FOSTERING SUSTAINABLE FEEDSTOCK PRODUCTION FOR ADVANCED BIOFUELS ON UNDERUTILISED LAND IN EUROPE

D2.5 FEASIBILITY STUDY UKRAINE -AGRONOMIC FEASIBILITY

SECBio – BI

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Project No.	691846
Project acronym	FORBIO
H2020 Call topic	LCE-14-2014 - Market uptake of existing and emerging sustainable bioenergy
Start date of the project	01.01.2016
Duration	36 months
Deliverable ID	D2.5 Feasibility Study Ukraine – Agronomic Feasibility
Due date of deliverable	M12
Lead beneficiary for this deliverable	SEC Biomass (P7)

	NAME	ORGANIZATION
AUTHOR(S)	Tetiana Zheliezna	SECBio
	Olha Haidai	SECBio
	Valeria Kovach	BI
CONTRIBUTOR(S)	Tommaso Barsali	BIOCHEMTEX

DISSEMINATION LEVEL

■ Public

DOCUMENT HISTORY

VERSION	DATE	NOTE	ISSUED BY
0.8	02/12/2016	draft	Olha Haidai (SECBio)
0.9	07/12/2016	Final for proofreading	Olha Haidai (SECBio)
1.0	14/12/2016	Final	Olha Haidai (SECBio)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Contents

This deliverable reflects only the author's view and the Innovation and Networks Executive Agency and the Commission are not responsible for any use that may be made of the information it contains.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

1. Introduction

The aim of this work is to carry out an agronomic feasibility study of bioenergy feedstock production, in order to provide a rigorous and exhaustive knowledge base for the implementation of non-food cellulosic chains and biorefineries in Ivankiv area (Kyiv oblast, Ukraine). Due to the unsatisfied soil conditions and bad economic conditions in the region (the Chernobyl exclusion zone is a part of Ivankiv region), agricultural lands were partially converted into marginal land, thus representing an interesting opportunity to prove the feasibility of non-food crops for land restoration and alternative systems of bioenergy production [1].

This study is divided into four different sections:

1. the first sections objective is to describe the study region concerning climate conditions, common agriculture production and potential for production of non-food cellulosic crops;

2. the second section objective is to develop a comprehensive database of cellulosic biomass crops, based on literature data and field trial results in Ukraine;

3. the third section objective is to build a model of water requirements through the CROPWAT tool on selected biomass crop on the case study site;

4. the last section processes information obtained during the field trials on growing willow on the case study site and aims to evaluate feedstock cost based on the obtained information.

The outcome of this study strives to provide new insights into agronomic and methodological implementation of bioenergy crops at large scale, while also providing useful information for bioenergy developers, scholars and policy makers in the agriculture and in the energy sectors.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

2. Case study site location description

2.1. Site description

The study area is located at southwest of Ivankiv region at the north part of Kyiv oblast, Ukraine (N 50º 49.9855´: E 029º 36.7206´) (Figure 1). The area is in the zone of mixed forests called Polissia that is characterized by moderately continental climate with relatively mild winters and warm summers. Duration of vegetation period is 198-204 days. Annual rainfall amount is between 500 - 600 mm. The temperature range is from -6 ^{0}C in January to +19.5 ^{0}C in July.

Low-lying relief, sandy and sandy-clay sediments, thick river net, wide river valleys, adequate moisture, high level of groundwater, widespread of pine forests are the main characteristics of Ivankiv region concerning natural environment.

The soils are mainly sandy: 50%, sandy-loam: 20%, clayey sand: 12%, sod-podzolic: 5%, mull-mud: 5%, clay: 5%, peat-mud: 3%. There is natural potential of peat, clay, building sand.

Fourteen rivers with the total length of 295 km flow on the region area. Main rivers are Teteriv with the length of 58 km, Zhereva - 30 km, Zdvyzh - 29 km.

Total territory of Ivankiv region is 361,600 hectares (12.8% of the Kyiv oblast). Distance to the Kyiv (the capital of Ukraine) is 80 km; to the Teteriv train station: 40 km, to the international Boryspil airport: 130 km. The length of roads is 533.5 km, including the length of roads of national importance of 78 km.

Ivankiv region has borders with Poliskyi, Vyshgorodskyi, Borodiaskyi regions, Zhytomyr and Chernihiv oblasts and Republic of Belarus (Figure 2).

On March 1, 2016 population of the Ivankiv region was 30,021 people (in the Ivankiv town - 10,569 people and in rural areas - 19,452 people), representing 1.7% of the total population of Kyiv oblast.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Ivankiv region has the below land fund structure:

Ivankiv region land fund structure (thousand hectares)

Total area	361.6
including:	Agricultural lands 80.9
	of which: Arable lands 51.2
	Forests and wooded areas 161.9
	Built-up lands 14.2
	Water fund lands 42.8
	Other lands 61.8

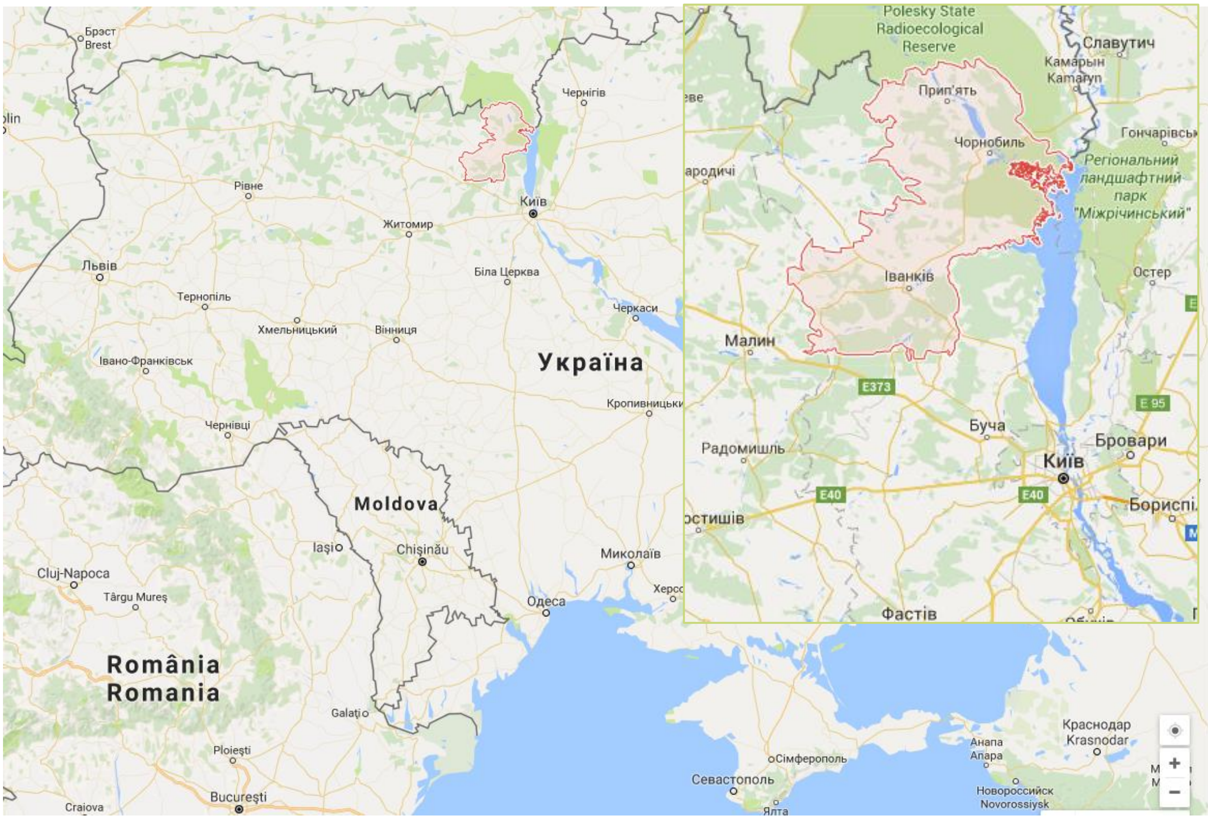


FIGURE 1. LOCATION OF IVANKIV REGION AT THE MAP OF UKRAINE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

CHORNOBIL EXCLUSION ZONE

Ivankiv region increased in 1986 after the disestablishment of the Chornobyl region due to the Chornobyl disaster. Today the Ivankiv region administers the former territory of the depopulated region that is majorly part of the zone of alienation and supervised by the State Agency of Ukraine on Exclusion zone management. Total area of Chornobyl exclusion zone that is located in the territory of Ivankiv region is 181,800 hectares.

Chernobyl radiation-ecological Biosphere Reserve has been created in 2016 at the territory of Ivankiv region that belongs to the Chernobyl exclusion zone (excluding zone at 10 km radius from the former nuclear power plant, that is now industrial area) [2]. Biosphere Reserve created in order to preserve the natural state of the most common natural systems of Polissia, support and improve the barrier function of the Chernobyl exclusion zone and zone of unconditional (obligatory) resettlement, stabilize the hydrological regime and rehabilitation of areas contaminated with radionuclides, promoting the organization and conduct of international research.

Other part of Ivankiv region has unfavourable socio-economic conditions. Before the Chernobyl nuclear power plant explosion the main employment sectors were the energy sector and animal husbandry (including milk production). Most of the agricultural enterprises were closed. The withdrawal of large areas of land from cultivation on the territory of Kyiv Polissia (within the exclusion zone) led to the intensification of agricultural production in the rest of Ivankiv region territory causing soil depletion and degradation [3].

Today North of Ukraine (including Ivankiv region) is 6 times less populated than other regions [4] due to the unsatisfying conditions for conducting common agricultural activities (unproductive and degraded lands are unsuitable for agricultural production and economically unprofitable).

Local authorities are looking to attract investors into the area, to create new work places and to renew the social infrastructure.

Until quite recently there were plans to ensure economic development of the region by growing technical and energy crops on agricultural lands in the exclusion zone [5, 6]. However, after the creation of Biosphere Reserve, any kind of activities is prohibited and other parts of Ivankiv region could become the center of the development of agriculture.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

![FORBIO logo]

FIGURE 2. IVANKIV REGION

A 10 km zone from the Chernobyl nuclear power plant became the zone of special industrial use. State Agency of Ukraine on Exclusion zone management declares plans to attract investors in this area for the development of renewable energy production - in particular construction of biofuel plants and biomass/solar power stations [7].

Electricity networks, including substations, high-voltage power lines that are essential components of renewable energy projects exist at the study area. Land rental price is low in the region. In addition, the State Agency of Ukraine on Exclusion zone management created a "single window for investors" having to remove administrative barriers for businesses.

Thereby today, Ivankiv region is a special industrial area with good conditions for investors, with the Chernobyl Radiation and Environmental Biosphere Reserve playing the role of buffer zone and other parts of the region presenting abundance of

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

vacant, abandoned lands not suitable for common agriculture production due to their exhaustion. All these factors constitute good starting conditions for the bioenergy production in Ivankiv region.

RADIOLOGICAL DESCRIPTION OF THE INVESTIGATED TERRITORY

One of the most effective methods to search radioactive sources, and for prospecting of radiation state of the territory which had been contaminated by radiation, is the method of distant measurements of ground gamma rays, with the help of aerogramme-spectroscopy. The method is based on the evaluations with sufficiently small spatial step for radiation fields using gamma-spectrometer of total absorption and it is located on aircraft`s board. In particular, assuming, that sources of gamma radiation are located on a ground surface and based on the results of measurements, with the presence of corresponding calibration, it's possible to receive radionuclide content and activity of such sources on all territory of surveying.

Due to that in the Department of Nuclear and Physics Technologies of the State Institution "Institute of Environmental Geochemistry of the National Academy of Sciences of Ukraine" was created by V. Burtniak and improved by Y. Zabulonov specialized means of airborne gamma spectrometric measurements and methods of their processing, which are free from disadvantages and allow to detect different radioactive (technogenic) sources and to determine their characteristics without using any priori information. The special unmanned vehicle "Octocopter" was created and designed for these purposes by mentioned authors as well.

In 2015 was initiated a pilot project to investigate all districts that border with exclusion zone or suffer from the Chornobyl accident using airborne gamma spectrometry method.

Ivankiv district borders with the Chornobyl exclusion zone, but only part of the territory is contaminated with ^{137}Cs and ^{90}Sr [8]. The case study area as it can be seen from the results of gamma survey (Fig.3 and Fig.4) is not contaminated with radionuclides and can be used by locals and by companies as well for different purposes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

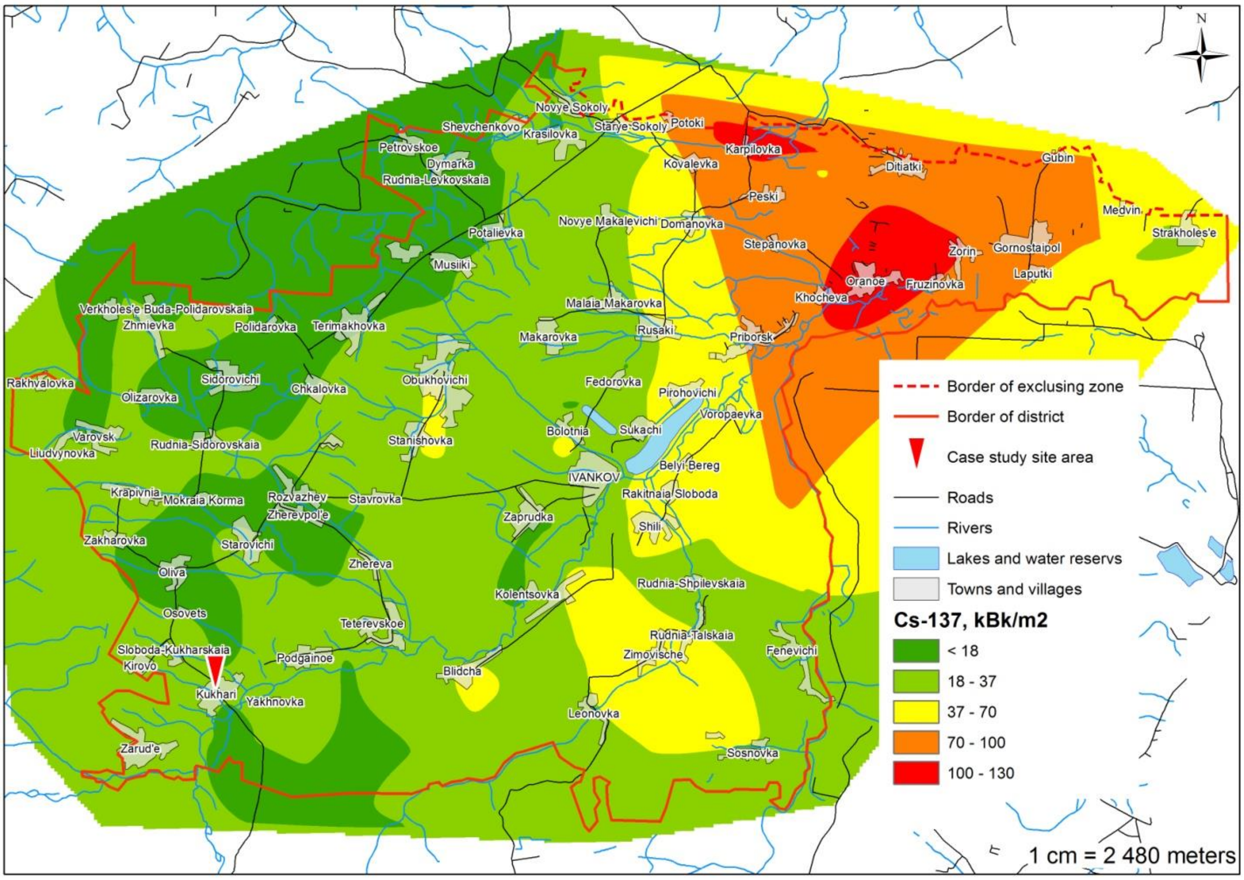


FIGURE 3. ISOLATED ANOMALIES OF THE LOCAL COMPONENT OF THE INTEGRATED CHANNEL ^{137}CS

All the researches were performed by unmanned flying vehicle (UAV) «Octocopter» (Figure 5) [9].

Technical components of chosen UAV: flight controller: DJI A2; navigation set (GNSS (GPS + GLONASS+ Galileo); controller OSD; engines AXI 2814/22 (Czech Republic); propellers APC 14" (carbon); engines controllers 60A ESC OEM; set of silicone cables; onboard camera; video Transmitter 5.8 mHz 600mV; 3-axis magnetometer; 3-axis gyroscope; 3-axis accelerometer; ultrasonic sensor: used for analyzing of flight at altitude up to 8 m; barometer; frame OKTO TOP Series (carbon); electronic system of stabilization; management System Futaba 14; accumulator 16A 6S Tattoo.

