MODERN PHYTOMORPHOLOGY

ISSN 2226-3063
e-ISSN 2227-9555

Volume 18 (2024)

Article Type: Research
J Name: Modern Phytomorphology
Short name: MP
ISSN: ISSN 2226-3063/eISSN 2227-9555
Year: 2024
Volume: 18
Page numbers: 130 - 137
DOI: 10.5281/zenodo.200121
(10.5281/zenodo.Year-Volume-PDFNo.)
Short Title: Economic and energy assessment of willow and poplar cultivation depending on the density of the plantation and the nutritional background

RESEARCH ARTICLE

Economic and energy assessment of willow and poplar cultivation depending on the density of the plantation and the nutritional background

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Received: 08.07.2024, Manuscript No: mp-24-141086 **| Editor Assigned:** 11.07.2024, Pre-QC No. mp-24-141086(PQ) **| Reviewed:** 28.07.2024, QC No. mp-24-141086(Q) **| Revised:** 03.08.2024, Manuscript No. mp-24-141086(R) **| Accepted:** 08.08.2024 **| Published:** 15.08.2024

Abstract

In Ukraine, during the last decade, much attention is being paid to improvement of biofuel and bioenergy usage efficiency, which allows to reduce dependence of the national economy on import of energy sources, bring down its energy capacity and ensure economic development. The results of conducted research show that energy consumption for growing poplar biomass is 9.1-10.0 times lower than amount of energy accumulated in it. The most intensive economic effect when growing energy willow grew in the variants with planting density of 15 thousand pcs/ha and 12 thousand pcs/ha and application of mineral fertilizers, where profit of 22.6 thousand UAH/ha-23.8 thousand UAH/ha was achieved. The most energy-efficient variant among those used in the research was the one with planting density of 12 thousand pcs/ha and application of mineral fertilizers, at which energy efficiency coefficient reaches 7.9. The most intensive economic effect when growing energy poplar grew in the variants with planting density of 6.7 thousand pcs/ha and 5.6 thousand pcs/ha and application of mineral fertilizers, where profit of 33.9 thousand UAH/ha-30.9 thousand UAH/ha was achieved.

Keywords: Willow, Poplar, Biofuel, Planting density, Nutrition background, Economic efficiency, Energy assessment

Introduction

With the beginning of new century, mankind has been actively seeking for replacement of traditional energy sources with renewable ones. This necessity is largely caused by depletion of world hydrocarbon reserves, braking of natural ecosystem balance, global environmental problems, in particular increase of hotbed gas concentrations in atmosphere leading to frequent natural disasters and drastic weather changes on the earth surface. Therefore, development of such a new branch of science as bioenergy is becoming increasingly important. It can become an important element in reducing deficit of fossil hydrocarbons and the basis for sustainable provision of the state with bioresources and energy security. World civilization development is closely connected with energy resources which significantly affect independent policy of countries. Taking into account current energy crisis caused by the shortage of fossil fuels, problems of renewable energy source usage and sustainable economic development are becoming increasingly important. Improving existing principles of using natural resource potential, substantiating ways to effective usage of its reserves contribute to solving energy problems.

