



THE ROLE OF TECHNOLOGY IN THE SOCIO-ECONOMIC DEVELOPMENT OF THE POST- QUARANTINE WORLD

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2.2. THE ROLE OF INNOVATIONS IN THE DEVELOPMENT AND MANAGEMENT DURING THE OPTIMIZATION OF CULTIVATION TECHNOLOGIES OF INDUSTRIAL CROPS IN THE POST-CORONAVIRUS WORLD

At present, food and energy problems will be intensified both for Ukraine and for developing countries in the post-coronavirus world. The first problem of food security, based on providing the population with protein, has remained unsolved at a sufficient level so far. The level of productivity and quality of the agricultural products in our country, compared to European ones, is at a rather low level. This is especially true for the main food crop – soft winter wheat. Therefore, the problem of increasing gross harvest and improving quality of grain crops remains open. The problem of reduction of Ukraine's energy dependence on the basis of renewable energy sources (RES), also remains open. However, Ukraine receives the main energy resource from nuclear power plants, the service life of which has almost expired. Other non-renewable energy sources such as natural gas and oil are mostly imported and produced in small quantities in the country. Besides, renewable energy sources are not fully used, including alternative energy of plant resources, energy of the sun, wind and geothermal energy. Therefore, the issue of rational use of natural resources – remains open, but not sufficiently studied.

The innovative method of optimizing the cultivation of field crops for food use and energy plants for biofuel production has been proposed in order to solve these problems. This will allow:

- to increase the protein content in winter wheat grain (as the main food crop) using seed of different qualities, taking into account the weather conditions of the period of seed formation on the maternal plants;

- to increase the yields of energy crops (switchgrass, miscanthus, perennial sorghum and paulownia), by intercropping with legumes;

- to get an additional product – vegetable fodder protein for animal husbandry;

- to save material and labor resources, to optimize production processes;

- to reduce time and number of employees needed for industrial crops cultivation;

- to increase the profitability of agriculture;

- to ensure the ecological balance of the environment, etc.

Among the most influential factors affecting the yields and quality of agricultural products and energy crops, scientists³¹⁸ identify weather-climatic and environmental factors, and only then anthropogenic impact (human activity).

In accordance with the authors³¹⁹, agroecology has the perspective of comprehensive changes in the agricultural and food systems, which prevails over the modern technical innovations. Agrobiodiversity must be expanded according to the general rethinking of environmental, technological, socio-economic and political aspects of agriculture as to the improvement of the food systems sustainability.

Throughout the 21st century, local droughts were recorded both in the Forest-Steppe zone and the Steppe zone almost every year, which negatively affects the agricultural sector of Ukraine. This leads to the considerable losses of agricultural enterprises because of the negative effects of atmospheric and soil droughts and their complex harmful impact on the plants³²⁰.

³¹⁸ Halytska M. A., Pysarenko P. V., Kulyk M. I. (2018). Humifikatsiino-mineralizatsiini protsesy yak pokaznyk akumulatsii karbonu v gruntakh. *Tavriiskyi naukovi visnyk*. Kherson, Vyp. № 102. S. 130-136.

³¹⁹ Chable, V., Nuijten, E., Costanzo, A., Goldringer, I., Bocci, R., Oehen, B., Rey, F., Fasoula, D., Feher, J., Keskitalo, M., Koller, B., Omirou, M., Mendes-Moreira, P., Van Frank, G., Kader, A., Jika, N., Mathieu, T., and Adanella Rossi. (2020). Embedding Cultivated Diversity in Society for Agro-Ecological Transition. *Sustainability*, 12, 784. doi:10.3390/su12030784.

³²⁰ Boiko, P. Y., & Kovalenko, N. P. (2008). Paru v proshlom y sovremennom zemledel'ly [Clean lands in the past and modern agriculture]. *Ahrovisnyk Ukrainy*, (25), 14-17 (in Ukrainian).

