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ORIGINAL RESEARCH PAPER

Effect of cultivation technology on switchgrass (*Panicum virgatum* L.) productivity in marginal lands in Ukraine

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Abstract

Growing plants for biofuel production on marginal lands is of major importance in many developing countries. As a biomass source, switchgrass (*Panicum virgatum* L.) is a most adaptable plastic crop, forming extensive ground cover and vegetative biomass, providing a very high productivity over a short period of time. This study investigated the effects of cultivation (type of growing conditions and N fertilization rates) on biomass yields and changes in the structure of the switchgrass phytocenosis in different types of cropping systems. The biomass yields in stripe and mixed crops were higher than in single crops in the third year of cultivation. Switchgrass plants in intercrops were characterized by a greater height and number of shoots per unit area compared to mixed crops and monocultures. Biomass yields increased with each year of this research. The maximum biomass yields were attained with 30 kg ha^{-1} of N fertilization and the minimum yields where there was no fertilization.

Keywords

switchgrass (*Panicum virgatum* L.) cultivation; marginal land; plant biomass; biofuel

Introduction

Many developing countries depend on external energy sources, such as fossil fuels from abroad, produced in the territory of another country. There is therefore a need to embrace the latest developments in fuel and energy technology and to utilize alternative fuels such as plant biomass. This will increase the ecological balance of agroecosystems, decrease the dependence of a country on imported energy sources and will reduce the specific consumption of natural resources by using plant biomass. In this regard, the driver is to create plant sources of biofuels on marginal lands. It will be good to use a perennial crop which is well adapted to the growing region and which has a very high productivity. One such suitable energy crop is switchgrass (*Panicum virgatum* L.) which, amongst potential energy crops, is more adaptable to the conditions of cultivation. This grass produces a massive biomass and has a high productivity in a short period of time [1]. It is a thermophilic, perennial crop plant which has straight stems reaching up to 2.7 m in height, an inflorescence 15–50 cm, and a prolific root system reaching down to 3 m in the soil. The plant reproduces both by seed and vegetatively [2]. Switchgrass is drought-tolerant and is simple to cultivate without any irrigation and with minimal fertilizer application. Moreover, switchgrass is a plant which does not require much management as a crop. It is not a competitor to food crops because it will grow on marginal lands [3]. As a crop it has a low cost of cultivation and high biomass productivity, which does depend on cultivation technology [4]. It has a very wide tolerance of acidic soil conditions with pHs as low as 4.9 to base-rich soils as high as pH 8.9–9.1. However, optimal pH conditions for switchgrass cultivation are in circum-neutral soils. The biofuel from switchgrass can be used for the production of both solid (fuel pellets, briquettes) and liquid biofuels (cellulose ethanol) [5]. It could therefore have a positive influence on the reduction of energy consumption and the costs of production, and also greenhouse gas emissions.

Switchgrass cultivation has ecological impacts on soils especially in marginal lands. González-Sánchez et al. [6] and Aguilera et al. [7] have shown that growing herbaceous perennial crops has been widely acknowledged as an effective soil carbon building practice under Mediterranean conditions. Results from a review study by Lemus and Lal [8] show that switchgrass production could restore soil organic carbon (SOC) in surface soils. Switchgrass also has the potential for storing a significant quantity of soil carbon in the Northern Great Plains [9]. However, there is currently a scarcity of experimental data concerning switchgrass adaptability to the climatic conditions of Central and Northern Europe, and the improvement of agrotechnological operations for switchgrass cultivation [10,11]. Furthermore, there is only limited information on the ability of switchgrass to adapt to local environments, crop establishment from seed, and its productivity and management. It is therefore timely to investigate the effects of switchgrass cultivation on marginal land. The aim of this research was therefore to increase switchgrass productivity and to investigate the legume (lupine) and grass (switchgrass) symbiosis. The specific objectives of the study were then to evaluate the effects of cultivation technology (type of growing conditions and N fertilization rate) on biomass yields and to evaluate the changes in the structure of the switchgrass phytocenosis in the different types of cropping systems.

Material and methods

Site description and conditions of the experiment

This study was performed at Poltava Experimental Field Station in the central part of the forest-steppe zone of Ukraine (49°00′36″ N, 34°00′33″ W). It was a long-term experiment from 2010–2016. The main soil properties at the site (0–30 cm depth) were: soil type – grey podzolic middle loam, organic matter – 3.17%, N – 81 mg kg^{-1} dry soil, P – 139 mg kg^{-1} dry soil, K – 118 mg kg^{-1} dry soil, pH – 6.8.

