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Theses of doctoral (PhD) dissertation

THE PRESENT SITUATION OF ENERGY FOREST PLANTATIONS IN HUNGARY – ALTERNATIVES OF OPERATION AND EXPLOITATION

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1. BACKGROUND AND OBJECTIVES

Global energy consumption as well as environmental pollution increase from year to year. Renewable energy resources appear to be the appropriate alternative for satisfying our future need for energy and to preserve our environment.

The annual energy consumption of Hungary is estimated 1000-1100 PJ[1]. With domestic energy production decreasing continuously our dependence on import has been increasing steadily.

It would be wiser to build our future on a green economy basing on local renewable resources instead of depending on import-based and incalculable energies.

The utilizable proportion of Hungary's annual renewable resource growth (2600-2700 PJ per annum) is 405-540 PJ per annum which could cover about the half of the annual needs. Regarding the capabilities of Hungary, the type of renewable energy which could be produced sustainably and competitively in the long run, is biomass. Not only has biomass a significant role in energetics but is an important factor to rural and agricultural development too.
Hungary's total stock biomass is about 350-360 million tons, which represents nearly two-thirds of the total renewable energy resources of our country. Only about one sixth of the feasible resources have been hitherto harnessed. The majority of this biomass is wood-based[2,3].

This is explained by the fact that wood can easily be handled, it contains low amounts of sulphur and ash, while its calorific value is close to that of brown coal. When burned, it produces only that much CO_2 which the living tree has taken up from the atmosphere, that is wood is an environmentally friendly energy resource in many respects.

Large volumes of timber can be produced on energy forest plantations in a relatively short time. The woody dendromass is suitable for direct burning as well as for gasification, pyrolysis, ethanol and methanol production. Thermal energy, electric power (green electricity) and biofuels can also be derived from dendromass.

Nevertheless, in order to harvest dendromass, first it has to be grown.
Because of the constant increase in demands, hopefully, the establishment of several ten thousand hectares of those energy plantations can be expected in Hungary during the next years. Plantations can be set up in a proper rate only by the use of appropriate and state-of-the-art cultivation technology. Concerning short rotation energy forest plantations many questions have not been answered yet in Hungary, regarding authorization, installation, cultivation, harvesting, utilization of dendromass, etc. The mentioned issues gave me reason, for choosing this important and current field as the subject of my doctoral theses.

2. AIMS OF RESEARCH

Research dealing with energy forests has already commenced several decades ago in Hungary and the results are straightforward. Several aspects were still unclear however, at the starting of the doctoral work. For these reasons the author has set the following objectives to the aims of her doctoral research:

- studying the relevant Hungarian and international scientific literature to provide background for research:
    - energy consumption; Significance and distribution of energy resources in Hungary and throughout the world;
    - regulations, undertakings and tendencies respecting renewable resources;

[1] **KÖZPONTI STATISZTIKAI HIVATAL (KSH)** adatbázisa, 2013. www.ksh.hu
[2] **GŐGÖS Z.** (2005): Biomassza potenciál és hasznosítása Magyarországon. In: Agrárágazat, Mezőgazdasági havilap, augusztus.
[3] **CZUPY I. - VÁGVÖLGYI A. - HORVÁTH B.** (2012): The Biomass Production and its Technical Backgorund in Hungary In: Proceedings of 45th International Simposium on Forestry Mechanization: "Forest Engineering: Concern, Knowledge and Accountability in Today's Environment". Dubrovnik; Cavtat, Horvátország, 10.08-10.12. Zagreb: University of Zagreb. pp. 1-9. ISBN:978-953-292-025-3.

    - situation of renewables in Hungary, domestic biomass potential;
    - energy forest plantations in Hungary and in other countries;
- analysis of the legal background of energy forest plantations;
- possibilites of subsidizing solid biomass utilization
- estimation of the area occupied by energy forests in Hungary (according to size, distribution between counties, types of settlements, species);
- evaluation of the properties of poplar, being the most common plantation species;
- analysis of the situation of short rotation energy poplar plantations in Hungary;
- carrying out field measurements for the estimation of future yields;
- comparing the applicability of yield estimation procedures;
- investigation of the habitat conditions of energy forest plantations;
- choice of the proper cultivation technology;
- evaluation of the stengths, weaknesses, opportunities and threats of plantations;
- throughout analysis of the relationship between plantations and the market;
- energy balance of plantations.

