Original Paper

Improvement of technological methods of switchgrass (*Panicum virgatum* L.) growing in the Vinnytsia region

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Cultivation of switchgrass, development and improvement of technological methods and optimized cultivation technology will ensure the reduction of energy dependence of Ukraine, which will generally affect the improvement of the economy and the welfare of the population. It determines the priority and the relevance of the research. The article presents a solution to an important scientific problem – increasing the yield of switchgrass by establishing optimal technological methods of cultivation. The yield of dry biomass of switchgrass is directly dependent on the row spacing, with an increase in the row spacing, the yield increases. Plant height is inversely related to row spacing in turn. The highest values of plant height were established with narrowed row spacing from 30 to 15 cm. However, the height of plants, according to the results of our research, does not play a decisive role in shaping the level of productivity of switchgrass. The row spacing is of decisive importance. In the case of cultivation of varieties studied for a row spacing of 15 and 30 cm, a significantly lower dry biomass yield was obtained compared to a row spacing of 45 cm. The highest yield of dry biomass was obtained in the experimental treatments, where row spacing was 45 cm for both Cave-in-Rock and Carthage (Keiv-in-rok Kartadzh) switchgrass respectively, the average yields for the growing season were 14.1 t/ha and 11.7 t/ha. The highest productivity of dry biomass of rod-shaped millet was obtained in the study, which used variant pre-sowing cultivation and pre- and post-sowing coating, which ensured better moisture supply in the upper seed layer of the bases for rod-shaped millet plants and was reflected in the better development of plants in the second to sixth year of vegetation in the variety Cave-in-Rock – 13.9 t/ha, and in the Carthage variety – 12.2 t/ha.

Keywords: dry biomass, number of stems, plant height, row spacing, switchgrass, yield

1 Introduction

Nowadays, the world is paying more and more attention to the possibility of alternative energy sources utilization including specially grown energy crops and the available potential of crop residues in conditions of energy shortages (Kaletnik et al., 2020c). According to experts' data, the renewable energy sources share in the global fuel and energy balance could reach 50% in 2050. According to the World Energy Council, the renewable energy sources share in the global fuel and energy balance could reach 80–90% by the end of this century. Germany and Sweden plan to generate all their energy from renewable sources by the end of this century (Kaletnik et al., 2020a; Karkanis et al., 2016). The largest areas of energy crops are located in such European countries as Norway, Denmark, Germany, Austria, Poland, and Sweden (Biliavska et al., 2021; Kaletnik et al., 2020b). Ukraine has a great potential for biomass available for energy utilization, it has got preconditions for expanding crop residues utilization for biofuels. We forecast a dynamic increase of biomass energy utilization, i.e., from 5 million tons of oil equivalent (TOE) or 2.5% of total energy consumption in 2015 to 20 million TOE or 10% in 2030 (Kaletnik et al., 2020c; Didur and Mostovenko, 2020; Tkachuk, 2021).

According to authors (Mazur et al., 2020a), Ukraine is the country with favorable conditions for food security, it has a high potential to create a stable market for energy crops used in the biofuel industry. Attracting of renewable energy sources by transforming photosynthesis energy

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in an accessible form will help to reduce the energy dependence of Ukraine. Most regions of Ukraine have favorable soil and climatic conditions for growing species with large biomass, these crops can grow on unproductive degraded lands (Solona et al., 2020; Mazur et al., 2020a; Telekalo and Melnyk, 2020).