Three factors (Factor A, B, and C) affecting biomass yield were researched:

- Factor A – the year of switchgrass cultivation. Productivity of switchgrass plants during 7 years of growth were analyzed.
- Factor B – type of growing conditions; the experiment included the following types of croppings: single crops (Sw), monocultures with specified row spacing that create conditions close to optimal for plant growth and development in the phytocenosis; stripe crops (Sw|L), crops of two or more kinds of plants on one plot of land (field) with specified predetermined alternation of rows or separate bands of crops. In such crops, one (mainly a grain crop) is the main component and another (a legume) is a subsidiary. Seeds are not mixed and sown separately in stripes or by two agrotechnological operations. This method of plant cultivation is used for maximizing yield from the area, with minimal production costs; mixed crops (Sw:L), crops of two or more types, seeds of which are mixed before planting or twice-repeated separate sowings on the same area. This sowing method is mainly used for growing fodder crops to obtain a high yield from a plant mixture.
- Factor C – N fertilization rates; effect of different rates of N fertilization (15, 30, 45, and 60 kg ha^{-1}) on switchgrass cultivation.

The weather conditions during the growth period of switchgrass between 2010–2016 were favorable. In some periods, the air temperature was higher than the annual average and during the years of experiment it ranged from 14.7–23.7°C (Fig. 1).

The amount of atmospheric precipitation was close to the annual average and during this period of time varied from 14.4 to 26.4 mm per month (Fig. 2).

A more reliable statistic is the hydrothermal coefficient (HTC), which varied from 0.7 to 1.2. Having analyzed weather conditions over the vegetation period according to

HTC indices, we have established that years 2011–2013 were dry, 2015 was subhumid, and 2010, 2014, and 2016 were with average humidity (Fig. 3).

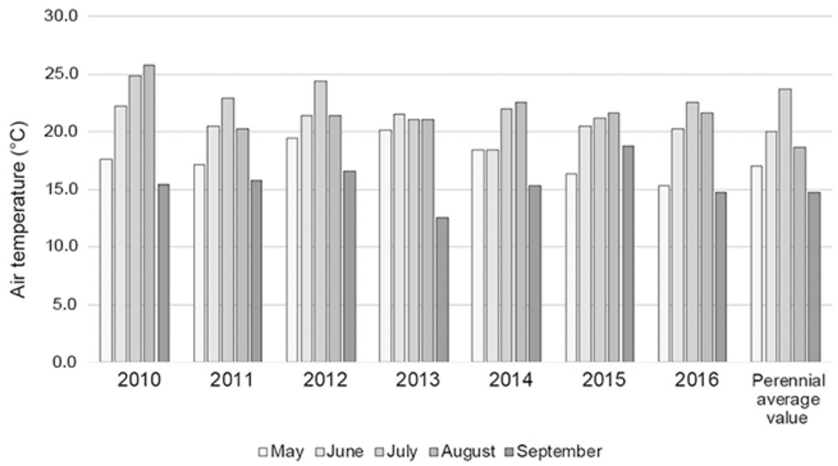

Fig. 1 Air temperatures (°C) during switchgrass cultivation 2010–2016.

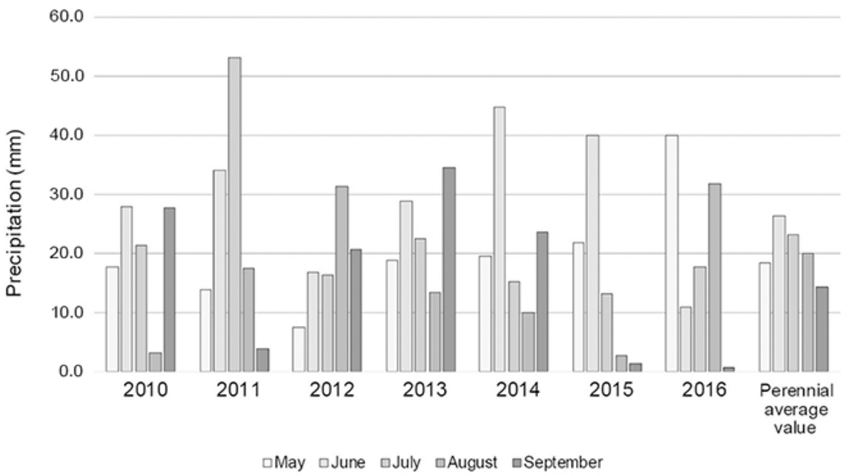

Fig. 2 Monthly precipitation (mm) during switchgrass cultivation 2010–2016.

