THE LONG-TERM ASSESSMENT OF MISCANTHUS× GIGANTHEUS CULTIVATION IN THE FOREST-STEPPE ZONE OF UKRAINE
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БАГАТОРІЧНА ОЦІНКА ВИРОЩУВАННЯ MISCANTHUS× GIGANTHEUS У ЛІСОСТЕОВІЙ ЗОНІ УКРАЇНИ

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Keywords*: Miscanthus, weather, yield, planting density, energy output, prediction*

ABSTRACT

Multi-year results of research of Miscanthus x giganteus cultivation in several parts of Ukrainian Forest-Steppe zone: western, central, and left parts are presented. The weather conditions at four research sites, based on the meteorological data for years 2011-2015 were analysed. Two subzones of unstable and insufficient rainfall distribution were selected. The influence of climatic conditions to Miscanthus x giganteus production was evaluated. The equation of the regression of yield dependence on hydrothermal coefficient and planting density was calculated. It was established that the indexes of environmental conditions in observed climate zones of Ukraine varied from - 0.41 to 0.29 conventional units. The proposed approach provided the opportunity to predict the yield and energy output of Miscanthus x giganteus when the data of planting density are known.

РЕЗЮМЕ

Багаторічні результати досліджень вирощування Miscanthus x giganteus в декількох частинах лісостепової зони України: Західної, Центральної і лівої частини. Погодні умови в чотирьох науково-дослідних стаціонарах, на основі метеорологічних даних на 2011-2015 роки були проаналізовані. Були обрані дві підзони нестійкого та недостатнього розподілу опадів. Вплив кліматичних умов на вирощування Міскантуса x giganteus був оцінений. Рівняння регресії залежності врожайності від гідротермічного коефіцієнта і щільність посадки було розраховано. Було встановлено, що показники екологічної обстановки в спостережуваних кліматичних зонах України коливаються - від 0,41 до 0.29 умовних одиниць. Запропонований підхід надає можливість прогнозувати урожайність і вихід енергії Miscanthus x giganteus, коли відомі дані щільності посадки.

INTRODUCTION

The using of perennial grasses biomass and fast growing wood is increasing globally (*Pyter et al,* 2010; *Otepka 2014; Gubišová et al, 2016*). It is driven by the climate change phenomena and the obligatory goals to increase sharing of alternative energy by 20% until 2020 forced by European Union countries. Ukraine is an energy-dependent country and for resolving energy consumption issues has to replace exhaustive energy sources by renewable ones, including biomass production. The estimated sharing of renewable energy in country's total primary energy balance is expected to be 8% for year 2020 and 25% for year 2035 (*Geletukha et al., 2016*). The soil and climatic conditions in the main regions of Ukraine are favourable for energy crops cultivation with high level of biomass energy accumulation. The perennial grass Miscanthus x giganteus (M.x giganteus) is considered to be one of the most promising bioenergy crops. The plant is a sterile, triploid hybrid, has a C-4 photosynthetic pathway and high conversion efficiency. Besides, it has a good environmental profile with the potential to increase soil carbon, soil fertility and biodiversity, and to reduce nutrient run-off and leaching (*Faber et al., 2007; Brosse et al., 2012*). These crop first plantations in Ukraine were grown last decade. Since that time the planted areas with Miscanthus have been rapidly expanded and currently reach about 1,000 ha. Recently, the several species of herbivorus from six taxonomic orders were recorded at M.x giganteus (*Stefanovska et al., 2017*).

The study of Miscanthus crop economic efficiency has a practical usefulness for farmers wanting to invest in energetic crops *(Vasylieva, 2013; Velychko, 2014; Sorică, 2015)*. The process of achieving the high-yield of Miscanthus biomass requires the optimisation of the crop production technologies. In fact, the crop harvest is determined by soil and climatic conditions, planting density, the quality of planting material, soil tillage and fertilization. It is important to determine the optimal parameters of the above-mentioned factors and their interactions (*Hastings et al., 2009*).