Thus, the introduction of new non-traditional plants characterized by ecological plasticity, resistance to weather conditions, weeds, pests, diseases, and high productivity will solve the energy crisis problems. The scientists prefer perennial species such as switchgrass (*Panicum virgatum* L.). Since switchgrass (*Panicum virgatum* L.) is one of the phytoenergy crops, its vegetative mass is used to produce solid fuels, these plants grow on different types of soils. There are several million hectares of such lands in Ukraine, that's why the research of growing crops on these lands is relevant (Kulyk et al., 2020; Kupchuk et al., 2021; Kovbasa et al., 2021). It is also important that the cultivation of switchgrass on these lands reduces erosion and improves the environment (Kulyk et al., 2020; Mazur et al., 2021a; Mostovenko, 2020). Perennial introduced species ensure high productivity of arable land, minimize tillage, and improve its agronomic and agrochemical properties. These plants have a strong root system, they are undemanding to growing conditions having prospects for growing on eroded and reclaimed soils (Tkachuk, 2021; Vdovenko et al., 2018; Biliavska et al., 2021). Other scholars identified the specifics of the switchgrass biomass and miscanthus application in energy and fibre production; they found out that these crops have a high rate of clean energy production per hectare, low production costs; insignificant needs of plants in nutrients, low ash content in raw materials, high moisture utilization rate, wide range of plant distribution, simplified cultivation technology, and high adaptability. They recommend growing energy crops on unproductive soils, degraded lands, and without changing land use. The switchgrass biomass has typical components for biofuel raw materials, i.e., 50% cellulose and 30% lignin. Dry biomass has a lower ash content (2–4%) and lower potassium and sodium content than cereal straw; it has higher calcium and magnesium content. These characteristics cause high combustion temperatures and reduce slag during combustion in solid fuel boilers. The cost of switchgrass biomass growing ranges from 20 to 40 euros per ton of dry matter in different countries (Kulyk et al., 2020). Switchgrass is used for electricity generation through gasification, combined combustion in coal plants, ethanol production for fuel, and production of fuel pellets (Kulyk et al., 2020; Mazur et al., 2019). Nowadays, switchgrass is being researched as a biofuel raw material for thermal energy, pulp production for papermaking, fiber reinforcement for plastic composites and other products (Kulyk et al., 2020; Kaletnik et al., 2020c). Switchgrass (*Panicum virgatum* L.) is a perennial cereal crop; its yield is 15 tons of dry matter per 1 ha or 255 GJ of thermal energy per 1 ha. Switchgrass biomass can be harvested for 15 years. Switchgrass growing requires the technology research, i.e., varieties, sowing dates, seeding rates, standing density, row spacing, mineral nutrition, and methods of seeds preparing for sowing (Kulyk et al., 2020).

The publications (Kulyk et al., 2020) research the technology of switchgrass growing. Development of certain elements of cultivation technology, their introduction and subsequent cultivation on marginal lands will increase the yield of switchgrass dry biomass reducing the energy dependence of Ukraine. This determines the relevance of our research. The aim of the research was to improve the technological methods of cultivation to obtain the maximum yield of switchgrass dry biomass and energy yield.

2 Material and methods

The experiments involved laboratory and field research in the research field of Vinnytsia National Agrarian University with switchgrass plants in 2015–2019. This area is characterized by gray forest soils of light medium-loamy mechanical composition. The soil has average humus content, high phosphorus supply, and low potassium supply. Soil acidity is close to neutral. We used two varieties of switchgrass in the research (Table 1).

The program of research work included the following experiments:

Experiment 1. Determining of dry biomass yield of switchgrass depending on the pre-sowing tillage methods.

Determining the yield of dry biomass of switchgrass depending on the spring tillage combined the research of factor A (variety): 1st option is Cave-in-Rock, 2nd option is Carthage and factor B (pre-sowing tillage): 1st option is two cultivations, 2nd option is 2 cultivations + pre- and post-sowing rolling; 3rd option no till sowing.

Experiment 2. Formation of switchgrass yield depending on the width of the rows.

Determining the yield of dry biomass of switchgrass depending on the width of the rows combined research of factor A (variety): 1st option is Cave-in-Rock, 2nd option is Carthage and factor B (width between rows): 1st option is 15 cm width, 2nd option is 30 cm width, 3rd option is 45 cm width. The estimated area was 50 m^2, the repetition was four times.

We planned experiments according to methodological recommendations (Pysarenko et al., 2011; Parrish and

Table 1 Characteristics of switchgrass varieties

Variety	Ecotype	Fertility	Origin	Maturity term	Weight of 1,000 seeds (g)
Cave-in-Rock	high	octaploid	South Illinois	medium-late	1.66
Carthage	high	octaploid	North Carolina	late	1.59

Fike, 2009), the method of state varietal testing of crops (Volkodava, 2001) and the classification of perennial grasses development phases (Metcalfe and Nelson, 1985).

Field experiments were planned and carried out considering all the requirements of the methodology of the experimental case according to (Dospekhov, 1985). The seed sowing rate is 300 pcs/m^2, with the help of the Klen-6 precision seed drill.

