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*ORIGINAL ARTICLE*

# Effect of growing technology on the energy crops yield in Precarpathian conditions

**N.L. Tkachuk[1], A.O. Butenko[2*], V.I. Onychko[2], T.O. Onychko[2], I.M. Masyk[2], D.V. Litvinov[3], G.A. Davydenko[2], O.M. Kobzhev[2], O.V. Antonovskyi[4], V.P. Poriadynskyi[4]**

*[1]Precarpathian State Agricultural Experimental Station of Institute of Agriculture of Carpathian Region of National Academy of Agrarian Sciences of Ukraine, 21 a S. Bandery Str., Ivano-Frankivsk, 76014, Ukraine*
*[2]Sumy National Agrarian University, 160 Herasym Kondratiev Str., Sumy, 40021, Ukraine*
*[3]National University of Life and Environmental Sciences of Ukraine, 12 Heroiv Oborony Str., Kyiv, 03041, Ukraine*
*[4]Poltava State Agrarian Academy, 1/3 Skovorody Str., Poltava, 36003, Ukraine*
** Corresponding author email: andb201727@ukr.net*
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The study showed that the highest yield of energy willow biomass was obtained with a variant with a planting density of 15 thousand units/ha and mineral fertilizers, namely 113.7 t/ha of green mass and 64.4 t/ha of dry mass. In the fifth growing year of energy willow, an annual increase was achieved in the yield of freshly cut wood from 21.2 t/ha per planting step of 40 cm and without fertilizer application to 24.7 t/ha per planting step 50 cm with full fertilizer application.
The highest yield of poplar energy biomass was obtained in the variant of planting density of 6.7 thousand units/ha, namely 149.7 t/ha of green mass and 84.7 t/ha of dry mass. Application of mineral fertilizers increases the yield to 21.9-31.6 t/ha of green mass and 12.5-17.7 t/ha of dry mass in all variants of the experiment. Having analyzed the yield increase by years of vegetation, it should be noted that for the fifth growing year of energy willow, the lowest annual increase in yield of freshly cut wood was achieved from 5.3 t/ha per planting step of 40 cm and without fertilizer up to 14.0 t/ha per step planting 60 cm with full fertilizer application. The largest increase was obtained in the third growing year from 31.5 t/ha to 62.1 t/ha. Having analyzed the yield increase of poplar by vegetation years, it should be noted that for the fifth growing year, an annual increase in yield of freshly cut wood was achieved from 21.2 t/ha per planting step 40 cm and without fertilizer to 24.7 t/ha per planting step 50 cm with the introduction of the full rate of fertilizer. The same trend is observed in previous growing years.
**Keywords:** biomass; bioenergy crops; productivity; fertilizers; dry mass

## Introduction

The development of world civilization is closely connected with energy resources, affecting the country's independent policy. Given the current energy crisis caused by the lack of fossil fuels, using renewable energy sources (RES) and sustainable economic development remains relevant. Improving the existing principles of using natural resource potential and substantiating effective use methods facilitate the solution to energy problems. In the last decade in Ukraine, much attention is paid to improving biofuels and bioenergy efficiency. It reduces the national economy dependence on energy imports and its energy intensity and ensures economic development. A promising renewable fuel source is the biomass of grass and wood crops. Among wood energy crops, the most extensive plantations of poplars and willows are grown (Tkachuk, 2019; Savina, 2011).