Octocopter dimensions: 1040x1040 mm, carrying capacity up to 8 kg. Speed of flights of non load device can reach 10 m/s, time of residence in air - 20-25 minutes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

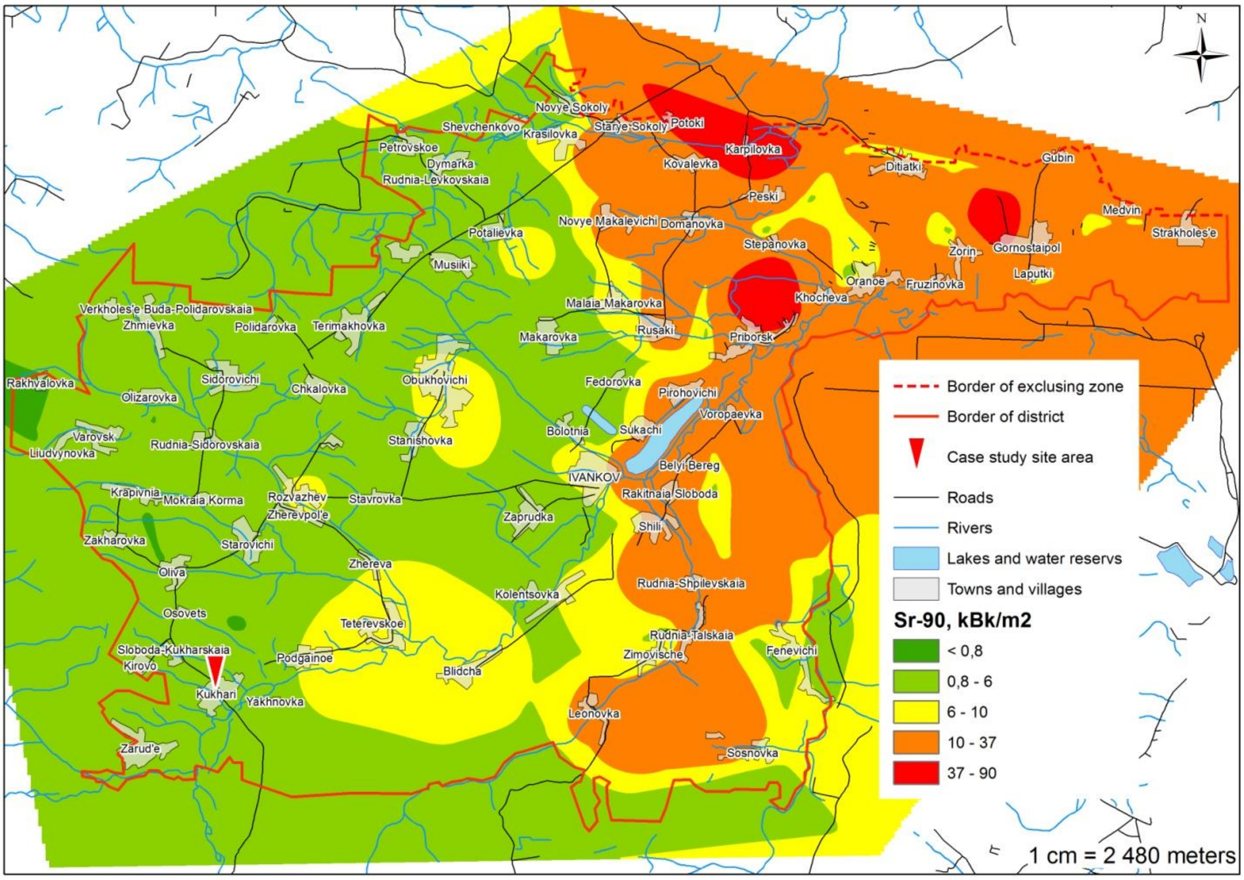


FIGURE 4. ISOLATED ANOMALIES OF THE LOCAL COMPONENT OF THE INTEGRATED CHANNEL ^{90}SR

FIGURE 5. UAV FOR SOLVING TASK CONNECTED WITH AERO GAMMA SPECTROMETRY

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

2.2 Climate

The study area is located in Ivankiv region that is geographically a part of Ukrainian Polissia, the zone of mixed coniferous-deciduous forests. The zone occupies the northern part of Ukraine (Figure 6). It is part of the zone of mixed forests of the East European Plain, that includes the Poliska province, located on the territories of Ukraine, Russia and Belarus.

FIGURE 6. AGRO-ECOLOGICAL ZONES OF UKRAINE

Polissia is characterized by moderately continental climate with relatively mild winters and warm summers. Relief is flat. Average January temperatures vary from west to east from -4.5 °C to -8 °C, in July respectively from +17 to +19.5 °C. The frost-free period lasts for 160-180 days. The average annual precipitation is 550-650 mm that is the biggest number on the flat part of the country. The snow cover lasts for 90-100 days. Vegetation period lasts from the second decade of April until the third decade of October. The period with average daily temperatures of over +15 °C is approximately 95-125 days. The annual sum of temperatures exceeding + 10 °C is about 2 600 °C. Period without light frosts on the ground is 160-180 days [10].

Rivers are characterized by long spring snowmelt flood with wide overflow, lowest water level in winter. Groundwater is the source of power of rivers and lakes. Lowland fens are significantly spread.

Mixed-forest, coniferous-broadleaf landscapes that evolved in temperate warm humid climate in sandy sediments dominate in the area. They are characterized by widespread of sod-podzolic soils under pine and pine-oak forests, complex alternation of glacial sandy plains, valley-terraced, meadow and wetland natural systems with melioration systems. There are treeless areas with landscapes of north-steppe character in the south zone (study area).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

The forest coverage of the area ranges from 10 to 60% (30% in average). Pine (*Pinus sylvestris* L.), birch (*Betula pendula Roth*.), oak (*Quercus robur* L.), hornbeam (*Carpinus betulus* L.), linden (*T. platyphyllos Scop*.), maple (*Acer platanoides*) grow there. Oak and pine forests, which occupy 45% of the forest area, are the most common. Pine forests are located on the sandy areas. Up to 10% of the area is located under meadow landscape in floodplains. Motley-cereal groups dominate in their grass. Marsh natural systems, including low-lying herb-moss and forests swamps dominate in the landscape.

The eastern boundary of the Ivankiv region is Dnieper River with Kyiv reservoir. The region is located on the slope of the Ukrainian shield; the foundation is submerged to a depth of 300-400 m. It overlie rocks of Cretaceous, Paleogene, Neogene and Anthropogenic periods. Relief is a moraine-hilly plain, with river valleys. The main rivers are the Prypiat, Uzh, Teteriv, Zdvizh, Irpin.

Natural complex of sand and river sand plains, with sod-podzolic soils, pine and oak-pine forests is a major landscape structure of the territory. Moraine-sand plains with medium sod-podzolic soils (now occupied by agricultural land) widespread in the southern part of Kiev Polissia (the study area). Natural conditions of Kyiv Polissia are favourable for agriculture and forestry use, recreation, environmental objects [10].

The main climate characteristics of the study area are summarized in the table below:

Climate	moderately continental
Average temperature in January	– 6 °C
Average temperature in July	+19 °C
Annual average temperature	6.9 °C
Average altitude	131 m
The annual radiation balance	45 kcal/cm^2
Moisturizing factor (the ratio of precipitation to evaporation)	1.0-1.2
Annual precipitation	550-650 mm
Relief	flat
Annual air humidity	80 %
Wind direction	north-west
Soils types	sandy, sandy loam, sod-podzolic[1]

[1] Names of soil types are in accordance with soil types classification that used in Ukraine (Soil classification USSR, 1977; Field identification of soils 1981).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

2.3 Description of the common agriculture production in the region

Arable land covers only 33% of Polissia (the zone of mixed forest), that is 4 million hectares. Hayfields cover 1.2 million hectares, pastures cover 0.7 million hectares. This area is a broad spatial base for the production of grain crops (rye, oats and buckwheat), industrial crops, flax, hops, sugar beet and potatoes, and flax, meat and dairy products processing [11].

Agricultural land covers only about 22% of Ivankiv region (Table 1). Only 17,600 hectares of arable lands was used in 2015 as the sown area by all categories of land users (agricultural enterprises, households).

TABLE 1. STRUCTURE OF AGRICULTURE LANDS IN IVANKIV REGION (THOUSAND HECTARES)

TOTAL TERRITORY OF THE REGION	361.6
AGRICULTURAL LANDS, INCLUDING	80.9
ARABLE LANDS	51.2
PERENNIAL CROPS	0.9
HAYFIELDS	13.8
PASTURES	10.5
LAYLANDS	4.5

Ivankiv region has the lowest indicators of agriculture production in Kyiv oblast: the share of the region in the grain crops production of the Kyiv oblast is only 0.24%, in the sunflower production 0.3% (Table 2). The yield of grain crops is 2-3 times lower than the average indicator in Kyiv oblast. The yield of sunflower is 6 times lower. Structure of sown area differs from year to year. Data of 2014 for rapeseed production in the area (the production started in 2006): harvested area is 880 hectares, production – 1,300 t, yield – 1.47 t/hectare (average for Kyiv oblast is 2.87 t/hectare). As agriculture in the area is not very well developed, the structure of sown areas depends on the chosen crop rotation of each particular farmer [12].

Starting from 2000 there has been no vegetables, fruit and berry production in Ivankiv region (excluding production for self-consumption).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

TABLE 2. SELECTED INDICATORS OF AGRICULTURE PRODUCTION IN IVANKIV REGION IN 2015

	IVANKIV REGION	KYIV OBLAST
SOWN AREA, TH. HA		
TOTAL	**17.6**	**1153.0**
IN AGRICULTURAL ENTERPRISES	**10.01**	**889.23**
HARVESTED AREA OF, TH. HA		
GRAIN CROPS, INCLUDING	**3.8**	**462.6**
WHEAT *(TRITICUM L.)*	**1.7**	**171.9**
RYE *(SECALE CEREALE)*	**1.4**	**6.5**
MAIZE FOR GRAIN *(ZEA MAYS)*	**0.2**	**222.4**
SUNFLOWER *(HELIANTHUS L.)*	**1.89**	**113.25**
PRODUCTION, TH. T		
GRAIN CROPS, INCLUDING	**5.93**	**2450.9**
WHEAT *(TRITICUM L.)*	**3.85**	**837.4**
RYE *(SECALE CEREALE)*	**1.46**	**15.1**
MAIZE FOR GRAIN *(ZEA MAYS)*	**0.36**	**1372.8**
SUNFLOWER *(HELIANTHUS L.)*	**0.78**	**285.6**
YIELD, T/HA		
GRAIN CROPS, INCLUDING	**1.58**	**5.3**
WHEAT *(TRITICUM L.)*	**2.25**	**4.87**
RYE *(SECALE CEREALE)*	**1.03**	**2.32**
MAIZE FOR GRAIN *(ZEA MAYS)*	**1.81**	**6.17**
SUNFLOWER *(HELIANTHUS L.)*	**0.4**	**2.52**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Low yield of main agricultural crops in the region is connected first of all with the type and condition (exhaustion) of the soil. Nevertheless, the other main factor is insufficient usage of mineral and organic fertilizers by farmer enterprises. Thus in 2015 mineral fertilizer was used only on 4,400 hectares (44% of the sown area in agricultural enterprises), organic fertilizer was used on 45 hectares (0.45% of the sown area). Total amount of mineral fertilizer that was applied in 2015 by enterprises was 362.7 t that was 82 kg/hectare of the fertilized area (220.5 t of nitric, 67.5 t of phosphatic, 74.7 t of potash fertilizer). Total amount of organic fertilizer that was applied in 2015 by enterprises was 464 t that was 10 t/hectare of the fertilized area [12].

The largest contribution to the development of the agricultural sector is done by 18 agricultural enterprises (Table 3), including 6 agricultural production cooperatives, 9 agricultural Limited Liability Company (LLC), 1 joint-stock company (JSC), and 2 farms. 22,704 hectares of arable land is operated by agricultural enterprises of the region. They concluded 4492 agreements for the lease of land shares [13].

TABLE 3. MAIN AGRICALTURAL ENTERPRISES OF THE IVANKIV REGION

AGRICULTURE SECTOR	COMPANY NAME AND ADDRESS
GROWING OF AGRICULTURAL CROPS	1. OLIZARIVSKYI COOPERATIVE, OLIZARIVKA VILLAGE, 1 MYRU STR.
	2. PEREMOHA COOPERATIVE, KUKHARI VILLAGE, 4 LENINA STR.
	3. ZERNOPROM-IVANKIV LLC, PRYBIRSK VILLAGE, 1, SHEVCHENKA STR.
	4. ZELENA KHVYLIA LLC, TERMAKHIVKA VILLAGE, 13, POLISKA STR.
	5. AGROVEY COMPANY LLC, MUSIYKY VILLAGE, 145, LENINA STR.
	6. ZARUDDIA-AGRO LLA, ZARUDDIA VILLADE, 50A, POLOVA STR.
	7. ZAPRUDKA FARNMING, ZAPRUDKA VILLAGE
	8. PIONER FARNMING, BOLOTNIA VILLAGE
	9. COOPERATIVE NAMED AFTER MICHURIN, DYTIATKY VILLAGE, 1, LENINA STR.
	10. AGRO-OTSETEL LLC, SOSNIVKA VILLAGE, 44, LENINA STR.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

GROWING OF AGRICULTURAL CROPS, ANIMAL HUSBANDRY	1. MUSIYKY COOPERATIVE, MUSIYKY VILLAGE, 145 LENINA STR. 2. MAKARIVSKE LLC., MAKARIVKA VILLAGE, 18A, LENINA STR. 3. ZHMIIVSKE JSC, ZHMIIVKA VILLAGE, 5, DZERZHINSKOGO STR. 4. PROMIN COOPERATIVE, SYDOROVYCHI VILLAGE, 24, SKHIDNO-SHEVCHENKIVSKA STR. 5. MRIIA COOPERATIVE, HORNOSTAYPIL VILLAGE, 2, CHORNOBYLSKA STR. 6. AGRO KOLOS UKRAINE LLC, KROPYVNIA VILLAGE, 82, LENINA STR.
SWINE (PIG) BREEDING	1. APIK LLC, IVANKIV TOWN, 49, FRUNZE STR.
INDUSTRIAL CROPS GROWING	1. UKRAGROENERGO LLC, IVANKIV TOWN, 34, POLISKYI SHLIAKH STR. *(CASE STUDY SITE)*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

2.4 Identification of underutilized lands in the region

Identification of underutilized lands in the region within 100 km radius from Ivankiv town (potential location of bioenergy unit) will be done using statistical analysis. This analysis is used for estimating the present and future potential of biomass energy from annual and perennial crops [14].

There are three approaches for estimating the present and future theoretical, technical and economic potentials of biomass energy crops: statistical analysis, spatially explicit analysis, and cost-supply analysis. All three focus on the resources available for energy crop production. Typically, only "underutilized land" is allowed to be used for energy crop production, i.e. land that is not needed for other purposes. Underutilized land may include different categories, e.g. set-aside land, abandoned agricultural land, marginal land and low productive land. In this assessment, the underutilized land is a theoretical construct that is derived by subtracting the amount of land needed for feed, food and biomaterial production from the total available area.

UNDERUTILIZED LANDS - STATISTICAL METHOD

Two categories of land are considered as an underutilized in the assessment [14]:

- Abandoned agricultural land, i.e. land that is not needed any more for the production of food and feed crops or for other purposes;
- Degraded or low productive land, i.e. land that is not suitable or no longer suitable for conventional commercial agriculture.

ABANDONED AGRICULTURAL LAND

Statistics on abandoned agricultural land are usually not available, because the abandoned agricultural land is usually not left idle, but used for other purposes and thus is not classified as surplus land. Therefore, data on abandoned agricultural land typically refer to a decrease of the area of agricultural land.

Specific attention should be paid to the difference between the total area classified as 'arable land' and the 'sown area' (Table 4) when calculating the area of abandoned agricultural land. Compatibility of the two data-sets can be evaluated indirectly by computing the ratio of area harvested to arable land, i.e. the cropping intensity (CI). This is also an important parameter that can signal defects in the land use data. The cropping intensity in West Europe and North America is typically in the range of 0.6-0.7, which indicates that the difference between arable land and sown areas is too large to be ignored when investigating biomass energy potentials.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Cropping intensities larger than 1 are also possible, in case of multiple harvests (double or triple cropping).

DEGRADED AND LOW PRODUCTIVE LAND

The rationale for using these areas is that these areas are not suitable for conventional agriculture and that these areas can be used for bioenergy production without competition with the production of food. However, competition with food production is in reality an economic issue, but economic aspects are not investigated in the basic statistical method.

The simplest best-practice basic statistical method to estimate the potential of degraded and low productive land is to use statistics in combination with estimations of the yields of energy crops on these areas. There are data on layland (neglected field) in official statistical publications as on national and regional level in Ukraine. Those data will be used for estimation of underutilized lands considering the category of degraded and low productive lands.

Data about the productivity of degraded or low productive types of land are typically not readily available from statistical databases. Ideally, the productivity is evaluated taking into account the specific soil or climate conditions. This can be done using crop growth models, field measurements or by using statistics that are corrected for degradation or by estimating the impact of soil quality on the yields that are reported in literature. In addition, field trials and expert judgement are important sources of information.

TABLE 4. DEFINITIONS OF LANDS USED IN THE ASSESSMENT [15]

LAND CATEGORY	DEFINITION
Agricultural land	Land that is systematically used to produce agricultural products; it includes arable land, layland, perennial crops, hayfields and pastures. Agricultural lands may be owned, rented and used on a temporary or permanent basis by agricultural enterprises and individuals.
Arable land	Land that is systematically cultivated and used in agricultural crops sowing, including perennial grasses and fallow lands, areas of greenhouses and hothouses. Arable land does not include hayfields and pastures ploughed up for full improvement and when they are permanently used under grass fodder crops for hay-mowing and livestock grazing as well as inter-row spaces in orchards used for sowing.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Perennial crops	Lands under artificial perennial tree, bush and grassy plantations intended for the production of fruit-berry, industrial and herb crops and for decoration of the territories
Hayfields	Agricultural lands that are systematically used for hay-moving
Pastures	Agricultural lands that systematically used for livestock grazing
Laylands	Lands that had been previously plowed, and then more than a year since the fall, not used for sowing crops and not prepared to use as a fallow land
Sown area	A part of arable land or other cultivated land, which is actually occupied by crops: winter crops, which are sown last fall and survived until the end of spring sowing period and spring crops under harvest of this year
Fallow land	A part of arable land that is free from crops in the growing season and kept clean of weeds

With the usage of the abovementioned methodology and with consideration of local conditions and statistical data availability authors developed method of calculation of the underutilized lands on regional level [16]. For the calculation of the underutilized land availability, the following formula will be used:

$$\boldsymbol{S_{und.l}} = \sum_{i=1}^{n}(\boldsymbol{S_{ar.l_i}} - \boldsymbol{S_{s.a_i}} - \boldsymbol{S_{f.l_i}} + \boldsymbol{S_{l.l_i}}),$$

where $\boldsymbol{S_{und.l}}$ –total area of underutilized land, ha;

$\boldsymbol{S_{ar.l}}$ – area of arable land in the region, ha.

$\boldsymbol{S_{s.a}}$ – sown area in the region, ha;

$\boldsymbol{S_{f.l}}$ – area of fallow land in the region, ha;

$\boldsymbol{S_{l.l}}$ – area of the layland in the region, ha.

Ivankiv region is located in Kyiv oblast between Zhytomyrska and Chernihivska oblasts (Figure 7). Estimation of underutilized land will be done within 100 km radius [17] from the possible location of biofuel production plant, which is considered to be in Ivankiv town. All the regions within 100 km radius from Ivankiv town have similar climatic and geographical characteristics as they belong to Polissia area (the zone of mixed forest).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

There are the following regions in the 100 km zone from the centre of Ivankiv region:

- Kyiv oblast: Ivankivskyi, Poliskyi, Vyshgorodskyi, Borodianskyi, Makarivskyi, Kyivo-Sviatoshynskyi, Brovarskyi, Vasylkivskyi (1/2), Fastivskyi (1/2), Boryspilskyi (1/3);
- Zhytomyrska oblast: Narodnytskyi, Malynskyi, Radomyshlianskyi, Korostyshivskyi (2/3), Korostenskyi (1/2), Cherniakivskyi (1/3), Ovrutskyi (1/4).
- Chernihivska oblast: Kozeletskyi, Chernigivskyi (1/3).