The increase of air temperature and uneven distribution of precipitation, which are shower and local in nature during the warm period and do not provide effective accumulation of moisture in the soil, result in the growth of droughts frequency and intensity³²¹. The increase in the number and intensity of droughts occurred after 2000 and reached a maximum in 2007-2012³²². During the period of the most intense warming, the frequency of natural phenomena increased and the ratio of natural phenomena changed in comparison with the previous years³²³. As established by the authors³²⁴, the changes of annual temperature in the Forest-steppe conditions over the last 100 years are 0.7-0.9°C toward warming. In winter, warming is 1.2°C, in spring is 0.8°C, the changes are insignificant in summer and autumn. Snow cover in the west and south is formed in the second half of December and lasts for 60-80 days, reaching a height of 20 cm. The studied period was characterized by the predominance of spring-summer droughts. The droughts in 2000, 2003, 2007, 2017 were the harshest in all three zones, when their intensity reached the criteria of strong and extreme. The growing seasons of 2007, 2009, 2012, 2017 turned out to be completely arid.

The physical and geographical location of Ukraine largely determines its rather complex variable climatic conditions, which leads to the frequent changes and formation of baric units³²⁵. On the territory of Ukraine, yield losses because of adverse weather conditions in some years can reach up to 45-50 %.

Therefore, in the extreme conditions, with continuous climate changes, the decisive factor is the rational placement of crops in area and time, taking into account their agrobiological characteristics, soil and weather conditions, which allows to increase yields by 15-20%³²⁶.

Our recent³²⁷ studies have established the dependence of yield and protein content in wheat grain on the weather conditions and seed quality. This trait was characteristic for both winter wheat varieties of different origin

Our previous studies³²⁸ also have established regularities of growth of the yield of energy crops biomass. They are determined by the growing conditions and nitrogen fertilization of crops and depend on changes in the structure of the phytocenosis with legumes

The effectiveness of energy crops cultivation is achieved by optimization of cultivation technology, which in combination with the weather conditions allows to increase the biomass productivity for the production of biofuels³²⁹.

Thus, summarizing the research results of the scientific publications, it has been determined that in order to reduce the impact of climate changes and the extreme weather conditions, it is

³²¹ Польовий А. М., Божко Л. Ю. Вплив кліматичних змін на режим зволоження вегетаційного періоду в Україні. *Український гідрометеорологічний журнал*. 2015. № 16. С. 128-139.

³²² Семенова І. Г. Синоптичні та кліматичні умови формування посушливих явищ в Україні: дис. ... докт. географічних наук: 11.00.09 «Метеорологія, кліматологія, агрокліматологія». Одеса, 2015. 296 с.

³²³ Кульбіда М. І., Єлістратова Л. О., Барабаш М. Б. Сучасний стан клімату України. Проблеми охорони навколишнього природного середовища та екологічної безпеки. 2013. Вип. 35. С. 118-130. URL: http://nbuv.gov.ua/UJRN/Ponp_2013_35_14.

³²⁴ Білявський Ю. В., Білявська Л. Г. Аналіз агро-кліматичних та ґрунтових умов Лісостепу України для вирощування сільськогосподарських та енергетичних культур. Оптимальні енергетичні системи з урахуванням наявного потенціалу відновлюваних джерел енергії у Лісостепу України : колективна монографія / За заг. ред. М. І. Кулика, О. В. Калініченка. Полтава: ПП «Астроя», 2019. С. 7-17.

³²⁵ Адаменко Т. Стихійні гідрометеорологічні явища та їх вплив на сільське господарство України. *Агроном*. 2007. № 4 (18). С. 16-19.

³²⁶ Saiko, V. F. (2008). *Zemlerobstvo v konteksti zmin klimatu [Agriculture in the context of climate change]*. *Zbirnyk naukovykh prats NNTs «Instytut zemlerobstva NAAN»*. Spets. vyp., 3-14 (in Ukrainian).

³²⁷ Kulyk M. I., Rozhkov A. O., Kalinichenko O. V., Taranenko A. O., Onoprienko O. V. (2020). Effect of winter wheat variety, hydrothermal coefficient (HTC) and thousand kernel weight (TKW) on protein content, grain and protein yield. *Agronomy Research*. URI <http://hdl.handle.net/10492/6116>. <https://doi.org/10.15159/ar.20.187>.