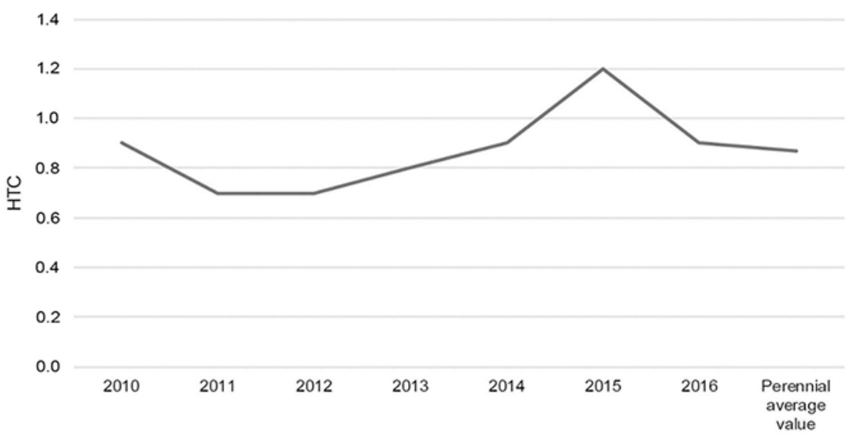

Fig. 3 Hydrothermal coefficients (HTC) during switchgrass cultivation 2010–2016.

Field measurements and processing

Agronomic operations for switchgrass cultivation included ploughing, spring soil cultivation, seeding, and rolling the crop. Multirow soil cultivation was carried out after the emergence of switchgrass shoots in the first year of crop establishment. In the following years, soil cultivation was not carried out, except for a spring application of N according to the experimental scheme. Seeding of switchgrass was carried out in the first 10 days of May. The width between rows was 45 cm. For seeding the legume, lupine (*Lupinus* L.) and switchgrass, the seed box of the drill was divided into sections by metal partitions to create rows of legume and the grass. The percentage of lupine seeds was 40% and switchgrass 60%, and the seed sowing rate 300 seeds per 1 m^2 at a depth of 1–1.5 cm.

Phenological monitoring of growth and development of plants was carried out and a calculation of plant density made when biomass was maximal, before the end of vegetative growth in the fall. For visual assessment of plant traits, the guidelines of the International Union for the Protection of New Varieties of Plants (UPOV) were also used [12].

Shoot heights were measured at the end of the switchgrass growth period. Plants were harvested by cutting at a height of 10 cm for each plot of 1 m^2, with four replications on the diagonal of each plot. Shoot height was recorded as the distance from the excised stem to the panicle. Hundred shoots were measured to give an average value per plot. A count of shoot numbers in rows of 1 m was also made at harvest.

Biomass yields of lupine and switchgrass were made in the field by complete plot harvesting at a height not less than 5 cm. Cutting of the 1-m wide plots was performed using special machines. Average dry matter yield for all cuts was determined by weighing plants harvested and then calculating on a per plant or per plot basis. Dry biomass yields were determined by drying 500 g of herbage samples at 105°C to constant weight.

All experimental data were analyzed statistically by dispersive and correlative tests using STATISTICA ver. 6.0 software. The significances of differences between means were tested at the $p < 0.05$ probability level.

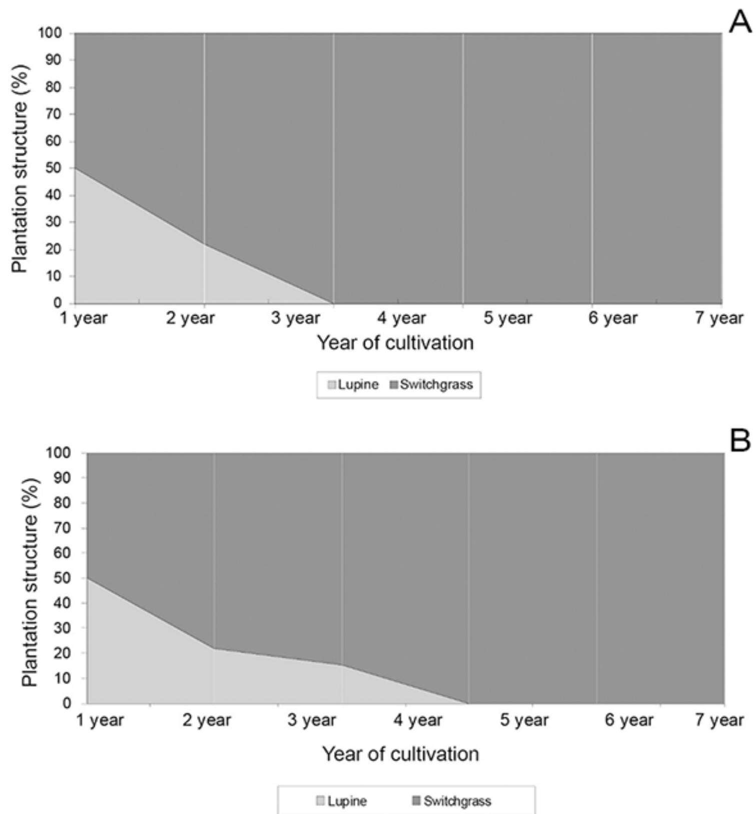

Fig. 4 Structure of energy plantations of switchgrass with lupine: in Sw|L (**A**) and in Sw:L (**B**), between 2010–2016.