FIGURE 7. REGIONS WITHIN 100 KM RADIUS FROM IVANKIV TOWN

Statistical data on agriculture lands within 100 km radius from Ivankiv town that was used for the assessment of underutilized lands in 2015 are presented in Table 5. Same data that was obtained from Regional statistical office in Kyiv, Zhytomyrska and Chernihivska oblasts by request was used to calculate potential of underutilized lands from 2013 to 2016.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

TABLE 5. STATISTICAL DATA ON AGRICULTURE LANDS IN 2015

REGION	ARABLE LAND, TH.HA	SOWN AREA, TH.HA	FALLOW LAND, TH.HA	LAYLAND, TH.HA
KYIV OBLAST, INCLUDING:	**910.56**	**889.23**	**7.70**	**2.38**
IVANKIVSKYI	23.28	10.01	-[2]	2.22
POLISKYI	3.84	3.79	-	-
VYSHGORODSKYI	4.32	3.08	0.01	-
BORODIANSKYI	13.60	11.30	-	-
MAKARIVSKYI	32.68	31.41	-	3.55
KYIVO-SVIATOSHYNSKYI	8.53	8.05	0.04	-
BROVARSKYI	28.43	28.00	0.04	-
VASYLKIVSKYI	22.79	22.71	0.04	-
FASTIVSKYI	18.61	18.42	-	0.64
BORYSPILSKYI	14.80	14.56	0.24	-
ZHYTOMYRSKA OBLAST, INCLUDING:	**647.49**	**606.49**	**3.19**	**32.4**
MALYNSKYI	19.84	13.99	-	1.71
NARODNYTSKYI	10.86	8.13	-	0.57
RADOMYSHLIANSKYI	30.47	28.88	-	2.23
KOROSTYSHIVSKYI	15.30	13.75	-	-
KOROSTENSKYI	8.29	7.21	-	0.38
CHERNIAKIVSKYI	11.75	9.03	-	0.09
OVRUTSKYI	5.42	5.25	-	0.48
CHERNIHIVSKA OBLAST, INCLUDING:	**980.20**	**973.3**	**1.66**	**30.20**
KOZELETSKYI	43.40	43.40	-	-
CHERNIGIVSKYI	20.50	20.10	-	-

[2] there is no statistical data on land of this category in the region

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

The results of the assessment presented at Table 6 and Figure 8 (for 2013-2016) and at Figure 9 (the average value for four years).

Generally, according to deep statistical analysis, potential of underutilized lands in the 100 km zone from Ivankiv town estimates in 46-67 thousand hectares annually. This amount divides almost equally between Kyiv and Zhytomyrska oblasts; Chernihivska oblast covers small percent due to the geographical location. The summary of the average underutilized lands availability in each region depending on the distance from Ivankiv presented in Table 6a.

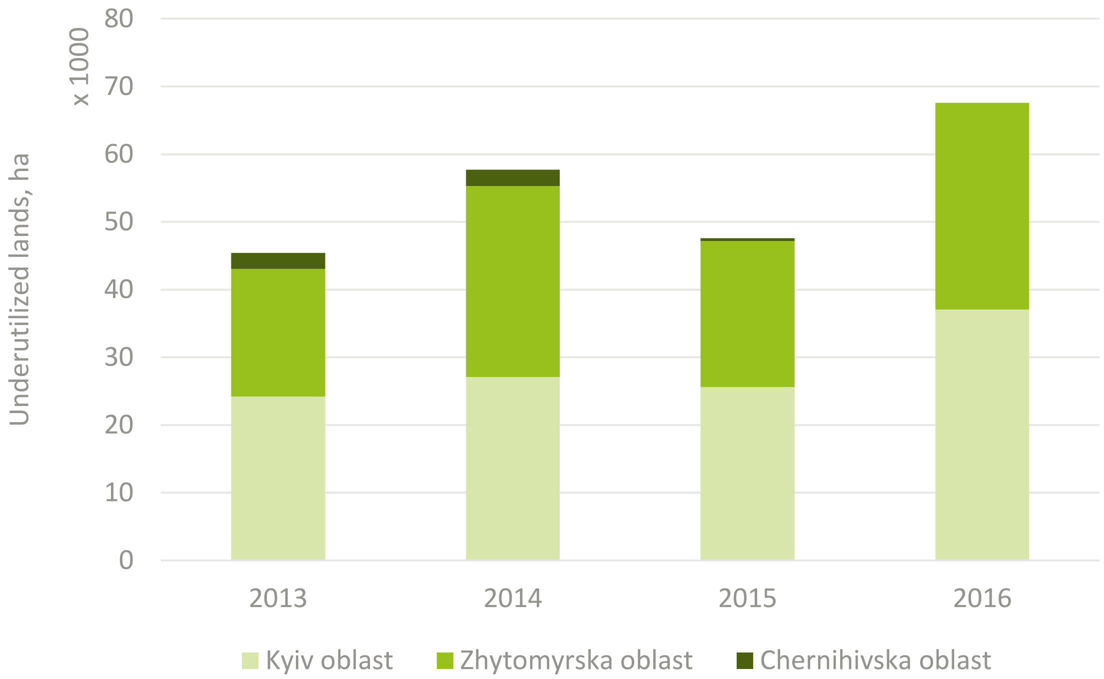


FIGURE 8. UNDERUTILIZED LANDS POTENTIAL WITHIN 100 KM ZONE FROM IVANKIV TOWN

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

TABLE 6. POTENTIAL OF UNDERUTILIZED LANDS IN 100 KM ZONE FROM IVANKIV TOWN, THOUSAND HECTARES

REGIONS	2013	2014	2015	2016
REGIONS IN KYIV OBLAST, INCLUDING:	**24.39**	**27.49**	**25.62**	**37.49**
IVANKIVSKYI	8.33	11.55	15.49	16.72
POLISKYI	1.54	4.92	0.04	9.81
VYSHGORODSKYI	1.38	1.94	1.23	1.25
BORODIANSKYI	0.85	0	2.31	0
MAKARIVSKYI	4.67	3.89	4.83	5.20
KYIVO-SVIATOSHYNSKYI	0.45	0.67	0.45	0.97
BROVARSKYI	5.05	2.35	0.42	1.06
VASYLKIVSKYI	0.95	0.60	0.04	1.45
FASTIVSKYI	0.99	1.57	0.82	1.03
BORYSPILSKYI	0.18	0	0	0
REGIONS IN ZHYTOMYRSKA OBLAST, INCLUDING:	**19.45**	**28.16**	**21.16**	**29.78**
MALYNSKYI	3.97	8.02	7.56	12.95
NARODNYTSKYI	0.54	1.67	3.29	1.34
RADOMYSHLIANSKYI	5.63	7.19	3.82	5.37
KOROSTYSHIVSKYI	0.29	1.05	1.55	1.94
KOROSTENSKYI	5.09	6.72	1.47	5.56
CHERNIAKIVSKYI	3.09	2.89	2.82	2.06
OVRUTSKYI	0.82	0.62	0.64	0.55
REGIONS IN CHERNIHIVSKA OBLAST, INCLUDING:	**2.40**	**2.41**	**0.40**	**0**
KOZELETSKYI	1.93	0.70	0	0
CHERNIGIVSKYI	0.47	1.72	0.4	0
TOTAL IN 100 KM ZONE	**46.24**	**58.08**	**47.18**	**67.26**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

TABLE 6A. DISTRIBUTION OF UNDERUTILIZED LANDS POTENTIAL DEPENDING OF THE DISTANCE FROM IVANKIV TOWN

REGIONS	DISTANCE[3] FROM IVANKIV TO ADMINISTRATIVE CENTRE OF THE REGION, KM	UNDERUTILIZED LAND, THOUSAND HECTARES
IVANKIVSKYI	0	13.00
BORODIANSKYI	45	0.79
POLISKYI	52	4.08
VYSHGORODSKYI	64	1.45
MALYNSKYI	69	8.13
MAKARIVSKYI	69	4.65
KYIVO-SVIATOSHYNSKYI	82	0.63
RADOMYSHLIANSKYI	87	5.50
NARODNYTSKYI	90	1.72
BROVARSKYI	100	2.22
POTENTIAL IN THE REGIONS THAT TOTALY LOCATED IN 100 KM RAGIUS FROM IVANKIV		**42.17**
OVRUTSKYI	102[4]	0.66
VASYLKIVSKYI	116	0.76
FASTIVSKYI	118	1.11
BORYSPILSKYI	118	0.05
KOROSTENSKYI	118	4.71
KOROSTYSHIVSKYI	125	1.21
CHERNIAKIVSKYI	131	2.72
KOZELETSKYI	149	0.66
CHERNIGIVSKYI	198	0.65
POTENTIAL IN THE REGIONS THAT PARTIALLY LOCATED IN 100 KM RAGIUS FROM IVANKIV		**12.53**

[3] Measured by roads

[4] Distance more than 100 km refers to the cities that belongs to target region (within 100 km radius from Ivankiv) but road length to the administrative center of the region is more than 100 km (potential of underutilized lands in this case calculated for the part of the region).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

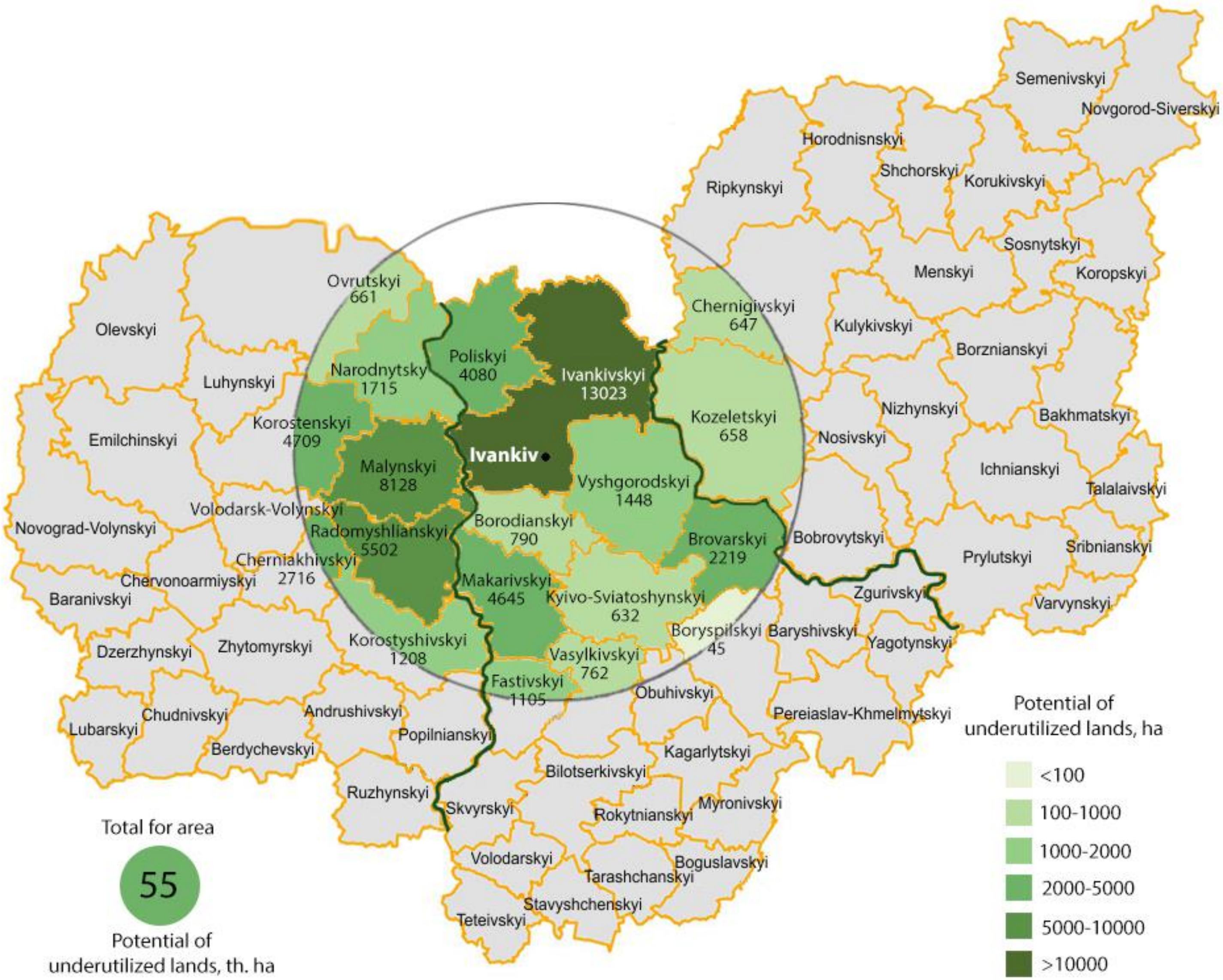


FIGURE 9. AVERAGE UNDERUTILIZED LANDS POTENTIAL WITHIN 100 KM ZONE FROM IVANKIV TOWN

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

3. Data collection on bioenergy feedstock

3.1. Feedstock identification and description

Introduction of bioenergy crops into farming is a complex process, which is now on its initial stage in Ukraine. Growing bioenergy crops in Ukraine is now mostly at a research stage with small and not numerous field trial plots. Although there are some industrial plantations, which use mostly well-developed bioenergy crops, such as *Salix viminalis* L. and *Miscanthus x giganteus*.

The biggest industrial plantation of willow in Eastern Europe belongs to a company "Salix Energy" and occupies about 1700 ha in western Ukrainian regions (Lviv and Volyn'). The company mostly cultivates Swedish varieties of *Salix viminalis* L. but also has bred and registered in 2013 a new variety "Martsyiana" in State Register of plant varieties suitable for dissemination in Ukraine. Biomass from plantations is used for export and for heating of municipal buildings of the nearest town.

Biomass of *Miscanthus x giganteus* from one of the known industrial plantations (33 hectares in Dnipropetrovsk region) is used for pellet production. Plantation belongs to Agro holding KSG Agro, which uses biomass from it together with agro residues from own fields to produce pellets for further heating of own piggeries.

Still, industrial introduction of bioenergy crops is rare due to lack of best practice experience and unsolved legislation issues that create burdens for crops introduction at a large scale. Nevertheless, bioenergy crops are subject of research for universities and research institutes of the National Forestry Academy of Sciences, National Agrarian Academy of Sciences, as well as some Botanical Gardens. Unfortunately, due to different research tasks, not all published sources contain information about experimental trials, nor indicate yields of cultivated energy crops. Another barrier for the efficient identification of promising crops is the absence of a unified electronic catalogue of research papers and of an electronic version of a significant number of publications.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

To identify the most promising bioenergy crops for cultivation in Ukraine in general and in Polissia region, in particular, a thorough screening was performed. The screening included search in the electronic catalogue of Vernadsky National Library of Ukraine, as well as catalogues of libraries of institutions of the National Academy of Agrarian Sciences of Ukraine [18], along with Google Scholar search. The search was performed in English and Ukrainian and analysed articles and papers published in peer-reviewed journals, technical reports, conference abstracts, dissertations and books.

According to search results, among known types of bioenergy crops, studied in Ukraine, there are species that can be potentially used as a feedstock for solid biofuels production, as well as for liquid biofuels and biogas.

The biggest Ukrainian gene pool of energy crops is created at the National Botanic Garden and consists of 522 taxons [19] (Figure 10).

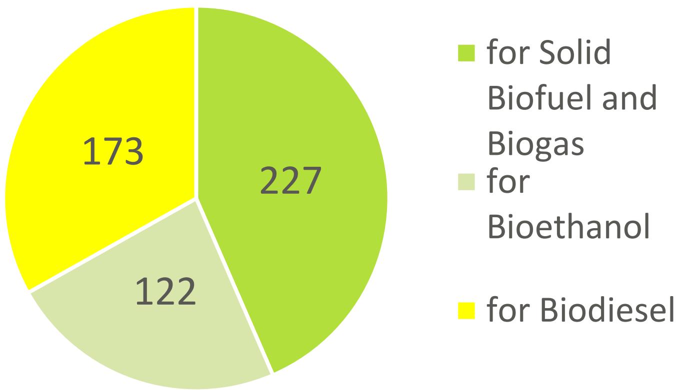


FIGURE 10. RESOURCE POTENTIAL OF ENERGY CROPS TAXONS FOR DIFFERENT TYPES OF BIOFUELS

The investigated energy crops for different types of biofuels are presented at Table 7 and the most promising of them are described.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

TABLE 7. SUMMARY OF THE PROMISING TYPOLOGIES OF BIOMASS CROPS FOR DIFFERENT BIOFUELS

TYPOLOGY	HERBACEOUS PLANTS		WOODY PLANTS
	ANNUAL	PERENNIAL	
LIGNOCELLULOSIC CROPS	MALLOW (MALVA MELUCA GRAEBN)	MISCANTHUS SWICHGRASS SIDA CUP PLANT	POPLAR WILLOW SCOTS PINE BLACK LOCUST
OLEAGINOUS CROPS	RAPESEED AMARANTH TURNIP X WILD CABBAGE HYBRID ROCKET-CRESS CAMELINA		
SUGAR CROPS	SWEET SORGHUM JERUSALEM ARTICHOKE	COLUMBIAN GRASS	
STARCH CROPS		SORREL	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

JERUSALEM ARTICHOKE *Helianthus tuberosus* L.

Jerusalem artichoke (Topinambur) is a perennial plant of about 1 - 4 m in height (sometimes 6 m) with erect downy stem, ovate leaves and yellow inflorescences-baskets 6-10 cm in diameter, each consisting of 10-20 flowers. Leaves are paired on the bottom of the plant and alternate at the top. Underground shoots produce underground lateral shoots (stolons), which, due to the plastic substances content become thicker at the ends and transform into cylindrical, pear-like or round shape tubers with bulging buds of white, yellow, purple or pink colour (depending on variety) 7.5-10 cm long and 3-5 cm in diameter. Tubers are covered with thin skin without a cortical layer, which, like in potato, provides protection from mechanical damage and decay. The flesh is tender, juicy with a pleasant sweet taste. The maximum height increment is observed at the beginning of the tuber formation stage (July-August). The fruit is conical achene, consisting of a pericarp and a seed. The weight of 1000 seeds ranges from 7 to 9 g. Plant penetrates to a depth of 2 m.

