

Use of winter rye for production of biogas

Yegorov D., Zmiyevska O., Demianenko S.

V. Yuriev Institute of plant industry of NAAS, Mos-covskyi ave., 142, Kharkiv, 61060, Ukraine;
e-mail: yuriev1908rye@gmail.com

The purpose. To determine suitability of grades and hybrids of winter rye for production of alternative kinds of fuel. **Methods.** Field, laboratory, statistical. **Results.** Variability in productivity of green and dry mass, content of dry matter and exit of biogas depending on genotype, phases of growth of a plant and hydrothermal conditions of vegetation is established. In phase of shooting according to productivity of green material they selected 1 sample (26,7 t / hectare), to phase of swelling — 5 samples with productivity of 31,2 – 35,7 t/hectare. **Conclusions.** Grades and hybrids of winter rye of domestic selection provide lump of biomass with high exit of biogas for a unit of the area. But it is necessary for Ukraine to create power hybrids of winter rye with stably high productivity of green mass and resistance to adverse conditions of vegetation.

Key words: winter rye, biofuel, bio-power crops, green material, dry mass, biomass.

<https://doi.org/10.31073/agrovisnyk201805-10>

Now the renewable energy sources (RES) take the important place in an energy balance of the countries of the world. One of the important sectors of RES in the world takes production and energy use of biogas. It is known that the European Union is the leader in biogas production, at the same time the important place is taken by Germany [1]. More than 70% of renewable energy sources are made by biomass, in the agrarian sector it is, first of all, the energetic crops, processing waste of agricultural production and raw materials for receiving biogas. In general, biomass takes the fourth place among all fuel which is applied in the world. It gives about 2 billion t of the conditional fuel a year that makes about 14% of the common consumption of primary energy supplies in the world [2].

Significant rise in the cost of traditional fuels for a short time term in Ukraine opens a way to an intensification of use of its alternative types, including biogas. By realization of economic potential of biomass, Ukraine can satisfy up to 18% of the common need for primary energy supplies [3].

The winter rye is considered an ideal crop for biogas production because of high reproduction stability of a harvest due to resistance to abiotic stresses, in particular to a drought, and low input in the soil's fertility. It is proved that when usage a winter rye on sandy soils makes it possible to receive high yield of energy [4]. The German scientists confirmed high suitability of any rye genotypes for receiving a renewable bioenergy [5]. According to T. Piechota rye hybrids had advantage over varieties on fresh and dry matter yield [6].

Literary data demonstrate that the main signs for a bioenergetic rye, to which the breeder has to pay attention, are fresh and dry matter yield [7-8]. It is established that the highest amount of biomass from rye plants can be received at the milk-ripening [9], but an exit of biomass depends on the soil and climatic conditions: in some regions of the world the yield can be five times higher, than, for example, in Germany [10]. In Ukraine there are no researches on using of winter rye for bioenergy production, therefore our research is relevant.

Research objective. The research objective was to establish suitability of varieties and hybrids of winter rye for production of alternative fuels, in particular biogas, by determination of fresh and dry matter yield, dry matter content and biogas yield level per hectare.

Methods. Researches were conducted during 2015-2017 on the experimental field at Plant Production Institute nd. by V.Ya. Yuriev of NAAS (PPI NAAS). Weather conditions in research period were changeable. Features of the vegetative period of 2015-2016 were a very droughty period of autumn vegetation (September-October HEC 0,2) and a sufficient supply with moisture during an overwintering

and spring - summer development of plants (April-June HEC 2,8). The vegetative period of 2016-2017 was characterized by a very cold spring vegetation period (average daily temperature in April did not exceed 10 C, rainfall existence like a snow and frosts in separate days to - 5 C) and a droughty ripening period (HEC 0, 5) that has an adverse effect on rye plants development.

Varieties and hybrids of winter rye for food usage of breeding at Plant Production Institute nd. by V.Ya. Yuryev of NAAS, including four varieties Pamyat` Hudoyerka, Hamarka, Dikhar, Stoir and three hybrids Jupiter F₁, Saturn F₁, Slobozhanets F₁ were used. A winter rye was sown with seeding rate of 4 million grains ha⁻¹ on experimental plots of 10 m². Winter rye plants were slanted at the stem elongation and at the beginning of milk ripening to determinate a fresh matter yield. Plants mowed manually by means of sickles from area of 1 m² in quadruple frequency. A dry matter yield was defined when a fresh matter was dried up in an open air. A dry matter content and a biogas yield were defined by a calculation method. Statistical data were processed by means of the package Microsoft Excel 2010 and Statistics 10 programs.