The study conducted by Randall *et al*. (2016) at two locations in Missouri, USA was focused on assessing the rhizome quality and the soil depth from the surface to claypan affecting the establishment of the crop. Results showed a *M. x giganteus* growth potential in terms of early growth or yield and confirmed earliest obtained results *(Christian et al, 2001; 2008).* It was shown that propagating larger rhizomes led to the better plantation establishment. However, Randall et al (2016) did not detect the impact of claypan soils to the establishment of the crop.

Another study initiated in 2008 in Iowa, USA *(Lok, 2015)* was focused on identifying the management practices for M. x *giganteus* to maintain soil resources during the establishment of the crop, which included soil characteristics (soil bulk density, soil aggregate stability, and steady-state infiltration) and the percent plant cover (live plant, mulch, and bare soil). The experiment was carried out with miscanthus and four accompanion crops: *Secale cereal* (Rye), *Avena sativa* (Oats), *Trifolium incarnatum* (Crimson clover), and *Trifolium repens* (White clover). A little influence of cover crops on soil quality parameters through miscanthus establishment was found. It was mentioned that intermediate aggregate size fractions were the only variables that significantly responded to the addition of cover crops. Thus, the changes in these size fractions were indicative of probable belowground differences that were slowly occurring from bioenergy crop and cover crop root growth. The numerous field studies' results indicated that *M.xgiganteus* had a good tolerance to temperate climate conditions (*Anderson et al., 2011*).

The analysis of literary sources proved that during the vegetation period the crop required a low amount of mineral fertilizers. The average annual recommended dose of nutrients which applied in practice was the following: 60-100 kg N ha^{-1}; P 7-15 kg P ha^{-1} and 50-130 kg K ha^{-1} (*Caslin et al., 2011*). However, the data about nitrogen impact on plant's yield was rather controversy. Several studies indicated that *M.x giganteus* had the low nitrogen needs for growth. Water available for Miscanthus production affected responses to nitrogen. The studies on nitrogen fertilizers impact on *M.x giganteus* biomass yield and plant morphometrical characteristics *(Ercoli et al., 1999; Christian & Haase, 2001; Danalatos et al., 2007; Cadoux et al., 2008; Christian et al., 2008)* indicated only a little or no effect on that impact. Nitrogen fertilizers were added in the amount of 60-240 kg N ha^{-1} in non-limiting water conditions. Other studies showed the trend of increasing *M. x giganteus* yield while fertilizing (*Lewandowski and Schmidt, 2006; Cosentino et al., 2007*). In that research nitrogen fertilizers were applied in ratio of 110 kg N ha^{-1}. The significant positive effect was recorded during the third year of plant's growth in limiting water conditions. The same researchers while investigating two- or three-year-old crops indicated the impact of crop age to the nitrogen properties. However, absence of nitrogen effect was observed in the mature plantation (above 10 years old) of *M.x giganteus (Lewandowski et al. 2000; Danalatos et al. 2007; Christian et al. 2008)*. The recent results *(Lee et al. 2017)* showed that fertilization of the soil increased the yield components and contributed to *M.x giganteus* biomass production.

The annual recirculation of nutritional elements was carried out *(Zub and Brancourt-Hulmel, 2010)*. In that research the outflow of nitrogen and other nutritional substances from the aerial to the earth parts of the plant in an autumn to spring period was monitored. It was shown that nutritional elements were being accumulated in rhizomes and after were reused during new vegetation season. The root system of the plant could penetrate deep enough and used nutritional substances from the deeper soil layers *(Tuomisto et al. 2012)*. The features of this crop allowed providing its cultivation at the marginal lands and ensuring the sustainable energy production.

Just a few study results are available regarding the response of *M.x giganteus* production to the plant density *(Danalatos et al. 2007)*. It was observed that biomass production improved while increasing density from 0.67 to a 1- and 2-plants m^{-2}.

