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 ORIGINAL PAPER

MISCANTHUS GIGANTHEUS AND AGRI-RESIDUES AS SUSTAINABLE ENERGY RESOURCES FOR HOUSEHOLD AND SMALL FARMS HEATING SYSTEMS

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Abstract. The use of energy crops and agricultural residues for heating systems to provide renewable energy for rural communities has opened new perspectives about available solid biomass conversion in thermal energy. Considering alternative options to demonstrate sustainability of biomass supply chain (logistics for available quantities, processing technology and equipments, customers' needs), the most important role for promoting the development and fair competitiveness of targeted renewable resource as *Miscanthus giganteus* is to design pilot-projects that include pressed products (pellets, briquettes) and adapted technology to create optimal conversion of biomass in the local heating systems. Miscanthus giganteus is a C4 perennial grass with large potential for intensive use of marginal lands, especially taking in consideration the fuel versus food competition. Moreover some indigenous resources (cereal straw, wood biomass - orchard trees pruning, saw dust, wood chips) or other agricultural residues (vegetable residues and low quality products) may ensure the local requirements for heating by promoting low-carbon technologies and to achieve European and national target for renewable energy by 2020.

Key words: Miscanthus giganteus, heating systems, agri-residues, pilot-project, sustainability.

Introduction

The bio-economy concept relates to global orientation of the economy towards sustainable development of society integrating new and old technologies for balanced progress of humanity within nature`s limits. Tony Juniper remembers us what always science demonstrates, the biomass capacity to absorb solar energy by photosynthesis, this renewable source should may have more applications rather than using fossil fuels as energy sources.

Romania has developed national strategies regarding renewable energy and recently, various energy crops was included as alternative option for fossil fuel and offers special approach in order to sustain its market growth in Eastern

European region. New projects and laws have been advanced by some dedicated association of investors and researches increasing the interest for energy crops investments [1].

Miscanthus×giganteus is a perennial tall C4 grass (3-4 m), with long productive life-span (15-20 years) that is harvested each year and is a *Miscanthus sinensis* hybrid characterized by a very high potential yield and resistance to environmental conditions species, suitable for economic bioenergy production growth [2]. Due to an efficient production of biomass, this energy plant have an important role in the sustainable agriculture for biomass production as a solid fuel, especially due the fact that reclaim marginal lands [3]. Moreover *Miscanthus giganteus* (Miscanthus) is a valuable energy plant, which can be successfully cultivated in Romania, on polluted soils with Pb and Cd, ensuring solar energy conversion into bio-energy from the surface of different contaminated lands [4].

Using short technological value chain for bioenergy production from solid biomass, *Miscanthus giganteus* can be considered one of the promising energy crop for a sustainable, profitable and reliable long-term investment. Taking in consideration other energy crops also (energy willow, switch grass, *Arundo Donax,* or oleaginous plants – rapeseeds, sunflower, camelina), Miscanthus represents a perennial crop, the most accessible and sustainable resource for medium and small farms, adapted on various soils in different regions of Romania. The incidence of Miscanthus crops in Romania is relevant, as shown in figure 1 on a vegetation map [3].

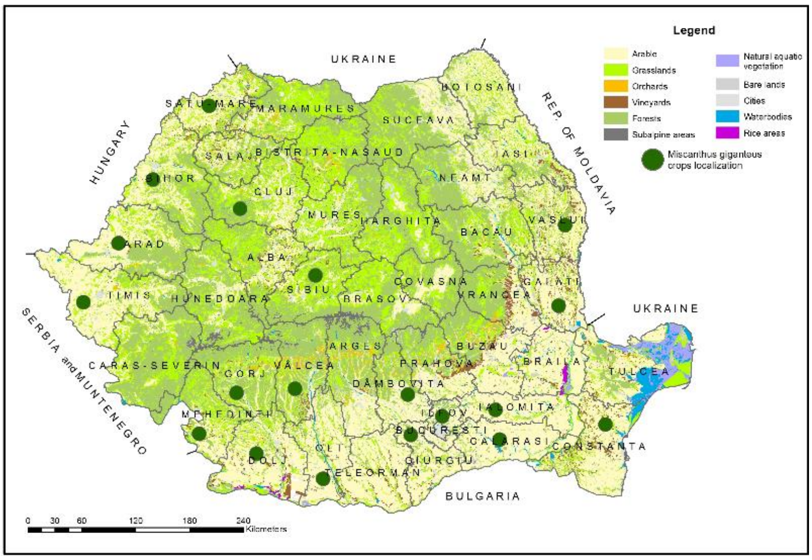

Fig. 1. *Miscanthus crops* established in Romania, 2008-2014 ([3], [5])

Different researches and also the actual study, analyse and demonstrate alternative opportunities for farmers to use blends of Miscanthus biomass with agricultural residues (straw, orchard pruning, chaff and other unconventional residues of biomass not accepted as a commercial products).