One of the main factors of balanced ecological and economic development of Ukraine is efficient usage of natural resources, in particular, renewable energy sources in the balance of agro-industrial and forest complex of the country. It is known that European countries have reached 10% provision of their energy needs by renewable energetics (Churilov, 2012; Klymchuk et al., 2022). In Ukraine, this figure is only 4%, but energy strategy of Ukraine for the period up to 2030 obliges to increase the share of renewable energy sources to 10% (McCracken and Dawson, 2019; Christoffers et al., 2020; Karbivska et al., 2020). Our state is forced to import about 65% of energy sources. Predominant majority of import is natural gas (79%) and oil products (66%), the price of which is constantly rising (Boiko, 2017). Increase of energy consumption with rising energy prices and increasing harmful emissions into atmosphere makes development of bioenergy extremely important. Actual direction of bioenergy development in Ukraine is creation of long-term plantations of bioenergy crops, in particular energy willow and poplar. Nowadays, the impact of basic environmental conditions and cultivation technologies on crop yields and quality of agricultural crops has been disclosed in many scientific publications and literary sources. However, currently the issue of the impact of cultivation technology and soil-climatic factors on productivity of energy willow and poplar under conditions of Pre-Carpathian region is poorly studied and insufficiently highlighted in scientific publications, which determines topicality of this issue. The potential of Ukraine concerning production of renewable energy sources is quite large. First of all, it is connected with the fact that Ukraine has a scarce world resource land. We have large amount of arable areas, which are not used in agricultural production due to different causes and which would be quite suitable for growing bioenergy crops. Thus, there are all prerequisites for creation of national bioenergy complex (Roik et al., 2015). Moreover, global growth in demand for energy crops contributes to rising prices for bioenergy raw materials, which, in its turn, generates growth in supply. Therefore, agriculture of Ukraine has every chance to become an industry which can provide not only food but also, to some extent, energy security of the country (Roik, 2011a; Makarchenko, 2012; Fuchylo, 2018). However, the share of renewable energy sources in the energy balance of Ukraine remains insignificant 2.7%, and 1.9% of which belongs to hydropower and only 0.8% to biofuels, energy of wind and solar. Thus, biofuels received from cultivation of energy crops can become a large reserve for increasing percentage of biofuel usage in energy balance of Ukraine (Lys et al., 2018). Dependence of Ukraine's economy on imports of energy sources stipulates the necessity for the search of alternative sources for their obtaining. The solution of this problem in the nearest future is extremely important due to the fact that in 7 years-10 years all explored world oil reserves will be depleted by 60%-65%, natural gas reserves will be sufficient only for 50 years-60 years, oil–for 25 years-30 years, coal for 500 years-600 years. Constantly rising tariffs for gas and public utilities additionally stimulate the search, implementation and usage of alternative, non-traditional energy sources (Dospekhov, 1985; Roik et al., 2015). Increase of energy consumption with rising energy prices and increasing harmful emissions into atmosphere, makes development of bioenergy extremely important. The usage of biomass as a source for biofuel production is receiving much attention in Germany, Poland, Sweden, and Denmark (Yu et al., 2020; Tonkha et al., 2021). Among the promising crops for green energetics are outlined such major energy crops as energy willow (*Salix*), poplar (*Populus*) miscanthus, switchgrass (*Panicum virgatum*), Sida perennial (Fuchylo, 2016). These crops are undemanding to soil and climatic conditions, in consequence of many years continuous cultivation improve soil structure, and fallen leaves and root residues remaining in the soil can slightly improve its fertility. Poplar is quite popular among woody plants in Ukraine and is considered to be one of the fastest growing. It became widespread during the creation of forest windbreaks, it was also planted as a "green filter" for cleaning polluted air in cities (Khivrych, 2016; Churilov, 2012). The usage of poplar is extremely diverse but today it is actively considered as a crop which can be used for production of solid fuels with further heat and electricity obtaining (calorific capacity of poplar about 18.5 GJ/t of dry weight). It is more desirable for biofuel production than many other woody crops because of its rapid growth up to 5 m/year, and sometimes more (depending on the clone and soil-climatic conditions of its cultivation), ability to produce a significant amount of bio-mass over a short period of time, high cellulose and low lignin content. On good soils poplar clones can produce up to 18 t/ha-20 t/ha of dry matter per year. One more positive point in growing poplar is that it can grow in many regions, has increased adaptability to soils, easy vegetative propagation and a fairly high resistance to pests. Energy poplars are harvested mainly in winter, which makes it possible to use released technical means being used in summer-autumn period. Currently, there appeared many companies in Ukraine which grow energy willow, but unfortunately, only a few of them have the experience of industrial cultivation of poplar as energy crop for biofuel production. Energy willow is the main energy crop for solid fuel production in the world. This is a plant with a very high mass increase (14 times higher than a forest growing naturally). The average annual yield increase per hectare is 15 tons-30 tons of wood. Harvesting is carried out every 2 years-3 years (Savina, 2011; Roik, 2013). Energy willow is a species of willow (*Salix*) which grows quickly and is suitable for usage as biomass. It is used by direct combustion of shredded biomass or for production of fuel pellets and it allows to reduce the loss of traditional energy sources. Among all energy plants in the world, today willow is used as the main energy crop for production of solid fuels (Ruzhylo, 2011; Karpenko et al., 2020). The largest willow plantations today are in Sweden, which cover 18 thousand hectares-20 thousand hectares, there are more than 6000 hectares in neighboring Poland. In Ukraine, despite the large number of unused non-agricultural land, industrial plantations of energy crops are still insufficient. The average mass increase of energy willow is -1.5 meters per year. Harvesting takes place every 2 years-3 years, the period of harvesting is November-February, when the leaves fall. The number of harvest cycles from one planting 7-8 times, after which land re-cultivation can be done for planting other crops or laying a new willow plantation. Nowadays willow is effectively used in anti-erosion measures for strengthening soils; it enriches soils with minerals and microelements, nutrients of natural origin; energy willow plantations are natural filters for removing wastes of agro-industrial production and they are used as buffer zones in places of farm biological waste accumulation; energy willow is a natural filter for cleaning soils from pesticides (Gnap, 2019). Willows can withstand periodic water cover but they are not water crops. Thus, willow survives in meadows and areas with periodic flooding where cultivation of ordinary crops is risky for some reasons. Another advantage of growing this crop is, comparing with traditional crops, energy willow plantations require 3 times-5 times less nutrients and replenish organic matter in the soil thanks to leaf fall. Their roots cover much deeper soil horizons than, for example, cereals, receiving additional nutrients and moisture. Created energy plantations significantly improve aesthetic, ecological condition of agricultural and urban landscapes, increase flora and fauna diversity (Roik, 2011b; Roik, 2012; Kravchuk, 2013). Willow plantations are widely used for consolidation of river banks and ravines, and due to their high transpiration capacity (intensive evaporation of moisture from the surface of leaf blade) are used for soil drainage (Ruzhylo, 2011). In addition, there is another not less important reason which motivates scientists to look for new, alternative energy sources it is ecology. Most "energy" plants form powerful vegetative mass which intensively photosynthesizes reducing the excess of carbon dioxide in atmosphere and the results of "greenhouse effect" of anthropogenic origin, and the root system, with long-term cultivation in one place, enriches organic matter content in the soil and so improves its fertility.