Results

Structure of the switchgrass phytocoenosis

The results of our experiment showed that in Sw|L, the legume component (lupine) was supplanted by the main crop (switchgrass), as shown in Fig. 4, during the third year of growth. Competition for light and nutrients resulted in dominance of the grass crop.

Lupine developed very slowly during the first year being sown in spring. It formed only a small rosette of leaves with long petioles. The root system might be up to 30–40 cm long until full development of the vegetation cover. During the second year, lupine grew in the period of mid-April – early May and had rapid growth of the vegetative mass as well as the root system. In the third year, lupine formed a rosette of leaves with stem and new root suckers. It flowered in the spring and formed bean pods with low seed set. Lupine formed a strong root system and low aboveground biomass (10–20 cm) that did not compete with the main component (switchgrass) in Sw|L and Sw:L. This plant cover of lupine formed a bio-herbicidal screen which suppressed weed growth. In Sw:L, the lupine life cycle was 3 years and after that switchgrass occupied 100% of the vegetation structure (Fig. 4). Lupine plants in Sw|L were characterized by a fast growth and development of the aboveground vegetative mass, 6–12% more in comparison with Sw, and 4–10% more in comparison to Sw:L.

It was established that quantitative growth parameters such as height and number of shoots changed and varied widely depending on the type of growing conditions and N fertilization rate. This was apparent after the third to fourth years of growth and the disappearance of the legume component in the phytocenosis. The average height and number of shoots of switchgrass plants differed slightly according to the type of growth environment. For Sw|L with 30–60 kg ha^{-1} N, plants were the tallest and had the greatest number of shoots between 2012–2016. Switchgrass plants in Sw and Sw:L on nonfertilized plots were inferior in all ways (Tab. 1, Tab. 2).

Plant height was substantially lower in Sw:L because lupine occupied the lower layer of the plant stand and the side rows of switchgrass plants were shaded. Plants in the intermediate rows were taller by 6% than plants in the side rows because of the effects of interspecies competition for light. Furthermore, the number of shoots in Sw was less than in Sw|L and Sw:L. This is related to the development of their root systems and the growth of lateral shoots into spaces between rows which were occupied by lupine until the third to the fourth year.

Switchgrass plants in Sw|L were taller and had more shoots per unit area in comparison to Sw and Sw:L. This tendency was typical during the first 3 vegetation years until the stage of disappearance of the legume component. Consequently, this affected further years of plant development with a tendency to increase plant height during the annual growth cycle and the phytocenosis productivity of aboveground vegetative biomass, especially after a spring application of nitrogen.

In Sw, plant height significantly impacted on the switchgrass biomass. Positive correlation was found between the number of shoots and the biomass 0.53 (correlation coefficient, $r = 0.53$).

In Sw|L another linear dependency was established; a rise in the number of shoots resulted in an increase in biomass yield ($r = 0.69$). Plant height had only a slight influence with a correlation coefficient of $r = 0.31$; similarly with the determination coefficient, $d = 0.10$. Formation of switchgrass biomass yields in Sw:L depended upon the number of shoots and upon plant height. The results show that plants in Sw|L and Sw:L formed a greater number of shoots than plants did in Sw. Plant height was also higher in Sw|L and Sw:L.

Biomass yields dependent on year of switchgrass cultivation

Switchgrass productivity was recorded since the third year of growth. This was because from up to the third year all phenological phases of switchgrass cultivation and intensive growth of roots and vegetative mass were noted. The average value of biomass yields at the beginning of experiment was 1.15 kg m^{-2}; at the end it was 1.49 kg m^{-2}. Overall, the average increase in yields was 0.34 kg m^{-2} for the years 2012–2016. Over the course of one year of the research, switchgrass biomass yields had been increasing by 0.07–0.1 kg m^{-2}. Statistical analysis showed the important influence of the year of switchgrass cultivation (Factor A) on biomass yields (Fig. 5).

In the light of our results, we come to the conclusion that over multiyears of switchgrass cultivation, biomass yields increased.

Effect of different types of switchgrass growing on biomass yields

Biomass yields of switchgrass were recorded since the period it was harvested as a raw material for biofuel production (third year of the trial). The average value of biomass yields varied from between 1.14–1.50 kg m^{-2} (Tab. 3). This difference is related to improvements of fertility conditions and the phytocenosis structure.