Nowadays, the influence of primary environmental conditions and cultivation technologies on crop yields and quality have been disclosed in many scientific publications and literary sources. However, the influence of cultivation technology and soil and climatic factors on the productivity of energy willow and poplar plants in the Precarpathian region is understudied and insufficiently highlighted in scientific publications that determine its relevance issue (Khivrych, 2016; Shevchuk, 2013). One of the main factors of the balanced ecological and economic development of Ukraine is the efficient use of natural resources, in particular renewable energy sources, in the balance of the agro-industrial and forestry complex of the country. It is known that European countries have reached 10% of their energy needs through renewable energy (Churilov, 2012). In Ukraine, this index is only 4%, but Ukraine's energy strategy for the period up to 2030 obliges to increase the share of renewable energy sources to 10% (Shcherbyna, 2011; McCracken & Dawson, 2019). Our state is forced to import about 65% of energy. The vast majority of imports are natural gas (79%) and petroleum products (66%), the price of which is continually rising (Boiko, 2017). At the same time, Ukraine's potential in terms of renewable energy production is quite immense. First of all, Ukraine owns a scarce resource in the world – the land. We have many arable lands that, for one reason or another, are not used in agricultural production and would be quite suitable for growing bioenergy crops. Thus there are all the prerequisites for creating a national bioenergy complex (Roik, 2015). Moreover, the global growth of energy crops contributes to rising prices for bioenergy raw materials, which generate supply growth. Therefore, agriculture in Ukraine has every chance to become an industry that can provide food and energy security of the country (Makarchenko, 2012; Fuchylo, 2018; Roik, 2011).

However, in Ukraine's energy balance, the share of renewable energy sources remains insignificant - 2.7%; 1.9% is accounted for hydropower and only 0.8% for biofuels, wind, and solar energy. Thus, a large reserve of increasing the percentage of biofuel use in the energy balance of Ukraine can be biofuels got from the cultivation of energy crops (Lys et al., 2018). Ukraine's economic dependence on energy imports requires the search of alternative sources to obtain them. The solution to this problem shortly is essential as in 7-10 years the world's proven oil reserves will be depleted by 60-65%, natural gas reserves will be enough only for 50-60 years, oil - for 25-30, coal - for 500-600 years. Constantly rising tariffs for gas and utilities further stimulate the search, implantation, and use of alternative non-traditional energy sources (Dospekhov, 1985; Roik, 2015). Increasing energy consumption with rising energy prices and increasing harmful emissions into the atmosphere makes bioenergy extremely important. The use of biomass as a biofuel production source pays much attention in Germany, Poland, Sweden, and Denmark (McCracken & Dawson, 2019).

Among the perspective crops for green energy are such significant crops as energy willow, poplar, miscanthus, candle glass, perennial sedge. These crops are undemanding to soil and climatic conditions. Due to many years of cultivation, these crops improve soil structure, and fallen leaves and root residues can slightly improve fertility (Fuchylo et al., 2019; Fuchylo, 2016).

Poplar is quite popular among woody plants in Ukraine and is considered one of the fastest-growing plants. It became widespread during the creation of windbreaks forest area, and it was also planted as a "green filter" to clean polluted air in cities (Churilov, 2012). The use of poplar is exceptionally varied, but today it is considered a crop that can be used to produce solid fuels with subsequent production of heat and electricity (calorific value of poplar is about 18.5 GJ / t dry weight). It is more desirable for biofuel production than many other wood crops, given the rapid growth - up to 5 m / year and sometimes more (depending on the clone and soil and climatic conditions of its cultivation). It can produce significant amounts of biomass in a short period, high cellulose and low lignin. Poplar clones can produce up to 18-20 t/ha of dry matter per year on good soils. The positive point in growing poplar is that it can grow in many regions. Poplar has increased adaptability to soils, easy vegetative propagation, and relatively high resistance to pests. Energy poplars are harvested mainly in the winter. This makes it possible to use the released technical means that were taken in the summer-autumn period. Currently, many companies in Ukraine grow energy willow, but industrial poplar cultivation as an energy crop for biofuel production, unfortunately, has only a few companies (Fuchylo et al., 2012; Sinchenko, 2017; Sinchenko & Hnap, 2018; Karbivska et al., 2020).

Energy willow is the primary energy crop for solid fuel production in the world. This is a plant with a very high weight gain (14 times larger than a forest that grows naturally). The average annual increase in yield per hectare is 15-30 tons of wood. Harvesting is carried out every 2-3 years (Roik, 2013). Energy willow is willow (Salix) species that overgrows and is suitable for use as biomass. It is used by direct combustion of shredded biomass or fuel pellet production, reducing the loss of traditional energy sources. Among all energy plants globally, willow is used today as the main energy crop for solid fuel production (Ruzhylo, 2011; Fuchylo, 2013; Fuchylo & Sbytna, 2009). Today the most extensive willow plantations are in Sweden, which is about 18-20 thousand hectares, and in neighboring Poland, there are more than 6000 hectares.