Results. The variability of winter rye varieties` and hybrids` fresh matter yield depending on a genotype, plant development stage and hydrothermal conditions of the vegetative period were established. So, on average at the milk ripening it has been received 1,2-2,0 times more fresh matter, than at the stem elongation (table 1). At the stem elongation Hamarka was allocated with high fresh matter yield 26,7 t ha⁻¹, which reliable exceeded the standard on 9,8 t ha⁻¹. Hybrids Jupiter F₁ (32,0 t ha⁻¹), Saturn F₁ (32,7 t ha⁻¹) and varieties Pamyat` Hudoyerka (31,2 t ha⁻¹), Hamarka (31,8 t ha⁻¹), Stoir (35,7 t ha⁻¹) were allocated at the milk ripening. The excess over the standard amounted from 11,5 to 15,3 t ha⁻¹ or 53,7-75,4%. The analysis of average data on varieties` and hybrids` fresh matter yield has shown, that varieties exceeded hybrids on average in a two year trail. Hybrids have been created for food use and therefore their breeding has been directed to decrease in vegetative mass amount and increase in grain yield and also steady a short-stem manifestation, that causes lower potential of hybrids on fresh matter yield than at varieties.

The weather conditions of the vegetative period had the considerable influence on fresh matter yield. So, at the stem elongation in the conditions of 2017 on average it was received 2,1 times less fresh matter, than in the conditions of 2016, that is caused by a snow mold damage because of overwintering adverse conditions in 2017 and droughty conditions of vegetation during the spring period. Hamarka was the best on fresh matter yield in the conditions of 2017, and hybrid Saturn F₁ was the best in the conditions of 2016.

Table 1. Fresh matter yield of winter rye varieties and hybrids, t ha⁻¹

Sample	Stem elongation			Milk ripening		
	2016	2017	An average	2016	2017	An average
Slobozhanets F ₁ (st.)	26,0	7,6	16,8	28,0	12,6	20,3
Jupiter F ₁	21,0	12,2	16,6	32,6	31,3*	32,0*
Saturn F ₁	20,2	21,6*	20,9	23,5	42,0*	32,7*
Hybrid average	22,4	13,8	18,1	28,1	28,6	28,3
Pamyat` Hudoyerka	29,1	10,1	19,6	30,8	31,6*	31,2*
Hamarka	40,0*	13,3	26,7*	34,7	28,8*	31,8*
Stoir	22,1	13,5	17,8	25,6	45,8*	35,7*
Dikhar	29,3	9,4	19,4	25,4	23,9*	24,6
Variety average	30,1	11,6	20,8	29,1	32,4	30,8
Trail average	26,8	12,5	19,7	28,7	30,9	29,8
SSD _{0,05}	6,9	7,1	6,8	6,8	8,2	7,3

*– reliable at the level 0,05

The essential difference on average fresh matter yield between years was not revealed at the beginning of milk ripening. Essential differences between variants in 2017 were noted. If in 2016 the

fresh matter yield was within 23,5-34,7 t ha⁻¹, then in 2017 the index value fluctuated ranging from 12,6 up to 45,8 t ha⁻¹. The maximal fresh matter yield (45,8 t ha⁻¹) was noted at Stoir. Hybrid Saturn F₁ demonstrated less yield (42,0 t ha⁻¹), that Stoir did. It was established that in the conditions of 2016, favorable for rye plants development, varieties were more productive, and in unfavorable conditions of 2017 hybrids were more productive, as hybrid organisms are steadier against stressful conditions of cultivation because of heterosis effect.

