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## FORMATION OF CROP YIELDS OF ENERGY CROPS DEPENDING ON THE SOIL AND WEATHER CONDITIONS

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The article presented discusses the need to use plant biomass made of energy crops grown in marginal soils as an alternative energy source. Variability of biometric indicators of the plant vegetative parts (productivity elements) was experimentally established: stem quantity per area unit and stem height depending on the soil and weather conditions. Based on the five-year research, there was observed a significant influence of soil and climatic growing conditions (average daily air temperature; rainfall; soil fertility) on formation of crop energy productivity. Results showed that the variability of stem density and height; dry phytomass productivity of millet switchgrass and giant miscanthus during observed years depended on the studied factors. Correlation-regression analysis proved and characterized the influence of soil and climatic conditions during the growing season of energy crops on the yield of dry phytomass of millet switchgrass and giant miscanthus in the central part of the Ukraine forest-steppe. The impact proportion share of weather conditions and plant productivity elements on the level of energy crops yields was calculated.

**Keywords:** millet switchgrass; giant miscanthus; biometric indicators of plants; phytomass productivity

Currently, there is a tendency for the gradual depletion of non-renewable energy resources (oil, gas, coal) all over the world. As Tian et al. (2017) pointed out, nowadays, world energy demand is covered using oil (35%), coal (23%), natural gas (21%) and by nuclear fuel (7%). All these resources are non-renewable. Given the significant projected increase in energy demand, experts estimate that coal reserves will last for 250–300 years, natural gas reserves for 50–70 years, and oil reserves for 30–40 years, which is why the world scientific community puts so much emphasis on alternative energy sources, especially on potential of plants (Mehmooda et al., 2017). At the same time, there is a significant number of biomass energy sources for biofuel production in Ukraine: crop residues, waste from wood industry, and energy crops (Kurylo et al., 2013). The last type is represented mainly by perennial plants, which are acclimated to the growing conditions and it is possible to produce a high yield of phytomass by their cultivation in low-yielding soils. Among them, the following crops are distinguished: perennial sorghum, miscanthus (ivory), switchgrass (millet rod), willow, etc. Energy crops are herbs, shrubs, fast-growing trees, or other plants, the phytomass of which can be used as biofuel feedstock. The most common are miscanthus, millet (switchgrass) and willow (Costanza et al., 2017). Millet switchgrass belongs to the family of cereals (Gramineae); it has hollow stems of different colours reaching up to 3 meters in height, forms an inflorescence –

paniculate – that can have 15–50 cm length, and reproduces by seeds and rhizome division. Miscanthus belongs to the cereal family (Gramineae); the most frequent species are *Miscanthus giganteus*, *Miscanthus sinensis*, and *Miscanthus sacchariflorus*.

Plants of the *Miscanthus giganteus* species (giant miscanthus) are very tall – up to 5 meters – they form a powerful phytomass, with an average winter hardiness and drought resistance. Giant miscanthus was an allotriploid derived from *Miscanthus sinensis* and *Miscanthus saccharifolius* and its mother form was *Miscanthus saccharifolius* (Chramiec-Głąbik et al., 2012). It reproduces only vegetatively and is the most common species in Ukraine (Kulyk et al., 2019). Samson et al. (2005); Christian and Elbersen (1998) identified the benefits of using biomass made of millet switchgrass and miscanthus in energy and fibre production: high clean energy production per hectare; low costs; low plant nutrient requirements; low ash content in raw materials, high moisture utilization; wide spread; easy cultivation, easy adaptation to growing conditions for cultivation in low-yielding soils, and ability to store carbon in the soil. They recommend growing energy crops in low-productive soils and degraded lands (Matias et al., 2019), which can be considered marginal soils – these are soils, at which the agricultural production is economically inefficient due to the low soil fertility and environmental restrictions that result from soil degradation, hydrophobicity, etc.