Despite many unused non-agricultural lands, there are not enough industrial plantations of energy crops in Ukraine. The average weight gain of energy willow is 1.5 meters per year. Harvesting takes place every 2-3 years, and the harvest period is November-February, when the leaves fall. The number of harvest cycles from one planting is 7-8, after which it is possible to remediate lands for planting other crops or lay a new willow plantation. Today, the willow is effectively used in anti-erosion measures to strengthen soils; it enriches soils with minerals and microelements and natural origin nutrients. The energy willow plantations are natural filters for waste removal of agro-industrial production they are used as buffer zones in places of accumulation of farm's biological waste; energy willow is a natural filter for cleaning soils from pesticides (Hnap, 2019; Sinchenko & Pyrkin, 2016; Tonkha et al., 2021). Willows can withstand the periodic flooding, but it is not a water crop. Thus willow survives in meadows and areas with periodic flooding where the cultivation of conventional crops is risky (Shershun, 2012; Karpenko et al., 2020). Another advantage of growing this crop is that compared with traditional crops, energy willow plantations require 3-5 times less nutrients and resupply organic matter in the soil due to leaf fall. They cover much deeper soil horizons than, for example, cereals receiving additional nutrients and moisture from them. The created energy plantations significantly improve the aesthetic, ecological condition of agricultural and urban landscapes and increase flora and fauna (Kravchuk, 2013; Roik, 2011, 2012). Willow plantations are widely used to consolidate the banks of rivers and ravines, and due to their high transpiration capacity (intensive evaporation of moisture from the surface of the leaf blade), they are used to drain soils (Ruzhylo, 2011b; Christoffers et al., 2002).

Besides, ecology is another critical reason motivating scientists to look for new alternative energy sources. Most "energy" plants form a powerful vegetative mass that intensively photosynthesizes, reducing the excess carbon dioxide in the atmosphere and the effects of the "greenhouse effect" of anthropogenic origin and the root system with long-term cultivation one place enriches the organic matter content in the soil and its fertility.

## Materials and methods

The research was conducted on the experimental fields of the Carpathian State Agricultural Research Station of the Institute of Agriculture of the Carpathian region of NAAS and in laboratory conditions. The soil of the experimental field is turf and ash. The thickness of the humus horizon is 40 cm. The granulometric composition of the soil is coarse-dusty-medium loam. The structure of the arable layer is sprayed (lumpy-dusty). Therefore, after rains, these soils can be floated, and they form a crust. Agrochemical characteristics are as follows: pH-salt (potentiometric) is 4.6, the amount of absorbed bases (Ca + Mg) is 11.4 mg-eq / 100 g (according to Kappen), humus content (according to Tyurin) is 2.54%, alkaline hydrolyzed nitrogen (according to Cornfield) is 79.0, mobile phosphorus (according to Kirsanov) is 48.0, mobile potassium (according to Kirsanov) is 82.0 mg/kg of soil; mobile forms of microelements: boron (according to Berger and Truog) is 1.00, molybdenum (according to Grieg) is 0.20, manganese (according to Peive and Rinkis) is 48.0 mg/kg of soil. Soils are poorly supplied with floating phosphorus and potassium.

**Weather conditions in the research area.**

Climatic conditions of the region are very diverse. This is due not only to the complexity of the territory (mountains, hills, plains, river valleys) and extensive forests. Due to these conditions, the supply of heat and moisture is not the same in different regions. The annual amount of precipitation in the Precarpathians ranges is from 600 to 750 mm. The highest amount of precipitation per year falls on mountain tops is (1000-1600 mm). The total annual rainfall to 70-80% falls in the warm season. Durable snow cover is formed only in the high mountains. The average height of snow cover varies between 20-47 cm; the minimum is 5-10 cm. Weather conditions for the reporting period differed from the average long-term both in the amount of precipitation and air temperature (Table 1).