During the years of this research, the lowest biomass yields was from the control plots with no N application – from 0.85 to 1.34 kg m^{-2} (Sw), 1.11–1.53 kg m^{-2} (Sw|L)

Tab. 1 Mean heights of switchgrass plants over years 3–7 of the study (cm).

Type of growing (Factor B)	N fertilization rates (Factor C)	Year of switchgrass cultivation (Factor A)					Average
		3 year	4 year	5 year	6 year	7 year	
Sw	N0	155.4	170.3	180.1	180.6	180.4	177.9
	N15	160.2	178.8	190.4	190.0	190.3	187.4
	N30	171.3	182.5	196.5	196.4	195.0	192.6
	N45	183.3	190.5	203.4	202.7	203.0	199.9
	N60	184.0	191.2	204.1	203.8	203.5	200.7
Sw|L	N0	204.7	211.1	218.4	217.1	219.2	216.5
	N15	208.8	212.4	219.8	218.3	220.7	217.8
	N30	222.0	221.1	225.1	232.4	237.1	228.9
	N45	221.0	226.8	231.4	233.6	239.1	232.7
	N60	230.6	232.3	235.0	237.4	240.5	236.3
Sw:L	N0	175.4	183.3	192.1	198.6	199.2	193.3
	N15	179.1	185.5	193.6	198.8	199.0	194.2
	N30	183.7	190.9	205.2	206.1	207.4	202.4
	N45	201.0	211.3	218.5	219.6	219.1	217.1
	N60	200.6	210.5	220.0	218.5	220.3	217.3
Mean		192.1	199.9	208.9	210.3	211.6	207.7
LSD_{05} (Factor A)	7.32	-	-	-	-	-	-
LSD_{05} (Factor B)	3.62	7.34	6.60	6.40	6.01	6.23	-
LSD_{05} (Factor C)	7.00	18.46	15.23	12.49	13.08	14.58	-
LSD_{05} (Factors ABC)	2.45	2.27	2.41	1.73	2.08	1.83	-

Tab. 2 Number of shoots of switchgrass plants per meter.

Type of growing (Factor B)	N fertilization rates (Factor C)	Year of switchgrass cultivation (Factor A)					Average
		3 year	4 year	5 year	6 year	7 year	
Sw	N0	198.5	201.4	219.8	225.1	224.7	217.8
	N15	199.2	202.0	225.1	232.8	233.4	223.3
	N30	203.7	212.4	246.8	252.4	254.1	241.4
	N45	222.8	230.0	234.2	238.5	240.0	235.7
	N60	228.4	232.6	227.1	224.9	226.1	227.7
Sw|L	N0	405.7	421.1	506.8	515.1	517.2	490.1
	N15	412.4	432.5	513.0	532.1	530.0	501.9
	N30	432.1	454.8	543.5	575.8	579.1	538.3
	N45	502.6	524.5	568.1	602.0	612.4	576.8
	N60	430.7	444.2	524.0	578.3	583.4	532.5
Sw:L	N0	312.5	326.1	345.6	386.7	401.0	364.9
	N15	312.8	326.3	346.0	388.2	402.1	365.7
	N30	322.1	328.2	348.1	595.4	409.3	420.3
	N45	328.5	340.2	362.2	412.3	413.5	382.1
	N60	327.1	344.4	359.9	413.8	415.0	383.3
Mean		322.6	334.7	371.3	411.6	402.8	380.1
LSD_{05} (Factor A)	48.82	-	-	-	-	-	-
LSD_{05} (Factor B)	14.69	14.78	15.59	10.00	33.86	14.81	-
LSD_{05} (Factor C)	50.40	8.87	9.39	11.75	13.19	12.83	-
LSD_{05} (Factors ABC)	6.37	2.77	1.82	2.31	2.11	1.49	-

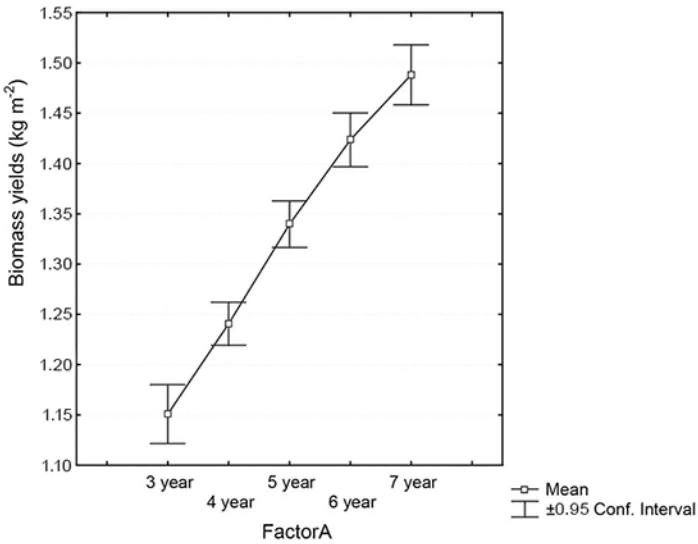

Fig. 5 Biomass yields for the years of switchgrass cultivation (Factor A), 2012–2016.