³²⁸ Taranenko A., Kulyk M., Galytska M., Taranenko S. (2019). Effect of cultivation technology on switchgrass (*Panicum virgatum* L.) productivity in marginal lands in Ukraine. *Acta Agrobot.* 72 (3): 1786. URL: <https://doi.org/10.5586/aa.1786>.

³²⁹ Kulyk M., Kurylo V., Pryshliak, N., Pryshliak, V. (2020). Efficiency of Optimized Technology of Switchgrass Biomass Production for Biofuel Processing. *Journal of Environmental Management and Tourism*, [S. l.], v. 11, n. 1: 173-185, doi: [https://doi.org/10.14505/jemt.v11.1\(41\).20](https://doi.org/10.14505/jemt.v11.1(41).20).

necessary to find the ways to eliminate these negative phenomena in close connection with the agricultural measures of industrial crops cultivation. Which in the future will increase productivity, help to reduce product losses as well as to obtain stable and high yields of appropriate product quality even in the adverse weather conditions. At the same time, introduction of energy crops into the structure of sown areas together with legumes (sowing of the main crop) and involving them in the component composition of forest shelter belts will allow to obtain an additional product – vegetable raw materials for biofuels.

Therefore, the aim of our research was to determine the impact of plant growing conditions and seed quality on productivity, variability of protein content in winter wheat grain and its yield. Also, our research comprised studying the possibility of involving perennial energy crops in the structure of field crop rotation.

To carry out a comprehensive research with industrial crops, we conducted many years' experiment in the central forest-steppe of Ukraine on the basis of practical and theoretical planning. During the experiments, the requirements of research in agronomy³³⁰, scientific and methodological recommendations for field experiments were observed.

The research involved two blocks of the study:

1. to study morphological and biological traits of energy crops (switchgrass, miscanthus, perennial sorghum, paulownia, poplar) and the possibility of their intercropping;

2. to establish the influence of quality of winter wheat seed and weather conditions on the yield and protein content in grain;

3. to make a model of the structure of the sown areas of industrial crops (food and biofuel purpose), and the involvement of woody and herbaceous energy crops into forest shelter belts.

The morphological and biological traits of energy crops, their productivity potential, and the possibility of intercropping cultivation were studied at the first stage of the research (Fig. 1).

The studied morphological and biological traits of energy crops are described in detail in the scientific work^{331, 332}. Here is a description of all energy crops.

Switchgrass (*Panicum virgatum* L.) is a perennial herb (up to 10-15 years in one place), belongs to the family of cereals (*Poaceae*).

Plants reach a height of 100-150 to 210-250 cm. The number of productive shoots per plant is from 12-14 to 30-35 pieces. Plants, depending on the shape, are straight and semi-delusional. The number of metamers per stem is from 3 to 7, and in individual forms – up to 9. The diameter of the stem base is 4-6 mm on average, but forms with thin and thick stems are found. The sheet plate reaches a length of 50-60 cm, in some forms can be much longer; width – on average 11-14 mm. In the form of drool is a loose, cheeky, oval, pyramidal, compressed.

The length of the vent is 30-40 cm, the width – 20-30 cm. By weight of 1000 pcs. grains are divided into three groups: with a low weight – up to 1.5 g, with an average weight of 1.5-1.8 and a large weight – more than 1.8 g.

Perennial rhizomes can be divided into 8-25 (vegetative reproduction) (up to 80) parts depending on the year of life and form of plants. Each landing unit has a length of 5-7 cm.

Yield: aboveground phytomass of plants during the period of panicle appearance is 42-64 t/ha, during the flowering period is 42.7-70.2 t/ha; dry weight is 10-15 t/ha; seeds is 500-600 (sometimes up to 1000) kg/ha.

Energy productivity of plants is 40-60 (up to 80) Gcal/ha.

³³⁰ Rozhkov A. O., Puzik V. K., Kalens`ka S. M. Doslidna sprava v agronomiyi: navch. posibnyk: u 2 kn. Kn. 1. Teoretychni aspekty doslidnoyi spravy. Za red. A. O. Rozhkova. Xarkiv, Majdan, 2016. 316 s.