The most important ways to make available Miscanthus biomass feedstock easily on the market are by producing briquettes or pellets, which facilitate biomass distribution and access to users for efficient combustion in heating systems. Different technologies and equipments were developed for manufacturing and for efficient burning of briquettes or pellets from sawdust, straw, Miscanthus, energy grasses and other biomass sources, described by Daraban (Oros), 2015 [3].

Following this study a pilot project can be considered and designed in the scientific farm Moara Domneasca – Ilfov, where it has been tested agricultural technologies for cultivation, harvesting and processing the energy crop *Miscanthus giganteus*. The main objective of this research was to demonstrate that all available biomass from a farm, energy plants and agricultural residues can provide local grown biofuels for on-site use as thermal energy supply. Optimal conversion of solid biomass in heating systems requires first adequate technologies by pressing the biomass in high caloric products as pellets and briquettes, to create sustainable usage and distribution. This article summaries the concept followed during the postdoctoral studies that describe a full chain valorisation of Miscanthus biomass for a heating system in small or medium farms as a pilot-project.

Materials and methods

In the scientific farm Moara Domnească were this study was conducted there are multiple sources of biomass. *Miscanthus giganteus* biomass harvest from 0.7 ha was tested for pressing capacity in briquetting and pelleting installations by varying mass percentage and adding different kind of vegetable biomass, in order to identify optimal blends by ensuring improved energy efficiency and cost-effective production.

Different experiments already presented in other research, studied the potential of Miscanthus biomass by mixing with saw dust for briquettes production and with blends of straw and other agricultural biomass for pellets production. The experimental tests made in different stages, showed that this energy crop is suitable to be mixed with other biomass (wood or agricultural residues), in order to provide locally sustainable products (briquettes and pellets) as solid biofuel for small scale heating systems [6]. The main advantages of briquetting energy crops and agricultural residues for thermal energy applications are: uniform combustion comparable with coal, reduced particulate emissions,

transport, storage and feeding, facts that demonstrate more efficiency use for pressed products then for loose biomass or normal bales.
Because pelleting process is more expensive in the presented experiments there were tested more options of briquetting process.

Materials and equipment used for pressing *Miscanthus* Biomass

Miscanthus giganteus biomass used in this study was harvested in two locations: Moara Domnească scientific farm on a field of 0.7 ha and INMA Bucharest farm on 0.6 ha. There are demonstrated some perspectives of using Miscanthus biomass blends with other biomass residues in order to produce briquettes or pellets (straw, sawdust, wood chips) as suitable and efficient resources for scale heating systems from 30 kWh to 200 kWh. The Miscanhtus biomass was milled at the particles size of 2 – 50 mm for briquettes, and 2 - 10 mm for pellets tests. Specific investigations were made to prove and find solutions for briquetting Miscanthus biomass with a screw press with single line (China model, capacity: 50 kg/h, figure 2a) and further with a double mechanical press (Poland model, capacity: 140 kg/h) by varying the particles size, humidity and Miscanthus mass percentage. To press Miscanthus biomass for pellets production was used an industrial installation used for agricultural residues (as cereals straw) of 300-400 kg/h capacity (figure 2b).