Scientific classification	Family: Asteraceae; Tribe: Heliantheae; Genus: Helianthus; Species: H. tuberosus
Class	C3 grass
Life cycle	1 year
Yield	Fresh biomass 50-65 t/ha, tubers: 35-45 t/ha
Growing season	Vegetation period for biomass: 120-140 days, for tubers: 170-195 days.
Temperature	Topinambur has high cold resistance and frost resistance. Spring shoots can withstand frost down to minus 4 ... 5 °C, and in autumn the plants vegetate to 7-8 °C below zero. Tubers can withstand temperatures down to 20 °C, without losing the vitality and covered with snow did not die in the harsh winters with frosts 25-30 °C. High temperatures plant tolerates well.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Rainfall	Jerusalem artichoke plants cannot withstand excessive moisture, flooding and high groundwater levels
Soil type	Jerusalem artichoke grows successfully in all soil types, except saline. The best for him is light-textured loamy and sandy loam soils.
Agronomic features	In Ukraine, the artichoke grows 2.7-3.4 m tall and forms a shrub of 2-5 productive stems. The stem is straight, green, with leaves and has 15-25 shoots. The leaves are large, ovate shape. Cones - multiflorous basket with bright yellow flowers. The diameter basket - 7-12 cm. Fruit - achene small. Mass of 1000 seeds - 7-9 g seeds in Ukraine conditions do not mature. Planting is in April – May. To ensure the required stand density, the rate of planting tubers is 0.7-2.0 t/ha. Planting depth is 8-10 cm.
Harvest	Usually in September, if harvested for biomass and tubers. If only for biomass, tubers can be left in the ground.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

COLUMBIAN GRASS *Sorghum almum Parodi*

	Columbian grass (Sorghum almum) is a hybrid resulted from the natural cross-pollination of Johnson grass (Sorghum halepense) with cultural species (Sorghum bicolor). In Ukraine conditions, Columbian grass forms a shrub of 3-5 productive stems with height of 230-300 cm. The main stem and all side shoots from the top end with panicle. The leaves are - long lanceolate, 60-80 cm long, 3-5 cm wide. Their number per plant ranges from 18 to 26 units. The leaves with their foundation cover the stem in half. Inflorescence - panicle 40-45 cm long. Seeds - elongated, brown and black. Weight of 1000 pcs. – 8.5-9.0 g. The root system is well developed and penetrates the soil to a depth of 2.0-2.5 m. During droughts capable of secondary roots.
Scientific classification	Family: Poaceae; Genus: Sorghum; Species: S. bicolor, S. almum Parodi
Class	C4 perennial grass
Life cycle	8-10 years
Yield	The first mowing at the beginning of panicle formation gives 30-35 t/ha biomass, during flowering - 45-50 t/ha and during the fruiting - 65-75 t/ha. Seed yield is 1.5-1.7 t/ha.
Growing season	Vegetation period for biomass: 70-80 days, for seeds: 110-120 days.
Temperature	Optimal sowing period is I-II decade of May when the soil warms up to a depth of 10 cm up to 12-14 °C. The optimum temperature for growth is +18 ... + 25 °C.
Rainfall	Optimal growing conditions are at annual rainfall ranging from 460 to 760 mm.
Soil type	Columbian grass is not very much demanding to soil types. Fertile, well-drained loamy soils or heavy clays, with soil pH ranging from 5 to 8.5. Columbian grass

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

	may withstand drought periods, but has no tolerance of waterlogging or flooding
Agronomic features	The viability of roots in the fifth year reduces and therefore for consistently high annual yields it is preferable to grow Columbus grass up to 4 years.
Harvest	Middle of September – end of October

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

CUP PLANT *Silphium perfoliatum* L.

	Under Ukraine conditions Cup Plant grows 2.3-3.0 m tall. The stem is straight, well-leafed, thick, four- and hexahedral. Number of productive stems of shrubs ranging from 6 to 12 pieces. The leaves are dark green, hard, jagged, 30 cm long and 13-15 cm wide. Inflorescence – a basket. The flowers are yellow, collected in a basket with a diameter of 3-5 cm. Mass of 1000 seeds – 18-25 g. In the first year, the plant forms its root system and rosettes of large leaves, thus the aboveground part grows very slowly. The stems develop only in the second and subsequent years of growth. Cup plant is attributed to plants of the long light day and is very demanding to the light intensity. Under natural conditions, it occupies the first tier of high-grass populations. For lack of light, the plants become severely depressed, especially in the first year.
Scientific classification	Family: Asteraceae; Tribe: Heliantheae; Genus: Silphium; Species: S. perfoliatum
Class	C4 perennial grass
Life cycle	15 - 20 years
Yield	In the first year of vegetation, cup plant does not produce high yields, therefore harvesting of biomass is advisable to begin in the second year of cultivation. In the budding phase aboveground mass yield is 50-60 t/ha, in the phase of flowering - 70-80, in the phase of fruiting - 90-110 t/ha. For long-term growing, cup plant plantations produce 19-31 t/ha of dry mass.
Growing season	The growing season from spring regrowth to ripening of seeds is 150-170 days.
Temperature	Cup plant vegetates in the temperature range from 5 to 40 °C. Its seeds germinate at 4-5 °C, but under such conditions, the shoots are individual and weak. Optimal for

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

	seed germination soil temperature (at a depth of seeding) is 10-12 °C. Plant growth starts at the average air temperature of 5 °C and higher. Plants are characterized by high resistance to cold and can tolerate spring frosts to -5 °C. Autumn vegetation stops at the reducing average daily temperatures below 5 °C. Plants are able to withstand low temperatures (up to -35 °C) in winter.
Rainfall	Cup plant is able to grow well in wet areas with close groundwater table and can withstand 10-15 daily flooding. However, it is adapted to the environment of temperate moisture and due to the well-developed root system, the plant does not suffer from short-term drought.
Soil type	The crop can be cultivated in flooded soils, low marsh and meadow areas with high groundwater table. The plant is sensitive to the reaction of the soil environment; a neutral or slightly acidic reaction of soil solution (pH 5.5-7.5) is optimal for it. Alkaline or acidic soils inhibit the development of roots as well as above-ground organs.
Agronomic features	In the first year of cultivation, to form 1 kg of green mass plant requires 143 kg of water. In the subsequent years, this figure drops to 66 kg, which indicates efficient utilization of water by plants.
Harvest	Beginning of September – middle of October

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

MISCANTHUS x giganteus J.M. Greef & Deuter ex Hodkinson &

Miscanthus x giganteus is a sterile hybrid of diploid ***Mischantus sinensis*** and tetraploid ***Mischantus sacchariflorus***. It can reach up to 5.0 m in height. Dark green leaves of 40-100 cm in length and 2.5 cm in width have a distinct middle white line. Miscanthus x giganteus flowers in autumn from September to October, depending on weather conditions. Its root system is fibrous. It does not have a main taproot and branches out evenly. Roots start their development from rhizomes (that are modified shoots). The roots can penetrate the soil to a depth of at least 100-150 cm, and reach 3 mm in diameter. However, the major portion of the roots (70 %) is located in the soil layer of 0-15 cm. Miscanthus x giganteus is a loose bunch plant and has a main and secondary shoots. The stem height ranges from 1.5 to 4.0 m in Europe and from 3.0 to 5.0 m in Southeast Asia. Plant height is determined by the number of interstices (up to 20) and their length. After sprouting, Miscanthus x giganteus plants start forming leaves one by one. One shoot can have 16 to 20 leaves. The leaves vary in length from 0.5 to 1.0 m, and from 1.0 to 2.5 cm in width.

Scientific classification	Family: Poaceae; Subfamily: Panicoideae; Genus: Miscanthus Species: Miscanthus giganteus
Class	C4 perennial grass
Life cycle	up to 20 years
Yield	15 – 20 dry t/ha after the 2nd year
Growing season	In Ukraine, growing season for miscanthus begins in April, when the soil temperature reaches 10-12 °C and ends with the onset of frost in October-November.
Temperature	The root system of miscanthus is capable of withstanding periodic low temperature (to - 23 °C) and snow. The plants become the most vulnerable after the first overwintering when the most intense growth and development of plants occur at a temperature of 25-32°C.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Rainfall	Miscanthus roots can penetrate at a depth of 2 m and effective use the available moisture resources. During the growing season, it needs about 700 mm of rainfall (it takes about 250 L of water to produce 1 kg of dry substance). When a prolonged drought occurs, leaves wilt, curl and die off.
Soil type	Namely on sands with low levels of ground water, on soils with regulated water regime, high organic matter content, on saline and alkaline soils.
Agronomic features	The technology of growing miscanthus includes pre-planting soil treatment to a depth of 12 cm. The seeds being non-viable, miscanthus can be propagated with parts of the roots (rhizomes), which are to be planted at a depth of 8-10 cm using special planters. The density of planting must be 10,000-20,000 seeds/ha. For planting, rhizomes of 10-30 g are used. During first vegetation season, miscanthus grows very slowly; therefore, main attention must be paid to weeds control. For this purpose, row tillage and herbicides application are required.
Harvest	Under adverse weather conditions in the first year of vegetation miscanthus forms low yield, less than 2 t/ha, so harvesting is economically worthless. Mostly, miscanthus is harvested after second-year vegetation with using common fodder harvesters. Harvesting may be carried out from late autumn to early spring. At this time the leaves fall leaving bare stalks, which contain little mineral elements. This way of harvesting ensures replenishment of soil organic matter. The collected miscanthus biomass can be crushed to chips or pressed into bales.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

POPLAR *Populus sp. L*

This is usually a tree, reaching heights of 40-45 m and a diameter of 1.5-2.0 m and more. The root system of poplar is strong. Its shape depends on the depth of groundwater and other characteristics of the soil profile. Poplar's type of branching is sympodial. The shoots are naked, without hairs or felty-downy. The leaves are simple, varying in their shapes: round, elliptical, ovate, rhombic, triangular or even lanceolate. The petiole is short and long, flattened laterally. Leaves can be three- and five-blade. Colour of leaves in different species varies from nitid bright light green to dull dark green or matte silvery-white. Some species have the whitish underside of leaves, while the others have green. Leaves of young shoots as well as of root shoots are very different from the leaves of the crown. The buds are relatively large, covered with multiple scales. The inflorescence is spicate panicle. Poplar blooms in early spring before leafing. Pollination occurs by the wind. Pollen quickly (within 1-2 days) falls down from the anthers. The seeds are small 1 to 2 mm long. One gram contains from 5,000 to 10,000 seeds. The seeds can be light grey or greenish-grey, with thin film-like skin and a small embryo, which does not contain nutrients. Once in the well-lit and wet surface, the seeds germinate within 10-15 hours. In dry conditions, the seeds quickly lose their germination.

Scientific classification	Family: Salicaceae; Tribe: Saliceae; Genus: Populus; Species: P. deltoides; P. nigra; P. canadensis Moenc; P.berlinensis Dipp.
Class	Woody plant
Life cycle	20-25 years
Yield	10-20 dry t/ha after 3-4 year of growing

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Temperature	The minimum growing temperature of the different Populus species has a range between 5°C and 10°C and the maximum growing temperature between 30°C and 40°C; the optimal growing temperature range is between 15°C and 25°C. Poplar species cannot survive if the temperature reaches 30°C or below.
Rainfall	Irrigation is beneficial to yield if the yearly rainfall is lower than 600 mm.
Soil type	Poplars are demanding for nitrogen, phosphorus, and calcium. They achieve the highest productivity on rich wet soils. The most favourable for them soil acidity is close to neutral (pH of 6-7). Under higher soil acidity, poplar cultivation requires prior liming. Soil pH of 4.5-5.0 is critical for poplar. Of the poplars species, the salt-tolerant ones are silver poplar and Bolle's poplar. Much less salt-tolerant are black poplar, eastern cottonwood, and some euroamericana hybrids. In particular, the most salt-tolerant is Populus euramericana cv. 'Marilandica'.
Agronomic features	Short-rotation poplar plantations are established using cuttings of 20-30 cm long, while the plantations for obtaining large assortment trees using 1-2-year-old woody cuttings. Soil tillage in both cases must be deep, with the loosening of the soil to a depth of 40-60 cm. The cuttings are planted in rows with 2 line each one, with the distance between rows of 1.5 m, and between the lines in the row of 0.75 m. The optimum planting density is 12,000-15,000 plants per hectare. In small plots, cuttings should be planted manually. For planting the cuttings in large areas, special machines are developed that cut willow cuttings during planting. The plantations for obtaining large trees should be arranged in squares placing cuttings 3.0 to 5 m from each other that corresponds to stand density from 1100 to 400. Tending of the plantations consists of complex of agronomic and chemical measures that ensure control of weeds, pests and diseases, fertilization, soil aeration and moisture preservation.
Harvest	In short rotations plantations, after the first growing season aboveground plant parts shall be cut to increase the number of shoots. Later on, the wood is harvested every 2-

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

	3 years during winter dormancy period. Cutting shoots are conducted at a height of 5-10 cm from the soil surface. After each harvest, tending soil and fertilization must be carried out. A lifetime of poplar plantations is about 25 years and longer. Plantations for obtaining large assortment trees grow 15-25 years with the periodic loosening of soil and cutting the lower branches to a height of 8.12 m in order to obtain knot-free wood. After cutting the plantations, new generation shoots can grow from root and stubs.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

SIDA *Sida hermaphrodita Rusby*

	All forms and varieties of Sida can grow in one place to 20 years, creating perennial plantations. Plants are tall, stems reach a height of 250-400 cm. The stem is straight, the cross section is round, flattened, many-sided. It is glabrous over the entire length, as if covered with a waxy coating. It has a different colour from light green to dark green and reddish-brown etc. By the end of the growing season stem coarsens, becomes wooden. The stem has an average of 45-46 knots. It forms, starting with 11-20 knot from the bottom, side shoots of the first order. Number of them changes significantly depending on the forms of plants. The leaves are large, with petioles of different lengths, placed alternately in a spiral. On the main stem during flowering and fruiting there are from 22 to 35 leaves (including fallen). Externally, they resemble the leaves of maple. Plants begin flowering in early August and continue until a hard frost. Mass of 1000 seeds ranges from 3.30 to 3.90 g.
Scientific classification	Family: Malvaceae; Genus: Sida; Species: S. hermaphrodita
Class	C3 perennial grass
Life cycle	15 - 20 years
Yield	During the first year of the ontogenetic development, individual organs of the perennial plant body are being formed. Despite this, sida manages to generate a significant amount of above-ground mass, especially starting from the stage of stem formation to budding. During these stages under the conditions of Ukraine, it produces more than 7 t/ha of biomass. On the second and subsequent years, the yield of aboveground mass significantly increases and reaches of about 80 – 100 t/ha of fresh biomass.
Growing season	Sida emerges from the soil in late April or early May, from buds at the base of the previous year's stems.
Temperature	Cold and dry conditions during spring may constrain seeds

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

	germination and development of new stems. Sida can survive without any problems under temporary lack of water and severe frost (-35 °C) in winter.
Rainfall	Sida can survive without a problem during the temporary deficit of water in summer.
Soil type	Due to the forming a strong root system, sida is suitable for fixing slopes, ravines, and sandy areas.
Agronomic features	Being a crop of high biological activity, sida makes a positive effect on agricultural, chemical and biological properties of the soil and promotes the growth, development, and productivity of subsequent crops. Perennial Sida grows better as a row crop with wide row spacing of 45 cm or 70 cm. The optimum seeding rate must be 5 to 6 kg/ha for 45 cm rows and 3-4 kg/ha for 70 cm. The depth of seeding on heavy soils should be 1-2 cm, on average 2-3 cm, and on soils of light texture 4 cm. After planting, pre-emergence and post-emergence harrowing with light harrows should be carried out.
Harvest	Dry stems can be harvested in winter with technical means of fodder collection.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

SORREL *Rumex patientia L x Rumex tianshanicus A. Los.*

Common sorrel or garden sorrel (Rumex acetosa), often simply called sorrel and also known as spinach dock or narrow-leaved dock, is a perennial herb that is cultivated as a garden herb or leaf vegetable. Sorrel is a slender plant about 60 cm high, with roots that run deep into the ground, as well as juicy stems and edible, oblong leaves. The lower leaves are 7 to 15 cm in length, slightly arrow-shaped at the base, with very long petioles. The upper ones are sessile, and frequently become crimson. It has whorled spikes of reddish-green flowers, which bloom in summer, becoming purplish. The stamens and pistils are on different plants (dioecious); the ripe seeds are brown and shining.

Sorrel was improved in the 1970s in Ukraine as a hybrid of Rumex patientia × Rumex tianshanious. This plant is similar in features to the wild sorrel, but it is much larger. Sorrel grows as tall as 180–200 cm and is a robust, rich flowering plant that creates well-ripened fruits. Sorrel is a photophilic plant that grows very quickly. It has a high content of proteins and vitamins: the protein content amounts to as much as 8 t/ha (from the whole above-ground mass).

Scientific classification	Family: Polygonaceae; Genus: Rumex acetosa L.; Species: R. patientia L. × R. tianshanious L.
Class	C3 perennial grass
Life cycle	8 - 10 years, up to 15 years
Yield	85 – 90 t/ha of fresh biomass (11.5 – 12 dry t/ha)
Growing season	Sorrel is sown in April in rows 50cm apart at an average of 6kg/ha seeds. The recommended depth of sowing is approximately 1.5–2cm. Because sorrel is a perennial plant, growth can also be established during the summer and autumn if the humidity is suitable for the germination of the seeds.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Temperature	Sorrel is unpretentious to external factors, drought-, cold- and frost resistant. At the beginning of the growing season (spring) can withstand frosts of minus 3-5 °C in the autumn - to minus 4-6 °C.
Agronomic features	The plant does not demand special treatment, and is covered abundantly with leaves every year. Sorrel is not particularly demanding with regard to nutrition, but it will benefit from rich organic manuring during the establishment of growth. Sorrel is propagated by seed. The seed should be treated by grinding off the small side wings. Sorrel will first produce seeds the second summer and the flower stalk will grow up to 2.6m.
Harvest	From the end of June till the end of July

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

SWITCHGRASS *Panicum virgatum* L.

Switchgrass is a perennial grass with slowly spreading rhizomes and a clump form of growth. Culms (stems) are erect and 50–250 cm tall, depending on variety and growing conditions. The stiff, tough stems are capable of withstanding moderate snowloads. The inflorescence is a panicle 15–50 cm long. Seeds are hard, smooth and shiny. Seed weights are variable and range between 0.7 and 2.0 g per 1000. Dormancy level may be high in newly harvested seed. Storing seed or other dormancy breaking techniques may be required before it can be sown. The grass is highly polymorphic, outcrossing, and has a basic chromosome number of nine. Most cultivars are tetraploids or hexaploids. Two major ecotypes can be distinguished. Lowland types are generally found in floodplains and are taller and coarser, while upland types are found in areas that do not flood, and have finer leaves and generally slower growth than lowland types.