Materials and Methods

Field research was laid in the fields of Pre-Carpathian State Agricultural Research Station of Institute of Agriculture in the Carpathian region on April 14, 2016 according to the method (Dospekhov, 1985) Experiment 1. To study peculiarities of growth, development of energy willow depending on cultivation techniques under conditions of Western region for the production of biofuels for many years of cultivation (Tab 1). The scheme of the experiment involves influence of a number of factors on the growth, development and productivity of the crop: Factor A- layout scheme for planting sites: Planting density: 18 thousand pieces/hectare, 15 thousand pieces/hectare, 12 thousand pieces/hectare. Factor B- mineral nutrition; The experiment is based on four repetitions. The area of the sown plot is 150 m^2, the accounting area is 125 m^2. The total area of the plots in the experiment is 0.36 ha. According to the planting scheme, the crops are planted in paired rows with a distance of 0.70 m; and interrow spacing of 2 m.

Table 1. Experiment scheme 1

Crop	Planting density Factor A		Mineral nutrition Factor B
Japanese Energy willow	1	18 thousand pcs/ha	Without fertilizers
	2	(planting step 40 cm)	$N_{40}P_{300}K_{300} + N_{40}$
	3	15 thousand pcs/ha	Without fertilizers
	4	(planting step 50 cm)	$N_{40}P_{300}K_{300} + N_{40}$
	5	12 thousand pcs/ha	Without fertilizers
	6	(planting step 60 cm)	$N_{40}P_{300}K_{300} + N_{40}$

Experiment 2. To study peculiarities of growth, development of energy poplar depending on cultivation techniques under conditions of Western region for the production of biofuels for many years of cultivation (Tab 2). The scheme of the experiment involves influence of a number of factors on the growth, development and productivity of the crop: Factor A layout scheme for planting sites: Planting density: 8.3 thousand pcs/ha; 6.7 thousand pcs/ha; 5.6 thousand pcs/ha. Factor B mineral nutrition; The experiment is based on four repetitions. The area of the sown plot is 150 m^2, the accounting area is 125 m^2. The total area of the plots in the experiment is 0.36 ha. According to the planting scheme, the crops are planted in 1 row with interrow spacing of 2 m.