Table 1) *Miscanthus* biomass blends with specific characteristics of particles size and humidity [1,6]

Sample No.	*Biomass specific (% of volume)*	*Particle sizes (mm)*	*Humidity of raw materials (wt %)*
Briquetts			
B1	M 80% + S 20%	0.2 – 20	9.5
B2	M 60% + S 40%	0.2 – 20	10.1
B3	M 20% + S 80%	0.2 – 20	10.4
B5	M 30% + W 70%	0.2 – 50	15.4
B6	M 50% + W 50%	0.2 – 50	13.2
B7	M 70% + W 30%	0.2 – 50	12.4
B	M 100%	0.2 – 10	9.8
Pellets			
P1	M 30% + S 70%	0.2 – 10	11.4
P2	M 50% + S 50%	0.2 – 10	10.2
P3	M 70% + S 30%	0.2 – 10	9.7
P	M 100%	0.2 - 10	10.5

[1]M- Miscanthus, S - straw from cereals, W - wood (sawdust and wood chips)

Fig. 2. Pressing *Miscanthus* biomass

a. Briquetting the *Miscanthus* blends of biomass by mixing with wood residues; **b.** Pelleting *Miscanthus* with cereals straw

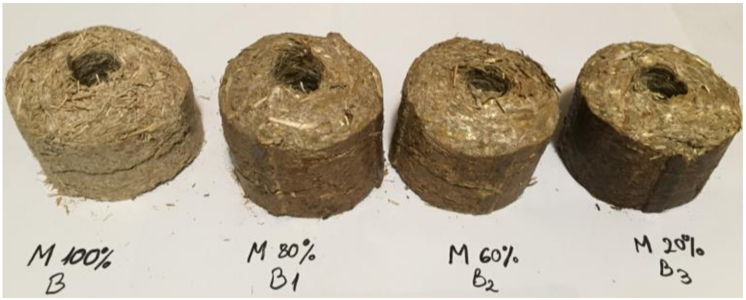

Fig. 3. Briquettes samples of Miscanthus (M) percentage blends with straw

Combustion tests of pressed *Miscanthus* biomass mixed with wood and straw residues

The combustion properties of briquettes and pellets obtained by mixing Miscanthus with other biomass were verified during experiments conducted with INCD – ECOIND (National Institute for Research and Development 2015, Bucharest) assistance, in their laboratory, by using specific equipments: an *Izoperibol* bomb calorimeter Model 6200 (figure 4a) and a CHNS-O elemental analyser. Afterwards, more tests were used for studying combustion properties using a calorimetric bomb IKA C200 and a CHNS-O elemental analyser with the support of Faculty of Energetics from Politehnica University Bucharest, (figure 4b) [1,6].

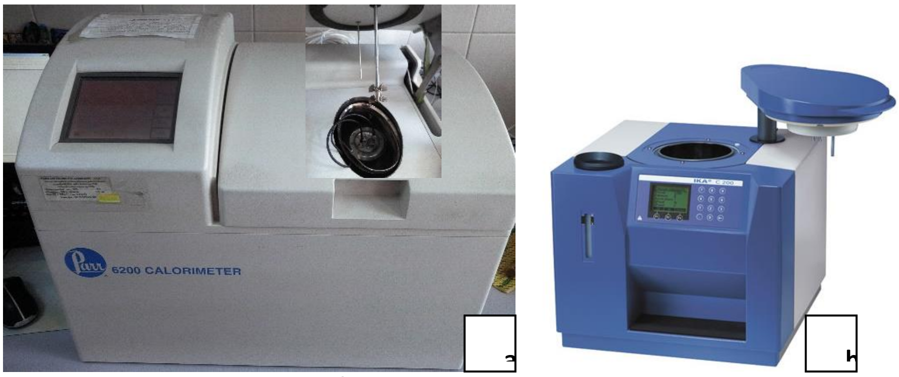

Fig. 4. Combustion characterisation of Miscanthus biomass blends with other agricultural residues
a. Bomb calorimeter Model 6200 **b.** Bomb calorimeter IKA C200

The pellets and briquettes biomass were prepared at the particles size of 0.2 mm, dimension necessary for the following determinations: absorptive humidity, hygroscopic and total humidity, ash content, C, H, S and N contents, higher calorific power.

The high calorific power (or gross calorific value - GCV) measures the heat performed by a fuel including the latent heat of water vaporisation during combustion process, meanwhile lower calorific power (or net calorific value - NCV) is calculated by excluding latent water vapours heat from GCV.

Water vapours resulting from biomass burning is formed from the hydrogen concentrations and the initial water content in the fuel during combustion. Generally, in thermo-energetics the water vapour condensation heat is not useful and convenient to relate for heating systems design and operation, which normally are working on lower calorific power calculation. Recently, only new heating systems as condensing boilers are using residual heat of flue gases to pre-heat the cold water and emerged the use of high calorific values for efficient designs [7].