The crop has rather good productivity when planted at the marginal agricultural *(Gopalakrishnan et al. 2011)* and moderately contaminated *(Pidlisnyuk et al. 2014; Pidlisnyuk et al. 2016)* lands. The crop cultivation is not in conflict with the food security requirements (IEA/FAO, 2017). From that stand points the determination of peculiarities of growing plant at the different arable and marginal lands in Ukraine and establishing the impact of climate conditions on the plant productivity have essential scientific and practical interests (*Zhukov and Zadorozhnaya, 2016; Zhukov et al. 2017*). A large part of low-yielding, degraded or slightly heavy metals contaminated soils are located at the Forest-Steppe zone of Ukraine. Those soils are a subject to cultivation, and one of the proposed approaches can be growing *M.x giganteus* on them. The study objectives were to examine the effects of climatic/soil conditions and plant density on biomass yield during long-term *M.x giganteus* cultivation in Ukraine. The research was focused on the following main tasks:

- to evaluate impact of climatic conditions and year of growing on miscanthus yield based on calculations of the environmental conditions index (Ij).
- to learn the specificities of yield formation depending on weather conditions for the different parts of forest-steppe zone of Ukraine.
- to analyse the productivity of plant in the third year of vegetation.
- to evaluate the regression equation for the yield and energy output of plant in the third year of vegetation.

MATERIALS AND METHODS

The research was conducted at the four sites located in the following parts of the Forest-Steppe of Ukraine: A, B – Western, C – Central, D - Left part. The sites were assigned to the subzone of sufficient rainfall distribution: the fields of Borshchiv Agricultural College (A, 48°47´13.63´´N, 26°02´35.92´´E), Yaltushanska (B, 49°00´01.25´´N, 27°27´12.12´´E) and Bilotserkivska experimental breeding stations (C, 49°43´33.10´´N, 30°06´15.20´´E), and the subzone of insufficient humidity at Veselo-Podilska (D, 49°36´19.63´´N, 33°13´32.79´´E) experimental breeding station. *M. x giganteus* autumn star flower variety (the selection breeder of the variety - Institute of bioenergy crops and sugar beets) was planted annually in spring at four sites during 2011-2015 using the similar cultivation scheme. The crop was planted manually on subplots with surface of 75 m^2 each and the soil loosening and tilling was conducted prior to planting. Mechanical control was used to eliminate weeds. The three planting density rates used were 10, 15, 20 thousand plants ha^{-1}. The experiment was performed in three repetitions.

Sampling, observations and analysis of plant growth

The meteorological indicators: daily air-temperature and precipitation were recorded using the Guide to Agricultural Meteorological Practices (2012). The effective temperatures sum (above 10 ^{0} C) were calculated. Average decade/monthly meteorological indicators were compared with long-term data.

Agrochemical analysis of soil was performed before and after the experiments; easily hydrolysed nitrogen was analysed by Cornfield's method; phosphorus and potassium were analysed in accordance with Kirsanov's method (*Arinushkina, 1970*). Biometric characteristics were estimated by measuring plants monthly:

a) the height of the main stem was measured from the soil surface to the top of the longest leaf, and during the phase of panicles - from the base to the top;

b) the number of stems in a stand was determined by calculation of all stems.

4. The yield of dry leaf-stem mass was determined continuously throughout the season.

5. Hydrothermal coefficient (HTC) was calculated as ratio of monthly precipitation ΣP toward total temperatures same month Hydrothermal coefficient (HTC) was calculated as ratio of monthly precipitation ΣP toward total temperatures same month ΣT (reduced for 10 times), HTC =ΣP/0.1ΣT (*Radzka et al. 2015*).

6. The statistical analysis was performed using computer programs Excel and 'Statistica 6.0'.

The environmental conditions index was calculated using the following formula (*Zykin et al., 2005*):

$$Ij = \Sigma Yij / v - \Sigma\Sigma Yij / vn \qquad (1)$$

where:

ΣYij – the amount of yield for the n^{th} year of research;

ΣYij – the amount of yield for all years of research;

v – the number of planting density studied indicators;

n – the number of researched years.