Table 2. Experiment scheme 2

Crop	Planting density *Factor A*		Mineral nutrition *Factor B*
Energy poplar Max-4	1	8.3 thousand pcs/ha	Without fertilizers
	2	(planting step 40 cm)	$N_{40}P_{300}K_{300} + N_{40}$
	3	6.7 thousand pcs/ha	Without fertilizers
	4	(planting step 50 cm)	$N_{40}P_{300}K_{300} + N_{40}$
	5	5.6 thousand pcs/ha	Without fertilizers
	6	(planting step 60 cm)	$N_{40}P_{300}K_{300} + N_{40}$

Results and Discussion

According to the results of research, it has been proved that the highest outcome of energy willow biofuel in the fifth year of vegetation was obtained in the variant with planting density of 15 thousand pcs/ha and application of mineral fertilizers, which amounted to 70.840 kg/ha (Tab 3). The outcome of energy was 1133440 MJ/ha in the variant with planting density of 15 thousand pcs/ha and application of mineral fertilizers, 938080 MJ/ha, in the variant with planting density of 18 thousand pcs/ha and 1064800 MJ/ha in the variant with planting density of 12 thousand pcs/ha. Application of mineral fertilizers provides an increase in the outcome of solid biofuels within limits from 13750 kg/ha to 21780 kg/ha in all variants of the experiment.

Table 3. Outcome of energy and solid biofuel from obtained biomass of energy willow in the fifth year of vegetation depending on planting density and nutrition background

№	Planting density	Mineral nutrition	Harvest of dry mass, t/ha	Outcome of solid bio-fuel, kg/ha	Energy outcome, MJ/ha
1	18 thousand pcs/ha	Without fertilizers	40.8	44880	718080
2	(planting step 40 cm)	$N_{40}P_{300}K_{300} + N_{40}$	53.3	58630	938080

3	15 thousand pcs/ha	Without fertilizers	44.9	49390	790240
4	(planting step 50 cm)	$N_{40}P_{300}K_{300} + N_{40}$	64.4	70840	1133440
5	12 thousand pcs/ha	Without fertilizers	40.7	44770	716320
6	(planting step 60 cm)	$N_{40}P_{300}K_{300} + N_{40}$	60.5	66550	1064800

The highest biofuel outcome from energy poplar in the fifth year of vegetation was obtained with planting density of 6.7 thousand pcs/ha and application of mineral fertilizers and amounted to 93.170 kg/ha (Tab 4). Energy outcome was 1335840 MJ/ha in the variant with planting density of 8.3 thousand pcs/ha and application of mineral fertilizers, 1490720 MJ/ha in the variant with planting density of 6.7 thousand pcs/ha and 1383360 MJ/ha in the variant with planting density of 5.6 thousand pcs/ha. Application of mineral fertilizers provides an increase in energy outcome within limits from 220040 MJ/ha to 311520 MJ/ha for all variants of the experiment.

Table 4. Outcome of energy and solid biofuels from obtained biomass of energy poplar in the fifth year of vegetation depending on planting density and nutrition background

№	Planting density	Mineral nutrition	Harvest of dry mass, t/ha	Outcome of solid bio-fuel, kg/ha	Energy outcome, MJ/ha
1	8.3 thousand pcs/ha	Without fertilizers	63.4	69740	1115840
2	(planting step 40 cm)	$N_{40}P_{300}K_{300} + N_{40}$	75.9	83490	1335840
3	6.7 thousand pcs/ha	Without fertilizers	67	73700	1179200
4	(planting step 50 cm)	$N_{40}P_{300}K_{300} + N_{40}$	84.7	93170	1490720
5	5.6 thousand pcs/ha	Without fertilizers	65.2	71720	1147520
6	(planting step 60 cm)	$N_{40}P_{300}K_{300} + N_{40}$	78.6	86460	1383360