Phenological observations during the growth and development of plants were carried out according to the «Methodology of the state variety testing of agricultural crops» (Volkodav, 2021) and according to the classification of the phases of development of perennial grasses (Metcalfe and Nelson, 1985; Elbersen, 2009). Quantitative indicators of vine millet (plant height, number of stems per 1 m^2, number of leaves and internodes per plant) were recorded at the end of plant vegetation (Kulyk, 2012).

Yield accounting (Wang et al., 2010; Kulyk and Elbersen, 2012) was carried out at the end of the growing season of plants by mowing the plants, weighing and converting to dry weight after determining the percentage of moisture.

The dry matter content of plant raw materials was determined by drying the test sample to a completely dry mass in a SESH-3M drying cabinet at a temperature of 100–105 °C for 4–6 hours, with cooling, weighing and calculation (Kulyk and Elbersen, 2012).

3 Results and discussion

According to research, biometric indicators of switchgrass depended on pre-sowing tillage (Table 2).

The highest results were obtained in the treatment with two cultivations and rolling before and after sowing in spring, it contributed to optimal moisture supply of the upper seed layer in switchgrass plants and positively affected the development of plants in the second-sixth year. This treatment has the highest plant height in the switchgrass varieties of Cave-in-Rock (136 cm) and Carthage (128.2 cm), it is by 7.1 and 7.2 cm higher than in the experimental with two cultivations in the spring. The figures on this option were 128.9 cm in the Cave-in-Rock variety and 121 cm in the Carthage variety. The lowest plant height was in the treatment, where the seeds were sown in no till soil, the height of plants in the Cave-in-Rock variety was 122.3 cm, and in the Carthage variety was 116.5 cm; the height was shorter by 13.7 and 11.7 cm, respectively.

This pattern was also observed in the number of stems. The highest number was obtained in the experiment treatment with two cultivations and rolling before and after sowing in spring. The variety Cave-in-Rock had 472.9 pieces per m^2, and the variety Carthage had 406.5 pieces per m^2. The lowest number of stems was obtained in the treatment with two cultivations, in the Cave-in-Rock variety 457 pieces per m^2, and the Carthage variety had 396.1 pieces per m^2, it is by 15.9 pcs/m^2 and 10.4 pcs/m^2 less.

Table 2 Biometric indicators of second-sixth year switchgrass depending on pre-sowing tillage and varietal characteristics

Variety (factor A)	Pre-sowing tillage (factor B)	Height of plants (cm)						Number of stems (pcs/m^2)					
		2015	2016	2017	2018	2019	average	2015	2016	2017	2018	2019	average
Cave-in-Rock	two cultivations	93.8	118.7	137.3	145.4	149.1	128.9 ±10.2	445.7	453.2	458.2	462.3	465.7	457.0 ±7.1
	two cultivations + rolling	99.2	123.6	143.7	154.9	158.6	136.0 ±11.0**	460.1	469.4	474.0	478.7	482.1	472.9 ±7.9*
	no till	86.7	113.8	125.7	140.6	144.5	122.3 ±10.4	409.1	415.7	416.7	419.5	423.4	416.9 ±4.4
Carthage	two cultivations	92.4	112.1	127.5	134.5	138.6	121.0 ±8.5	389.2	394.4	396.1	398.8	402.1	396.1 ±4.0
	two cultivations + rolling	96.3	116.5	135.8	143.7	148.9	128.2 ±9.7**	392.4	406.2	408.5	411.2	414.2	406.5 ±8.4*
	No till	83.4	112.7	122.1	129.6	134.5	116.5 ±9.0	371.1	382.5	387.6	389.8	402.5	386.7 ±11.4

* significant at P <0.05 compared with control group; ** significant at P <0.01 compared with control group

The lowest number of stems was obtained in the treatment of the experiment where the seeds were sown in no-till soil, the Cave-in-Rock variety had 416.9 pieces per m^2, and the Carthage variety had 386.7 pieces per m^2; it is by 56 pieces per m^2 and 19.8 pieces per m^2 less than in the treatment where two cultivations and rolling before and after sowing in spring. In terms of years of research, the highest plant height was obtained in the sixth year of vegetation from 134.5 cm to 158.6 cm. Switchgrass of the second year of vegetation (2015) was characterized by the lowest plant height (from 83.4 cm to 99.2 cm).