Scientific classification	Family: Poaceae; Genus: Panicum; Species: P. virgatum
Class	C4 perennial grass
Life cycle	10 – 15 years
Yield	The height of switchgrass plants grown in an area of insufficient moisture in Ukraine ranges from 1.0 to 2.5 m, and the yield of dry biomass from 7 t/ha to 14.2 t/ha, depending on the varietal characteristics.
Growing season	Depending on the varietal characteristics early plant forms complete intense growing season in the third week of August, average forms - by the end of September, the later forms -to end of October. In some years the plants of late and very late forms remain green to severe frost (-5...7 °C).
Rainfall	Switchgrass grows well in fine to coarse textured soils, and in regions where annual precipitation falls between 380 and 760 mm or more per year. It can tolerate wet sites and survive short-term flooding.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Soil type	Switchgrass is most productive on moderately to well-drained soils of medium fertility and at a soil pH range of 5.5 to 7.0. Switchgrass will tolerate acid conditions but establishment and growth will be better if soils are limed to correct the pH to neutral.
Agronomic features	Seeding must be carried out when average soil temperature at a depth of 10 cm reaches 12-15 °C. The seed can be sown using normal small seed drills or cereal drills fitted with fine seed rolls. Seed depth should not be more than 1 cm. The number of plants established can be up to 400 plants per 1 m2 (up to 4 million per hectare. Cultipacking after planting helps establish good contact with soil and speeds germination. At the first vegetation year, main attention must be devoted to weeds control. Weed competition is a major cause of seedling establishment failure. It is important to reduce weeds prior to planting. Pre-emergence herbicides are often used to reduce weed competition when switchgrass is not competitive.
Harvest	Switchgrass should be harvested with conventional haying equipment after the top growth has completely died back. This will occur from mid- to late October in most regions. Moisture should be 15 percent or less to facilitate quick baling and transport, and to ensure a higher quality feedstock.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

WILLOW *Salix viminalis* L.

	Willow (***Salix viminalis*** L.) is a tall bush or bush-like tree up to 6-8 meters tall, which area covers Central Europe. The bark on older shoots is dark grey with longitudinal cracks. The root system is strong, plastic, usually without the expressed taproot. Young shoots are long, flexible, grey or yellowish-green, naked, downy on top. The buds are adjacent to shoot, flattened, with a bent tip, greyish-pubescent. Leaves are narrow, linear-lanceolate, 10-20 mm wide, 12-20 cm long, plain, pointed, dark-green on the upper-side and almost white, silky-downy on the down-side. The petiole is up to 1 cm long, downy. Stipules are pointed, glandular-toothed. The aments are sessile, up to 6 cm long. The seed-bud is silky-downy. Flowers have two stamens. The willow flowers along with foliage appearance in March-April. The fruit is light-greyish-yellowish silky-downy sessile two-valvate capsule 3-4 mm long. It matures in the second half of May. The seeds are grey-green, oval, and very small (0.9-1.1 mm long). They spread by a bundle of hairs carried by the wind) over long distances).
Scientific classification	Family: Salicaceae; Genus: Salix; Species: S. viminalis; S. triandra; S. acutifolia; S. purpurea, S. pentandra, S. alba.
Class	Woody plant
Life cycle	20-25 years
Yield	Salix grows and accumulates wood very fast in the first years. In the first year of vegetation, the young trees on the well-moistened medium fertile soils established using cuttings have an average height of 203-220 cm; in the next year (after cutting the shoots) the height increases to 280-320 cm. At the same time, it accumulates 47.3 m^3 of fresh wood per hectare. Under the conditions of Polissia, the productivity of 5-7-year-old plantations of Salix viminalis ranges from 12.4 to 22.7 t/ha of fresh wood per year. The dry matter content in the green mass of the willow is 48.2% the energy output from 1 kg of absolutely dry matter is about 17 kJ/kg.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Temperature	Salix is photophilous. At a temperature of 2…3°C plant awakens from its winter sleep. With temperatures above 3°C a vegetation starts.
Rainfall	Annual rainfall should be about 600 mm.
Soil type	Salix can successfully grow in many types of soil, including wet, poorly drained or periodically flooded. The optimal conditions for the willow plantations are well drained sandy and wet loamy soil with a pH range of 6 to 7. Rarely is it able to successfully establish in chalky soils. Dry soils are not suitable for willow cultivation. The plant is resistant to pollution and strong winds.
Agronomic features	To establish plantations of Salix viminalis cuttings of 20-30 cm in length are used. Soil tillage must be deep with the loosening of the ground to a depth of 40-60 cm. The cuttings are planted in rows with 2 line each one, with the distance between rows of 1.5 m, and between the lines in the row of 0.75 m. The optimum planting density is 12,000-18,000 plants per hectare. In small plots, cuttings are planted manually. For planting the cuttings in large areas, special machines are developed that cut willow cuttings during planting. Tending of the plantations consists of using complex of agronomic and chemical measures that ensure control of weeds, pests and diseases, fertilization, soil aeration and moisture preservation. After the first growing season, the aerial parts of plants shall be cut to increase the number of shoots (so called 'technological' cutting). Later on, wood can be harvested every 3 years. Cutting of shoots is conducted at a height of 5-10 cm from the soil surface. After each harvest, tending soil and fertilization must be carried out.
Harvest	Harvesting starts after falling of leaves. Cutting height is in average of about 0.1 m. The natural drying of chopped willow in heaps, which reduces the moisture content by about 5% in one month, is associated with some risk of microbiological degradation and a possible auto-ignition. The mechanization of harvesting and transportation by machines with capacity of 5-6 hectares per day is considered to be cost effective in the area of plantation over 1,000 hectares.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

3.2. Comparison of agronomic characteristics

The current know-how on the agronomy of energy crops in Ukraine initiated from forest cultivation practice. Forests were cultivated mostly in those regions where they were not naturally abundant because of specific natural conditions, including unfavourable soil types, water supply and climate features. According to Fuchylo [20] the main wood plants for cultivation, are pine, spruce, larch, poplar and willow, which consist of autochthonous and introduced species for long, medium and short rotation.

Poplars are the most fast-growing tree species of the temperate zone. Especially fast growth occurs in the first 10-15 years [21]. In the south of Ukraine, even under relatively poor conditions on fresh sandy loam, 21-year-old poplar stands yield up to 14.1 m^3/ha per year, and in favourable wet conditions, 27-year-old plantation produces 36.8 m^3/ha [22]. Under more favourable conditions of Polissia poplar shows better yields. Thus, according to Litvin [23] high yields of poplar are obtained at "Boyarska forest research station" of NUBiP by such black poplar clones as "Vareecken" (29.7 t/ha), "Serotina" (24.5 dry t/ha) and black poplar hybrid "Rochester" (34.6 t/ha), if grown on relatively rich and wet soils (C_3 of trophicity-moisture edaphic net of Alekseev-Pogrebnyak[5] [24]) and cut at 3rd – 5th year of cultivation. Another black poplar clone "Toropogrytskogo" is more suitable for southern regions of Ukraine. If planted with density 4-6 thousand plants per hectare and cut with 5 year rotation it can provide about 30 t/ha annually. But according to Odarchenko [25] under relatively rich but semi-wet soils (C_2 of trophicity-moisture edaphic net of Alekseev-Pogrebnyak) poplar clone "Rochester" (1 dry t/ha) showed worse biomass yield compared to clones "Ghoy" (9 dry t/ha) and 'Ijzer-5' (4 dry t/ha). Generally, according to Redko [26], poplar plantations grow better on semi-wet, wet and even swamp relatively rich and rich soils.

Willows are able to grow efficiently under a wide range of forest growth conditions, but optimally require wet, humus rich, well drained sandy loam and loamy soils [27]. According to Fuchylo [28] for energy biomass production the following species can be used: *Salix viminalis* L., *Salix triandra* L., *Salix purpurea* L., *Salix pentandra* L., *Salix acutifolia* L., *Salix alba* L. etc. First four species were investigated in a research held in 2003 in Boyarske forestry, located in Kyiv Polissia region. Under relatively rich

[5] Ukrainian forest ecological school that uses the edaphic grid of soil moisture and nutrient regimes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

and semi-wet conditions of a plot *Salix viminalis* L. species showed the highest yield of 40.7 fresh t/ha (2-year plant), compared to *S. pentandra* L. (9.2 fresh t/ha), *S. purpurea* L. (18.3 fresh t/ha), *S. triandra* L. (19.3 fresh t/ha) [29]. Significant yields of willow species were obtained on drained peatlands of Panfylska research station of the National Scientific Centre "Institute of Agriculture of NAAS". The research was held in 2005-2012 and included, among other energy crops, three species of willow: *Salix triandra* L., *Salix viminalis* L., *Salix cinerea* L. The highest biomass yield at the observed period belonged to *S. triandra* L. (average annual 24.68 dry t/ha), compared to *S. viminalis* L. (23.41 dry t/ha, average annual) and *S. cinerea* L. (11.03 dry t/ha, average annual) [30].

Another species, *Salix matsudana* Koidz., which was planted at research plantation of Kharkiv National Agrarian University named after V.V. Dokucheyev in 2013 and has been investigated till 2015 showed on average 33 t/ha of fresh biomass yield for the 2-year plantings [31].

Summarization of the results of willow field trials presented in the Table below:

	Willow variety	Plantation age, years	Agro-Ecological zone	Annual yield, fresh t/ha	Annual yield, dry t/ha
Boyarske forestry	*Salix viminalis* L.	2	Polissia	40.7	-
	S. pentandra L.	2	Polissia	9.2	-
	S. purpurea L.	2	Polissia	18.3	-
	S. triandra L.	2	Polissia	19.3	-
Panfylska research station	*S. triandra* L.	7	Forest-steppe	50.11	24.68
	S. viminalis L.	7	Forest-steppe	45.94	23.41
	S. cinerea L.	7	Forest-steppe	20.38	11.03
Kharkiv National Agrarian University	*S. matsudana Koidz.*	2	Forest-steppe	33	-

Survival rate of 10 *Salix* L. species under different climate and soil conditions was investigated by Maurer [32] at 3 experimental sites of Kyiv (total area: 0.269 hectares) and Vinnytsya (total area: 0.315 hectares) regions. Plantations were set in 2016 from own mother plantations. Results has shown that on poor wet soils (A_3 of of trophicity-moisture edaphic net of Alekseev-Pogrebnyak) only varieties of Swedish

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

selection "Inger"', "Clara" and "Rotchild" and of Ukrainian selection "Panfylska" have shown 100% survival and better height and cingulum growth.

Perennial grass *Miscanthus spp.* has also the biggest number of investigations in Ukrainian research papers. According to results of the field trials held in 2009-2012 in Borshchiv district of Ternopil region with climate conditions of the west forest-steppe zone [33] *Miscanthus x giganteus* yields of the 2nd 3rd and 4th year of cultivation amounted respectively 13.1-15.2 t/ha, 21.1-21.8 t/ha and 24.1-24.8 t/ha. According to Hymentyk plantings during the investigation period were influenced by insufficient amount of precipitation in 2009 and 2011 that twice reduced yields of *Miscanthus spp.* compared to 2010 and 2012. Planting time and depth also have influence on survival and yields of *Miscanthus spp.* plantations and according to Humentyk increase in case of earlier planting time and optimal planting depth of 8-10 cm [34].

Polissia lands are more suitable for *Miscanthus spp*. Results of field trials on drained lands of Pamfylivska research station, located in Yagotyn district of Kyiv region showed 29.4 dry t/ha for *Miscanthus x giganteus* [35]. The experiment was held in 2010 – 2011 on existing plantations, which included also such perennial energy crops as *Helianthus tuberosus* L. (31.8 dry t/ha), *Silphium perfoliatum L.* (26.2 dry t/ha) and *Sida hermaphrodita Rusby* (26 dry t/ha).

Miscanthus × giganteus variety "Guliver", introduced and registered by the Gryshko National Botanic Garden as an energy crop suitable for cultivation in Forest-Steppe and Polissia regions has an above-ground biomass annual yield of 63-68 t/ha during 15-25 year lifecycle. *Miscanthus sinensis Anderss*. variety "Veleten" has even higher yield of 75-82 fresh t/ha annually for 15-25 year lifecycle [19].

Another promising bioenergy crop is Switchgrass (*Panicum virgatum* L.*)* which is less demanding, compared to *Miscanthus x giganteus*, although has lower yields. A field trial of Poltava State Agrarian Academy that took place during 2013-2014 in Forest-Steppe zone investigated varieties "Cave-in-Rock", "Carthage" and "Forestburg". The highest yields for the 3rd and 4th year of vegetation years showed variety "Carthage" with 10.9 and 12.5 dry t/ha respectively. Little less yields belonged to variety "Forestburg" with 11.7 and 12 dry t/ha respectively. The lowest yield was for "Cave-in-Rock": 11.6 and 11 dry t/ha respectively for the 3rd and 4rth years of cultivation. Higher yields of the varieties were obtained for row spacings of 45 cm compared to 15 and 30 cm [36].

Results of studies on the integral assessment of switchgrass crops subject to the seeding rate (initial stand density) and varietal features were made for conditions of

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

the Central Steppe of Ukraine in moderately wet years (HTC 1.5–1.6). It was established that variety "Cave-in-Rock" at a seeding rate of 7.70 kg/ha had the highest productivity (on the average over 2011–2014) [37].

Productivity of Switchgrass variety "Zoriane" introduced by M. M. Gryshko National Botanic Garden and registered in 2015 in State Register of plant varieties suitable for dissemination in Ukraine amounts in average 45-64 dry t/ha for the 10-15 lifecycle according to field trials [38].

Columbian Grass (*Sorghum almum* Parodi) for soil and climate conditions of Polissia shows good yields of average 60-80 fresh t/ha for a 8-10 year lifecycle [39]. But according to field trials of 2011-2013 for the South Steppe zone of Ukraine yields are significantly lower with 17.9 dry t/ha for irrigation and fertilization conditions and 9.4 dry t/ha without irrigation [40].

A distinctive feature of a "Columbo" variety is seed breeding. 1 ha of a mother plantation of such varieties produced at M. M. Gryshko National Botanic Garden can supply 200 ha with seeds (Table 8).

TABLE 8. PROSPECTIVE HIGH PRODUCTIVE FEEDSTOCK CROPS FOR BIOENERGY PLANTATIONS

CROP	LIFE CYCLE, YEARS	YIELD, T/HA
Sida hermaphrodita Rusby	15-20	80-100
Rumex patientia L x Rumex tianshanicus A. Los.	8-10	85-90
Galega orientalis Lam.	10-15	70-85
Silphium perfoliatum **L.**	15-20	80-100
Helianthus tuberosus L.	8-10	60-80

Well-developed and new species of bioenergy crops when introduced on marginal lands can contribute to biodiversity, soil fertility and carbon sequestration. However, in each separate case a thorough analysis of the selected crop and environmental conditions should precede its introduction.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

4. CROPWAT program

CROPWAT 8.0 is a computer program for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns [41].

All calculation procedures as used in CROPWAT 8.0 are based on the FAO guidelines as laid down in the in the publication No. 56 of the Irrigation and Drainage Series of FAO "Crop Evapotranspiration - Guidelines for computing crop water requirements" [42].

4.1. Initial data for modeling of evapotranspiration and water requirements

Investigated territory is located near Kukhari village (Ivankiv district, Kyiv oblast) with geographical coordinates N 50°49`, E 29°37`. Energy willow Salix viminalis L. (varieties "Tora", "Tordis", "Inger") will be planted on given territory.

The main task of this modeling is to develop irrigation schedule and water requirements of willow cultivars.

CROPWAT modeling requires initial data about climate and soils of territory and planned crop.

Climatic data include minimal and maximal monthly temperatures, humidity, wind speed, sunny hours and precipitation. These data were taken from "Reference data on climate of Ukraine" [43] (Figure 11).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Country	Ukraine				Station	Ivankiv	
Altitude	140 m.		Latitude	50.49 °N		Longitude	29.36 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m?/day	mm/day
January	-9.5	-2.7	87	111	2.2	3.4	0.20
February	-9.1	-1.7	85	122	2.6	5.4	0.34
March	-4.5	3.6	83	122	4.3	9.7	0.75
April	1.7	12.5	74	115	6.3	15.1	1.81
May	7.5	20.3	66	111	8.7	20.5	3.29
June	10.9	23.2	67	104	10.1	23.4	4.05
July	12.9	25.4	70	93	9.8	22.4	4.09
August	11.9	24.4	72	87	9.0	19.2	3.43
September	7.3	19.4	75	87	6.9	13.4	2.13
October	2.7	11.7	82	101	4.2	7.4	0.98
November	-1.6	4.2	88	111	1.7	3.5	0.41
December	-6.0	-0.7	88	111	1.2	2.4	0.24
Average	**2.0**	**11.6**	**78**	**106**	**5.6**	**12.1**	**1.81**

FIGURE 11. CLIMATIC DATA OF INVESTIGATED TERRITORY

For chosen territory ETo values are in range from 0.20 mm/day (in January) to 4.09 mm/day (in July) with average value 1.81 mm/day (Figure 12). Amount of monthly precipitation was taken from bibliography [43]. Minimal level of precipitation is observed in February (42 mm), maximal in July (76 mm). Values of effective rain were calculated according to USDA S.C. Method.