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Furthermore, multiple scientists (Tang et al., 2010; Thakrar et al., 2018) associate the term “marginal soils” with the trends of land utilization, and later – with soil quality. Thakrar et al. (2018) has determined the level of soil organic carbon and its amount obtained from plant material. Their research in the US and India showed that the conversion of crop residues to organic carbon and CO<sub>2</sub> is more of a conservation process occurring around the world. Mathematical calculations determined that the carbon intensity and the amount of CO<sub>2</sub> from plant residues per unit of energy in biofuels does not depend on the amount of residue removed and the location of the raw materials (Macák et al., 2015). According to Thakrar et al. (2018), the economic impact of the use of bio resources is partially dependent on the ability of the management to strategically identify land for the transition from current use to obtaining of raw materials for bio resource production.

Along with the findings of Baxter et al. (2014) regarding the use of agricultural biomass for energy purposes, Tang et al. (2010) analysed the current status and future potential of China’s marginal land resources, energy savings and energy reductions of harmful emissions. At the same time, the findings indicate that the country has enormous energy potential in terms of marginal land resources. Kulyk (2019) observed changes in soil at multiyear plantations of energy crops: the soil level in the layer 0–30 cm decreases, the content of available phosphorus in soil increases by 8–13%, changes in calcium and magnesium are minor (except for miscanthus plantations in which the first indicator decreased), changes in total nitrogen content are relatively large (4% more than in control samples).

Simultaneously, Čedík et al. (2018) pointed out the need to study environmental factors of the most common alternative fuel production – biodiesel biofuels made of bio-raw materials.

Given the significance of the aforementioned, this paper pays attention to:

- determination of variability of the plant productivity elements of millet switchgrass and giant miscanthus depending on the growing conditions;
- determination of relationship between the plant biometrics and yield of dry phytomass of these energy crops;
- determination of influence of the soil and weather conditions on the yield of conditionally wet and dry phytomass of millet switchgrass and giant miscanthus.

## Material and methods

Experimental work was carried out at Poltava State Agrarian Academy on the basis of scientific international project “P4R” (2010–2013) established between the Netherlands and Ukraine, state research topic “Agro-ecological principles of cultivation of energy crops in Ukraine” (2014–2017), and the applied research scientific project of the Ministry of Education and Science of Ukraine “Development of optimal energy systems taking into account the existing potential of renewable energy sources in the conditions of the forest-steppe of Ukraine” (2017–2019). Experiment with energy crops (millet switchgrass and giant miscanthus) took place

in the central part of the forest-steppe of Ukraine at the state agricultural enterprise “Jubilee” in Poltava district, village Brychkivka. Annual precipitation in this area is 450–550 mm; irrigation rate ranges from 1.9 to 1.3. Crops were planted in the experimental plot in 2010, and experimental studies were conducted during the period since 2012 to 2016. The experiment observed the cultivation of energy crops (millet switchgrass and giant miscanthus):

- option 1 – high-yielding soils – FS (humus content over 1.5%);
- option 2 – marginal lands soils – MF (humus content less than 1.5%).

In terms of climate and soil, the conditions were typical for this region and all technological operations were carried out simultaneously in both plots with energy crops: soil cultivation (autumn and spring); sowing of millet switchgrass seeds and planting giant miscanthus with the weeding in the optimal time, as weeds appear in the first and beginning of the second year of a plant vegetation. Further soil cultivation was not carried out, since the energy crops shaded row spacing with their phytomass, thus suppressing the weeds.

Over the research years, the energy crops were subjected to conventional (Dosphehov, 1985), as well as special research methods (Kurylo et al., 2013). Each year since 2012 to 2016, the experiments were repeated four times, the options were placed randomly, the total plot area for each crop was 60 m<sup>2</sup>, and the area of the reference plot was 50 m<sup>2</sup>.

In order to ensure the experiment reliability, the numbers of stems and plant heights of millet switchgrass and giant miscanthus plants were determined as the arithmetic average of 50 plants of each crop from the selected sheaf samples for each variant and this process was repeated four times in each year.

In order to prevent errors during the experiment, the productivity and yield of phytomass of energy crops were determined from the sheaf samples, which were diagonally sampled four times and weighed. Subsequently, the selected average sample was dried, and the dry weight mass was calculated taking into account the moisture content of the raw material at the end of the growing season (Ben Fradj et al., 2020; Kulyk et al., 2019).