RESULTS

The data on the climate conditions in the research regions are presented in Table 1. The climate in the research regions is moderate continental with insignificant amplitudes of temperature fluctuations and is characterized by short mild winter, warm damp summer and sufficient precipitation.

Table 1

The climate indicators in the location of the researched plots

Indicators	A	B	C	D
Climate	moderate continental			
The effective temperatures sum, ^{o}C	2500-2600	1942-2059	2500-2800	2600-2900
Precipitation during the vegetation period, mm	370-420	190-380	150-480	280-360
Annual precipitation, mm	570	550	538	457

In order to evaluate annual climate conditions, the index of environmental conditions (*Ij*) was calculated. The estimation showed that weather conditions had a significant impact on the formation of *M. x giganteus* yield. In particular, the assessment of weather conditions impact during the vegetation period showed that among all years of research, 2013 (A) was the most favourable for the production of biomass, when the environmental conditions index (*Ij*) was 0.26 conventional units, and the total annual sum of the index values was equal to 0.66. The year 2015 was considered the most unfavourable year, with the index values (*Ij*) fluctuating from (-0.05) to (-0.41), and the total sum of values was equal to -0.83 conventional units (Table 2).

Table 2

Environmental conditions index (Ij)

Study years	A	B	C	D	Total value per year
2011	-0.23	-0.22	0.02	-0.02	-0.45
2012	0.03	0.10	-0.11	-0.05	-0.03
2013	0.26	0.18	0.21	0.01	0.66
2014	0.11	0.14	0.29	0.11	0.63
2015	-0.17	-0.20	-0.41	-0.05	-0.83

The divergences between the variants were significant at P>0, 05. The analysis of the impact of weather conditions during vegetation period over five years of observations showed that the Western (A, B) and Central (C) parts of the Forest-Steppe of Ukraine were characterized by more favourable and sporadic unfavourable years, while the Left part (D) showed the low amplitude of environmental conditions oscillations. The analysis of dry miscanthus biomass yield in the first year of vegetation is presented in Figure 1.