3. HYPOTHESES

After setting the aims of the research the author has outlined the hypotheses of her doctoral work as follows:

H1: Research of energy forest plantations has already been carried out for several decades in Hungary. The volumes of dendromass grown on these plantations are significant in terms of energetic utilization.
H2: The technologies applied on energy forest plantations have not fully matured yet, several problems and shortcomings can still be pointed out. Landowners accept that beside traditional agriculture the relevance of energy forest plantations is established.
H3: Habitat conditions of the plantations (genetic soil type, water management, surface soil thickness, textural soil class) influence dendromass yield significantly.
H4: Because there are only a few power plants in Hungary which produce energy from biomass, there is no stable domestic market for the dendromass that could be grown.

4. MATERIAL AND METHODS

Research comprised of the review of scientific literature (collection and evaluation of data) and of the surveying and evaluation of field data:

- statistical evaluation of the data on energy forest plantations, provided by the Forestry Management of the National Food Chain Safety Office (NFCSO);
- review, analysis and evaluation of the legal background applying to energy forest plantations; Drawing conclusions;
- review of the possibilities of direct and indirect financial support of energy forest plantations using the available plans, action programmes, laws and homepages.
- questions concerning the suitability of technology, problems with special tasks, gathering data on plantations (consultation with landowners), preparing photo documentations by field surveys and by analysing planting and harvesting workflows.
- applying SWOT analysis to energy forest plantations;
- data collection on working and planned energy producing facilities; Analysis of the different input/ouput ballances of the plantations and energy producing units using Quantum GIS and Paragon route planning and scheduling softwares;
- field survey at energy forest plantations (19 locations, 36 parcels)

    - diameter at stump, and at breast height, stem height, mass;
    - characterisation of the habitat (climate, hydrology, genetic soil type, surface soil thickness, textural soil class);
    - laboratory analysis of the soil: $pH_{(H2O)}$, carbonated lime content, soil water-capacity, humus content;
- Evaluation of laboratory results and field data by principal component analysis and factor analysis using STATISTICA 11 software;
- Applying SPSS software to work out an evaluative point system;
- Questionnaire survey among the KITE partners;
- Investigation and analysis of the energy requirements of the machines applied on energy forest plantations on the basis of gasoline consumption with different land sizes (less than 3 hectares, 3-20 hectares, more than 20 hectares). Comparing results to the energy content of the produced dendromass.

5. SUMMARY OF THE RESULTS

5.1. Summary of research results

In the dissertation the present situation of energy forest plantations in Hungary has been analysed using scientific literature and field survey data. The location and area size of the plantations as well as planted wood species and varieties have been mapped.

The legal background of plantations as well as the indirect and direct support options have been also studied.

Problems arising with plantations have been summerized (habitat survey, planting, tending, harvesting, wood chip storage, marketing issues, etc.).

SWOT analysis has been carried out to reveal the strengths, weaknesses, opportunities and threats of energy forest plantations.

Basing on the diameter at stump and at breast height as well as on the mass data of poplar plantations with different ages, yield graphs have been established.

The biomass (wood chip) buring power stations of Hungary have been summarized with their biomass demand, which has been compared to the dendromass potential of the plantations.

The quantifiable site parameters (K_A, H%, pH_{H2O}, $CaCO_3$) of the examined plantations have been analysed using multivariate statistical methods. The results have shown clearly the main soil parameters influencing yield data of different plantations.

Regarding the unquantifiable site parameters (climate, hydrology, genetic soil type, physical properties of soil, soil depth) the author has elaborated a point system for rating the plantations.

The opinion of the plantation owners (reviewed by a questionnaire survey) has been also evaluated.

Finally, the machine work requirement of the energy balance of energy forest plantations have been analysed for different area sizes.