Specific soil properties (total available soil moisture, maximal rain infiltration rate, initial available soil moisture) were obtained during on-site survey performed by “Ukragroenergo” company. The obtained results of survey are described on Figure 13.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

	Rain	Eff rain
	mm	mm
January	45.0	41.8
February	42.0	39.2
March	43.0	40.0
April	43.0	40.0
May	55.0	50.2
June	68.0	60.6
July	76.0	66.8
August	71.0	62.9
September	54.0	49.3
October	43.0	40.0
November	49.0	45.2
December	48.0	44.3
Total	**637.0**	**580.3**

Station: Ivankiv district — Eff. rain method: USDA S.C. Method

FIGURE 12. LEVEL OF PRECIPITATION IN IVANKIV DISTRICT

Soil name: Sandy loam

General soil data

Total available soil moisture (FC - WP)	150.0	mm/meter
Maximum rain infiltration rate	50	mm/day
Maximum rooting depth	200	centimeters
Initial soil moisture depletion (as % TAM)	0	%
Initial available soil moisture	150.0	mm/meter

FIGURE 13. SPECIFIC SOIL PROPERTIES OF INVESTIGATED TERRITORY

Salix viminalis L. – is one of the willow species which is able to produce big amount of biomass in short term. Collection of biomass takes place once in 2-3 years, usually in period from November to February. Therefore all growth period was divided into three smaller periods: 2017, 2018 and 2019 years. Data about crop (growth stages, planting date, rooting depth) for each year were taken from bibliographic sources [44] and are described on Figure 14-16.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

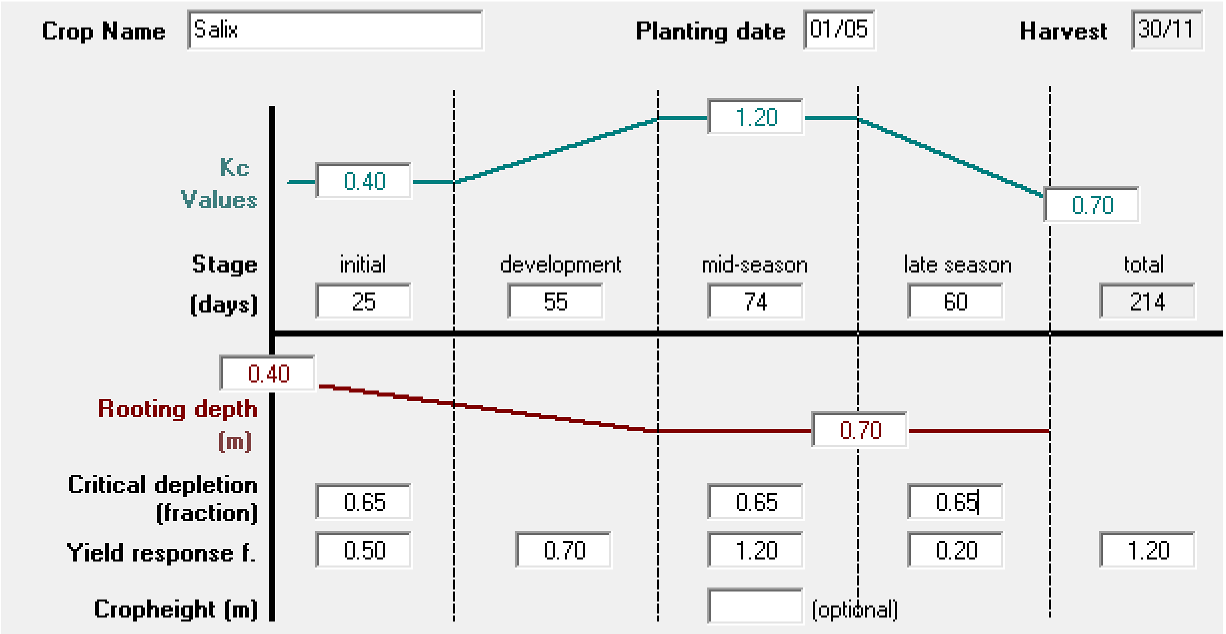


FIGURE 14. CROP DATA FOR THE 1-ST YEAR OF GROWTH

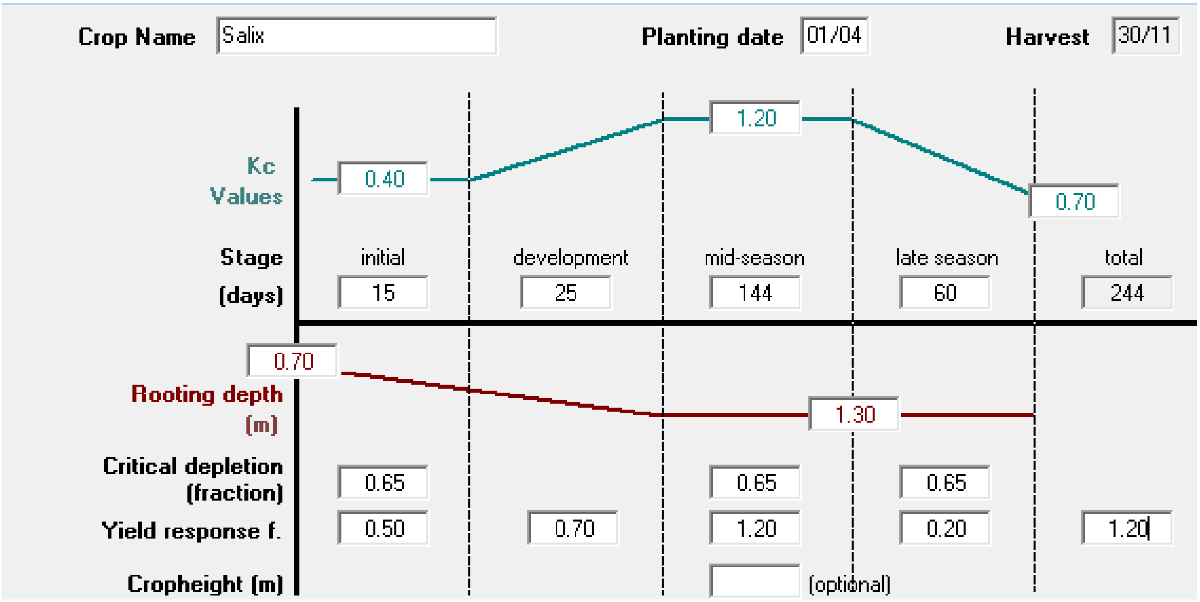


FIGURE 15. CROP DATA FOR THE 2-ND YEAR OF GROWTH

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

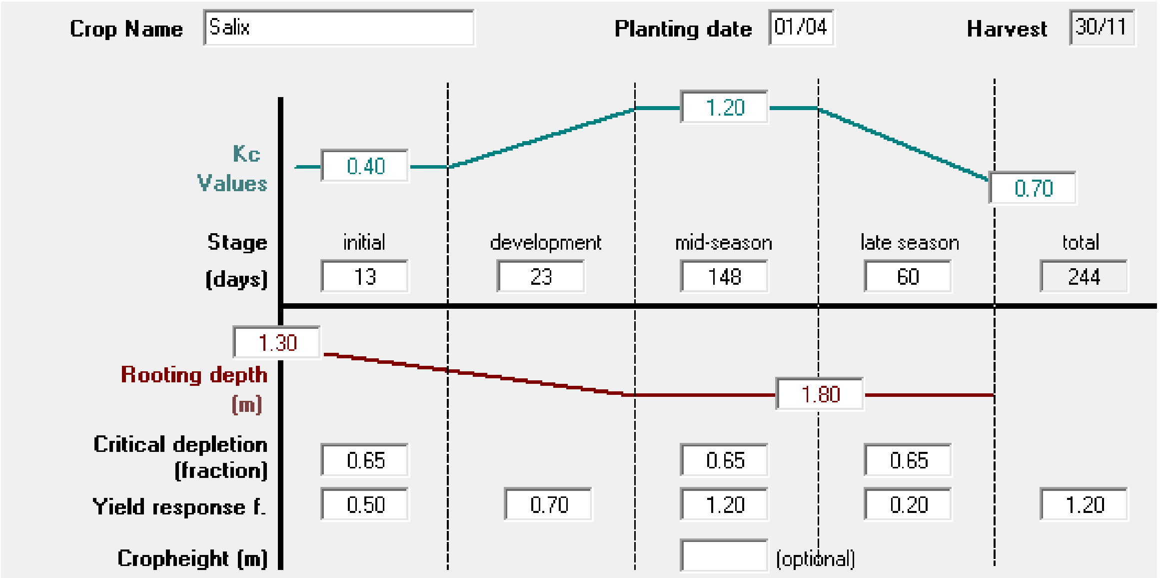


FIGURE 16. CROP DATA FOR THE 3-RD YEAR OF GROWTH

The growing periods are not same due to different growth stages. The growing periods are 214 days in first year and 244 day in second third years. Kc values remain same during all years.

4.2. Results of modeling

The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for Crop evapotranspiration under standard conditions (ETc) [45] and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration.

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach [46].

ETc is estimated with a ten day time step and over the total growing season using the effective rainfall. To calculate the effective rainfall, the method of the Soil Conservation Service of the United States Department of Agriculture (USDA SCS) was chosen.

$$ETc = ET0 \times Kc \text{ (mm) (1)}$$

where Kc refers to the crop coefficient, which incorporates crop characteristics and crop type, plant health and averaged effects of evaporation from the soil. ET0

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

represents the reference evapotranspiration, which expresses the evapotranspiration from a hypothetical grass reference crop not short of water.

The total Etc for the first growing year is 513.2 mm. Natural precipitations or effective rain (Eff. rain) creates 374.9 mm of water available for plant growing. Deficient water must be given by irrigation (Irr.req.) in amount 188.3 mm. The highest irrigation need is observed in 2-nd and 3-rd decades of July (24.2 and 28.9 mm respectively – Figure 17).

ETo station: Ivankiv | Crop: Salix

Rain station: Ivankiv district | Planting date: 01/05

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	1	Init	0.40	1.12	11.2	15.6	0.0
May	2	Init	0.40	1.31	13.1	16.7	0.0
May	3	Deve	0.43	1.52	16.7	17.9	0.0
Jun	1	Deve	0.57	2.15	21.5	19.1	2.4
Jun	2	Deve	0.71	2.89	28.9	20.4	8.5
Jun	3	Deve	0.86	3.49	34.9	21.0	13.9
Jul	1	Deve	1.00	4.09	40.9	21.9	19.0
Jul	2	Mid	1.15	4.69	46.9	22.7	24.2
Jul	3	Mid	1.20	4.64	51.1	22.1	28.9
Aug	1	Mid	1.20	4.38	43.8	21.7	22.1
Aug	2	Mid	1.20	4.12	41.2	21.4	19.7
Aug	3	Mid	1.20	3.60	39.6	19.8	19.8
Sep	1	Mid	1.20	3.08	30.8	17.9	12.9
Sep	2	Mid	1.20	2.56	25.6	16.3	9.3
Sep	3	Mid	1.20	2.10	21.0	15.3	5.6
Oct	1	Late	1.16	1.58	15.8	13.9	1.9
Oct	2	Late	1.08	1.05	10.5	12.7	0.0
Oct	3	Late	0.99	0.78	8.6	13.5	0.0
Nov	1	Late	0.90	0.54	5.4	14.7	0.0
Nov	2	Late	0.82	0.33	3.3	15.3	0.0
Nov	3	Late	0.74	0.26	2.6	15.1	0.0
					513.2	**374.9**	**188.3**

FIGURE 17. SALIX WATER REQUIREMENTS DURING 1-ST YEAR OF GROWTH

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

The total Etc for the second growing year is 686.6 mm. Natural precipitations or effective rain (Eff. rain) creates 415.1 mm of water available for plant growing. Deficient water must be given by irrigation (Irr.req.) in amount 324.4 mm. The highest irrigation need is observed in 2-nd and 3-rd decades of June (26.4 and 28.9 mm respectively– Figure 18).

ETo station	Ivankiv	Crop	Salix
Rain station	Ivankiv district	Planting date	01/04

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.40	0.58	5.8	13.0	0.0
Apr	2	Deve	0.45	0.81	8.1	12.9	0.0
Apr	3	Deve	0.74	1.69	16.9	14.2	2.8
May	1	Deve	1.06	2.95	29.5	15.6	13.9
May	2	Mid	1.20	3.94	39.4	16.7	22.7
May	3	Mid	1.20	4.25	46.8	17.9	28.9
Jun	1	Mid	1.20	4.56	45.6	19.1	26.4
Jun	2	Mid	1.20	4.86	48.6	20.4	28.3
Jun	3	Mid	1.20	4.88	48.8	21.0	27.8
Jul	1	Mid	1.20	4.89	48.9	21.9	27.0
Jul	2	Mid	1.20	4.91	49.1	22.7	26.4
Jul	3	Mid	1.20	4.64	51.1	22.1	28.9
Aug	1	Mid	1.20	4.38	43.8	21.7	22.1
Aug	2	Mid	1.20	4.12	41.2	21.4	19.7
Aug	3	Mid	1.20	3.60	39.6	19.8	19.8
Sep	1	Mid	1.20	3.08	30.8	17.9	12.9
Sep	2	Mid	1.20	2.56	25.6	16.3	9.3
Sep	3	Mid	1.20	2.10	21.0	15.3	5.6
Oct	1	Late	1.16	1.58	15.8	13.9	1.9
Oct	2	Late	1.08	1.05	10.5	12.7	0.0
Oct	3	Late	0.99	0.78	8.6	13.5	0.0
Nov	1	Late	0.90	0.54	5.4	14.7	0.0
Nov	2	Late	0.82	0.33	3.3	15.3	0.0
Nov	3	Late	0.74	0.26	2.6	15.1	0.0
					686.6	**415.1**	**324.4**

FIGURE 18. SALIX WATER REQUIREMENTS DURING 2-ND YEAR OF GROWTH

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

The total Etc for the third growing year is 692.3 mm. Natural precipitations or effective rain (Eff. rain) creates 415.1 mm of water available for plant growing. Deficient water must be given by irrigation (Irr.req.) in amount 415.1 mm. The highest irrigation need is observed in 2-nd and 3-rd decades of June (26.4 and 28.9 mm respectively– Figure 19).

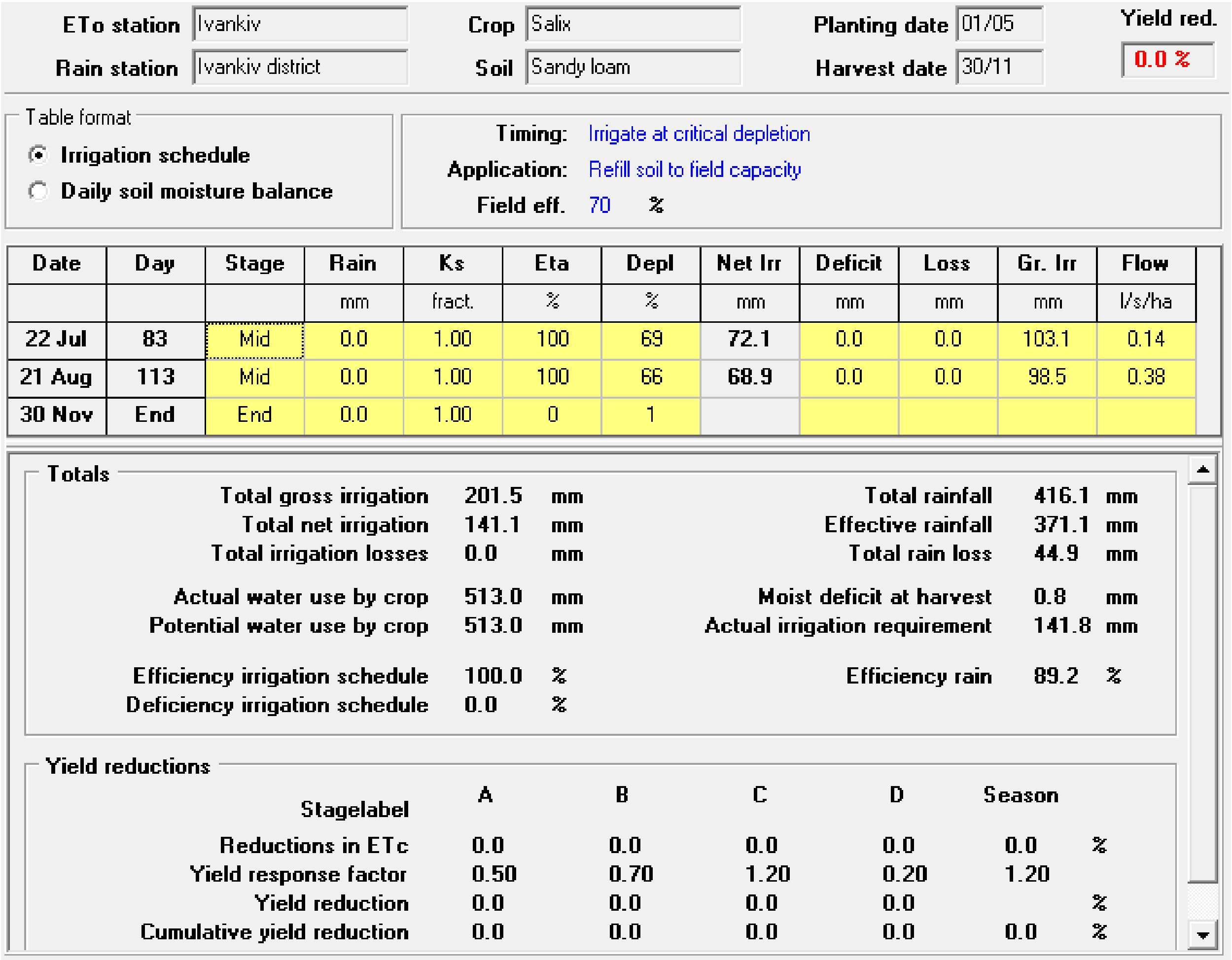
ETo station: Ivankiv
Rain station: Ivankiv district
Crop: Salix
Planting date: 01/04

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.40	0.58	5.8	13.0	0.0
Apr	2	Deve	0.50	0.90	9.0	12.9	0.0
Apr	3	Deve	0.83	1.92	19.2	14.2	5.0
May	1	Mid	1.15	3.21	32.1	15.6	16.5
May	2	Mid	1.20	3.94	39.4	16.7	22.7
May	3	Mid	1.20	4.25	46.8	17.9	28.9
Jun	1	Mid	1.20	4.56	45.6	19.1	26.4
Jun	2	Mid	1.20	4.86	48.6	20.4	28.3
Jun	3	Mid	1.20	4.88	48.8	21.0	27.8
Jul	1	Mid	1.20	4.89	48.9	21.9	27.0
Jul	2	Mid	1.20	4.91	49.1	22.7	26.4
Jul	3	Mid	1.20	4.64	51.1	22.1	28.9
Aug	1	Mid	1.20	4.38	43.8	21.7	22.1
Aug	2	Mid	1.20	4.12	41.2	21.4	19.7
Aug	3	Mid	1.20	3.60	39.6	19.8	19.8
Sep	1	Mid	1.20	3.08	30.8	17.9	12.9
Sep	2	Mid	1.20	2.56	25.6	16.3	9.3
Sep	3	Mid	1.20	2.10	21.0	15.3	5.6
Oct	1	Late	1.16	1.58	15.8	13.9	1.9
Oct	2	Late	1.08	1.05	10.5	12.7	0.0
Oct	3	Late	0.99	0.78	8.6	13.5	0.0
Nov	1	Late	0.90	0.54	5.4	14.7	0.0
Nov	2	Late	0.82	0.33	3.3	15.3	0.0
Nov	3	Late	0.74	0.26	2.6	15.1	0.0
					692.3	**415.1**	**329.2**

FIGURE 19. SALIX WATER REQUIREMENTS DURING 3-RD YEAR OF GROWTH

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

According to conducted modeling the actual irrigation requirement is 141.8 mm. It is necessary to conduct irrigation on 22 of July and 21 of August (72.1 and 68.9 mm respectively). Rain efficiency for this period is 89.2% (Figure 20).



Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
22 Jul	83	Mid	0.0	1.00	100	69	72.1	0.0	0.0	103.1	0.14
21 Aug	113	Mid	0.0	1.00	100	66	68.9	0.0	0.0	98.5	0.38
30 Nov	End	End	0.0	1.00	0	1					

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.50	0.70	1.20	0.20	1.20	
Yield reduction	0.0	0.0	0.0	0.0		%
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0	%

FIGURE 20. IRRIGATION SCHEDULE DURING 1-ST YEAR

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

According to conducted modeling the actual irrigation requirement is 270.1 mm. It is necessary to conduct irrigation on 22 of June and 12 of August (127.1 and 127.7 mm respectively). Rain efficiency for this period is 90.7% (Figure 21).