It is noted a small difference 1,9 t ha⁻¹ on fresh matter yield in the conditions of 2016 between development stages and an essential difference 18,4 t ha⁻¹ in the conditions of 2017. Plants' reaction to hydrothermal conditions is in case of the former caused by the sustained drought during the autumn period of vegetation, that led to late seedlings emergence (in the second decade of October) and reduction passage of all rye plant development stages. As a result at the stem elongation plants were developed unevenly, that affected a fresh matter yield level at the milk ripening. In the second case damage by a snow mold led to a reducing of fresh matter yield at the stem elongation, and droughty conditions of the vegetation period in June negatively affected yield of Slobozhanets F₁ and Hamarka, Dikhar at the stem elongation, which was lower in comparison with previous year. Despite of negative weather conditions impact on a rye fresh matter yield, positive fact is that plants created a high yield level within 30 t ha⁻¹ at the milk ripening, that demonstrates high compensatory properties of winter rye plants and provides to this crop appeal to use it as raw materials by alternative fuel production.

Sufficient dry matter content in biomass and a fuel yield per area unit is an important index for bioenergy crop. In the table 2 indicators of dry matter yield, biogas yield per area unit and dry matter content in biomass, which we received as a result of the research, were showed.

Table 2. Dry matter yield, dry matter content in biomass and biogas yield of winter rye varieties and hybrids, 2016-2017.

Sample	Stem elongation			Milk ripening		
	dry matter yield, t ha ⁻¹	dry matter content, %	biogas yield, m ³ ha ⁻¹	dry matter yield, t ha ⁻¹	dry matter content, %	biogas yield, m ³ ha ⁻¹
Slobozhanets F ₁ (st.)	4,9	30,7	2968,1	9,5	44,5	3588,4
Jupiter F ₁	5,5	34,6	2930,9	14,6	45,3	5642,8*
Saturn F ₁	7,8	37,5	3692,4	16,1*	46,6	5778,9*
Hybrid average	6,1	34,3	3197,2	13,4	45,5	5003,4
Pamyat` Hudoyerka	6,6	36,4	3454,7	16,1*	50,9	5516,4*
Hamarka	9,2*	35,7	4705,9*	15,3	50,1	5611,4*
Stoir	6,7	37,6	3143,3	20,0*	53,0	6295,8*
Dikhar	6,3	36,6	3420,3	11,8	48,5	4352,7
Variety average	7,2	36,6	3681,1	15,8	50,6	5444,1
Trail average	6,7	35,6	3473,7	14,8	48,4	5255,2
SSD _{0,05}	3,2	14,9	1199,4	6,0	15,9	1293,7

*– reliable at the level 0,05

Variability of a dry matter yield, a dry matter content and a biogas yield depending on plant development stages was established. At the milk ripening all of three indicators increased. A dry matter yield were received from 4,9 to 9,2 t ha⁻¹ at the stem elongation. A dry matter content at the

stem elongation compounded from 30,7 to 37,6%. A biogas yield per hectare fluctuated within 2930,9-4705,9 m³ ha⁻¹. At the milk ripening an average of dry matter yield in trail increased by 2,19 times in comparison with the stem elongation stage and fluctuated within 9,5-20,0 t ha⁻¹, also a dry matter content in biomass was 12,8% higher at the milk ripening. A calculated biogas yield at the milk ripening was within 3588,4-6295,8 m³ ha⁻¹, which was 1,5 times higher, than at the stem elongation.

Thus, rye plants are more productive at the milk ripening. But despite a less dry matter yield, which rye plants provide at the stem elongation in comparison with the milk ripening, a biomass already has the dry matter content not less than 30,7% during this period, that means good sign for biogas production.

It was statistically confirmed that samples were differed on dry matter yield and biogas yield, but they were not significantly differ on dry matter content. Hamarka were allocated by dry matter yield 9,2 t ha⁻¹ and biogas yield 4705,9 m³ ha⁻¹, which reliably exceeded the standard at the stem elongation. At the milk ripening hybrid Saturn F₁ and varieties Pamyat` Hudoerka, Stoir exceeded the standard on dry matter yield. Hybrids Jupiter F₁, Saturn F₁ and varieties Pamyat` Hudoerka, Hamarka, Stoir exceeded the standard on biogas yield. The usage of the allocated samples makes it possible to receive 16,1-20,0 t ha⁻¹ of dry matter and 5642,8-6295,8 m³ ha⁻¹ of biogas.