5.2. Theses of the dissertation

1. After reviewing the relevant scientific literature the author has concluded the following facts:
   - Fuel wood is the most commonly used biomass in Europe;
   - Research and experiments concering the cultivation and utilization of short rotation energy forest plantations have been carried out in several countries since the 1960s and 1970s. In Hungary research has commenced in the beginning of the 1980s.
   - Biomass represents the highest proportion of renewables in Hungary. Solid biomass production could become the leading branch for domestic renewable energies in the future;
   - Regarding biomass, the proportion of dendromass is highly significant. Besides natural forests, plantation forestry could also play a role in the future;
   - Nevertheless, the contribution of energy forest plantations to dendromass production is insignificant as of yet (2080 hectares in the year 2012);
   - Respecting the wood species, poplar has the highest proportion (65%) – The potentialities of the Carpathian Basin are highly suitable for the plantation cultivation of poplar.
   - Within poplar, the yield of the AF2 and of the Monsivo clones are the highest. These clones share the largest areas by now, too.

2. By carrying out SWOT analyses the author has established that energy forest plantations have several strenghts and opportunities. The count of threats and weaknesses is not significant, which justifies the role of these plantations in forestry management.

3. By experiments the author has proved that with plantations above 2 years age, the yield estimation carried out by using the diameter at breast height does not differ significantly from the value estimated using the diameter at stump (correlation between data is very good with R^2=0.90). This means that the easier measurable diameter at breast height is suitable for making exact estimations in the future. This method is also more ergonomic.

4. More than 700 measurements (for plantations with 1-7 years of age with AF2, Monsivo, Kopeczky, I214, AF6, Pannonia clones) have proven that with stump diameters between 8-112 mm or 2-90 mm diameters at breast height the mass of trees can be estimated, thus the yield of the plantation can be determined using the following third order polynomial equations:
   - Using the diameter at stump (d_0):
     $m_1 = 0{,}00001096 * d_0^3 + 0{,}00083985 * d_0^2 - 0{,}00286573 * d_0$;
   - Using the diameter at breast height ($d_{1,3}$):
     $m_2 = 0{,}00001724 * d_{1,3}^3 + 0{,}00198902 * d_{1,3}^2 + 0{,}00973998 * d_{1,3}$

5. By the author's comprehensive research the wood chip demand and capacity of the domestic energy producing facilities has been summarized. The value has been collated with the volumes of dendromass produced on domestic energy forest plantations. For setting up distance matrices the Paragon route planning and scheduling software has been used.
The results are as follows:

- the localization of biomass utilizing power plants and energy forest plantations is heterogeneous;
- the produced dendromass can cover only 1.3% of the demands of the planned and actually working biomass utilizing energy producing plants;
- assuming optimum transport distances 20% of the heating and power plants can be supplied completely with the dendromass produced on the plantations;
- according to the calculations of the Paragon software, in the case of 6 out of 103 Hungarian settlements it is possible to deliver dendromass to more than one heating or power plant, which can result a contention in the wood chip market;
- according to the calculations of the Paragon software, in the case of 5 out of 103 Hungarian settlements the delivering distance is 90 km or longer. Thus, the economic efficiency of the plantations with the current technologies is questionable.

6. The author has collected the planned biomass utilizing energy producing units too. The demands of the active and of the planned biomass utilizing energy producing units has been compared to the current dendromass production of energy forest plantations. The results are as follows:
- the produced dendromass can cover only about 0,7% of the demands of the planned and actually working biomass utilizing energy producing plants;
- assuming optimum transport distances 13% of the heating and power plants can be supplied completely with the dendromass produced on the plantations;
- in the case of 21 out of 103 Hungarian settlements it is possible to deliver dendromass to more than one heating or power plant, which can result a contention in the wood chip market;
- in the case of 2 out of 103 Hungarian settlements the delivering distance is 90 km or longer.

7. By analysing the climatic, habitat and hydrologic conditions of the plantations the author has established a point system (0-35 points) for the qualification of poplar plantations. As a result of this evaluation the author has concluded that 3 optimum habitat types can be distinguished which are suitable for setting up poplar plantations:

	Genetic soil type	**Hydrology**	**Surface soil thickness**	**Textural soil class**	**Points**
1.	Raw alluvial soil	Permanent water effect	Very thick	Adobe	33
2.	Humic alluvial soil	Independent of excess water	Very thick	Sand	31
3.	„Kovárvány” brown forest soil	Independent of excess water	Medium thick	Adobe	30

The investigated plantations have been characterized with only 14-22 points, indicating that these forests grow at sites, which can be classified as mediocre.