Tab. 3 Switchgrass biomass yields (kg m^{-2}).

Type of growing (Factor B)	N fertilization rates (Factor C)	Year of switchgrass cultivation (Factor A)					Average
		3 year	4 year	5 year	6 year	7 year	
Sw	N0	0.85	1.03	1.21	1.3	1.34	1.14
	N15	1.05	1.12	1.19	1.24	1.26	1.17
	N30	1.09	1.24	1.27	1.33	1.39	1.27
	N45	1.12	1.32	1.38	1.41	1.48	1.34
	N60	1.08	1.27	1.32	1.38	1.41	1.29
Sw|L	N0	1.11	1.21	1.32	1.45	1.53	1.32
	N15	1.29	1.37	1.52	1.64	1.67	1.50
	N30	1.28	1.29	1.47	1.56	1.60	1.44
	N45	1.25	1.28	1.36	1.45	1.54	1.38
	N60	1.21	1.26	1.33	1.4	1.43	1.33
Sw:L	N0	1.12	1.25	1.3	1.38	1.45	1.30
	N15	1.16	1.22	1.34	1.4	1.48	1.32
	N30	1.29	1.32	1.49	1.58	1.67	1.47
	N45	1.20	1.24	1.31	1.45	1.54	1.35
	N60	1.18	1.24	1.33	1.42	1.50	1.33
Mean		1.15	1.24	1.34	1.42	1.49	1.33
LSD_{05} (Factor A)	0.041	-	-	-	-	-	-
LSD_{05} (Factor B)	0.042	0.054	0.049	0.050	0.052	0.056	-
LSD_{05} (Factor C)	0.061	0.056	0.065	0.055	0.081	0.076	-
LSD_{05} (Factors ABC)	0.048	0.045	0.037	0.036	0.050	0.052	-

and 1.12–1.45 kg m^{-2} (Sw:L). More significant differences were observed between plots with N application; Sw|L with 15 kg ha^{-1} N – from 12.9 (in the third year) to 1.67 kg m^{-2} (in the seventh year). The highest mean biomass yields (1.50 kg m^{-2}) were in Sw|L with a N fertilizer rate of 15 kg ha^{-1}. The lowest biomass yield (1.14 kg m^{-2}) was in Sw without N fertilizer.

Dispersion analysis revealed the influence of switchgrass growing method (Factor B) on biomass yield. Large differences were confirmed at $p < 0.05$ and F > Ft. Our data

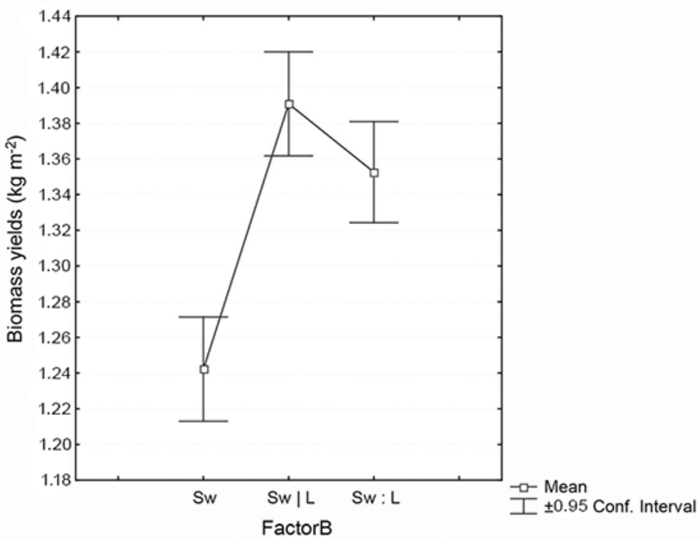

Fig. 6 Biomass yields of switchgrass in different growing conditions (Factor B), 2012–2016.

