propagation material, which in the case of energy crops should be particularly high. Development of modern and previously unused ecological methods of refining the propagation material involves the selection of suitable conditioning or bioconditioning parameters for seeds and seedlings. These treatments are intended to initiate all the metabolic processes that precede the penetration of the seed coat by the root, and rooting in seedlings. Seeds and seedlings in such an advanced state of metabolic processes immediately sprout/root, resulting in accelerated and leveled plant emergence in the short term, and accelerated plant growth under any environmental conditions. Conditioning of seeds in biological agents, known as bioconditioning, increases the effectiveness of this treatment and often improves their health [8]. Earlier and faster growing crops are more competitive for weeds, which are easier to destroy by mechanical and chemical treatments. Performing a spectrum of treatments at the same time is possible once the plants have reached the right development phase, which ensures pre-planting seed and seedling conditioning. The use of pre-planting methods to improve seed value also allows for decreasing the amount of material to be sown and increases the plant's resistance to environmental stresses, resulting in increased profitability of their production. In addition, accelerated root emergence and growth, being a consequence of the refinement, also allow plants to be grown under conditions of drought that are often present in the presently changing climate. The seedling/sowing of such seeds/seedlings in periodically wet soil allows for quick root overgrowth into the deeper layers of the ground, which makes the rooted plants independent of the subsequent drying of the surface layer [15, 16]. These data point to the validity of conducting multiplex research in the Renewable Energy Sources Technology Transfer Center in terms of improving the planting value of the energy crop propagation material, many species of which belong to the sparsely germinated perennial plants (Fig. 2) [17].

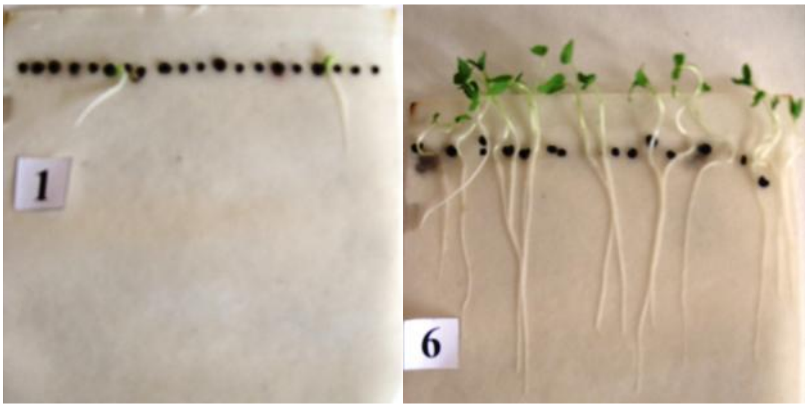

Fig. 2. Sprouting seeds of the garden tree-mallow (*Lavathera thuringiaca* L.) of the Uleko variety after 8 days after planting on paper substrate moistened with distilled water. Seeds not tarnished (left) and after pre-sowing scarification (right). Author: M. Grzesik

Development of energy crop agrotechnologies in the conditions of a specific agro-ecosystem

Preventing the widespread monocultural energy willow cultivation, which is harmful to the ecosystem and may shake up the energy system in the event of excess infection with diseases and pests in energy plantations, greater attention must be put on biodiversity. Different species of plants should be cultivated for energy purposes, which will more adapted to particular environmental conditions, favorably affecting the adjacent cultivations and at the same time positively impacting the entire agro-ecosystem. This requires a wide range of separate studies on the adaptation of plants to specific soil and environment conditions and the development of an agrotechnology for the cultivation of the most useful energy crops on weak soil, including biostimulators, ecological soil improvers, and non-toxic organic waste [12, 14, 18].