**Table 1.** Agrometeorological indicators 2016-2020 (according to the Ivano-Frankivsk Meteorological Station).

| **Indicators** | **Months** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **September** | **October** | **November** | **December** | **January** | **February** | **March** | **April** | **May** | **June** | **July** | **August** | **For the vegetation period** |
| Precipitation, mm (average long-term period) | 55 | 44 | 34 | 38 | 25 | 28 | 32 | 47 | 67 | 90 | 84 | 75 | |
| 2015/2016 | 50.8 | 35.4 | 62.3 | 7.7 | 29.0 | 24.0 | 36.8 | 73.5 | 97.0 | 125.0 | 60.3 | 37.7 | 639.5 |
| 2016/2017 | 34.4 | 126.2 | 55.8 | 30 | 8.1 | 24.4 | 48.8 | 31.2 | 84.0 | 75.6 | 82.5 | 50.9 | 651.9 |
| 2017/2018 | 171.9 | 46.74 | 44.0 | 47.6 | 38.6 | 47.3 | 52.0 | 19.6 | 44.7 | 138.6 | 93.1 | 29.1 | 773.3 |
| 2018/2019 | 42.1 | 22.2 | 39.0 | 70.6 | 35.9 | 14.1 | 21.2 | 25.9 | 231.4 | 53.7 | 89.5 | 15.4 | 661.0 |
| 2019/2020 | 46.9 | 32.9 | 19.6 | 32.8 | 12.6 | 58.4 | 48.6 | 12.3 | 120.7 | 235.9 | 122.9 | 22.2 | 765.8 |
| Average | 69.22 | 52.7 | 44.14 | 37.7 | 24.8 | 33.6 | 41.5 | 32.5 | 115.56 | 125.76 | 89.6 | 31.22 | 698.3 |
| Air temperature, °C (average long-term period) | +13.2 | +8.1 | +2.2 | -2.4 | -2.8 | -1.5 | +2.1 | +8.4 | +13.8 | +17.0 | +19.1 | +18.2 | |
| 2015/2016 | +15.9 | 7.7 | 5.01 | +2.6 | -3.56 | +3.71 | 4.8 | 10.82 | 13.87 | 15.78 | 19.99 | 18.5 | |
| 2016/2017 | +15.7 | +6.7 | -0.2 | -0.2 | -5.8 | -0.4 | +6.6 | +8.8 | +13.6 | +18.5 | +19.2 | 20.1 | |
| 2017/2018 | 13.9 | 8.8 | 4.0 | 4.01 | -0.9 | -3.67 | -0.75 | 13.83 | 16.5 | 18.45 | 19.7 | 20.2 | |
| 2018/2019 | 15.1 | 9.6 | 2.4 | -1.0 | -3.3 | 1.5 | 5.6 | 10.1 | 13.7 | 20.3 | 19.0 | 20.0 | |
| 2019/2020 | 14.8 | 9.82 | 5.91 | 1.8 | 0.12 | 2.53 | 4.5 | 8.81 | 11.72 | 18.64 | 19.08 | 19.85 | |
| Average | 15.8 | 8.52 | 3.42 | 1.44 | -2.68 | 0.73 | 4.15 | 10.47 | 13.8 | 18.33 | 19.39 | 19.73 | |
| Amount of active temperature, °C | 441.1 | 138.4 | 42.3 | - | - | - | 17.48 | 220.6 | 421.12 | 571.7 | 602.0 | 612.4 | 3067 |
| Amount of effective temperature, °C | 161.1 | 24.4 | 6.3 | - | - | - | 3.48 | 47.3 | 131.1 | 273.7 | 294.0 | 302.4 | 1243.7 |

Field research was laid in the Carpathian state agricultural research station of the Institute of agriculture of the Carpathian region on April 14, 2016, according to the method (Dospekhov, 1985).