Lower calorific power at constant pressure of original sample (Q_i) of a fuel represent the number of heating units which would be released by the complete combustion of a mass unit (kilogramme) from the fuel, in oxygen atmosphere, at constant pressure and is calculated from the higher calorific power (Q_s)with the following formula [8]:

$$Q_i = Q_s - 212 \cdot C_H - 0.8 \cdot C_{O_2} \cdot (\frac{100 - w_t^i}{100 - w^a}) - 24.5 \cdot w_t^i, \qquad (1)$$

where:

C_H and C_{O2} are the percentages of hydrogen and oxygen content in the biomass fuel;

W_t^i, W^a are moisture percentages of the initial mass, respectively of analysis` mass;

Coefficients 212, 0.8 and 24.5 take into account water and water vapour heat mass, respectively the latent heat mass of water vaporization (expressed in SI units).

Burning tests of *Miscanthus* 100 % pellets

In the laboratory combustion tests it was proven that *Miscanthus* briquettes and pellets are possible to obtain good calorific properties. Following this, more tests were run by burning pellets of 100 % Miscanthus in an automatized heating system (EcoHORNET) by incineration processes (temperature ≈ 1000°C), installation that achieves the complete burning of pellets and is presented in figure 3. The efficiency of thermal energy recovery from this heating systems is 93-96 %, comparing with dry wood gasifier (72-78 %) or natural gas heating systems (85-90 %). Residual gas emissions were analysed by an equipment integrated in the automatic system. The lower calorific power and the emissions rates (CO_2, NO, NO_x) of Miscanthus pellets were determined for 11 % water content (total humidity).

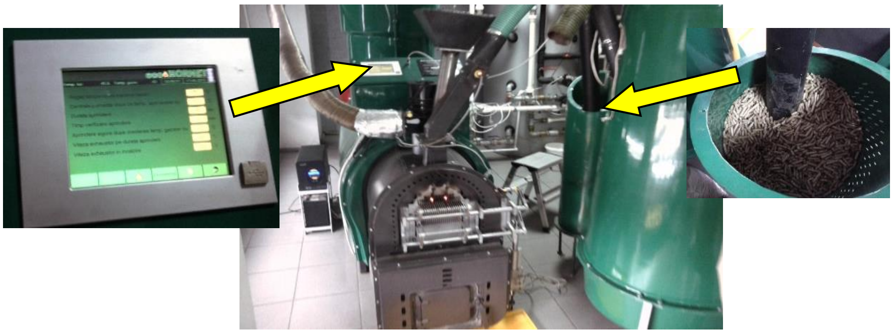

Fig. 5. Combustion characterisation burning tests in the EcoHORNET installation

Results and Discussions

Briquetting and pelleting process characterisation

In the case of briquetting process with the screw and mechanical press (one line and double lines) that we used for experimental tests, there were difficulties in order to establish the right moisture and the particle size of biomass. Good results for qualitative briquettes were obtained when the biomass humidity varied between 9 to 15 % and Miscanthus percentage in biomass blends was about 50 % and 70 %.

Briquetting is a multiple-characteristics pressing process depending on different aspects. *Miscanthus* biomass has good pressing properties tested in hydraulic press. In the case of mechanical screw press, which was used for these experiments, the behavior of *Miscanthus* materials had specific particularities.

Best pressing results for *Miscanthus* briquettes were obtained using blends of 50 % *Miscanthus* and 50 % wood residues (sawdust and wood chips).

The pelletizing process functioned in normal conditions and by adding *Miscanthus* biomass gradually in different percentage from the mass content, it was observed that pelletizing process is a great pressing method for this crop and blends with other biomass.

In this case it was also tested concentration of 100 % Miscanthus biomass for pellets and briquettes production and the results were surprising. The quality of 100 % *Miscanhus* pellets is good, comparing with the quality of blends with other agricultural residues as cereals straw and lower compering with wood blends.

Lower calorific power (net calorific value - NCV) of different *Miscanthus* blends with agricultural vegetable residues have presented values varying from 15.8 MJ/kg up to 18.1 MJ/kg depending on elemental contents (C, H, N, S) and lignin concentration, respectively the type of biomass burned (table 2).

The study pointed out a great potential of using solid biofuels, available in rural areas and therefore the opportunity of developing energy plants for local heating systems using sustainable biomass resources.