³³¹ Kurylo V. L., Rakhmetov D. B., Kulyk M. I. Biologichni osoblyvosti ta potentsial urozhainosti enerhetychnykh kultur rodyny tonkonohovykh v umovakh Ukrainy. Visnyk Poltavskoi derzhavnoi ahrarnoi akademii. Vyp. 1 (88), 2018. S. 11-17. DOI 10.31210/visnyk2018.01.01

³³² Kulyk Maksym, Shokalo Natalia, Dinets Olha (2019). Morphometric indices of plants, biological peculiarities and productivity of industrial energy crops. Development of modern science: the experience of European countries and prospects for Ukraine: monograph / edited by authors. 3rd ed. Riga, Latvia: «Baltija Publishing», p. 411-431. URL: <https://doi.org/10.30525/978-9934-571-78-7>

Miscanthus giganteus (*M. × giganteus*) is a tetraploid hybrid of the Chinese miscanthus (*M. sinensis* Anderss.) and a mucant mushroom (*M. sacchariflorus* (Maxim. Benth). A perennial herb with a C 4 – scheme of photosynthesis.

Plants reach a height of 220-310 cm (may reach 450-500 cm). The number of shoots in the bush is 10-15 (up to 70). The stem is straight, rounded. The diameter of the stem is 12-25 mm. The number of leaves on the stalk is 11-15 pieces, the width is 2.2-2.9 cm, and the length is 93-102 cm.

The valve has a spindle-shaped, cone-shaped or elliptical shape and reaches a length of 30-33 cm. Plants have a rifle-type planting. The number of rhizomes (rhizomes) in one plant is from 18 to 37 pcs., the length is 10-15 cm.

Spring branching begins in the second half of April, tillering – the end of June, entering the tube – the end of August. The vegetation is completed in the phase of the appearance of volatility (most often in the phase of entering the tube) in the first half of October. The life cycle of plants lasts 15-20 years.

The yield of green phytomass is from 60 to 150 t/ha, dry weight is 10-15 (to 32) t/ha.

The energy productivity of plants is 67-84 (up to 130) Gcal/ha.



Fig. 1. Energy crops: switchgrass (a), miscanthus (b), perennial sorghum (c), strip crops (d), poplar (e), paulownia (f)

Perennial sorghum (*Sorghum alnum* Parodi.) belongs to the family of *Poaceae*. The plant has a height of 230-300 cm. The main stem and all the side shoots on top end with panicle. Leaves – long-lance, 60-80 cm long, 3-5 cm wide. The number of them per plant varies from 18 to 26 pcs.

The leaves of the base cover the stem in half. Inflorescence is panicle of length 40-45 cm. Seeds are elongated, brownish-black. Weight of 1000 pieces is 8.5-9.0 grams. The root system is well developed and penetrates into the soil to a depth of 2.0-2.5 m. During drought, it can develop secondary roots. The optimal seeding time is the first and second decade of May, when the soil warms up to a depth of 10 cm to 12-14 °C. Field germination of seeds is 75-80 %. Optimal temperature for development is plus 18-25°C.

The yield of the green mass at the beginning of the panicle formation provides 30-35 t/ha, in the flowering period is 45-50 t/ha, and during the period of fruiting is 65-75 t/ha, the seed is 1.5-1.7 t/ha. The yield of dry phytosterol is 11-14 t/ha. The energy value is 3750-3810 kcal/kg.

Poplar (*Populus*) is a perennial plant of the family *Salicaceae*. It is a close relative of willow, which also has application in bioenergy.

Poplar is one of the most common tree-shrub forms, used for energy purposes.

Poplar is an erect plant, well leafed, leaves are broad, diamond-shaped or oval, pointed at the base, 12 cm long, 9 cm wide. Colour of leaves is light green. Flowers are long, hanging catkins. Male flowers are bright red. Flowers appear before the leaves.

In the natural environment, the plant is reproduced by seed, root suckers and seedlings. Poplar seed tufts are easily dispersed by wind over long distances.