ETo station	Ivankiv	Crop	Salix	Planting date	01/04
Rain station	Ivankiv district	Soil	Sandy loam	Harvest date	30/11

Yield red. 0.0 %

Table format
- (•) Irrigation schedule
- ( ) Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
22 Jun	83	Mid	0.0	1.00	100	65	127.1	0.0	0.0	181.5	0.25
12 Aug	134	Mid	0.0	1.00	100	65	127.7	0.0	0.0	182.4	0.41
30 Nov	End	End	0.0	1.00	0	8					

Totals

Total gross irrigation	363.9	mm	Total rainfall	459.1	mm
Total net irrigation	254.7	mm	Effective rainfall	416.2	mm
Total irrigation losses	0.0	mm	Total rain loss	42.9	mm
Actual water use by crop	686.3	mm	Moist deficit at harvest	15.4	mm
Potential water use by crop	686.3	mm	Actual irrigation requirement	270.1	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	90.7	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.50	0.70	1.20	0.20	1.20	
Yield reduction	0.0	0.0	0.0	0.0		%
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0	%

FIGURE 21. IRRIGATION SCHEDULE DURING 2-ND YEAR

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

According to conducted modeling the actual irrigation requirement is 262.7 mm. It is necessary to conduct irrigation on 12 of June (262.7 mm). Rain efficiency for this period is 93.5% (Figure 22).

ETo station	Ivankiv	Crop	Salix	Planting date	01/04	Yield red.	
Rain station	Ivankiv district	Soil	Sandy loam	Harvest date	30/11	0.0 %	

Table format
- (•) Irrigation schedule
- ( ) Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
12 Jul	103	Mid	0.0	1.00	100	67	179.8	0.0	0.0	256.8	0.29
30 Nov	End	End	0.0	1.00	0	31					

Totals

Total gross irrigation	256.8	mm	Total rainfall	459.1	mm
Total net irrigation	179.8	mm	Effective rainfall	429.4	mm
Total irrigation losses	0.0	mm	Total rain loss	29.7	mm
Actual water use by crop	692.1	mm	Moist deficit at harvest	82.9	mm
Potential water use by crop	692.1	mm	Actual irrigation requirement	262.7	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	93.5	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.50	0.70	1.20	0.20	1.20	
Yield reduction	0.0	0.0	0.0	0.0		%
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0	%

FIGURE 22. IRRIGATION SCHEDULE DURING 3-RD YEAR

CONCLUSIONS ON CROPWAT MODELLING

Conducted modeling has proved that growing of *Salix viminalis* L. ("Tora", "Tordis", "Inger" varieties) is possible. CropWat helped to estimate crop water requirement and to develop irrigation schedule for each year of growth: 1-st year – 141.8 mm; 2-nd year – 270.1 and 3-rd year – 262.7 mm. Such irrigation volumes are technically feasible.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

5. Willow field trials

This section of the report aims at giving the information on *Salix viminalis* L. field trials started in 2015 near Kukhari village in Ivankiv region. Taking into account the obtained information on crop yield and cultivation conditions on underutilized lands in Ivankiv region, the cellulosic feedstock cost will be identified.

Case study site is located at the area of 50 ha near Kukhari village (Figure 23), approx. 25 km from Ivankiv town.

Plantation area is operated by Ukragroenergo LLC, subsidiary of Ukrteplo group of companies, which implements energy efficiency projects on fossil fuels substitution by such local fuels as wood pellets, briquettes, chips, straw etc. Ukrteplo has replaced more than 50 million cubic meters of natural gas in 16 regions of Ukraine, and converted to solid fuel approximately 100 boiler-houses.

Underutilized agricultural lands used for the experimental trials are rented by a company and consist of untaken land shares (state property) and individual land shares (after canceling of cooperatives land was divided into shares and distributed to the population). Lands were abandoned 15 years ago because of unsatisfying soil conditions and bad economic conditions in the region.

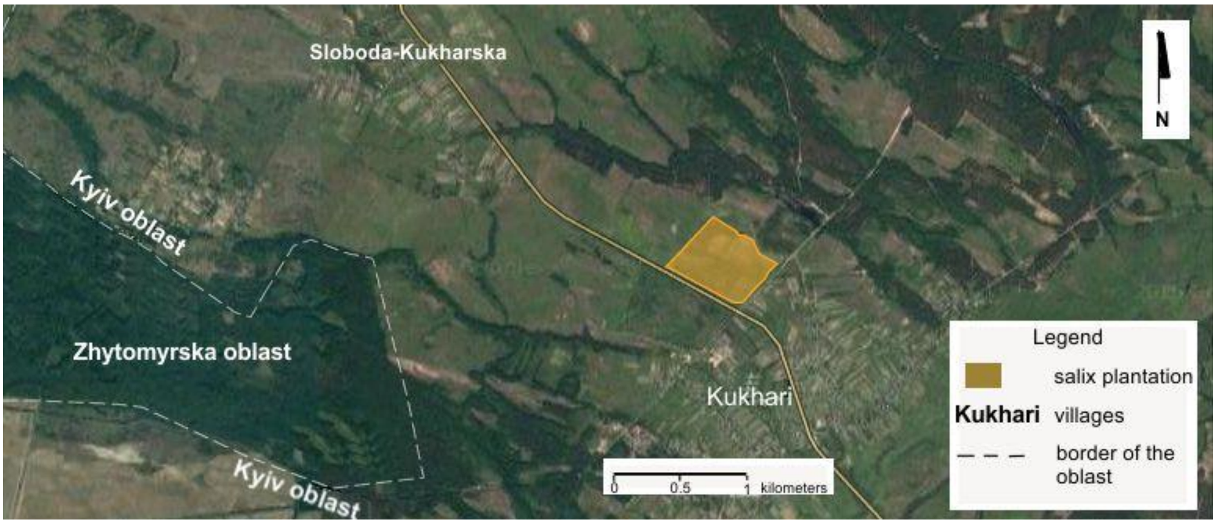


FIGURE 23. LOCATION OF THE CASE STUDY SITE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Experimental area is 50 ha with sandy, sandy loam soils (Figure 24).

Swedish *Salix viminalis* L. varieties "Tora", "Tordis", "Inger"grown on the plantation.

FIGURE 24. EXPERIMENTAL FIELD BEFORE SALIX VIMINALIS L. GROWING

Soil analysis (Table 9) shows low indexes of chemical fertility of the following elements: nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), zinc (Z), Cu (copper), boron (B).

TABLE 9. RESULTS OF SOIL ANALYSIS ON THE EXPERIMENTAL FIELD (CHEMICAL COMPOSITION, MG/KG)

N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Mo	B	Na
26	169	43	725	75	11	610	90	2.9	1.3	0.05	0.3	10

Level of pH_{KCl} is 5.20 (acid soil), the level of electroconductivity of soil (EC mS/cm=0.39) is low for growing common food agriculture crops.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

5.1. Flow process chart of willow

The agricultural company "Ukragroenergo" willow plantation took two stages. At the first stage (preparation one), a mother plantation was planted, which reached 50 ha in 2016.The mother plantation area will increase to 80 ha, and an industrial plantation of 50 ha will be planted in 2017 (Table 10). At the second stage, the seedlings, obtained from the mother plantations, will be planted over three years in three group of fields of 667 ha each to reach the industrial plantations area of 2000 ha. The cycle of willow biomass harvesting is 3 years. The planned lifecycle of industrial plantation is 24 years.

TABLE 10. PLANTATION PLANTING ARRANGED BY YEARS

Plantation type	Areas by years, hectares					
	2015	2016	2017	2018	2019	2020
Mother plantation	30	50	80			
Industrial plantation			50	667	667	667

Three different high-yielding varieties of *Salix viminalis* L.: "Tora", "Tordis", "Inger", will be used to stabilize wood biomass yield against unpredictability of weather conditions. It will also increase the resistance to diseases and reduce the negative impact of parasites.

MOTHER PLANTATION

Willow is planted in strips: the distance between the rows in a strip is 0.75 m and the distance between the strips is 1.5 m (Fig. 25). The density of the mother plantation planting is 30 thousand pieces per hectare. In contrast to the industrial plantation, the distance between plants in the row of the mother plantation is 2 times less. Technological operations for preparation of soil, planting and caring for willow plants are identical with the technological operations for industrial plantations. As the land has not been used for over 15 years, addition preparation operations should be used to obtain arable plain clean soil without plant residues. In general, soil preparation included: perennial weeds control (by means of chemicals), disking, plowing, treatment of compound fertilizers according to the results of soil tests and pre-plant alignment and roller compaction.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

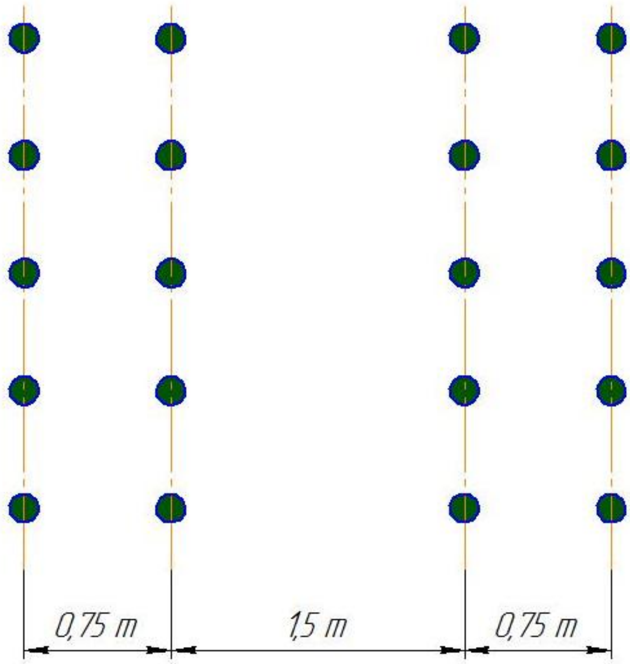


FIGURE 25. PLANTING SCHEME: distances between seedlings in a row are 0.3 m for mother plantation and 0.6 m for industrial plantation

To obtain seedlings, 1-2 m long and 0.7-2 cm thick 1-2-year offshoots are cut off. The willow offshoots are harvested in late autumn or early spring after heavy frosts and before budbreak. Cutting of seedlings is conducted 3-7 days before planting by a pruner and cleaning by a short garden pruner or a knife. Prepared in such a way seedlings are bundled (50 or 100 pieces in a stick for easy records). The 7-20 mm thick lateral branches can also be used as planting material. To prevent budbreak and damaging of seedlings, they are stored at temperatures from 0 to 40 °C. A team of 15 employees for 15 days can prepare long seedlings in an amount necessary for 100 ha of industrial plantations.

Before planting of seedlings, they are soaked in water for 1-2 days. For planting in mother plantations, a 4-row planting machine Egedal, which uses long seedlings, is used. In 2015, an abnormally dry and hot summer negatively affected the planting of willow. However, in 2016 the weather conditions were more favourable and the mother plantation has grown (Figure 26 a, b, c, d), ensuring the compliance with planting schedule of the industrial plantations. The cost of a long seedling, which the planting machine divides into 5 short pieces, for the industrial plantation is 0.184 EURO (5 UAH[6]).

[6] 1 Euro = 27.12 UAH - the official rate of the National Bank of Ukraine on 24.11.2016

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

FIGURE 26 (A). 1 MONTH MOTHER PLANTATION

FIGURE 26 (B). 2 MONTH MOTHER PLANTATION

FIGURE 26 (C). 3 MONTH MOTHER PLANTATION

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

FIGURE 26 (D). 1 YEAR MOTHER PLANTATION

INDUSTRIAL PLANTATION

Industrial plantation of willow will be planted on land where crops have not been grown for more than 15 years. Disking, spraying of non-selective glyphosate herbicide, fertilizing treatment taking into account a soil analysis, and plowing after the herbicide waiting period (2-3 weeks) will be done for preparation of fields in the preparatory year.

In the first year, a tractor with a special purpose planting machine will do pre-plant soil preparation – cultivation and planting. In addition, the planting material must be treated with insecticides. Preparation of seedlings will be performed manually, their transportation will be carried out by a tractor-trailer. Next, the operations on planting material tending, which combine chemical and mechanical methods of weed control, will be done. Immediately after planting in fields, herbicide with Pendimethalin as an active ingredient (concentration 330 g/l) spraying with simultaneous treatment of nitrogen fertilizers will be done.

Next, inter-row tillage will be done by a soil cutter. After that, if necessary, the first disking between rows must be carried out. Then the herbicide spraying and the second disking between rows must be done. Every third year after defoliation, willow harvesting will be done by a self-propelled combine. Tractor-trailers will be used for biomass transportation. After harvesting operations, fertilizers will be applied to overcome the lack of plant nutrients according the volumes of plant nutrients depletion and the soil analysis. In case of plant damage, necessary measures will be taken according to the situation. List of technological operations with approximate terms is given in Table 11.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

TABLE 11. TECHNOLOGICAL OPERATIONS FOR INDUSTRIAL PLANTATION

№	Name of technological operations	Terms, month
	Preparatory year	
	1. Primary tillage	
0-1	Disking up to 12 cm depth	VIII
0-2	Water supply for spraying	VIII
0-3	Preparation and spraying of herbicide	VIII
0-4	Mineral fertilizers transportation	IX
0-5	Fertilizer spreading	IX
0-6	Ploughing up to 30 cm depth	IX
	First year	
	2. Pre-plant tillage and planting	
1-1	Pre-plant cultivation	IV
1-2	Preparing and loading of seedlings	IV
1-3	Seedlings transportation	IV
1-4	Planting to 20 cm depth with inter-rows: double 1.5 cm and single 0.75 cm with insecticide treatment	IV
	3. Caring for plants	
1-5	Water supply for spraying	IV
1-6	Preparation and spraying of herbicide	IV
1-7	First inter-row cultivation with folding power harrow between adjacent rows	V
1-8	First inter-row disking	V
1-9	Water supply for spraying	V
1-10	Preparation and spraying of herbicide with carbamide	V
1-11	Second inter-row disking	VI
	Third year	
	4. First harvesting of biomass	
3-1	Harvesting on 3 year	after leaves falling
3-2	Biomass transportation	
3-3	Preparation and spreading of fertilizer	
	6, 9, 12, 15, 18, 21th year	
	4. Second and following harvesting of biomass	
6-1	Harvesting on 6 year	after leaves falling
6-2	Biomass transportation	
6-3	Preparation and spreading of fertilizer	
	24th year	
	4. Last harvesting of biomass	
24-1	Harvesting on 24 year	after leaves falling
24-2	Biomass transportation	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Six technological operations will be made in the preparatory year, 11 in the first year, 3 in every 3rd year.

It is planned to store wood chips in piles in the open air (Figure 27). According to the recommendations of Salix Energy LLC (first Ukrainian company that grow willow at commercial scale) [47], piles' height should be up to 4 m. At that, willow chips lost 7-10% of moisture over 2-3 months, but it should be periodically stirred. A telescopic wheel loader is used for cargo operations and stirring.

Willow chips will be transported from a harvester to a local storage located on the edge of the plantation field. After harvesting, willow chips will be transported by all available means of transport to a central store that is located 35 km away from the farthest field.

FIGURE 27. CHIPS PILE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

5.2. Feedstock cost

INVESTMENTS IN TECHNOLOGY EQUIPMENT

Equipment that needed to perform technological operations on mother and industrial plantations presented in Table 12. Ukragroenergo Company owns some of the equipment and have plans to purchase other within next years. Total estimated investment in equipment for the cultivation and harvesting of willow is 988 thousand EURO. Transfer of costs from Ukrainian currency Hryvnia (UAH) to Euro was carried out at the official rate of the National Bank of Ukraine on 24.11.2016: 1 Euro = 27.12 UAH.

TABLE 12. TECHNOLOGICAL EQUIPMENT FOR WILLOW PLANTATIONS

Type	Unit cost, thousands EURO	Presence, units	Need to purchase (min.), units
Tractors			
XTZ-242	50682	1	–
John Deere 6920	81268	1	–
MTZ-892	17883	1	–
John Deere 8360R	199115	1	–
K-700	19000	1	–
Machines			
Combine John Deere 7300	179204	–	1
Chipping Head HSAB's SRC	79646	–	1
Harrow BDVP-5,5	16114	1	–
Tanker RZS-6	20870	–	1
Sprayer HARDI RANGER	28872	1	–
Tractor-trailer 2PTS-6	4204	1	3
Fertilizer spreader RUN-0,8	1364	1	–
Plow KUHN with 6 moldboards	37426	1	–
Cultivator KPS-8	13164	1	–
Planter Egedal 4 rows	89602	1	1
Folding power harrow Celli Ranger 400	12832	1	–
Disc plough-harrow LSD-3,7	9027	1	–
Machine for liquid organic fertilizers VNC-20	25295	–	1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Standard machines have been additionally converted to perform inter-row cultivation. The design of Disc plough-harrow LSD have been changed (Figure 28): discs have been taken and metal channel bar that protect willow from damage have been inserted.

FIGURE 28. DISC PLOUGH-HARROW LSD FOR WILLOW PLANTATIONS

Four-row planting machine "Egedal" is used for seedlings of willow planting (Fig. 29). Two men charge long shoots into the machine that perform cutting of them into seedlings with length of 20 cm and planting at a given depth. Minimizing of the human factor during the planting will ensure compliance with required planting scheme and density trees.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

FIGURE 29. FOUR-ROWS PLANTER EGEDAL

Given the large area of plantations (over 250 hectares), self-propelled forage harvester with a special attachment for wood cutting and chopping is used for biomass harvesting (Fig. 30).

FIGURE 30. SELF-PROPELLED FORAGE HAVESTER JOHN DEERE 7300 WITH SPECIAL WODDY CUTTING HEAD HSAB'S SRC

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

Tractor with trailers will move together with harvesting combine. Trailers with capacity of 25 m^3 are used for chips accumulation and transportation to a local warehouse. For transportation to the central warehouse and to the future energy facilities, trucks with trailers for chips will be used.

INITIAL DATA FOR CALCULATION OF THE NET COST OF WILLOW CHIPS

Technological operations for field preparation will be conducted in year 0. The calculation is performed for 8 reproduction cycles, from 1 to 24 year. Thus, the whole cycle of industrial plantation operation for each of the group of fields will last 25 years. Table 13 shows the main characteristics of industrial plantations of willow.