The obtained research results were processed by means of analysis of variance in Statistica 6.0.

The theoretical value of the Fisher test ( $F$ ) was found based on the degrees of freedom for the variance of options and degrees for error. If the actual Fisher criterion is more than theoretical ( $F_a > F_{0.05}$ ), then there are significant variations in the experiment and the null hypothesis is rejected.

On order to determine the significant differences, the following was calculated:

1. experiment error ( $S_x$ ) and the difference of the standard deviation ( $S_d$ ):

$$S_x = \sqrt{\frac{s^2}{n}}, \quad S_d = \sqrt{\frac{2s^2}{n}} \quad (1)$$

where:

$s^2$  – dispersion

$n$  – number of repetitions

2. the least significant difference for the 5% significance level ( $HIP_{05}$ ) in absolute and relative terms:

$$HOP_{05} = t_{05} S_d \quad (2)$$

$$HIP_{05} = \frac{t_{05} S_d}{\bar{x}} 100 \quad (3)$$

where:

$t_{05}$  – tabular values of the criterion  $t$  for a 5% significance level

$\bar{x}$  – arithmetic mean value

The coefficient of variation was determined as the ratio of the standard deviation ( $S$ ) to the average level ( $\bar{x}$ ):

$$V = \frac{S}{\bar{x}} 100 \quad (4)$$

The smaller the coefficient of variation, the smaller the fluctuation of the trait in the aggregate and more homogeneous aggregate, and vice versa. The following values of relative fluctuations (variations) were used: insignificant –  $V < 10\%$ ; average –  $V = 10.1\text{--}30\%$ ; large –  $V > 30\%$ .

The correlation coefficients between the quantitative indices of plants (number of stems, plant height) and the dry phytomass yield of millet switchgrass and giant miscanthus were determined using the correlation-regression analysis. The linear correlation dependence was expressed by the regression equation  $y = a + bx$ .

To estimate the reliability of the correlation coefficient, its error ( $sr$ ) and materiality criteria ( $t_r$ ) were calculated as follows:

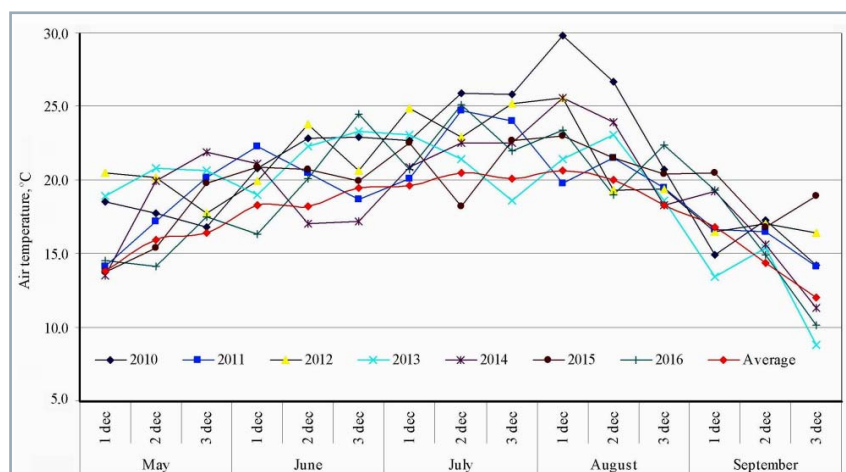
$$sr = \sqrt{\frac{1-r^2}{n-2}}, \quad t_r = \frac{r}{s_r} \quad (5)$$

where:

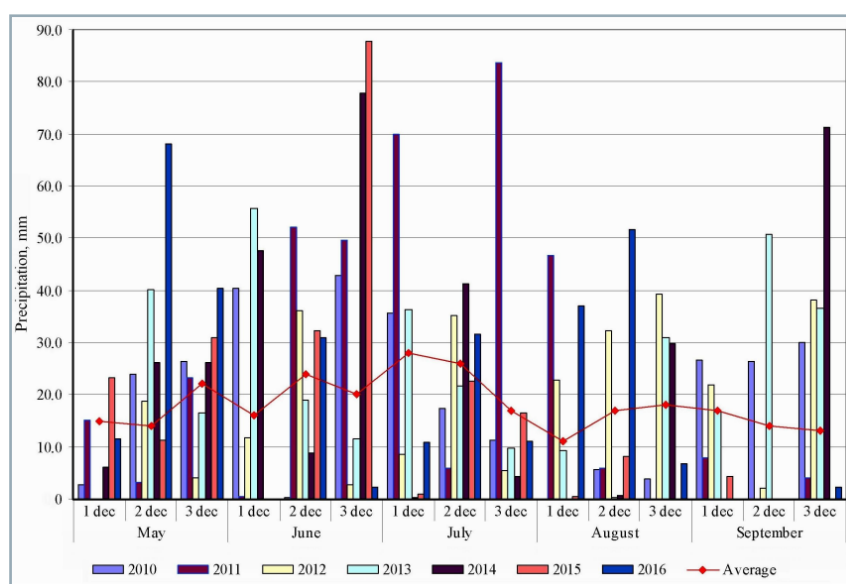
$r$  – correlation coefficient

If  $t_r > t_{theor}$  (theoretical value of the criterion), then correlation is significant and vice versa. It was accepted that if  $r < 0.3$ , the correlation is weak; if  $r = 0.3\text{--}0.7$ , the correlation is average, and if  $r > 0.7$ , then the correlation is strong.

## Results and discussion



**Fig. 1** Average decade air temperature in comparison to long-term average data (average  $b/d$ ) during the vegetation of energy crops (2010–2016)



**Fig. 2** Average decade rainfall in comparison to the long-term average data (average  $b/d$ ) during the vegetation of energy crops (2010–2016)

Weather conditions during the vegetative period of energy crops since the third to seventh year (2010–2016) were dynamically changing and showed values of temperature and rainfall that differed from the average long-term data (Figs. 1–2).

The aboveground vegetative mass of millet switchgrass and giant miscanthus for biofuel purposes was harvested after the third year of vegetation – this is due to rooting, growth rate and plant development, which determines the yield potential (Fig. 3). For this very reason, the study results for energy crops are presented since 2012.

Under the conditions of the central forest-steppe, the number of plant stems of millet switchgrass varied from 24.0 to 70.1 pcs. when cultivated in high-productive soils (the coefficient of variation  $V$  was 42.1%); the number of plant stems of giant miscanthus varied from 12.1 to 23.4 pcs. ( $V = 39.3\%$ ). Considering the marginal soils, this indicator varied from 21.3 to 34.1 pcs. with a coefficient of variation  $V = 17.8\%$  for millet switchgrass and from 11.4 to 21.3 pcs. with a coefficient of variation  $V = 25.8\%$  for giant miscanthus. When cultivated in high-productive soils, the height of millet switchgrass plants since the third to seventh year of vegetation varied from 110.3 to 172.1 cm ( $V = 34.7\%$ ); in marginal soils, this indicator varied from 112.4 to 179.3 cm ( $V = 15.4\%$ ).

Considering the giant miscanthus, there was observed a tendency to increase the plant height (since the

Cultures	2010 year				2011 year				2012 year				2013 year			
	s*	su	a	w	s	su	a	w	s	su	a	w	s	su	a	w
Millet switchgrass																
Giant miscanthus																
Marking:																

Cultures	2014 year				2015 year				2016 year				2017 year			
	s	su	a	w	s	su	a	w	s	su	a	w	s	su	a	w
Millet switchgrass																
Giant miscanthus																
Marking:																

**Fig. 3** Logistic chain of cultivation, plant care and harvesting of energy crops, 2010–2017  
 s – spring period, su – summer period, a – autumn period, w – winter period

third to seventh year of vegetation) in high-productive soils – from 172.1 to 345.8 cm ( $V = 41.2\%$ ); the number of plant stems varied from 15.3 to 202.3 pcs. ( $V = 64.7\%$ ). In marginal soils, the plant height varied from 162.2 to 325.5 cm ( $V = 24.4\%$ ) and the number of plant stems varied from 12.1 to 23.4 pcs. ( $V = 26.8\%$ ).