The highest yield of switchgrass biomass was obtained in the experimental variant with pre-sowing cultivation and pre- and post-sowing rolling. It contributed to optimal moisture supply of the upper seed layer in switchgrass plants and positively affected the development of plants in the second-sixth year (Table 3). The Cave-in-Rock variety had 13.9 t/ha, and the Carthage variety had 12.2 t/ha, it is by 0.6 t/ha and 0.5 t/ha higher than in the experiment option with two cultivations (the Cave-in-Rock variety had 13.3 t/ha and the Carthage variety had 11.7 t/ha). It indicates a deterioration of moisture supply in the upper soil layer.

The lowest yield of dry biomass was obtained in the experiment option with no till sowing, the yield was 10.8 t/ha and 9.8 t/ha. which indicates a deterioration of moisture supply in the upper soil layer. The highest yield of dry biomass was obtained in 2019, it varied from 13.9 t/ha to 17.4 t/ha in the Cave-in-Rock variety and from 12.6 t/ha to 15.7 t/ha in the Carthage variety. Quantitative indicators such as stem density and height of switchgrass (productivity elements) determine the yield of phytomass of the crop, it depends on the width of the rows and is determined by varietal characteristics. This is confirmed by the results of our research. Regarding the quantitative indicators of switchgrass, their variability from row spacing and varietal characteristics was established (Table 4).

The highest values of plant height were obtained with a row spacing of 15 cm in varieties of switchgrass of the second-sixth years of cultivation, the average values were 152.8 cm and 140.0 cm.

Table 3 Yield of switchgrass dry biomass depending on pre-sowing tillage and varietal characteristics, during 2015–2019 years

Variety (factor A)	Pre-sowing tillage (factor B)	Yield (t/ha)					
		2015	2016	2017	2018	2019	average
Cave-in-Rock	two cultivations	6.5	11.7	15.6	16.1	16.6	13.3
	two cultivations + rolling	6.8	12.4	16.1	16.8	17.4	13.9
	no till	4.7	9.4	12.7	13.5	13.9	10.8
Carthage	two cultivations	5.5	9.6	13.9	14.5	15.1	11.7
	two cultivations + rolling	5.7	10.0	14.5	14.9	15.7	12.2
	no till	4.2	8.9	11.4	11.8	12.6	9.8
$HIP_{0.05}$ factor A		0.12	0.11	0.19	0.2	0.22	
$HIP_{0.05}$ factor B		0.2	0.18	0.28	0.29	0.31	
$HIP_{0.05}$ cooperation AB		0.18	0.16	0.29	0.3	0.32	

Table 4 Quantitative indicators of the second- sixth year switchgrass depending on the row width depending on the width of the rows, during 2015–2019 years

Variety (factor A)	Row width (factor B)	Height of plants (cm)						Number of stems (pcs/m^2)					
		2015	2016	2017	2018	2019	average	2015	2016	2017	2018	2019	average
(Cave-in-Rock	15 cm	126.5	153.2	158.7	161.6	163.9	152.8 ±6.8**	249.1	274.7	280.9	283.4	287.1	275.0 ±6.8
	30 cm	114.8	142.4	143.3	145.8	148.3	138.9 ±6.1	379.5	393.2	404.3	407.8	409.5	398.9 ±5.6
	45 cm	98.7	127.2	129.6	132.7	135.1	124.7 ±6.6	458.3	468.5	473.8	476.5	479.3	471.3 ±3.7**
Carthage	15 cm	116.4	141.3	145.2	147.5	149.6	140.0 ±6.1**	213.6	240.1	251.7	259.7	263.2	245.7 ±8.9
	30 cm	105.3	136.6	140.3	143.1	145.8	134.2 ±7.4	317.2	325.8	338.2	345.4	348.7	335.1 ±6.0
	45 cm	91.6	124.1	130.7	134.2	137.6	123.6 ±8.3	393.0	406.2	410.0	415.6	418.5	408.7 ±4.5**