Experiment 1. To study the features of growth and development of energy willow depending on the cultivation techniques in the Western region for biofuels production for cultivation years (Table 2).

**The research scheme involves the influence of factors on the growth development and productivity of culture:**

Factor A - planting sites' layout: planting density: 18, 15, 12 thousand pieces/ha; Factor B - mineral nutrition. The research is based on four repetitions. The sown area is 150 $m^2$; the accounting area is 125 $m^2$. The total research area of the plots is 0.36 ha. According to the planting scheme, the crops are planted in paired rows with a distance of 0.70 m; and row spacing of 2 m.

**Table 2.** Research scheme I.

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

Experiment 2. To study the features of growth and development of energy poplar depending on the cultivation techniques in the Western region for the biofuels production for many years of cultivation (Table 3).

The research scheme involves factors on the growth development and productivity of culture: Factor A - layout of planting sites: Planting density: 8.3; 6.7; 5.6 thousand pieces/ha; Factor B - mineral nutrition.

**Table 3.** Research scheme II.

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

| | | |
|---|---|---|
| 6 | (planting step 60 cm) | $N_{40}P_{300}K_{300} + N_{40}$ |

The research is based on four repetitions. The sown area is 150 m$^2$; the accounting area is 125 m$^2$. The total research area of the plots is 0.36 ha. According to the planting scheme, the crops are planted in 1 row with 2 m rows. Traditional methods were used during the research.

## Results and Discussion

While growing energy plants for biomass, the yield of vegetative mass is one of the decisive criteria because the higher the yield is, the more profit per unit area will be. W revealed that the highest yield of energy willow biomass was obtained with an experiment with a planting density of 15 thousand units/ha and application of mineral fertilizers, namely 113.7 t/ha of green mass and 64.4 t/ha of dry mass, which is 19, 2 t/ha and 11.1 t/ha, respectively more compared to the experiment with a planting density of 18 thousand pieces/ha without fertilizers. (Table 4).

**Table 4.** Harvesting energy willow biomass of fifth-year vegetation depending on planting density and feeding background.

| **Experiment option** | **Planting density** ***Factor A*** | **Mineral nutrition** ***Factor B*** | **Harvesting of green mass, t/ha** | **Harvesting of dry mass, t/ha** | **The content of the absolutely dry substance in biomass,%** |
|---|---|---|---|---|---|
| 1 | 18 thousand pieces/ha (planting step 40 cm) | Without fertilizers | 72.2 | 40.8 | 56.5 |
| 2 | | $N_{40}P_{300}K_{300} + N_{40}$ | 94.1 | 53.3 | 56.6 |
| 3 | 15 thousand pieces/ha (planting step 50 cm) | Without fertilizers | 79.1 | 44.9 | 56.8 |
| 4 | | $N_{40}P_{300}K_{300} + N_{40}$ | 113.7 | 64.4 | 56.6 |
| 5 | 12 thousand pieces/ha (planting step 60 cm) | Without fertilizers | 71.6 | 40.7 | 56.9 |
| 6 | | $N_{40}P_{300}K_{300} + N_{40}$ | 107.3 | 60.5 | 56.4 |

$LSD_{0.5}$ t/ha: Factor A - 2.34, Factor B - 1.91, Interaction of AB - 2.58.

It should be noted that mineral fertilizers provided energy willow plants with a sufficient amount of nutrients, which in turn contributed to increased yields in all research variants. The mineral fertilizers application provides an average yield increase of 31 t/ha of green mass and 17 t/ha of dry mass.

Having analyzed the increase in yield by years of vegetation, it should be noted that for the fifth growing year of energy willow, it was achieved the lowest annual increase in yield of freshly cut wood from 5.3 t/ha per planting step of 40 cm and without fertilizer up to 14.0 t/ha per step planting 60 cm with full fertilizer application. The largest increase was obtained in the third growing year from 31.5 t/ha to 62.1 t/ha (Table 5).