The development of energy crops on weak soils is heavily dependent on the viability of fauna and flora in the soil. This issue is poorly studied and underappreciated by agricultural technicians [19]. The activity of beneficial fauna and flora is indispensable for the occurrence of many structural processes, decomposition of crop residues, and mineralization, which in total determines the fertility of the soil. Among other things, a large earthworm population can process 10 tons of organic matter ha^{-1} within a year, significantly improving crop yield. Worm holes in the soil, borne to a large depth, facilitate aeration and are filled with excrements and mucilage, which favors the development of roots beyond the very deep layers of soil (Fig. 3). The result of the activity of earthworms is to improve the biological activity and fertility of the soil, which positively influences the growth and yield of plants and reduces the required doses of fertilizers, which contaminate the environment. The role of soil flora and fauna, including earthworms and microorganisms, is the subject of much research in agro-ecotechnology of horticultural and agricultural plants, and should be further explored in relation to energy crops grown under less favorable soil and environmental conditions [12, 19].

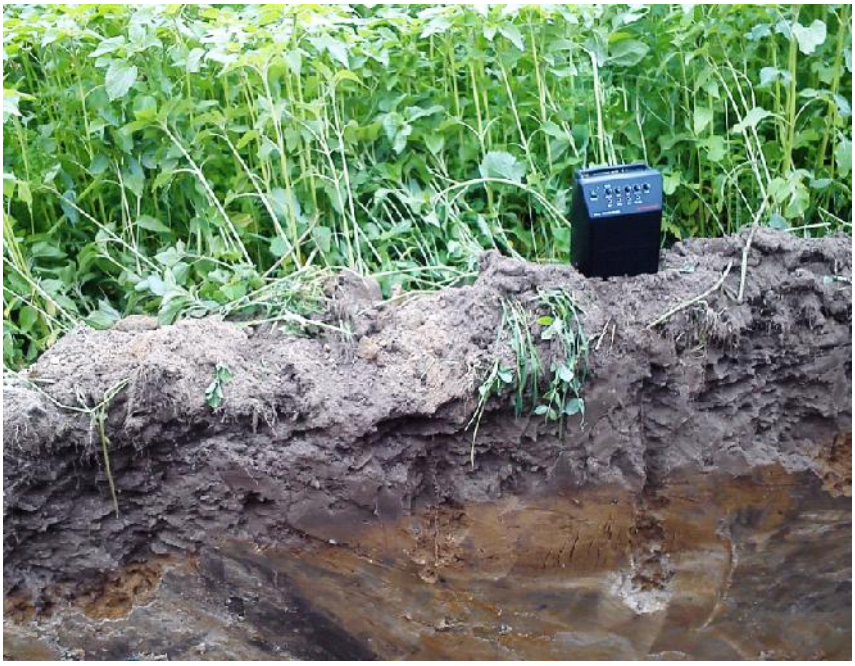

Fig. 3. The profile of the soil on which sunflower is grown mixed with legumes. Visible open canals hollowed by earthworms with crop roots growing in them vertically. Author: M. Grzesik

An important aspect of research in agro-ecotechnology is the development of a monitoring system for the diseases of energy crops, the diagnosis of their perpetrators, and the timely performance of plant protection treatments. The selection of stimulants of plant growth and their resistance to diseases and adverse agrometeorological conditions is also an important aspect. The problem of protecting energy crops against pests is very complex as it should concern the use of biological agents that effectively combat the perpetrators of diseases, while at the same time positively affect biomass yield and are environmentally friendly [8, 20, 21].

An important area of research is aimed at developing new agro-technical methods for energy crops, adapted to specific species and the environmental conditions of the changing climate. There is a concern that the predicted environmental conditions may cause currently unpredictable development of certain species of plants and pests, which may have a significant impact on the yielding of plant biomass and the functioning of the energy system based on its processing. It is therefore advisable to conduct many coherent thematic studies leading to the development of new agrotechnology of energy crop cultivation using certified waste from municipal treatment plants and biological agents, natural substances, and various organisms such as non-toxic cyanobacteria and chlorophytes. Those types of waste have a positive impact on the growth, development, and yield of biomass on low quality soils, as has already been reported for corn, Sida hermaphrodita, and willow (Fig. 4, 5, 6, 7) [16, 18, 22-27].