* significant at ** significant at P <0.01 compared with control group

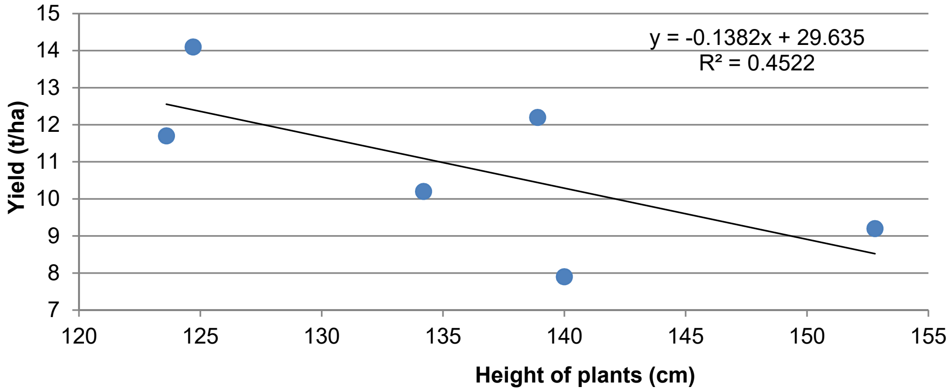

Figure 1 The relationship between dry biomass yield and switchgrass height at different row width

Switchgrass had a lower plant height with a row width of 45 cm; it was 124.7 cm of Cave-in-Rock variety and 123.6 cm of Carthage variety; it is by 28.1 cm and 16.4 cm less compared to the plant height indicators of these varieties with a row width of 15 cm.

The height of the switchgrass of both varieties with a row width of 30 cm took an intermediate position in the average values of the second-sixth years of cultivation; 138.9 cm for the variety Cave-in-Rock and 134.2 cm for the Carthage variety. The number of stems per 1 m^2 was the highest with a row width of 45 cm, 471.3 pcs/m^2 for Cave-in-Rock and 408.7 pcs/m^2 for the Carthage.

Switchgrass grown with row spacing of 15 and 30 cm had a much lower stem density, it was 275 pcs/m^2 and 398.9 pcs/m^2 in the Cave-in-Rock variety which is by 196.3 and 72.4 pcs/m^2 less, and 245.7 pcs/m^2 and 335.1 pcs/m^2 in the Carthage variety which is by 163 pcs/m^2 and 73.6 pcs/m^2 less.

The yield of switchgrass varieties increased from the second to the sixth year of plant vegetation (Table 5), the yield of the Cave-in-Rock variety increased from 5.8 t/ha to 17.3 t/ha; and the yield of the Carthage variety increased from 4.7 t/ha to 15.4 t/ha. The highest yield of switchgrass dry biomass was obtained in the experimental variant with 45 cm width rows, the average yields during the second-sixth years of vegetation were 14.1 t/ha (Cave-in-Rock) and 11.7 t/ha (Carthage).

We associate the high yield of switchgrass in the treatment with a 45 cm row spacing in both varieties with better bushiness (Table 5). In addition, despite the higher plant height of switchgrass varieties with narrowed row spacing of 30 cm, i.e., 138.9 cm (Cave-in-Rock) and 134.2 cm (Carthage) (Table 4) and higher plant height in the treatment with a 15 cm row spacing in varieties of switchgrass 152.8 cm (Cave-in-Rock) and 140.0 cm (Carthage), the number of stems, in our opinion, is more significant in terms of yield level. It is confirmed by the research results presented in Figure 1 and 2. A negative correlation relationship ($r = -0.67 \pm 0.04$) with a coefficient of determination of 45.2% was found between the dry biomass yield and the height of the switchgrass at different row spacing.

Table 5 Yield of switchgrass dry biomass, t/ha depending on the width of the rows during 2015–2019 years

Variety (factor A)	Row width (factor B)	Yield (t/ha)					
		2015	2016	2017	2018	2019	average
Cave-in-Rock	15 cm	5.8	8.9	10.0	10.5	10.9	9.2
	30 cm	6.4	10.1	14.3	14.8	15.4	12.2
	45 cm	6.9	13.2	16.4	16.9	17.3	14.1
Carthage	15 cm	4.7	7.8	8.5	9.1	9.5	7.9
	30 cm	5.1	8.2	12.1	12.5	12.9	10.2
	45 cm	5.4	8.5	14.5	14.9	15.4	11.7
$HIP_{0.05}$ factor A		0.11	0.22	0.22	0.25	0.26	
$HIP_{0.05}$ factor B		0.12	0.35	0.34	0.36	0.38	
$HIP_{0.05}$ cooperation AB		0.13	0.31	0.29	0.32	0.35	