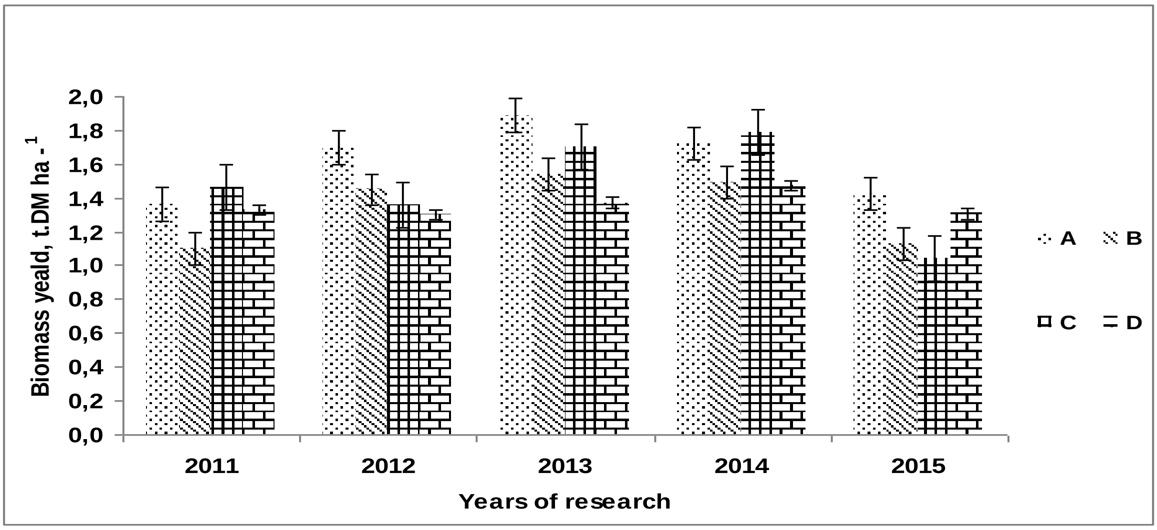

Fig. 1 - Dry Miscanthus biomass yield in the first year of vegetation

The results indicated that crop productivity varied depending on weather conditions and cultivation area. Indeed, the highest yield (1.9 ha^{-1}) was observed in 2013 (A), while the lowest (1.0 ha^{-1}) was obtained in 2015. Over the years of research, the yield of the dry biomass was mostly stable on D, the variation coefficient for planting density of 10, 15 and 20 thousand plants ha^{-1} was 5.8; 4.6 and 2.9% respectively. The highest fluctuations of the dry biomass yield were observed on C with the variation coefficient 22.1; 18.1 and 11.7%, which were associated with the changes of weather conditions, since in this zone the environmental conditions index (Ij) reached the lowest (-0.41) and the highest (0,29) values. The comparative analysis of the impact of different precipitation and air temperature values represented by the hydrothermal coefficient on miscanthus yield formation proved the existence of the direct close correlation (r=0.9733), i.e. increasing of HTC led to the increased yield. In the year 2011 (A) the yield was 1.4 ha^{-1} at the HTC value equal to 0.96, in 2013 the yield was 1.9 ha^{-1} and the HTC value was 1.78 (Fig. 2).

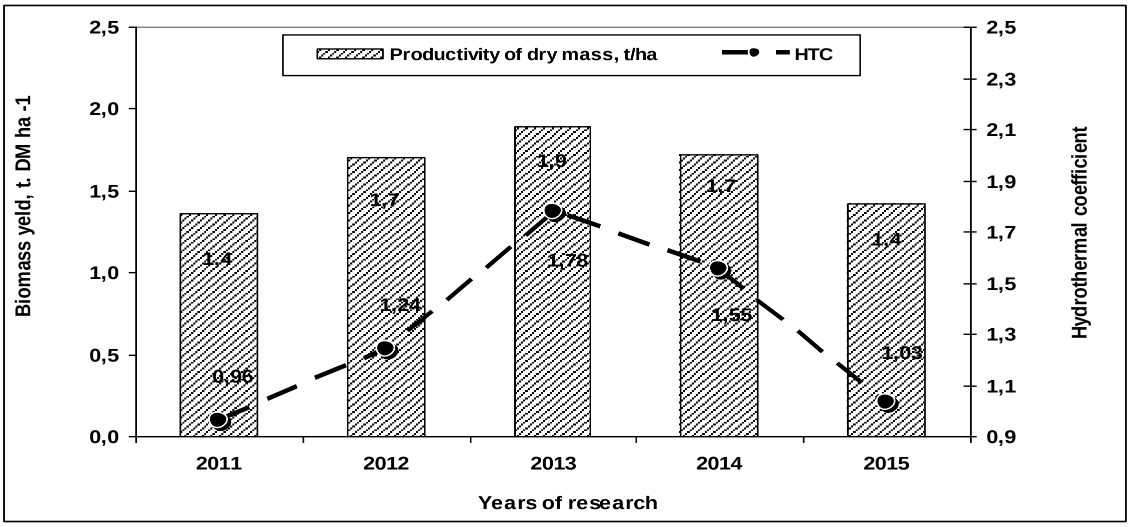

Fig. 2 - The hydrothermal coefficient and Miscanthus yield formation

Regression coefficient at the regression equation Y = 0.619 x+0.788 showed how many units the resulting characteristic was down. It was determined that increasing the HTC by 0.1 led to increasing the yield up to 60 kg ha^{-1}. During the first two years, the yield was insignificant and did not have a commercial value. The majority of literature data noted *(Christian et al. 2008; Angelini et al. 2009; Maksimović et al. 2016)* that under conditions of moderate continental climate, Miscanthus could provide a commercial yield starting from the third year of growth. The maximum yield of the dry biomass (16.3 ha^{-1}) after the third year of vegetation was obtained on field A with the planting density of 20 thousand plants ha^{-1}, whereas the lowest yield (10.4 ha^{-1}) was observed on field C with the planting density of 10 thousand plants ha^{-1} (Fig. 3).