Specific combustion properties of *Miscanthus* blends with other agricultural residues

This research was organised for Moara Domnească farm, which intends to develop an alternative heating systems based on locally available solid biomass. For efficient combustion, blends of pressed biomass (briquettes and pellets) were studied in order to provide optimal supply with on-site grown energy crops and other agricultural residues.

Lower calorific power (net calorific value - NCV) of different *Miscanthus* blends with agricultural residues have presented values varying from 15.8 MJ/kg up to 18.1 MJ/kg depending on elemental contents (C, H, N, S) and lignin concentration, respectively according with the type of biomass burned.

Combustion properties (*table 2*) revealed that *Miscanthus* blends with wood have increased net calorific values value up to 18.1 MJ/kg (dm - dry matter) then those with straw, respectively up to 15.7 MJ/kg (dm), due to lignin contents. NCV (Q_i) of *Miscanthus* blends depends on the percentage blends with wood or straw analysed (20 %, 30 %, 60 %, 50 %, 70 %, 80 %). The results indicate an average of 50-60 % of *Miscanthus* blends with agri-residues (straw or wood sawdust) can offer efficient and sustainable utilisation of on-site farm available biomass for its heating requirements.

Kristöfel C., 2012 presents similar combustion characterisation for Austrian heating systems (200 kW), NCV of 17.700 MJ/kg and ash content of 3.1

% [6,9,10]. Higher content of carbon and hydrogen relates with higher NVC, calorific value that is relevant for traditional heating systems from households and small farms. The ash content increases when Miscanthus blends has higher concentration of straw, therefore ash specific adjustment for collection from the combustion chamber of heating systems are needed in this case.

Table 2) Combustion specific properties of *Miscanthus giganteus* blends with other vegetal biomass [1,6]

Sample no/ Percentage of Miscanthus (M)	*Ash content wt.[1] % dm[2]*	*Water content wt[i] (Total humidy) wt.-%*	*Carbon wt.% dm*	*Hydrogen wt.% dm*	*Nitrogen wt.% dm*	*Sulphur wt.% dm*	*Qi MJ/kg dm*
B1 –M 20%	5.82	8.73	42.44	5.27	1.26	ND[3]	**15.8**
B2 – M 60%	4.25	9.12	45.53	6.34	1.14	ND	**15.9**
B3 – M 80%	4.54	7.95	46.18	6.17	1.05	ND	**16.25**
B – M100%	2.95	7.62	45.29	6.03	1.15	0.1	**16.5**
B1[i] –M 30%	*2.44*	*3.88*	*47.5*	*5.65*	*0.283*	*0.17*	***18.1***
B2[i] – M 50%	*3.3*	*4.2*	*48.4*	*4.9*	*0.292*	*ND[3]*	***17.7***
B3[i] – M 70%	*2.3*	*3.92*	*48.36*	*5.66*	*0.301*	*0.2*	***17.8***
P1[i] – M30%	*6.38*	*6.68*	*41.46*	*5.24*	*1.14*	*ND*	***15.7***
P2[i] – M50%	*5.11*	*6.97*	*46.53*	*6.24*	*1.23*	*ND*	***15.8***
P3[i] – M70%	*5.02*	*7.05*	*45.28*	*6.0*	*1.2*	*ND*	***16.01***
P[i] – M100%	*2.78*	*9.51*	*43.66*	*5.4*	*1.05*	*0.15*	***17.0***

[1]wt. = weight, [2]dm = dry matter basis, [3]ND = not detectable
[i]Results by Daraban Oros A.E. *et al.*, 2015 [6],

Consequently, in figure 6 it is illustrated that lower calorific power variations of *Miscanthus* briquettes and pellets depend on Miscanthus percentage and the residual biomass added.

The 100 % *Miscanthus* briquettes or pellets have better combustion properties than those with straw blends and less than with wood blends, hence this energy plant may replace wood or other common fuels for heating supply, depending on local climate, farming suitability and farmer acceptance for initial investment.