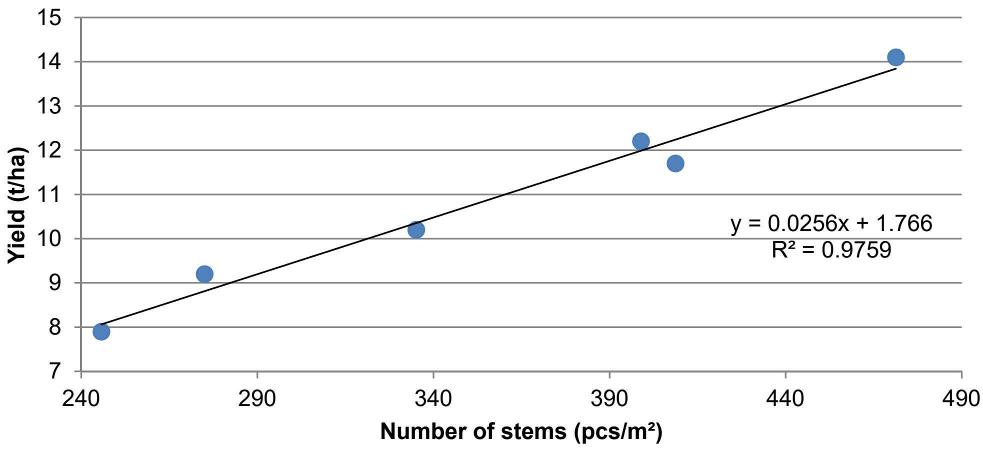

Figure 2 The relationship between dry biomass yield and number of stems with different row width

Thus, the greater height of plants did not increase yields but reduced it by reducing the number of stems with narrowed rows. By increasing the row spacing to 45 cm, the largest number of stems was formed for both variants of the experiment, namely 471.3 units/m^2 and 408.3 units/m^2 (Table 4), and the highest yield level of 14.1 t/ha and 11.7 t/ha, which is higher by 1.9 t/ha, 4.9 t/ha, 1.5 t/ha, 3.8 t/ha than the yield for 30 cm and 15 cm (Table 5).

A direct correlation was found between the dry biomass yield and the number of stems at different row spacing ($r = 0.98 \pm 0.02$) with a coefficient of determination (97.6%) (Figure 2). It indicates a straightforward relationship between these indicators and the crucial role of stems number in forming the dry biomass yield.

The results of our research coincide with other experiments (Ma et al., 2001), in which it was established that growing switchgrass with a row spacing of 80 cm, compared to 20 cm, increases the yield and carbon content in the obtained plant biomass. Similar results were obtained by Bransby et al. (1993). and he established that varieties of vine-like millet with a wide-row method of sowing, compared to narrow-row ones, form a higher yield. According to research carried out in the conditions of Ukraine, it was established (Kulyk, 2012). that the height of switchgrass plants in the first year of vegetation is more influenced by varietal features at a row width of 30 cm, and at 45 cm this difference disappears, which may indicate that with an increase of plant nutrition area, their competition for mineral nutrients is reduced, and there is a leveling of height in the studied varieties of switchgrass. This trend was also observed in relation to the density of plants per unit area, but for a larger number of varieties (Foresburg, Canlow and Cave-in-Rock). This indicates that this indicator (plant density) may be a more reliable parameter than height in evaluating the productivity of switchgrass cultivars for biomass production. The highest yield of dry biomass and the yield of energy from it were provided by options with a width between rows of 30 and 45 cm. On these options, as a result of inter-row loosening of the soil and an increase in the area of plant nutrition, the growth of rod-shaped millet is restored more intensively in the spring, which ensures high productivity (Humentyk, 2016).

4 Conclusions

Thus, the yield of switchgrass dry biomass is directly dependent on the width of the rows, with increasing width of the rows increases the yield. The height of the plants is inversely related to the width of the rows. Higher values of plant height were observed for narrow rows from 30 cm to 15 cm. However, according to our research, the height of plants is not crucial factor for the yield of switchgrass. The width of the row spacing is crucial. We obtained significantly lower yields of dry biomass with rows of 15 cm and 30 cm than rows of 45 cm. The dry biomass highest yields of both switchgrass varieties (Cave-in-Rock and Carthage) were obtained in an experiment with a 45 cm row spacing, respectively, the average yields during the growing season were 14.1 t/ha and 11.7 t/ha.