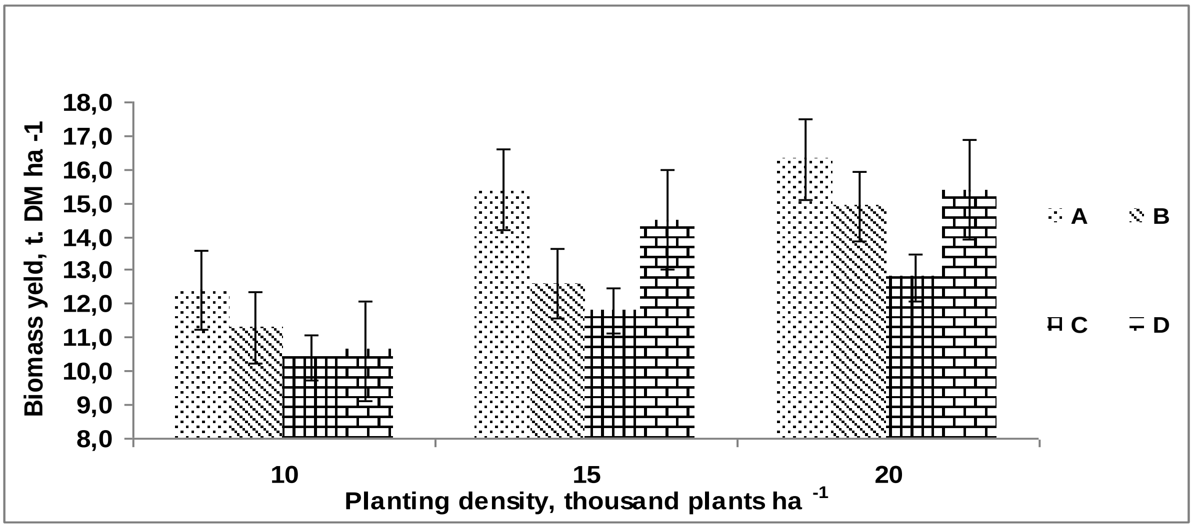

Fig. 3 – Miscanthus biomass yield dependence on planting density in fourth parts of forest-steppe zone

While analysing the yield-producing power of the dry biomass at the planting density of 15 thousand plants ha^{-1}, it can be seen that the highest value was on A, following by 14.5 ha^{-1} on D and 12.6 and 11.8 ha^{-1} on B and C, respectively. That observed order was probably due to the weather conditions. The obtained results demonstrated that the yield of *M.x giganteus* substantially differed depending on the location of the researched fields and years of cultivation. The age of plantations had a significant impact on the yield value, and the plants themselves were very sensitive to late spring frosts and lack of soil moisture in the middle of the vegetation period. Through the current study there were no late frosts observed on the experimental fields, however, dry summers in years 2011 and 2015 led to the slow development of the aerial parts of plants which was in accordance with the published study of *Maksimović et al., (2016)*. The results presented in Fig. 4 showed that the increased plant density led to the increased yield of miscanthus biomass.