The greatest increase in plant height for millet switchgrass was observed during the spring and summer, and in the spring for giant miscanthus, with an increase in growth rates in the spring and summer and a gradual decrease in July–August. This is primarily due to the amount of precipitation during this period and is confirmed by the conclusions of previous studies (Kulyk et al., 2019) and the results of other authors (Wang et al., 2015), who conducted similar research.

Along with the results of previous studies regarding the characteristics of the formation of energy crop yields (Kulyk et al., 2019), Kurylo et al. (2013),

Ben Fradj et al. (2020), and Macák et al. (2015) argue that, in contrast to agro-technical measures, cultivation conditions make a significant contribution to the yields of millet switchgrass and giant miscanthus. Therefore, this publication focuses on the study of the influence of soil and weather conditions of vegetation on the energy crop yields.

The highest values of quantitative indicators (density and height of the stem) for millet switchgrass and giant miscanthus were obtained during the period of the third to fifth year of vegetation when grown in high-productive soils. When cultivated in marginal soils, the productivity indicators (number of stems, plant height, etc.) were significantly lower in contrast to the high-productive soils. Regardless of the growing conditions, the highest values of plant quantitative indicators were obtained during the period of the sixth to seventh year of vegetation, which

was also confirmed by previous study (Kulyk et al., 2019).

It was determined that during the cultivation of millet switchgrass, the phytomass moisture content varied from 23.1 to 25.0% in high-productive soils, and from 20.0 to 25.2% in marginal soils. The higher yield of dry phytomass was recorded with the cultivation of millet switchgrass in high-productive soils during the period since the third to seventh year of vegetation ( $14.7\text{--}19.3\text{ t}\cdot\text{ha}^{-1}$ ; Fig. 4).

The moisture content in giant miscanthus phytomass was slightly different compared to millet switchgrass, and the productivity of the stem and plants increased since the third to seventh year of the vegetation under different growing conditions. Its moisture content varied from 24.2 to 33.1% when cultivated in high-productive soils, and from 29.1 to 33.0% when cultivated in marginal soils and depended on the weather conditions. The highest yield of dry miscanthus phytomass was shown by samples cultivated in high-productive soils during the fourth and sixth year of vegetation ( $16.7\text{--}23.9\text{ t}\cdot\text{ha}^{-1}$ ).

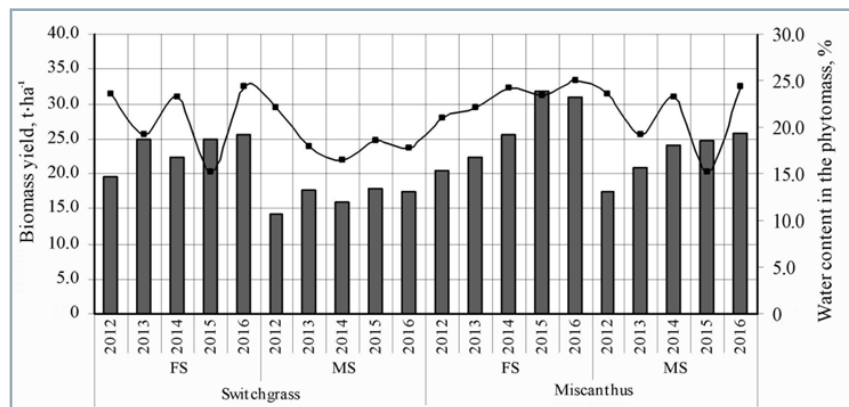
According to the results of the correlation and regression analysis at a 5% level of significance, it was determined that the number of stems of one plant has the greatest influence on the productivity of dry phytomass of millet switchgrass and giant miscanthus (Figs. 5–8).

The established regression dependence indicates that the increase in yield of dry phytomass of millet switchgrass under the Central Forest Steppe conditions is more determined by the number of stems per unit area ( $R = 0.78$ ) than the height of plants ( $R = 0.39$ ).