8. In the course of her invesigations the author has verified that principal component analysis and factor analysis are suitable for analysing the relations between habitat parameters (pH_{H2O}, $CaCO_3$, H%, K_A) and yield-influencing traits (diameters at trunk and at breast height, height, mass).

In the database investigated by the author the following parameters were regarded to influence yield factors advantageously:

- Average temperature;
- Weighted average of pH_{H2O} value for a given site;
- $Ph_{(H2O)}$ values of the uppermost soil layer;
- $CaCO_3$ contents of the uppermost soil layer;
- K_A value of the uppermost soil layer.

9. The author has set up technological models to estimate the energy balance of the applicable mechanized technologies on energy forest plantations considering three area classes. The author has established that assuming average values for the investigated examples in the case of all of the three categories, the energy gained from the produced dendromass is some multiple of the energy consumpition of the machines.

Considering the investigated examples, the energy balances are as follows:

- less than 3 hectares: 1:46;
- 3-20 hecatres 1:26; 1:35 (depending on harvesting technology);
- more than 20 hectares: 1:37.

5.3. Utilization of the results

The substance of knowledge provided by the dissertation, respecting the analysis of the Hungarian and international situation of energy forest plantations as well as the evaluation of the energy balances of such plantations, can be directly utilized for education purposes in the courses held by the Institute of Forest and Environmental Techniques at the University of West Hungary (e.g. Energetics, Ecoenergetics).

SWOT analysis is applicable for the identification of the strategically most important tasks on the plantations. Thus, investors (landowners) will be clear about the chances and the rate of financial returns in the business plan and about the possible difficulties.

The possibility to use diameter at breast height provides an ergonomically better method for the field surveying personnel.

The presented formulas are suitable to make yield estimations for energy forest plantations, without the cutting of the trees.

Using the Paragon software the connection between the dendromass producing plantations and the biomass utilizing units can be estimated and planned (shortest public road, lowest CO_2 output).

Using the established point system energy forest plantations can be qualified and estimations can be made concerning future yields.

By principal component analysis and factor analysis it can be proven that there is a connection between soil features and yield parameters. Thus, soil characteristics influence future yields essentially.

Energy balances have proven that with different rates of mechanization the ratios of in- and output energies are also different. This can be used for planning the mechanization of a plantation, broken down as well to single machine types.

5.4. Outlining new directions for research

Habitat conditions are significant influencing factors considering energy forest plantations, which makes the continuation of further research indispensable in order to unveil deeper relationships. More poplar clones and even other wood species should be involved in the

research, also investigating habitat conditions and their relationships with dendromass yield. By knowing these facts, the anomalies arising from different soil conditions could be compensated, thus yield could be increased.
It would be necessary to investigate the calculated energy balance data in practice, broken down to machine types with different land sizes and with financial calculations.
In the framework of the TÁMOP 4.2.2A-11/1/KONV-2012-0013 „Agrárklíma" project a decission support system has been developed which will help to outline the possibilities for adapting to the effects of future climate change in forestry and in the agricultural sector. The climate database of the decision support system includes the results of 12 regional climate models. The database also includes the latest, freely accessible time series on daily temperature and precipitation data until the year 2100.
By using the results of the project for estimating the habitat conditions of the plantations the effects of climate change could also be established in the results of the investigations. It would be advisable to research the possibility of intercrop cultivation on energy forest plantations (cultivating woody and perennial plants on the same area). E.g., in Italy there has been a tradition of intercrop cultivation for several years. As energy forest cultivation was categorized into the "field gowing of plants" class in Hungary, intercrop cultivation is possible. It would be important to work out a clear and easy to use system for the control, subvention, technology structure and for the utilization of the produced dendromass of domestic energy forest plantations. The results established by the SWOT analysis could be used for this aim too.

6. LIST OF PUBLICATIONS

6.1. Books, chapters in books

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6.2. Conference presentations and journal articles

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