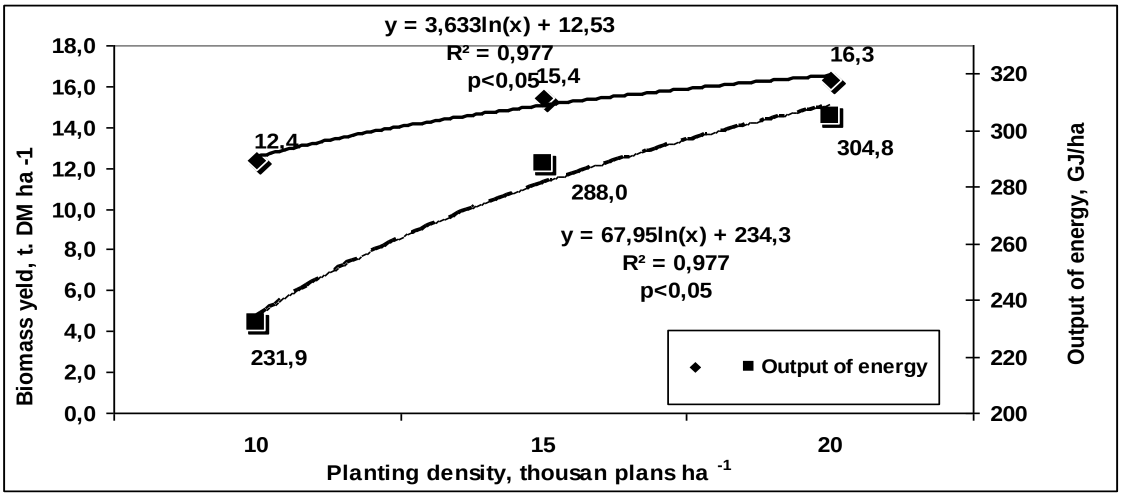

Fig. 4 - Relation between Miscanthus biomass and energy output

Therefore, the output of solid biofuel was going to increase as well. Indeed, at the planting density of 10 thousand plants ha^{-1} the energy output equalled 231.9 gigajoule ha^{-1}, at the density of 15 thousand plants ha^{-1} - 288.0 gigajoule ha^{-1}, at the density of 20 thousand plants ha^{-1} - 304.8 gigajoule ha^{-1}. The highest energy output (288.0-304.8 gigajoule ha^{-1}) was observed at the planting density of 15-20 thousand plants ha^{-1}. The lowest energy output (231.9 gigajoule ha^{-1}) was registered at the planting density of 10 thousand plants ha^{-1}.

Based on the research results the following regression equation was calculated:

$$Y=3,633\ Ln\ (PD)\ +12,\ 53 \qquad (2)$$

where *Y* - the yield of the dry biomass of *M.x giganteus* in the third year of vegetation, ha^{-1}; *PD* - planting density, thousand plants ha^{-1}; and

$$E=67.95Ln\ (PD)\ +234.3 \qquad (3)$$

where *E* - the energy output of the biomass of *M.x giganteus* in the third year of vegetation, gigajoule ha^{-1}; *PD* - planting density, thousand plants ha^{-1}. The proposed regression equations may be used to predict the yield and energy output when the data of planting density of *M.x giganteus* will be known for another plantation.

CONCLUSIONS

The analysis of weather conditions at the experimental plant-breeding stations during the monitoring years 2011-2015 showed that the temperature regime significantly exceeded the average long-term values for these subzones in Ukraine. Average annual precipitation was within the range of average long-term values. However, their distribution over months was random. The assessment of environmental conditions index (Ij) showed that the Western (A, B) and Central (C) parts of the Forest-Steppe of Ukraine were characterized by more favourable and sporadic unfavourable years, while the left part (D) was regarded as rather neutral, close to zero. The obtained results demonstrated that the yield of *M.x giganteus* substantially differed depending on the location and years of cultivation. The main factors of biomass formation were precipitation and average daily temperature during the vegetation period, represented by a hydrothermal coefficient (HTC). Based on the regression equation Y = 0.619 HTC+0.788 it was possible to calculate the yield of the dry biomass during the first year of vegetation. On fields A with planting density of 20 thousand plants ha^{-1} the yield equal to 16.3 ha^{-1} of the dry biomass was obtained. Starting from the third year of vegetation, the yield of the Miscanthus ranged from 10.4 to 16.3 ha^{-1}. The yield level also depended on planting density. Based on the data of Miscanthus yield in the third year of vegetation the equations of regression for the yield Y=3.633 Ln (PD) +12.53 and energy output E=67.95 Ln (PD)+234.3 were proposed. These equations provided the opportunity to further predict the yield and energy output when the data of planting density will be known.

ACKNOWLEDGEMENT
The research was partly supported by NATO SPS MYP G4687.

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