Fig. 4. Sida *(Sida hermaphrodita)* plants grown on peat soil. From the left: unfertilized and fertilized with three different doses of certified sludge from a municipal treatment plant.
Author: M. Grzesik.

Fig. 5. Field cropping in low quality soils fertilized with various doses of certified sludge from a municipal treatment plant
Author: Z. Romanowska-Duda.

Fig. 6. Field cultivation of plants in low quality soil. From the right: unfertilized and fertilized with three different doses of certified sludge from a municipal treatment plant.
Author: Z. Romanowska-Duda.

Fig. 7. Corn plants grown on low quality soil. From the left: control plants (sprayed with water) and plants sprayed three times with unsonificated and sonificated monocultures of cyanobacteria (*Microcystis aeruginosa*). Author: M. Grzesik

Increasing the profitability of energy crops, in addition to the methods of ecological fertilization, foliar application of biological agents, non-toxic cyanobacteria and chlorophytes, also requires the development of new agro-technical methods. One of them is, for example, the no-plow cultivation of plants, which is more economical than traditional plow-based systems. However, it requires costly specialized equipment, which is easier to depreciate in large area farms, and these should include energy biomass production companies. The conducted microscale studies based on the collection of the RES Technology Transfer Center will indicate the usefulness of this method in the cultivation of the energy crops gathered.

Fig. 8. Rape seedlings cultivated in the plowing-free system. Author: M. Grzesik

Development and implementation for production of technologies for improving the planting value of propagating material, and the ecological use of organic waste, soil improvers and bio-stimulants in the production of energy crops biomass, should increase yields on weak soils while also solving a very serious storage dilemma for such waste, which is cumbersome, expensive, and dangerous to the environment. In addition, energy crops will provide favorable conditions for preventing adverse climate change, generating pollution and degrading the environment by reducing greenhouse gas emissions and disposing of organic waste.

Evaluation of the phytoremediating role of energy crops in cleaning of the environment

Previous literature data indicate that energy crops can play the role of phytoremediators and be used to reduce ecosystem pollution and restore degraded areas to their natural state. The level of heavy metals rising in recent years has been one of the most cumbersome elements of environmental pollution. The persistent nature of heavy metal pollutions and their integration into the food chain are very dangerous because of the risk they pose to human health. The effects of their actions are not immediate and often reveal themselves after many years. Heavy metal pollution is a reflection of air, water and soil contamination by dust, industrial gases, sewage, waste, and coal combustion. The concentration of heavy metals in the environment is quite varied, and their effect depends on the dose taken, the type of element, the chemical form in which it occurs, and even on the condition of the body. Recultivation of soils contaminated with heavy metals is very expensive and used on a small scale. In recent years, promising results have been obtained from studies on the phytoremediation of plants with natural ability to accumulate these elements and remove them from the soil. There are known species that accumulate up to 1-2% of metals in tissues (hyperaccumulators), for example pennycress (*Thlaspi* sp.). In theory, they can remove up to 200-1000 kg of metal from the soil from an area of 1 hectare per year, but there is no developed agrotechnics for their cultivation. There are also studies on the use of crop plants in phytoremediation - the brown mustard, corn or pumpkin. They accumulate fewer metals as compared to the hyperaccumulators, but they produce large biomass, which increases the efficiency of the process. There is little research on the use of energy crops in the phytoremediation process. These plants can play a dual role in obtaining renewable energy (biomass) and in restoring the quality of polluted and degraded soil and water. The advantages of phytoremediation technologies are, among others, their low cost, ease of use, and acceptance in society [28].

Environmental profits from the application of phytotechnology lead, inter alia, to: (i) increasing the adaptive resilience of the ecosystem and reducing the effects of human activities, (ii) preventing pollution release and environmental degradation, (iii) monitoring pollution and environmental processes to reduce environmental degradation, iv) remediating and rehabilitating degraded ecosystems, and (v) using environmental quality indicators for monitoring and evaluating the condition of the environment [28].