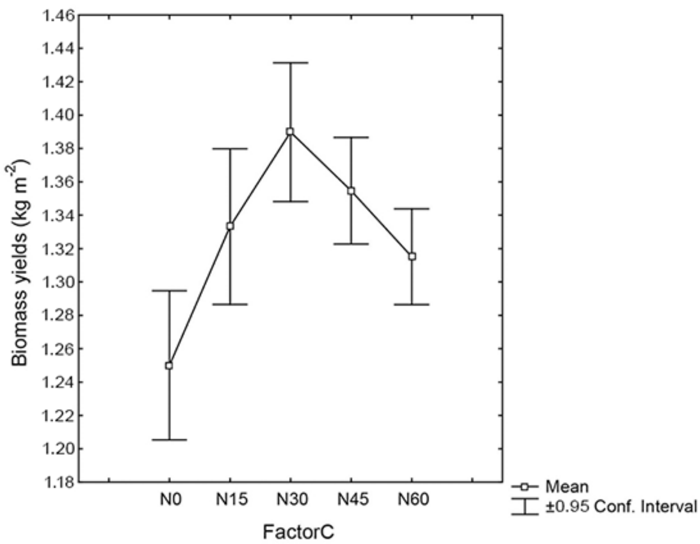

Fig. 7 Biomass yields in relation to N fertilization rates (Factor C), 2012–2016.

show that in Sw|L switchgrass plants had higher biomass yields than Sw:L and Sw (Fig. 6).

Sw had the lowest mean value of biomass yield – 1.24 kg m^{-2}. Maximum possible productivity was in Sw|L – 1.39 kg m^{-2}. The difference between biomass yields in Sw|L and Sw:L was not significant, only 0.04 kg m^{-2}. Switchgrass cultivation with a row spacing of 45 cm with legumes was very effective. In Sw|L and Sw:L crops, the biomass yields were higher by 0.15–0.11 kg m^{-2} in comparison to Sw crops.

Impact of N fertilization on switchgrass biomass yields

The influence of N fertilization rates (Factor C) on biomass yields is summarized in Fig. 7. Over the 5-year period, much greater yields (1.50 and 1.44 kg m^{-2}) were amassed by the crops in Sw|L that were fertilized with 15 and 30 kg ha^{-1} N. The highest biomass yield (1.39 kg m^{-2}) was in plots with fertilization with 30 kg ha^{-1} N and the lowest (1.25 kg m^{-2}) where there was no N fertilization. Furthermore, it was shown that higher rates of N fertilization (45 or 60 kg ha^{-1}) with Sw|L reduced the biomass yields by 0.06–0.17 kg m^{-2}. In Sw:L crops, biomass yields were much greater (1.47 kg m^{-2}) with fertilization with 30 kg ha^{-1} N. With applying less N (15 kg ha^{-1}) and more (45 and 60 kg ha^{-1}) N, yields were greatly decreased by 0.17 and 0.12 kg m^{-2}, respectively. In Sw, increasing biomass yields were achieved with N fertilizing rates of 15–45 kg ha^{-1}. Biomass yields in plots with no N fertilization were from 0.03 to 0.20 kg m^{-2}, and those with fertilization by 60 kg ha^{-1} N were within the limits of the LSD_{05}.

On the basis of the full statistical analysis of the data, we can confirm that N fertilization increases switchgrass biomass yields from by 0.17–0.20 kg m^{-2}. The optimal rate of N fertilization is 30 kg ha^{-1}.

Discussion

The results of trials by Carlsson and Georg [13] show that growing a mixture of plants on marginal lands encourages the development of resource saving and lessens impacts on the climate. This contributes to the synergies between productivity and biodiversity in terms of climate change and multifunctional uses of biomass. The use of grass mixtures as energy crops reduces N inputs. Yang [14] claims that by decreasing mineral N applications, switchgrass biomass crops greatly decreases the N losses from a field.

Amongst the components of different grass mixtures, lupine has a great N-fixing effect. Ledda et al. [15] discovered that the productivity and ability of white lupine (*Lupinus albus* L.) to fix N varies greatly between locations and climatic conditions. These authors found that after white lupine cropping, the N content in the soil was raised from negative indices up to 160 kg ha^{-1}. It was discovered that 60, 34, 8, and 6 kg of N t^{-1} are fixed by seeds, bean pods, stems, and roots, respectively, so confirming that the fixed N is mainly amassed in seeds at physiological maturity. Because of its high potential to fix

N, white lupine is a therefore a good precursor for grain and grass crops. As stated by Dybzinski et al. [16], including legumes in four perennial legume-grass mixtures with grains favors N fixation and increases soil fertility, so fixing large amounts of carbon and N in the grass and legume roots. Perennial legume–grass mixtures are therefore able to produce a high and stable productivity of energy crop biomass with low risks of losing N which is therefore very effective in resource utilization [17,18].