**Table 5**. Dynamics of energy willow productivity for years of vegetation.

| **Experiment option** | **Planting density** ***Factor A*** | **Mineral nutrition** ***Factor B*** | **Research years** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **2016** | **2017** | **2018** | **2019** | **2020** | **Average for the year** |
| | | | **Harvesting of green/dry mass, t/ha** | | | | | |
| 1 | 18 thousand pieces/ha (planting step 40 cm) | Without fertilizers | 11.4 / 6.2 | 26.3 / 14.9 | 60.3 / 34.4 | 66.9 / 37.8 | 72.2 / 40.8 | 14.4 / 8.2 |
| 2 | | $N_{40}P_{300}K_{300} + N_{40}$ | 13.2 / 6.4 | 28.1 / 15.9 | 75.6 / 42.8 | 85.4 / 48.3 | 94.1 / 53.3 | 18.8 / 10.7 |
| 3 | 15 thousand pieces/ha (planting step 50 cm) | Without fertilizers | 14.7 / 7.3 | 24.8 / 14.1 | 56.3 / 32.0 | 69.6 / 39.5 | 79.1 / 44.9 | 15.8 / 9.0 |
| 4 | | $N_{40}P_{300}K_{300} + N_{40}$ | 15.9 / 8.2 | 26.4 / 14.9 | 80.6 / 45.3 | 98.7 / 55.9 | 113.7 / 64.4 | 22.7 / 12.9 |
| 5 | 12 thousand pieces/ha (planting step 60 cm) | Without fertilizers | 19.4 / 9.7 | 21.2 / 12.1 | 60.2 / 34.3 | 66.6 / 37.9 | 71.6 / 40.7 | 14.3 / 8.1 |
| 6 | | $N_{40}P_{300}K_{300} + N_{40}$ | 21.9 / 10.2 | 23.8 / 13.4 | 85.9 / 48.5 | 93.3 / 52.7 | 107.3 / 60.5 | 21.5 / 12.1 |

$LSD_{0.5}$ t/ha: Factor A - 2.34, Factor B - 1.91, Interaction of AB - 2.58.

**Table 6**. Harvesting energy poplar biomass of fifth-year vegetation depending on the planting density and feeding background.

| Experiment option | Planting density *Factor A* | Mineral nutrition *Factor B* | Harvesting of green mass, t/ha | Harvesting of dry mass, t/ha | Content of absolutely dry substance in biomass, % |
|---|---|---|---|---|---|
| 1 | 8.3 thousand pieces/ha (planting step 40 cm) | Without fertilizers | 112.2 | 63.4 | 56.5 |
| 2 | | $N_{40}P_{300}K_{300} + N_{40}$ | 134.1 | 75.9 | 56.6 |
| 3 | 6.7 thousand pieces/ha (planting step 50 cm) | Without fertilizers | 118.1 | 67.0 | 56.8 |
| 4 | | $N_{40}P_{300}K_{300} + N_{40}$ | 149.7 | 84.7 | 56.6 |
| 5 | 5.6 thousand pieces/ha (planting step 60 cm) | Without fertilizers | 114.6 | 65.2 | 56.9 |
| 6 | | $N_{40}P_{300}K_{300} + N_{40}$ | 139.3 | 78.6 | 56.4 |

$LSD_{0.5}$ t/ha: Factor A - 2.34, Factor B - 1.91, Interaction of AB - 2.58.