The highest productivity of dry millet biomass was obtained in the variant of the experiment, where pre-sowing cultivation and pre- and post-sowing rolling were used, which ensured better moisture supply in the upper seed layer of the soil for rod millet plants and was reflected in the better development of plants in the second to sixth years of vegetation in the Cave-in-Rock variety -in-rock – 13.9 t/ha, and in the Carthage variety – 12.2 t/ha.

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References

Biliavska, L. et al. (2021). Adaptability and breeding value of soybean varieties of Poltava breeding. *Bulgarian Journal of Agricultural Science*, 27(2), 312–322.

Bransby, D. I. et al. (1993). Compatibility of switchgrass as an energy crop in farming systems of the southeast- ern USA. *Biomass Conf. of the Americas*. Burlington (pp. 229–234).

Bulgakov, V. et al. (2019). Results of experimental investigations of a flexible active harrow with loosening teeth. *Agronomy Research*, 17(5), 1839–1845. https://doi.org/10.15159/ar.19.185

Bulgakov, V. et al. (2020). Theoretical Studies of the Vibration Process of the Dryer for Waste of Food. *Rural Sustainability Research*, 44, 32–45. https://doi.org/10.2478/plua-2020-0015

Didur, I., & Mostovenko, V. (2020). Photosynthetic activity of vegetable peas depending on varietal characteristics, soil liming and food system. *Agriculture and forestry*, 4(19), 42–50. https://doi.org/10.37128/2707-5826-2020-4-4

Dospekhov, B.A. (1985). *Methodology of field experience*. M.: Kolos (p. 336).

Elbersen, W. (2013). Draft Protocols for Ukraine Switchgrass experiments. *Food and Biobased*, 1–26.

Hrushetskyi, S. et al. (2021). The heap parts movement on the shareboard surface of the potato harvesting machine. *Bulletin of the Transilvania University of Braşov. Series II: Forestry, Wood Industry, Agricultural Food Engineering*, 14,63(1), 127–140. https://doi.org/10.31926/but.fwiafe.2021.14.63.1.12

Humentyk, M.Ia. (2016). The influence of the method of sowing and plant care on the productivity of millet biomass in the conditions of the forest-steppe of Ukraine. *Bulletin of the Poltava State Agrarian Academy*, 25, 14–23.

Kaletnik, G. et al. (2020a). The World Experience in the Regulation of the Land Circulation. European. *Journal of Sustainable Development*, 9(2), 557–568. https://doi.org/10.14207/ejsd.2020.v9n2p557

Kaletnik, G. et al. (2020b). Development and examination of high-performance fluidised-bed vibration drier for processing food production waste. *Agronomy Research*, 18(4), 2391–2409. https://doi.org/10.15159/ar.20.234

Kaletnik, G. et al. (2020c). The Waste-Free Production Development for the Energy Autonomy Formation of Ukrainian Agricultural Enterprises. *Journal of Environmental Management and Tourism*, 3(43), 513–522. https://doi.org/10.14505//jemt.v11.3(43).24

Karkanis, A. et al. (2016). Field pea in European cropping systems: Adaptability, biological nitrogen fixation and cultivation practices. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 44(2), 325–336. https://doi.org/10.15835/nbha44210618

Kovbasa, V. et al. (2021). Functions derivation of stresses in the soil and resistance forces to the motion of a plough share for cavity creation. *UPB Scientific Bulletin, Series D: Mechanical Engineering*, 83(3), 305–318.

Kulyk, M.I. (2012). The influence of growing conditions on the quantitative parameters of switchgrass plants (*Panicum virgatum* L.) in the first year of vegetation. *Bulletin of the Poltava State Agrarian Academy*, 3, 62–67.

Kulyk, M., & Elbersen, W. (2012). Methods of calculation productivity phytomass for switchgrass in Ukraine. *Poltava*, 10.

Kulyk, M. et al. (2020). Efficiency of Optimized Technology of Switchgrass Biomass. Production for Biofuel Processing. *Journal of Environmental Management and Tourism*, 1(41), 173–185. https://doi.org/10.14505//jemt.v11.1(41).20

Kupchuk, I. et al. (2021). Multicriteria compromise optimization of feed grain grinding process. *Przegląd Elektrotechniczny*, 97(11), 179–183. https://doi.org/10.15199/48.2021.11.33

Li, M.M. et al. (2020). Identification of traits contributing to high and stable yields in different soybean varieties across three Chinese latitudes. *Frontiers in plant science*, 10, 1642. https://doi.org/10.3389/fpls.2019.01642

Ma, Z. et al. (2001). Impact of row spacing, nitrogen rate, and time on carbon partitioning of switchgrass. *Biomass Bioenergy*, 20, 413–419.