In the climatic conditions of Ukraine, poplar requires a lot of moisture and light for intensive growth and development, so the greatest yield of biomass will be provided in the conditions close to moderately and excessively humid.

Poplar is valued for its fast growth and resistance to pests and the ability to grow on poor soils. In most cases, it does not require the application of pesticides and fertilizers. Poplar can grow on contaminated, infertile soils, minimizing competition between bioenergy and food crops³³³.

Paulownia is a perennial tree of the *Paulowniaceae* family. Plants are characterized by the rapid linear growth, forming a trunk up to 15-20 m, shoots quickly regenerate and grow after pruning. Large leaves of a rounded-oval shape are symmetrically placed on the trunk. Paulownia forms beautiful inflorescence (up to 30-50 cm long) with pale purple (sometimes white) flowers that have a pleasant aroma. Paulownia seeds are tiny, the weight of 1000 seeds is up to 1 g.

Paulownia plants are undemanding to the growing conditions, except for the initial periods of growth and development. They are able to adapt to the different climatic conditions, to survive at the extreme temperatures from -20°C to +45°C, and to generate new shoots at more favorable temperatures. Plants are undemanding to soil fertility, resistant to pests and diseases.

Paulownia is used in ornamental horticulture, apiculture, woodworking industry (for example, in construction, for furniture purposes) and is studied as an energy crop for biomass production³³⁴.

According to the new results of practical researches, it has been established that herbaceous energy crops are characterized by the intensive growth and development, after 2 years of the growing season, they completely cover the soil with their phytomass. Woody energy crops in the first years are less fast-growing, but starting from the second-third years show a dynamic to the rapid increase in the linear growth of stems and shoots.

The wide row-spacing of wood energy crops (up to 6 meters) should be used for growing herbaceous energy crops. It has been determined that perennial sorghum plants grow intensively in row-spacing of paulownia, smaller increase of aboveground phytomass was provided by miscanthus and switchgrass. Perennial sorghum plants move outside the plot for the third-fourth years of vegetation. This tendency was due to self-germination of seed and growth of perennial sorghum rhizomes. This trait was not observed for other energy crops. Switchgrass grew within the bushes, miscanthus giganteus grew due to the lateral shoots, formed from the dormant rhizome buds.

³³³ Kulyk M. I., Kurylo V. L., Kalinichenko O. V., Galytska M. A. Plant energy resources: agroecological, economic and energy aspects: monograph/ Edited by authors. Poltava: Astraya, 2019. 150 p.

³³⁴ D'omin Dmytro, Kulyk Maksym, Kulinich Andrii. Ahrotekhnolohichni aspekty vyroshchuvannya novoi enerhetychnoi kultury – pavlovnii (Paulownia). Materialy Mizhnarodnoi naukovo-praktychnoi Internet-konferentsii «Tendentsii ta perspektyvy rozvytku nauky i osvity v umovakh hlobalizatsii»: Zb. nauk. prats. Pereiaslav, 2020. Vyp. 58. S. 466-469.

Due to the fact that poplar, according to the technology, was cut on a stump after the first year of vegetation (to obtain a bushy form of plants), the growth of lateral shoots in row-spacings was observed in the following years. This inhibited the growth of all herbaceous plants and made it difficult to control weeds and blocked the passage of agricultural machinery.

All energy crops responded well to growing in stripe crops. Cultivation of miscanthus and lupine, miscanthus and alfalfa, switchgrass and lupine, switchgrass and clover provided the largest phytomass. We connect this regularity with the additional supply of nitrogen from legumes to the main component of the phytocenosis – energy plants. As well as a bioherbicide screen that is created by legumes in row-spacings of energy crops. Legumes in the phytocenosis with perennial sorghum lasted out for one year, which can be explained by the intensity of growth and development of grain crop, its growth in row-spacings, shading and displacement of the companion crop (Fig. 2).