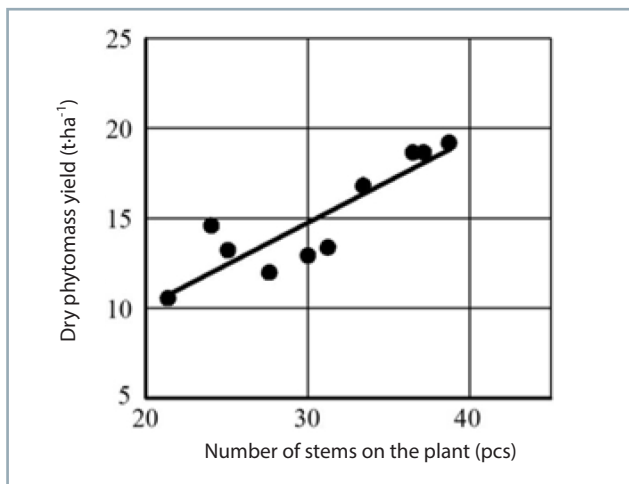
In terms of giant miscanthus, the following dependence was established: with an increase in its stem density ( $R = 0.85$ ) and height ( $R = 0.75$ ), the dry phytomass yield will increase and vice versa.

Weather conditions (average daily air temperature and precipitation amount during the growing season May–September) also significantly contribute to the formation of the phytomass yield of energy crops taken for the study (Table 1).

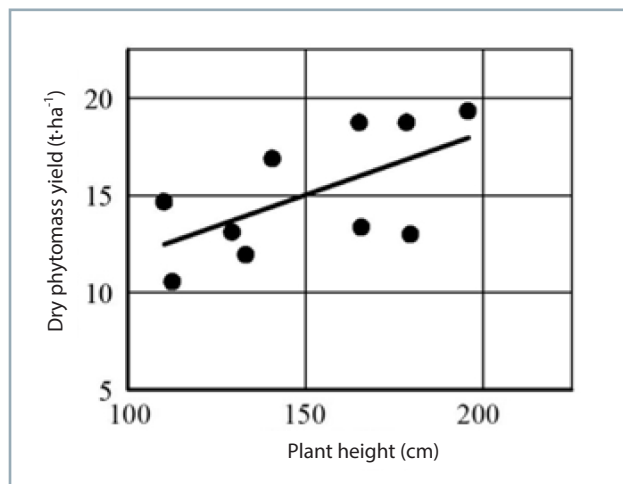
The yield of energy crops in marginal soils showed a strong inverse



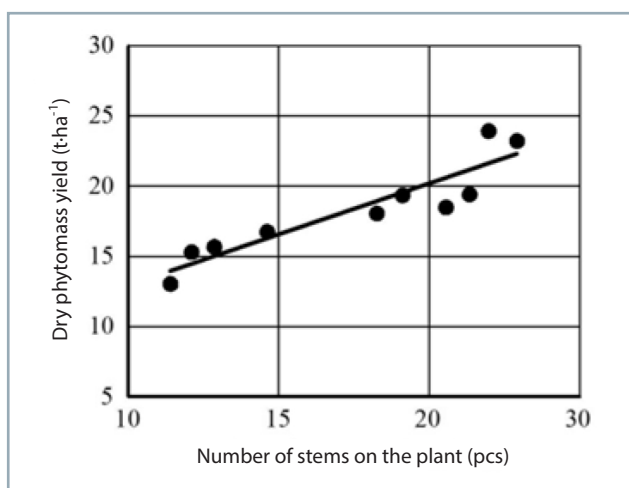
**Fig. 4** Productivity and moisture content in the phytomass of energy crops during the period of 2012–2016  
 $HIP_{05}$  (cultures) = 2.71;  $HIP_{05}$  (soils) = 5.04;  $HIP_{05}$  (years) = 1.68; FS – highly-productive soils; MS – marginal soils