Mazur, V. et al. (2020a). Agroecological prospects of using corn hybrids for biogas production. *Agronomy Research*, 18, 177–182. https://agronomy.emu.ee/wpcontent/uploads/2020/03/AR2020_314_Mazur.pdf

Mazur, V. et al. (2020b). Photosynthetic productivity of potato plants depending on the location of rows placement in agrophytocenosis. *Ecology, Environment and Conservation*, 26(2), 46–55. http://www.envirobiotechjournals.com/

Mazur, V. et al. (2021a). Agroecological stability of cultivars of sparsely distributed legumes in the context of climate change. *Scientific Horizons*, 24(1), 54–60. https://doi.org/10.48077/scihor.24(1).2021.54-60

Mazur, V. et al. (2021b). Ecological suitability peas (*Pisum sativum*) varieties to climate change in Ukraine. *Agraarteadus*, 32(2), 276–283. https://doi.org/10.15159/jas.21.26

Mazur, V.A. et al. (2019). Influence of the assimilation apparatus and productivity of white lupine plants. *Agronomy Research*, 17, 206–219. https://agronomy.emu.ee/wpcontent/uploads/2019/03/Vol17No1.pdf_Mazur.pdf

Metcalfe D. S., & Nelson, C. J. (1985). The botany of grasses and legumes. In: M. E. Heath et al. (eds.). *Forages: The science of grassland agriculture*. Iowa State Univ. Press, Ames, IA. (pp. 52–63).

Mostovenko, V. (2020). Study of plant density and duration of vegetation period of vegetable peas depending on technological methods of cultivation. *Agriculture and forestry*, 2(17), 235–245. https://doi.org/10.37128/2707-5826-2020-2-21

Mostovenko, V., & Didur, I. (2021). Economic and energy efficiency of growing vegetable peas. *Colloquium-journal*, 12 (99), 47–52. https://doi.org/10.24412/2520-6990-2021-1299-47-52

Palamarchuk, V., & Telekalo, N. (2018). The effect of seed size and seeding depth on the components of maize yield structure. *Bulgarian Journal of Agricultural Science*, 24(5), 785–792. https://www.agrojournal.org/24/05-08.pdf

Palamarchuk, V. et al. (2021). The Modeling of the Production Process of High-Starch Corn Hybrids of Different Maturity Groups. *European Journal of Sustainable Development*, 10(1), 584–598. https://doi.org/10.14207/ejsd.2021.v10n1p584

Poberezhets et al. (2021). Effect of probiotic supplement on nutrient digestibility and production traits on broiler chicken. *Agraarteadus*, 32(2), 296–302. https://doi.org/10.15159/jas.21.28

Solona, O. et al. (2020). Analytical study of soil strain rate with a ploughshare for uncovering slit. *Agraarteadus*, 31(2), 212–218. https://doi.org/10.15159/jas.20.22

Telekalo, N., & Melnyk, M. (2020). Agroecological substantiation of medicago sativa cultivation technology. *Agronomy Research*, 18(4), 2613–2626. https://doi.org/10.15159/ar.20.181

Tkachuk, O.P. (2021). Biological features of the distribution of root systems of perennial legume grasses in the context of climate change. *Scientific Horizons*, 2, 70–76. https://doi.org/10.48077/scihor

Varchenko, O. et al. (2020). Supply chain strategy in modernization of state support instruments for small farms in Ukraine. *International Journal of Supply Chain Management*, 9(1), 536–543.

Vdovenko, S. et al. (2018). Symbiotic potential of snap beans (*Phaseolus vulgaris* L.) depending on biological products in agrocoenosis of the right-bank forest-steppe of Ukraine. *Ukrainian Journal of Ecology*, 8(3), 270–274. https://www.ujecology.com

Volkodav, V.V. (2001). Methodology of the State variety testing of agricultural crops (cereal, cereal and leguminous crops) K. (69 p.).

Wang, D. et al. (2010). A quantitative review comparing the yield of switchgrass in monocultures and mixtures in relation to climate and management factors. *GCB Bioenergy*, 2, 16–25. https://doi.org/10.1111/j.1757-1707.2010.01035.x