Fig. 6. Energy crops grown on soil contaminated with cadmium.
Author: Z. Romanowska-Duda

The versatile use of phytotechnology can be helpful in optimizing the restoration of the quality of the environment and facilitating the selection of energy crops with special functional efficiency. Therefore, it is advisable to carry out a study to examine the possibility of improving the development of various species of energy crops and their phytoremediation capacity, and to enhance these properties through the application of non-toxic metabolic stimulants.

Evaluation of soil and water contamination using bioindication methods

The increase of pollution of the aquatic environment by heavy metals and cyanotic toxins caused the need to monitor their harmfulness, enabling to continuously undertake measures aimed at the protection of human living conditions. So far, chemical methods for assessing environmental contamination are mostly costly, troublesome and difficult to perform, and often indicate the harmfulness of only certain contaminants. Hence, they may not show the exact harmful effects of pollution on the environment. Consequently, in recent years, biotests have been sought to show the complex effects of contamination on organisms. Previous studies indicate that plants and animals can be used for this purpose, by which it is possible to quickly determine the extent of ecosystem contamination. It has been shown that plants that are easier to use than animals can be used for monitoring pollutants in the aquatic environment such as heavy metals, cyanogenic toxins, and water treatment agents. Due to the relatively limited literature indicating the suitability of particular species, and the way they are tested, the development of biotests requires the identification of species susceptible to environmental contamination and specification of the methods by which this sensitivity can be demonstrated. Because this sensitivity can be modified by environmental conditions that shape the resistance to the stresses of the plants cultivated, it seems necessary to develop these methods for contamination and vegetation present in individual regions. Previous studies carried out by the authors pointed to the possibility of testing contaminants in central Poland using effective, fast, cheap, and feasible biotesting for assessing the degree of water contamination. These tests are based on the natural biological response of seeds, macrophytes of the *Lemnaceae* family, and invertebrates to water and soil contamination. There is a need to improve these methods of assessing environmental contamination, which requires study planning.

Improved bioindication tests will be the most useful tool for assessing environmental, waste and soil contamination. They will be indispensable for both farmers and large companies, including biomass producers, energy companies, drainage services, and local governments. Indicative biotests are a tool in the proper management of the environment and will act as an early warning system (Real Time Biomonitoring), used to monitor the quality of soil, water, toxicity of organic waste and to assess the suitability of soil for the cultivation of individual energy crop species [29-31].

Energy crops biomass refinement technologies

Improving logistics and processing biomass into energy requires the use of energy biomass refining, inter alia, by pelleting and carbonizing it. Carbonization (torrefaction, charring) is one of the most effective and innovative methods of refining biomass, aimed at improving its physio-energetic properties. It is a process of high temperature drying to convert biomass into biofuel with properties closer to coal. This enables the biomass to become a more carbon-like material with better grinding properties and reduces the cost of grinding and hydrophobic properties, which results in safer biomass storage and a lower risk of biological degradation. In the carbonization process, there is a modification of the structure of the main components such as lignin and hemicellulose, and to a lesser extent cellulose. This process is performed under anaerobic conditions, at a temperature of 200 to 300°C, under unaltered atmospheric pressure. Carbonization, carried out through appropriate methods, is more profitable than other less efficient methods of refining, and therefore the interest in using this method in the refining of biomass is increasing worldwide.

The research on the improvement of biomass through the carbonization method mainly concerns the selection of the best and cost-effective method for initial preparation of biomass as a fuel for a specific energy boiler, analysis of selected species of energy crops and the possibilities of refining them this way, the fuel characteristics of such plants, determination of combustion kinetics, co-incineration of biomass with coal and technical-economic analysis of the biomass circulation in the heat system of the heating plant. Given the limited amount of available data, it is reasonable to examine the efficiency and suitability of carbonization of a wide range of energy crop species. This will allow the preparation of a concept of an installation that will be used to pre-process biomass in existing small boiler houses, power plants, and cogeneration plants that incinerate or co-incinerate biomass with coal [13, 32].

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