Thus, application of mineral fertilizers provides an increase in the outcome of solid biofuels and energy from energy willow and poplar in all variants of the experiment. Economic efficiency of growing energy crops was calculated proceeding from cultivation costs and biomass selling price (according to selling price of LLC Salix Energy) (Roik et al., 2015). Economic assessment of energy willow cultivation depending on planting density and nutrition background showed that economic effect grew the most intensively with planting density of 15 thousand pcs/ha and 12 thousand pcs/ha and application of mineral fertilizers, where profit of 22.6 thousand UAH/ha-23.8 thousand UAH/ha was achieved. (Tab 5). To assess efficiency of growing different crops more objectively, is used the index of energetic efficiency of its cultivation technologies energy coefficient, which is determined by the ratio of accumulated energy in their yield with the energy spent on its production. The total energy consumption for growing bioenergy crops are determined for each agronomic measure. Energy accumulated in fuels and lubricants, fertilizers, seeds, pesticides, machines and mechanisms, vehicles is also determined.

Table 5. Economic efficiency of growing energy willow depending on planting density and nutrition background

№	Planting density	Mineral nutrition	Outcome of dry biomass, t/ha	Costs of growing thousand UAH/ha	Income from realization thousand UAH/ha	Conditional pure income, thousand UAH/ha
1	18 thousand pcs/ha	Without fertilizers	40.8	35.1	40.8	5.7
2	(planting step 40 cm)	$N_{40}P_{300}K_{300} + N_{40}$	53.3	43.5	53.3	9.8
3	15 thousand pcs/ha	Without fertilizers	44.9	32.3	44.9	12.1
4	(planting step 50 cm)	$N_{40}P_{300}K_{300} + N_{40}$	64.4	40.8	64.4	23.6
5	12 thousand pcs/ha	Without fertilizers	40.7	28.6	40.7	12.1
6	(planting step 60 cm)	$N_{40}P_{300}K_{300} + N_{40}$	60.5	37.7	60.5	22.8

The results of research show that cultivation of energy willow is highly efficient (Tab 6). Energy consumption for growing willow biomass is 5.5 times-7.4 times lower than amount of energy accumulated in it. The most energy-efficient variant among those used in the research is the one with planting density of 12 thousand pcs/ha and application of mineral fertilizers, in which energy efficiency coefficient reaches 7.9. The obtained results confirm conclusions of other researchers who studied energy efficiency of crops and who found that energy efficiency coefficient of energy willow is quite high (Roik, 2013).

Table 6. Energy assessment of growing energy willow depending on planting density and nutrition background

№	Planting density	Mineral nutrition	Outcome of dry biomass, t/ha	Total energy consumption GJ/ha	Energy outcome GJ/ha	Coefficient of energetic efficiency
1	18 thousand pcs/ha	Without fertilizers	40.8	128	718.1	5.6
2	(planting step 40 cm)	$N_{40}P_{300}K_{300} + N_{40}$	53.3	163.8	938.1	5.7
3	15 thousand pcs/ha	Without fertilizers	44.9	119.2	790.2	6.6
4	(planting step 50 cm)	$N_{40}P_{300}K_{300} + N_{40}$	64.4	153.2	1133.4	7.4
5	12 thousand pcs/ha	Without fertilizers	40.7	104.4	716.3	6.8
6	(planting step 60 cm)	$N_{40}P_{300}K_{300} + N_{40}$	60.5	135.3	1064.8	7.9

Economic assessment of energy poplar cultivation depending on planting density and nutrition background showed that economic effect grew the most intensively with planting density of 6.7 thousand pcs/ha and 5.6 thousand pcs/ha and application of mineral fertilizers, where profit of 33.9 thousand UAH/ha-30.9 thousand UAH/ha was achieved (Tab 7).