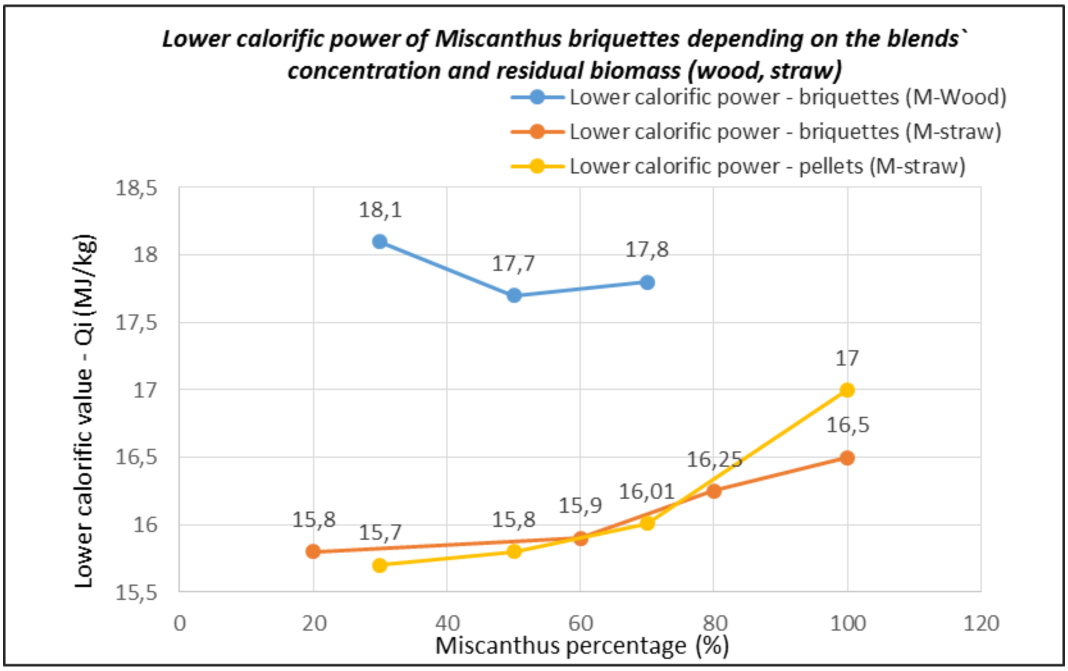

Fig. 6. Lower calorific power variation of *Miscanthus* blends with wood and straw (briquettes and pellets)

Conclusions

Conclusion (1).

Miscanthus biomass and agricultural residues represent solid biofuels, which can replace in a sustainable manner the wood or natural gas supply for thermal energy in efficient heating systems, especially in rural areas.

The main advantages of briquetting energy crops and agricultural residues for thermal energy applications are: uniform combustion comparable with coal, reduced particulate emissions, transport, storage and feeding, facts that demonstrate more efficiency use for pressed products then for loose biomass or normal bales. Pelleting process is more expensive and doesn`t offer great solutions for small and medium scale investment and were tested more alternative for briquetting process, which is much more accessible for farmers.

This study results identify the main issues considered in the *Miscanthus* processing chain, which may enable the development of optimal management choices to assist further progress in a developing biomass industry in rural areas in Romania.

There are lots of technologies and installations available to burn ligno-cellulosic plants as *Miscanthus*, straw, wood residues, corn stover and others, but different blends of energy crops and agri-residues must be assessed in further researches at pilot scale in order to demonstrate higher efficiency and sustainability.

The potential for scale up *Miscanthus* cultivation is currently restricted by the planting and harvesting capacity, grower acceptance and technology compatibility. There is also social resistance for energy crops that needs to be approached sensitively, especially where perennial energy crops are proposed on long-term land use change. Romania experiences with multi-annual energy crops is low and in this situation it is crucial that national strategies and fundings will provide to farmers much more support and guidance.

Conclusion (2).

The use of *Miscanthus* in blends with other agricultural residues for energy production in an efficient and optimal operational farm strategy offers many environmental benefits including; less climate impact, soil fertility, increasing local biodiversity and bioremediation reducing organic pollutants, where is necessarily. The great advantage of biofuels is that they are considered to be 'carbon neutral' as they use up as much carbon dioxide during growth, as they release as a fuel.

Conclusion (3).

Bioenergy crops offer rural progress may differ in various regions depending on farmers` perception and acceptance, supported by programs established at national and local level for bio-renewable energy resources. It is proven that many economic benefits of bioenergy production by cultivation of *Miscanthus giganteus* may contribute to a multifunctional agriculture, especially for polluted or marginal land, by developing the rural areas.

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