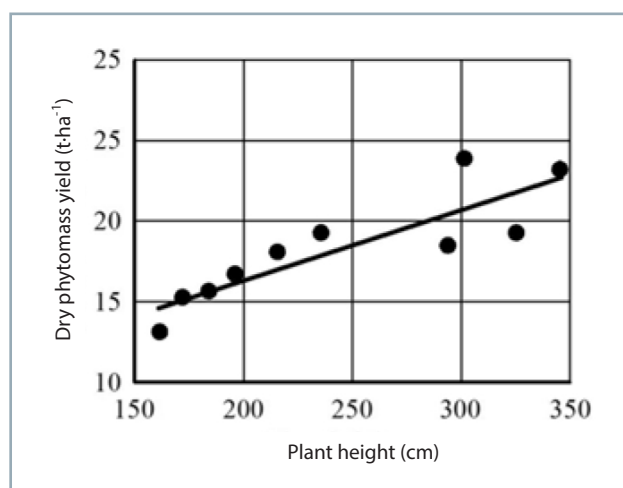
**Fig. 5** Relationship between stem density and phytomass yield of millet switchgrass (2012–2016)



**Fig. 7** Relationship between plant height and phytomass yield of millet switchgrass (2012–2016)



**Fig. 6** Relationship between stem density and yield of giant miscanthus phytomass (2012–2016)



**Fig. 8** Relationship between plant height and phytomass yield of giant miscanthus (2012–2016)

relationship with the average daily air temperature, which indicates that the increase in one indicator will decrease the other and vice versa. To a moderate degree, the yield of giant miscanthus was influenced by the volume of precipitation during plant vegetation in high-productive soils; when grown in marginal soils, this relationship disappeared.

Determining the degree of influence of studied factors on dry phytomass yield of energy crops made it possible

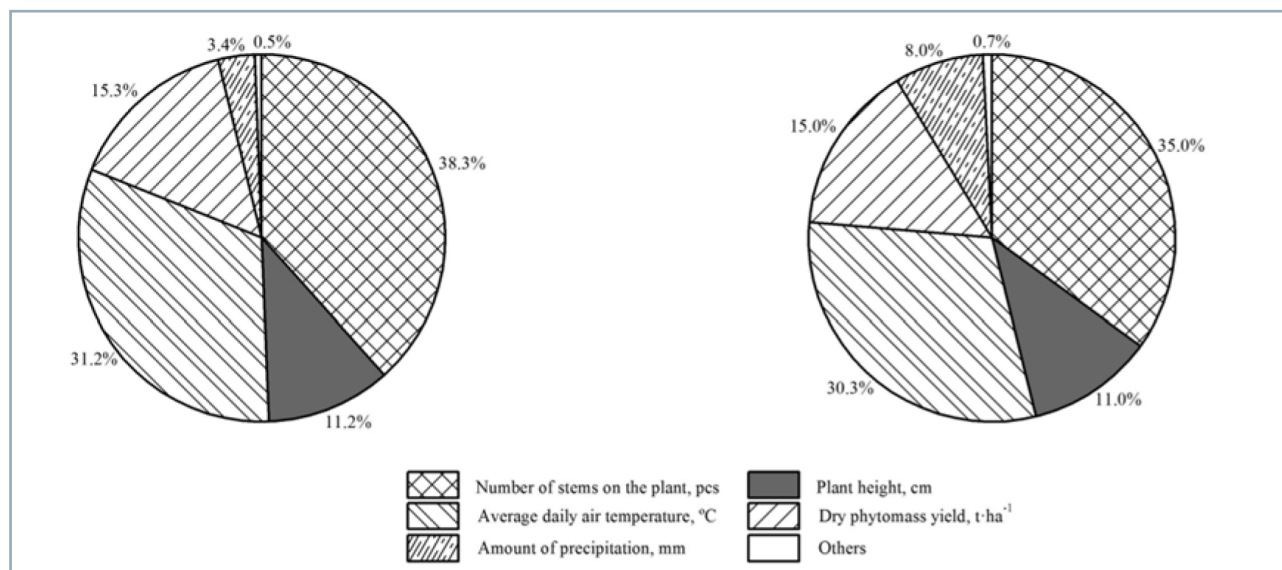
to single out the most significant among them (them (Figs. 9a and 9b).