Table 7. Economic efficiency of energy poplar cultivation depending on planting density and nutrition background

№	Planting density	Mineral nutrition	Outcome of dry biomass, t/ha	Costs of growing thousand (UAH/ha)	Income from realization thousand (UAH/ha)	Conditional pure income, thousand (UAH/ha)
1	8.3 thousand pcs/ha	Without fertilizers	63.4	45.1	63.4	18.3
2	(planting step 40 cm)	$N_{40}P_{300}K_{300} + N_{40}$	75.9	53.5	75.9	22.4
3	6.7 thousand pcs/ha	Without fertilizers	67	42.3	67	24.7
4	(planting step 50 cm)	$N_{40}P_{300}K_{300} + N_{40}$	84.7	50.8	84.7	33.9
5	5.6 thousand pcs/ha	Without fertilizers	65.2	38.6	65.2	26.6
6	(planting step 60 cm)	$N_{40}P_{300}K_{300} + N_{40}$	78.6	47.7	78.6	30.9

The results of research show that energy consumption for growing biomass from energy poplar is 7.2 times-9.2 times lower than amount of energy accumulated in it. The most energy-efficient variant among those used in research is the one with planting density of 5.6 thousand pcs/ha and application of mineral fertilizers, in which energy efficiency coefficient reaches 9.2 (Tab 8).

Table 8. Energy assessment of growing energy poplar depending on planting density and nutrition background

№	Planting density	Mineral nutrition	Outcome of dry biomass, t/ha	Total energy consumption GJ/ha	Energy outcome GJ/ha	Coefficient of energetic efficiency
1	8.3 thousand pcs/ha	Without fertilizers	63.4	138	1115.8	8.1
2	(planting step 40 cm)	$N_{40}P_{300}K_{300} + N_{40}$	75.9	173.8	1335.8	7.7

3	6.7 thousand pcs/ha (planting step 50 cm)	Without fertilizers	67	129.2	1179.2	9.1
4		$N_{40}P_{300}K_{300}$ + N_{40}	84.7	163.2	1490.7	9.1
5	5.6 thousand pcs/ha (planting step 60 cm)	Without fertilizers	65.2	114.4	1147.5	10
6		$N_{40}P_{300}K_{300}$ + N_{40}	78.6	145.3	1383.4	9.5

Conclusions

The highest outcome of biofuel from energy willow was obtained in the variant with planting density of 15 thousand pcs/ha and application of mineral fertilizers, it amounted to 70.840 kg/ha. The energy outcome was 1133440 MJ/ha, in the variant with planting density of 15 thousand pcs/ha and application of mineral fertilizers, 938080 MJ/ha in the variant with planting density of 18 thousand pcs/ha and 1064800 MJ/ha in the variant with planting density of 12 thousand pcs/ha. Application of mineral fertilizers provides an increase in the outcome of solid biofuels within limits from 13750 kg/ha to 21780 kg/ha in all variants of the experiment. The highest outcome of biofuel from energy poplar was obtained in the variant with planting density of 6.7 thousand pcs/ha and application of mineral fertilizers and it amounted to 93.170 kg/ha. The energy outcome was 1335840 MJ/ha in the variant with planting density of 8.3 thousand pcs/ha and application of mineral fertilizers, 1490720 MJ/ha in the variant with planting density of 6.7 thousand pcs/ha and 1383360 MJ/ha in the variant with planting density of 5.6 thousand pcs/ha. Application of mineral fertilizers provides an increase in energy outcome within limits from 220040 MJ/ha to 311520 MJ/ha in all variants of the experiment. Economic effect for cultivation of energy willow grew the most intensively in the variant with planting density of 15 thousand pcs/ha and 12 thousand pcs/ha and application of mineral fertilizers, where the profit of 22.6 thousand UAH/ha -23.8 thousand UAH/ha was obtained. The most energy-efficient variant among those used in the research was the one with planting density of 12 thousand pcs/ha and application of mineral fertilizers in which energy efficiency coefficient reaches 7.9. Economic effect for cultivation of energy poplar grew the most intensively in the variant with planting density of 6.7 thousand pcs/ha and 5.6 thousand pcs/ha and application of mineral fertilizers, where the profit of 33.9 thousand UAH/ha-30.9 thousand UAH/ha was obtained. The results of conducted research show that energy consumption for growing biomass from energy poplar is 9.1 times-10.0 times lower than amount of energy accumulated in it.

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