Comparing data of biogas yield from a winter rye and a corn it is possible to confirm that from winter rye varieties and hybrids of food use it is possible to receive rather a high yield of biogas. According to corn breeding laboratory of PPI NAAS a modern corn hybrids provide from 35,0 to 52,0 t ha⁻¹ of fresh matter. Theoretically at the biogas yield of a corn silo 185,3 m³/t it is possible to receive from 6485,5 to 9635,6 m³ ha⁻¹ of biogas, that 2133,0 - 3340,0 m³ ha⁻¹ higher, than from a rye. But the prime cost of winter rye raw materials is lower than a corn at the expense of low costs of cultivation and therefore both winter rye varieties and hybrids can be used with success in alternative fuel production.

The analysis of dry matter yield, dry matter content and biogas yield demonstrates that varieties are more productive, than hybrids, as the majority of the allocated samples on signs were varieties. Average data on varieties and hybrids also confirm this fact.

The results of our researches point out that the hybrids of food use, created by us, are less suitable for biogas production, than varieties, though the hybrid Saturn F₁ is an example of successful domestic breeding development for energy needs of Ukraine.

Conclusions

Winter rye varieties and hybrids of breeding at Plant Production Institute nd. by V.Ya. Yuryev of NAAS provides rather high biomass amount with a high biogas yield per area unit, and the padding value of crop as bioenergetic crop consists in a possibility of winter rye to provide high amount of raw materials during this period (May - June) when other crops, for example a corn, did not create the maximal potential of raw materials yet. However in Ukraine there is a need of targeted breeding of rye hybrids with a steadily high fresh matter yield and a resistance to adverse factors of vegetation for energy needs of Ukraine.

Bibliohrafiya

1. Geletuha G., Kucheruk P., Matveev Ju. (2013). Perspektivy proizvodstva i ispol'zovaniya biogaza v Ukraine. [The prospects of biogas production and use in Ukraine]. *Analiticheskaja zapiska BAU*. 4. 22 s. [in Russian].
2. Dubovin V., Mel'nichuk M., Mironenko V., Polishhuk V., Dragnev S. (2007). Ukrainskoe biotoplivo budet kachestvennym. [The Ukrainian biofuel will be qualitative]. *Zerno*. 5(14), S. 98-103. [in Russian].

3. Geletuha G., Zhelezna T., Zhovmir M., Matveev Ju., Drozdova O. (2011). Otsinka enerhetychnoho potentsialu biomasy v Ukraini. [The biomass energy potential estimation in Ukraine]. *Prom. teplo tehnika*. Vol.33,1, Is. 2, S. 57-64. [in Ukrainian].
4. Scholz V., Ellerbrock R. (2002). The growth productivity, and environmental impact of the cultivation of energy crops on sandy soil in Germany. *Biomass and Bioenergy*. V. 23. Is. 2. P. 81–92.
5. Roux S., Wortmann H., Schlathöller M. (2010). Breeding capability of rye (*Secale cereale* L.) for biogas production. EUCARPIA-International Symposium on Rye Breeding and Genetics. Minsk, Belarus: UP "IVC Minfina" P. 29.
6. Piechota T., Sawinska Z., Kowalski M. et al. (2017). Plonowanie i zdrowotność wybranych odmian żyta ozimego uprawianego z przeznaczeniem na biogaz. *Fragm. Agron.* R. 34, 2. S. 67–74.
7. Hübner M., Oechsner H., Koch S. et al. Impact of genotype, harvest time and chemical composition on the methane yield of winter rye for biogas production. *Biomass and Bioenergy*. 2011. V. 35(10). P. 4316–4323.
8. Marlen Gottwald (2014). Phenotypic and molecular analyses of grain and biomass productivity under irrigated and rainfed conditions in hybrid rye: dissertation zur Erlangung des Grades eines Doktors der Agrarwissenschaften vorgelegt der Fakultät Agrarwissenschaften von Diplom-Agrarbiologin Marlen Gottwald (geb. Hübner) aus Hofheim am Taunus Stuttgart-Hohenheim, Germany.
9. Miedaner T., Hübner M., Koch S. et al. (2010). Biomass yield of self-incompatible germplasm resources and testcrosses in winter rye. *Plant Breeding*. V. 129(4). P. 369–375.
10. Deublein D., Steinhauser A. (2008). Biogas from Waste and Renewable Resources: An Introduction. Weinheim: WILEY-VCH Verlag GmbH & Co. KGaA. 444 p.