TABLE 13. CHARACTERISTICS OF INDUSTRIAL PLANTATION

	Units	Value
Plantation area for annual harvesting	ha	667
Growing cycle	years	3
Annual rent for the land	EURO/ha	12.9
Density of seedlings planting	units/ha	15000
Seedling cost	EURO/unit	0.037
Expected annual yield of biomass with water content W=50%	t/(ha·year)	20
1 and 8 Harvesting - biomass yield 60%	t/ha	36
2-7 Harvesting - biomass yield 100%	t/ha	60
Local storage facility on the field at the distance	km	2
Central storage facility at the distance	km	25
Diesel fuel price	EURO/l	0.77
Amortization rate for technics	years	8

To protect the willow, different plant protection products will be used. According to the gained experience of mother plantations tending, two herbicides and insecticides are planned to use (Table 14). However, the range and application rate of plant protection products will vary according to the situation and expert advice.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

TABLE 14. PLANT PROTECTION PRODUCTS FOR PLANTATION

Year	Type of protection	Active ingredient	Norm, l/ha	Price, EURO/l	Costs, EURO
1	Herbicide	Glyphosate 450 g/l)	2.4	8.37	13392
1	Herbicide	Pendimethalin 330 g/l	3	10.07	20133
1	Insecticide	Imidacloprid 600 g/l	0.5	21.33	7112

It is planned to apply next fertilizers during the plant growing: chlorine-free compound mineral fertilizer of plant origin during primary tillage; addition carbamide fertilization, and carbamide ammonia mixture (mass fraction of nitrogen is 32%) after harvesting (Table 15). Chlorine-free compound mineral fertilizer of plant origin contains 28–41% potassium (K2O), 4-6% phosphorous (P_2O_5), 8-12% magnesium (MgO), 8-16% sulphur (SO_4), 10-17% calcium (CaO) and key trace elements: iron (Fe) – 1340 mg/kg, boron (B) – 1000 mg/kg, zinc (Zn) – 900 mg/kg, copper (Cu) – 240 mg/kg, manganese (Mn) – 150 mg/kg, chromium (Cr) – 6.3 mg/kg, molybdenum (Mo) – 1.5 mg/kg, cobalt (Co) – 0.37 mg/kg. According to a soil analysis, rates and dosage of fertilizers will be adjusted.

TABLE 15. FERTILIZERS FOR PLANTATION

Year	Name	Norm, kg/ha	Price, EURO/t	Costs, EURO
1	Mineral fertilizer	250	221.24	36873
1	Carbamide (N46.2)	10	294.99	1967
after harvest	Carbamide ammonia mixture (CAM-32)	469	199.12	62257

In the first year, costs of protection of industrial plantations on 667 ha will amount to 60,769 EURO, fertilizer – 38,840 EURO. Mineral fertilizers should be applied after each harvest to the value of 62,257 EURO.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

CALCULATION RESULTS OF WILLOW CHIPS NET COST ON THE LOCAL STORAGE FACILITY

Flow process chart is formed for calculation of costs of *Salix viminalis* L. growing and harvesting on the industrial plantation. The chart represents the list and sequence of technological operations (Table 11), terms of their carrying out, the configuration of machinery tractor units, the outputs per shift and the rates of fuel consumption, the needs for machine operators and support staff, the need for fuel, the need for technics, labor costs, costs of fuel and lubricants, costs of materials (seedlings, plant protection products and fertilizers), costs of amortization, costs of technics maintenance and repairs. The calculation results are shown in Table 16.

Technological operations costs (*Salix viminalis* L. growing and harvesting on the industrial plantation) will be 2469 thousand EURO during 25 years operation cycle. The cost of annual land rent is 12.9 EURO/hectare. It is smaller in comparison with the cost of the farmland rent due to the fact that the plantations are on underutilized lands. There are the calculation results of willow chips net cost in the local storage facility by years in Table 17.

The production cost of willow chips is ***9.3 Euro/fresh t without VAT*** in case of own fund investments (without bank loan) and with a 24 years term of industrial plantation. In this case, the possible biomass yield from 1 hectare will be 432 tons (during 24 years). If the life of plantations is reduced to 21 years, the cost of chips will rise ***to 9.7 Euro/fresh t without VAT.*** The market price of wood chips in Ukraine is around 31.3 €/fresh t without VAT.

TABLE 16. COSTS BY TECHNOLOGICAL OPERATIONS

№	Labor costs, EURO	Costs of fuel and lubricants, EURO	Costs of materials, EURO	Costs of amor-tization, EURO	Costs of main-tenance and repairs, EURO	Total costs, EURO
			Preparatory year			
0-1	110	5162	–	8349	5689	19311
0-2	56	361	–	12767	7172	20357
0-3	78	516	13392	5844	4785	24617
0-4	76	484	–	10684	5086	16330
0-5	85	723	36873	2406	1773	41860
0-6	252	11202	–	29568	19432	60454
					Sum	**182928**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

			First year			
1-1	55	1962	–	7981	6207	16204
1-2	5338	–	–	–	–	5338
1-3	339	1162	368732	10684	5086	386002
1-4	437	9292	7112	36090	20011	72942
1-5	0	0	0	12767	7172	19939
1-6	0	0	20133	5844	4785	30763
1-7	192	3820	0	7939	6101	18053
1-8	192	2271	0	11287	5508	19258
1-9	0	0	0	12767	7172	19939
1-10	0	0	22099	5844	4785	32729
1-11	192	2271	0	11287	5508	19258
					Sum	**640424**
			Third year			
3-1	417	10841	0	31796	28135	71188
3-2	967	13752	0	10684	5086	30490
3-3	136	2891	62257	28051	14729	108064
					Sum	**209742**
			6, 9, 12, 15, 18, 21th year			
6-1	463	12389	0	32356	28673	73881
6-2	1792	22920	0	10684	5086	40482
6-3	136	2891	62257	28051	14729	108064
					Sum	**222427**
			24th year			
24-1	417	10841	0	31796	28135	71188
24-2	967	13752	0	10684	5086	30490
					Sum	**101678**
Total costs for 667 ha plantation during 25 years						**2469337**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

TABLE 17. CALCULATION RESULTS OF WILLOW CHIPS NET COST ON THE LOCAL STORAGE FACILITY BY YEARS

Years	0	1	3	6	9	12	15	18	21	24
Costs of growing and harvesting, thous. EURO	182.9	640.4	209.7	222.4	222.4	222.4	222.4	222.4	222.4	101.7
Costs of land rent, thous. EURO	8.6	8.6	17.2	25.8	25.8	25.8	25.8	25.8	25.8	25.8
Total costs, thous. EURO	191.5	649.0	226.9	248.2	248.2	248.2	248.2	248.2	248.2	127.5
Increasing costs, thous. EURO	191.5	840.6	1067.5	1315.7	1564.0	1812.2	2060.5	2308.7	2556.9	2684.4
Biomass yield, t/ha			36.0	60.0	60.0	60.0	60.0	60.0	60.0	36.0
Mass of chips from plantation, thous. t			24	40	40	40	40	40	40	24
Increasing mass of chips from plantation, thous. t			24	64	104	144	184	224	264	288
Net cost of chips, EURO/t without VAT			44.5	20.6	15.0	12.6	11.2	10.3	9.7	9.3

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

6. Conclusion

The results of agronomic feasibility study for perennial energy crops growing on underutilized lands by the example of case study site located in Ivankiv region, Kyiv oblast, Ukraine are presented in the report.

Deep statistical analysis was undertaken to evaluate the amount of underutilized land available for biomass crop cultivation in the study area. In total, according to the statistical analysis, on the average **55,000 hectares** of agricultural land are available in the 100 km radius from potential biorefinery. Those lands include the following categories: free arable lands and layland. Availability of underutilized lands in the region is due to the general economic conditions of the region that in turn is due to closeness of Chornobyl Exclusion zone. Traditional agriculture in this area is not well developed, the land is unsuitable for growing of common grain crops because of low soil fertility: economic indicators are not very attractive (low yields).

To make his choice of a certain dedicated crop to be cultivated on suitable marginal land for bioenergy purposes, the decision-maker should take into consideration different aspects and impacts: if productivity and cost-effectiveness is the primary objective of the end-user, ecological services have an important role, especially in long-term scenarios, together with scarcity or temporary unavailability of agronomical inputs (e.g. water).

Climatic conditions in the region are most suitable for growing willow. Literary analysis and review of field research indicates that this culture is the most common in Ukraine in general, and in particular for the demonstration area. From the reviews of field trials performed on the species considered in this study, in the case of Ukraine, the first among the most promising bioenergy crops for a large-scale deployment appear to be willow ***Salix viminalis*** **L.**

Results of crop water requirement modeling (with the help of CropWat model tool) show that growing of *Salix viminalis* L. in the case study site area requires additional irrigation at the amount of: ***1-st year – 141.8 mm; 2-nd year – 270.1 and 3-rd year – 262.7 mm.***

Field trials of the *Salix viminalis* L. (varieties "Tora", "Tordis", "Inger") growing at the case study site (50 ha experimental field with sandy, sandy loam soils that is used as a mother plantation) show that the possible biomass yield of industrial plantation could reach **10 dry tons/hectare/year**.

In case of 24 years term of industrial plantation theproduction cost of willow chips is estimated at ***18.6 Euro/dry t*** *excluding tax and interests.* If the life of plantations is reduced to 21 years, the cost of chips will rise *to 19.4 Euro/dry t without VAT.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

References

1. Fahd, S.; Fiorentino, G.; Mellino, S.; Ulgiati, S. Cropping bioenergy and biomaterials in marginal land: The added value of the biorefinery concept. Energy2012, 37, 79–93.

2. On the establishment of the Chernobyl radiation-ecological biosphere reserve. President of Ukraine; Decree on 26.04.2016 № 174/2016. http://zakon0.rada.gov.ua/laws/show/174/2016

3. Raychuk L.A. Some aspects of Agricultural Manufacturing at the radioactively contaminated land of Kiev Polissia. Scientific Bulletin of National Forestry University of Ukraine. Ecology and Environment. 2015, 25.9, 161-166.

4. Statistical yearbook of Kyiv oblast in 2015. Department of Statistics in Kiev region. Kyiv, 2016.

5. Chernobyl zone will produce energy from renewable sources: http://www.radiosvoboda.org/a/24210082.html

6. "Zone" 30 years later: 30 little-known facts about the Chernobyl nuclear power plant: http://www.ukrinform.ua/rubric-economics/2006710-zona-30-rokiv-potomu-desat-malovidomih-faktiv-pro-cornobilsku-aes.html

7. Ostap Semerak on benefits for investors in Chornobyl zone: http://www.menr.gov.ua/press-center/news/123-news1/5012-ostap-semerak-nadiishlo-kilka-realnykh-propozytsii-vid-kanadskykh-investoriv-shchodo-budivnytstva-soniachnykh-elektrostantsii-u-chornobylskii-zoni

8. Zabulonov Yu.L. Development of selective sorption-membrane methods ^{90}Sr and ^{137}Cs removal from polluted solutions of nuclear objects / Yu.L. Zabulonov, V.M. Burtniak, V.O. Kovach // Coll. of scient.works. Institute of modeling problems in energy sector of G.E.Puhov, NAS of Ukraine. – 2015. – Ed. 59. – P. 8–16.

9. Burtniak V.M. Theoretical background of radiation monitoring methods and recommendations for their practical implementation / V.M. Burtniak, Yu. L. Zabulonov // Informational systems. –2015. – Iss. 10(135). – P. 182–186.

10. Zubets M.V. Scientific bases of agricultural production in the area of Polissia and Western Ukraine/ Acad. Agrar. Science. Kyiv. 2004, 560 p.

11. Butko V. A. The impact of climatic changes on the food orientation of Polissia's agricultural enterprises. Economy of Ukraine. 2014, 10 (635), 44-50.

12. Statistical digest "Agriculture of Kyiv oblast in 2015". Department of Statistics in Kiev region. Kyiv, 2016.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

13. Investment passport of Ivankiv region of Kyiv oblast. Ivankiv district administration, Ivankiv District Council. 2016. http://ivankiv-rda-rada.gov.ua/ua/content/3964.html

14. M.W. Vis, D. van den Berg. Harmonization of biomass resource assessments. Volume I. BEE Best Practices and Methods Handbook. BEE project. FP7 GRANT AGREEMENT N°: 213417.

15. Statistical yearbook "Agriculture of Ukraine 2015". State Statistics Service of Ukraine, Kyiv, 2016.

16. Geletukha G.G., Zheliezns T.A., Zhovmir M.M., Matveev Y.B., Drozdova O.I. Assessment of energy potention of biomass. Part 2. Energy crops, liquid biofuels, biogas. Industrial Heat Engineering. 2010, 33, №1, 57-64.

17. Jose Leboreiro, Ahmad K Hilaly. Biomass transportation model and optimum plant size for the production of ethanol. Bioresource Technology 2011, 102 (3), 2712–2723.

18. Electronic library of the National Academy of Agrarian Sciences, http://naas.gov.ua/content/literatura/

19. Zaimenko N.V., Rakhmetov D.B., Rakhmetov S.D. Application outlook on new and rare energy crops as raw material for solid biofuel in Ukraine, «Bioenergy» journal, 2016, 1(7), 4 -10.

20. Fuczylo Ya.D. The forest plantations in Ukraine: perspectives of development, Scientific papers of Forest Academy of Sciences: a collection of scientific papers, 2008, Issue 6, P.97-99.

21. Fuchylo, Ya.D. Plantation forestry: theory, practice and prospects. Kyiv: Logos, 2011. [in Ukrainian]

22. Fuchylo, Ya.D., Litvin, V.M. & Sbytna, M.V. Growing plantation of poplar in Kyiv Polissia. Kyiv: Logos, 2012. [in Ukrainian]

23. Litvin V.M. Energy plantations of poplar (Populus L.) in the context of renewable energy sources, 2014. [in Ukrainian]

24. D. D. Lavrinenko. Interaction of wood species in different types of forests. Indian National Scientific Documentation Centre, 1972.

25. I. Odarchenko, V. Maurer "Stump" type of poplar plantation management in Polissia region of Ukraine" (2016). Series "Forestry and ornamental horticulture", 2016, Issue 238, p.169-175. [in Ukrainian]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

26. Redko, G.I. (1975). Biology and culture of poplar. Leningrad: Leningrad University Press. [in Russian]

27. Fuchylo, Ya.D. (2009). Prospects for the development of forest plantations in Ukraine, Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine, 2009, Issue 135, p.123-129. [in Ukrainian]

28. Fuchylo Ya.D., Sbytna M.V., Fuchylo O.Ya., Autochton willows of Ukraine. Actual problems of forestry science, foresty and inventory, forest management and economics. Scientific bulletin of the Ukrainian National Forestry University, 2013, Issue 23.6. [in Ukrainian]

29. Fuchylo Ya.D., Sbytna M.V., Derkach D.F. The perspectives of using of species of Salix L. for planting on energy plantations in Ukraine, Ukrainian Phytosociological Collection. - Kyiv, 2007. Iss.C, vup.25. [in Ukrainian]

30. Kaminskii V.F., Tkachov O.I. Drained peat soils - the most prospective Ukrainian lands for energy crops. Scientific Bulletin of the National Scientific Centre "Institute of Agriculture of NAAS", 2013. Iss.3-4, p.3-7. [in Ukrainian]

31. Bulat A.G., Taran Ya.V.Justification of the Expediency for the Cultivation of Energy Plantations of Matsud Willows (Salix matsudana Koidz.) on Agricultural Land. Scientific Bulletin of the Ukrainian National Forestry University, 2015, Iss.25.8, p. 174-178. [in Ukrainian]

32. V. Maurer, L.Melezhyk, Features of growth fast-growing cultivar genus (Salix L.) in conditions of Kyiv Polissia, Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine, 2016, Iss.238, 139-147. [in Ukrainian]

33. Humentyk M., Kwak V., Zamoyski O. Biomass miscanthus yield depending on climatic conditions growing in Western Ukraine Forest Steppe, Bulletin of Lviv National Agrarian University. Series: Agriculture. - 2013. - № 17 (1). - P. 76-82. [in Ukrainian]

34. Humentyk M. J., Kvak V.M., Miscanthus planting technology elements Optimization in the Western Forest Steppe of Ukraine conditions, Scientific Bulletin of Vinnytsya National Agrarian University, 2012, Iss. 1(57), P.168-173. [in Ukrainian]

35. Slyusar I.T., Solyanyk O.P., Tkachov O.I., Viryovka V.O., Satsyk M.I., Ecological and technological aspects of wetlands use, Scientific Bulletin of the Ukrainian National Forestry University, 2012, Iss.1-2, P. 3-9.

36. Kulyk M.I., Row spacing influence on formation of yields of switchgrass varieties, Bulletin of Poltava State Agrarian Academy, 2015, N3, 62-65. [in Ukrainian]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.

37. Mandrovska S. M., Balan V. M., Productivity of switchgrass (Panicum virgatum L.) subject to seeding rate and varietal features, Scientific Bulletin of the Institute of Bioenergy Crops and Sugar Beet of NASU, 2015, Iss.23, P.44-49. [in Ukrainian]

38. D.B. Rakhmetov, O.M. Verhun, S.O. Rakhmetova, Panicum virgatum l. — promissing introduced crop in M.M. Gryshko National Botanic Garden, Introduction of plants, 2014, N3, P.3-14. [in Ukrainian]

39. Ya.B. Blyum, G.G. Geletukha, I.P. Gryhoriuk, V.O. Dubrovin, A.I. Yemets, H.M .Zabarnyi, H.M. Kaletnik, M.D. Melnychuk, V.H. Myronenko, D.B. Rakhmetov, S.P. Tsygankov, New technologies of bioenergy conversion, Kyiv, "Agrar Media Group", 2010, 326.

40. Vlashchuk A.M., Voitashenko D.P., Zheltova A.G., Influence of irrigation and fertilization on productivity of of perennial Sorghum, Irrigated agriculture, Scientific Bulletin, 2014, Iss.61, P.52-54. [in Ukrainian]

41. CropWat: [Electronic resource]. – Access mode: http://www.fao.org/nr/water/infores_databases_cropwat.html

42. Crop Evapotranspiration - Guidelines for computing crop water requirements: [Electronic resource]. – Access mode: http://www.fao.org/docrep/X0490E/X0490E00.htm

43. Methodical guidelines "Reference data on climate of Ukraine"/O.I. Galik, T.O. Basyuk. – Rivne: NUWENU, 2014. – 158 p.

44. Modelling of biomass utilisation for energy purpose/Anna Grzybek, Mariusz Stolarski. – Warszawa: Institute of Technology and Life Sciences, 2010. – 136 p.

45. Crop evapotranspiration under standard conditions: [Electronic resource]. – Access mode: http://www.fao.org/docrep/X0490E/x0490e09.htm

46. Penman-Monteith equation: [Electronic resource]. – Access mode: http://www.fao.org/docrep/x0490e/x0490e06.htm

47. I. Gnap. The experience of energy willow growing / Seminar "Perspectives of energy willow growing in Ukraine" (urban-type village Doslidnytske, 30th June 2016).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691846.