For Sw:L, our research data show that a decrease in atmospheric N fixation because of shading plants by the dominant grass component. The type of plant nutrition as well as the nutrition itself is highly important; improved nutrition favors fast growth of the grass component comparing to the legume. For Sw|L, the components produced different heights forming a stepped structure which allows plants to make better use of solar energy. It also allows placement of the root systems in different soil layers that assist with a more efficient use of nutrients and moisture. Lupine, due to its leaf arrangement creates a suitable microclimate that improves the temperature regime, increases air humidity, and accelerates microbiological soil processes. The phyto-herbicidal screen from lupine enables a decrease in weeds in switchgrass rows especially in the early stages of main component's growth and development.

Improvement of fertilization conditions via the phytocenosis structure was confirmed by our research. Plants in Sw|L and Sw:L formed more stems than plants in Sw. Average plant height was also greater in Sw|L and Sw:L. The correlation analysis of the structure of switchgrass phytocenosis showed that the number of stems compared to plant height has a greater effect on switchgrass productivity in all types of sowings ($r \geq 0.7$ testifies the strong link between indices). This conclusion has also been confirmed both by Lemus and Lal [10] and Anderson et al. [19] who claim that any increase in stem dominance in the total phytomass of switchgrass phytocenoses may result in an improvement in biomass quality on account of the higher fiber content and lesser N content in stems, both of which are useful for bioenergy technology and for fermentation.

Our experiments show that starting from the third year of switchgrass cultivation, there is a need for N fertilizing the crop in order to raise its yield. N fertilization affected harvest increase more than just the type of switchgrass growing conditions. Our statements agree with the conclusions of Vogel et al. [20] and Lemus et al. [21] that annual application of N fertilizers will increase switchgrass harvesting quality. Miesel et al. [22] have investigated applying N and conclude that it will favor N accumulation in plants after its later growth stages and so improve crop productivity. The experiments performed by Carlsson et al. [13] show that for nonfertilized high-diversity mixtures of energy crops the average biomass productivity was in the range 3–9 t ha^{-1} for several years. However, applying 60–120 kg ha^{-1} N ensured a higher productivity. Lemus et al. [21] recommend fertilizer application after each harvest or before crop renewal. Vogel et al. [20] state that the optimal time period for fertilizing is once a year during May or June. For switchgrass, maximum productivity it is reasonable to apply fertilizers after crops have reached some maturity. However, using inorganic fertilizers for P and K additions does not seem to give any significant increases in switchgrass productivity [23].

Conclusion

In this study, we found for the first time that the application of agrotechnical measures (type of cultivation method and N fertilization rate) contributes to an increase in the biomass yield of switchgrass on marginal lands. Yields increased over each year of the research. Most importantly, our results demonstrate the great effectiveness of switchgrass cultivation with a mixture of a legume. In our Sw|L and Sw:L crops, biomass yields were higher by 0.15–0.11 kg m^{-2} in comparison to the Sw crops. Plants in Sw|L and Sw:L formed a greater number of shoots than did plants in Sw; plant heights also were also greater in these. This allows the addition of less N from the third year of establishment, the period useful for industrial harvesting of a switchgrass crop. Applying N fertilizer increased biomass yields by 0.17–0.20 kg m^{-2} and the optimal rate of N fertilization was 30 kg ha^{-1}. We believe that our findings can raise the profile of switchgrass as a biomass source for biofuel production. This knowledge base should contribute to the production of energy crops on marginal lands in Ukraine.

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Wpływ technologii uprawy na produktywność prosa rózgowego (*Panicum virgatum* L.) uprawianego na gruntach marginalnych Ukrainy

Streszczenie

Uprawa roślin do produkcji biopaliw na gruntach marginalnych ma ogromne znaczenie w wielu krajach rozwijających się. Proso rózgowe (*Panicum virgatum*) łatwo dostosowuje się do warunków siedliskowych, wpływa na pokrycie gleby i jest źródłem biomasy. Roślina ta charakteryzuje się bardzo wysoką produktywnością biomasy w krótkim okresie czasu. W pracy badano wpływ uprawy (rodzaj uprawy, dawka nawozu azotowego) i zmiany w strukturze fitocenozy na plon biomasy. W trzecim roku uprawy plony biomasy w uprawie pasowej i mieszanej były wyższe niż w monokulturze. Rośliny prosa rózgowego w uprawie pasowej były wyższe i charakteryzowały się większą liczbą pędów wytwarzanych na jednostkę powierzchni w porównaniu z uprawą mieszaną i monokulturą. Plony biomasy rosły z każdym rokiem badań. Maksymalne plony biomasy zostały osiągnięte przy dawce nawożenie N 30 kg ha^{-1}, a minimalne przy braku nawożenia.