Considering the long-term cultivation of millet switchgrass in high-productive soils and marginal soils, their yield was determined by the number of stems per unit area (38.3 and 35.0%, respectively), the average daily air temperature during the growing season (31.2 and 30.3%) and the dry content substances in phytomass (15.3 and 15.0%); the productivity was affected to a lesser extent by

**Table 1** Coefficients of linear correlation between weather conditions and dry phytomass yield of energy crops (Pearson), 2012–2016

Crops	Conditions	The average daily air temperature (°C)	Correlation relationship	Precipitation (mm)	Correlation relationship
Millet switchgrass	high-productive soils	-0.87*	strong	0.08	weak
	marginal soils	-0.79*	strong	0.03	weak
Giant miscanthus	high-productive soils	-0.54*	average	0.46*	average
	marginal soils	-0.77*	strong	-0.07	weak

\* Note: relationships are significant at 5% significance level



**Fig. 9** Effect of plant quantitative indicators and weather conditions on the dry phytomass yield of millet switchgrass in 2012–2016 when cultivated in a) high-productive soils; b) marginal soils

plant height (11.2 and 11.0%), the precipitation amount during the growing season (3.4 and 8.0%), rest of the factors showed effect less than 0.7%.

The phytomass yield of giant miscanthus over the research years in high-productivity soils and marginal soils was produced thanks to the height of plants (23.9% and 25.6%, respectively), the number of stems per unit area (20.9% and 28.8%, respectively), average daily temperature during the growing season (16.9% and 22.5%), dry matter content in the phytomass (14.0% and 14.1%), and the amount of precipitation during the growing season (23.3% and 7.9%), other factors showed significance less than 0.8%.

### Conclusion

It has been determined that at present, cultivation possibility of multiyear energy crops (millet switchgrass and giant miscanthus) in marginal soils as a raw material for the purposes of biofuel production in both Ukraine and abroad was investigated. In the long-term run, this should reduce energy dependence of Ukraine on imported energy sources by utilization of renewable energy sources.

Over the years of research, there was observed a significant variation in the biometric characteristics of energy crops when cultivated in high-productive soils and marginal soils; differences in productivity indicators were of average values. Millet switchgrass showed the largest increase in the productivity indicators: the highest stem density and plant height occurred from the fourth to sixth vegetation year. Considering the giant miscanthus plants, these indicators increased since the third to seventh vegetation year. Another trend was observed in the cultivation of these crops in marginal soils – there was a clear trend towards an increase in biometric indicators starting since the third to seventh vegetation year.

An increase in plant biometric parameters at the end of the vegetation season, especially the plant height in more fertile soils, is more characteristic for giant miscanthus than for millet switchgrass. Millet switchgrass showed an increase

in plant density during cultivation in more fertile soils (with humus content greater than 1.5%) in contrast to less fertile marginal soils (with humus content less than 1.5%), in which the increase in plant height was recorded at the cost of stem density reduction.

In marginal soils, millet switchgrass showed a trend towards an increase in the yield since the third to seventh vegetation year ranging from 10.6 to 13.0 t·ha<sup>-1</sup>; giant miscanthus showed yield increase from 13.1 to 19.3 t·ha<sup>-1</sup>. In relation to high-productive soils, giant miscanthus showed an increase in this indicator in the fourth to sixth vegetation year – from 16.7 to 23.9 t·ha<sup>-1</sup> compared to millet switchgrass, yield of which increased in the third to seventh vegetation years under these conditions – from 14.7 to 19.3 t·ha<sup>-1</sup>.

In general, under the conditions of the central forest-steppe of Ukraine, the yield of phytomass of energy crops depends on the productivity of each plant regarding the phytocenosis, biometric indicators and growing conditions. The increase in the dry phytomass yield of millet switchgrass, depending on soil conditions of cultivation, is more determined by the number of stems per unit area. Considering the giant miscanthus, it is additionally determined by the plant height. The yield of energy crops in marginal soils depends on the average daily air temperature; the precipitation amount has a less significant effect on this indicator, with the exception of the giant miscanthus.

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