**Table 7.** Dynamics of energy poplar productivity by years of vegetation.

| Experiment option | Planting density *Factor A* | Mineral nutrition *Factor B* | Research years | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2016 | 2017 | 2018 | 2019 | 2020 | Average for the year |
| | | | Harvesting of green/dry mass, t/ha | | | | | |
| 1 | 8.3 thousand pieces/ha (planting step 40 cm) | Without fertilizers | 21.3 / 12.2 | 52.2 / 29.4 | 70.5 / 39.8 | 90.5 / 51.0 | 112.2 / 63.4 | 22.4 / 12.7 |
| 2 | | $N_{40}P_{300}K_{300} + N_{40}$ | 23.0 / 12.4 | 54.0 / 30.6 | 92.9 / 52.6 | 112.9 / 63.9 | 134.1 / 75.9 | 26.8 / 15.2 |
| 3 | 6.7 thousand pieces/ha (planting step 50 cm) | Without fertilizers | 23.9 / 13.3 | 55.5 / 30.8 | 74.9 / 41.4 | 99.7 / 55.3 | 118.1 / 67.0 | 23.6 / 13.4 |
| 4 | | $N_{40}P_{300}K_{300} + N_{40}$ | 25.6 / 14.2 | 57.0 / 31.7 | 97.0 / 53.9 | 125.0 / 69.5 | 149.7 / 84.7 | 29.9 / 16.9 |
| 5 | 5.6 thousand pieces/ha (planting step 60 cm) | Without fertilizers | 25.1 / 13.7 | 49.2 / 27.5 | 66.2 / 37.0 | 90.2 / 50.4 | 114.6 / 65.2 | 22.9 / 13.0 |
| 6 | | $N_{40}P_{300}K_{300} + N_{40}$ | 27.7 / 15.2 | 52.8 / 29.6 | 91.8 / 51.5 | 118.8 / 66.6 | 139.3 / 78.6 | 27.9 / 15.7 |

$LSD_{0.5}$ t/ha: Factor A - 2.34, Factor B - 1.91, Interaction of AB - 2.58.

In the reporting year, the highest yield of energy poplar biomass was obtained with an experiment with a planting density of 6.7 thousand units/ha, namely 149.7 t/ha of green mass and 84.7 t/ha of dry mass, which is 15.6 t/ha and 8.8 t/ha, respectively compared with the variant of a planting density of 8.3 thousand units/ha and 10.4 t/ha and 6.1 t/ha, respectively compared with the experiment of planting density of 5.6 thousand pieces/ha. Application of mineral fertilizers provides an increase in yield of 21.9 - 31.6 t/ha of green mass and 12.5-17.7 t/ha of dry mass for all variants of the experiment (Table 6). It should be noted that mineral fertilizers provided energy willow plants with a sufficient amount of nutrients, which in turn contributed to yields growing in all variants of the experiment. Having analyzed the increase in yield by years of vegetation, it should be noted that for the fifth growing year of energy willow, it was achieved an annual increase in yield of freshly cut wood from 21.2 t/ha per planting step 40 cm and without fertilizer up to 24.7 t/ha per planting step 50 cm with the introduction of the full rate of fertilizer (Table 7). The same trend is observed in previous growing years.

## Conclusions

The research results have established that the highest yield of energy willow biomass was obtained with a variant of a planting density of 15 thousand units/ha and application of mineral fertilizers, namely 113.7 t/ha of green mass and 64.4 t/ha of dry mass that is higher on 19.2 t/ha and 11.1 t/ha respectively compared with the experiment of planting density of 18 thousand pieces/ha without fertilizers.

Having analyzed the increase of yield by years of vegetation, it should be noted that for the fifth growing year of energy willow it was achieved an annual increase of freshly cut wood yield from 5.3 t/ha at a planting step of 40 cm and without fertilizer to 14.0 t/ha per step of the planting of 60 cm with the application of full norm fertilizers.

The highest yield of energy poplar biomass was obtained from the experiment with a planting density of 6.7 thousand units/ha, namely 149.7 t/ha of green mass and 84.7 t/ha of dry mass that is higher on 15.6 t/ha and 8.8 t/ha respectively compared with the experiment of a planting density of 8.3 thousand units/ha and 10.4 t/ha and 6.1 t/ha and is also higher respectively compared with the experiment of a planting density 5.6 thousand units/ha. Application of mineral fertilizers provides an increase in yield of 21.9-31.6 t/ha of green mass and 12.5-17.7 t/ha of dry mass in all variants of the experiment.

During the fifth vegetation year of energy willow, an annual increase in freshly cut wood was achieved in the experiment of 21.2 t/ha per planting step of 40 cm and without fertilizer application up to 24.7 t/ha and per planting step of 50 cm and 20.5 t/ha a step of the planting of 60 cm with the application of full norm of fertilizers.

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