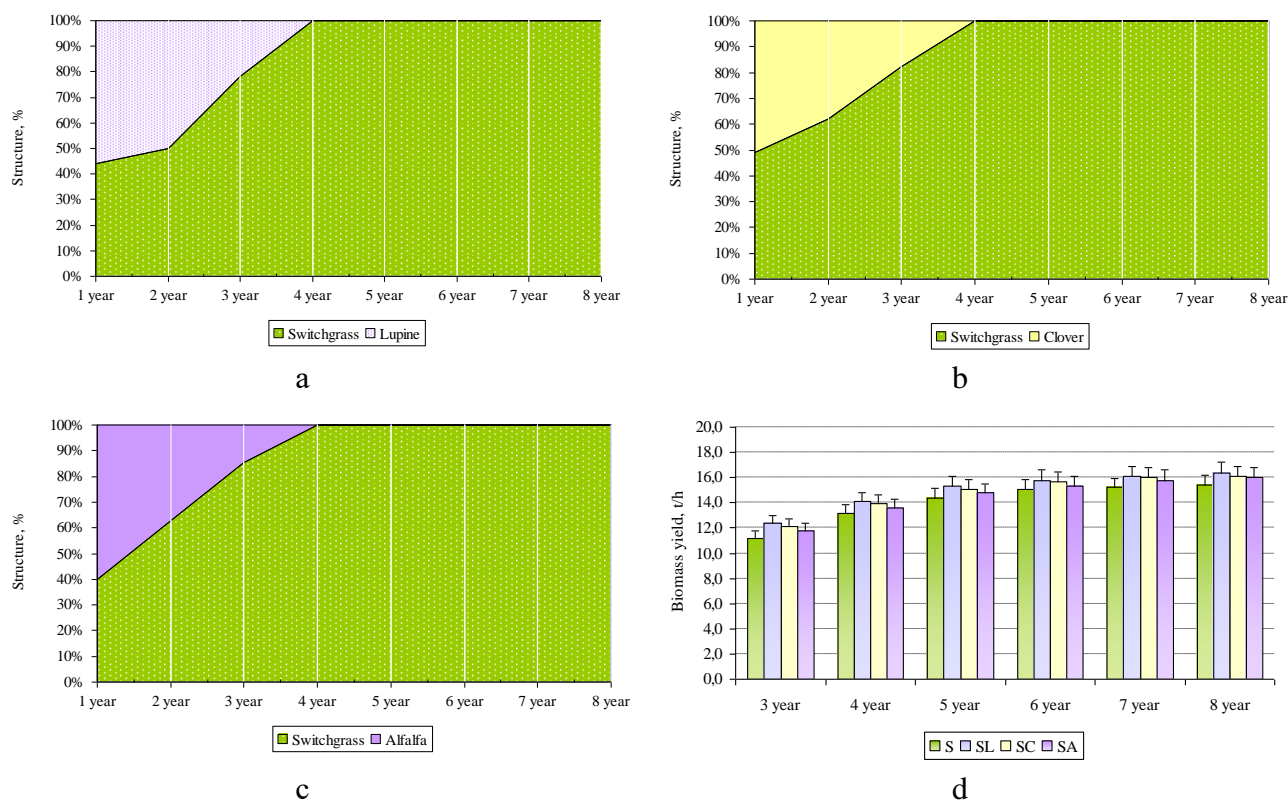


Fig. 2. Variability of the phytocenosis structure in the cultivation of switchgrass with legumes: lupine (a), alfalfa (b) clover (c) and biomass yields (d)

44-49% of the intercropping cultivation, switchgrass took 100% of the crops, displacing all legumes, involved in the experiment for the 4th year of the growing season. Alfalfa was the fastest to be displaced, followed by clover and lupine.

A significant growth of dry biomass yield of switchgrass and miscanthus giganteus, compared to the control (monocrop) while their intercropping cultivation with legumes was provided.

Phytocenosis structure had a similar tendency while the cultivation of miscanthus giganteus in strip crops. During intercropping cultivation of miscanthus with legumes, biomass increases greater in comparison with the control (monocrop) (Fig. 3).

Thus, we have made preliminary conclusions according to the results of the first stage of research:

- compared to poplar, perennial sorghum is more compatible with growing in paulownia row-spacings;
- in strip crops of miscanthus and switchgrass it is appropriate to grow alfalfa, lupine and clover, which significantly increases the biomass yields of energy crops.

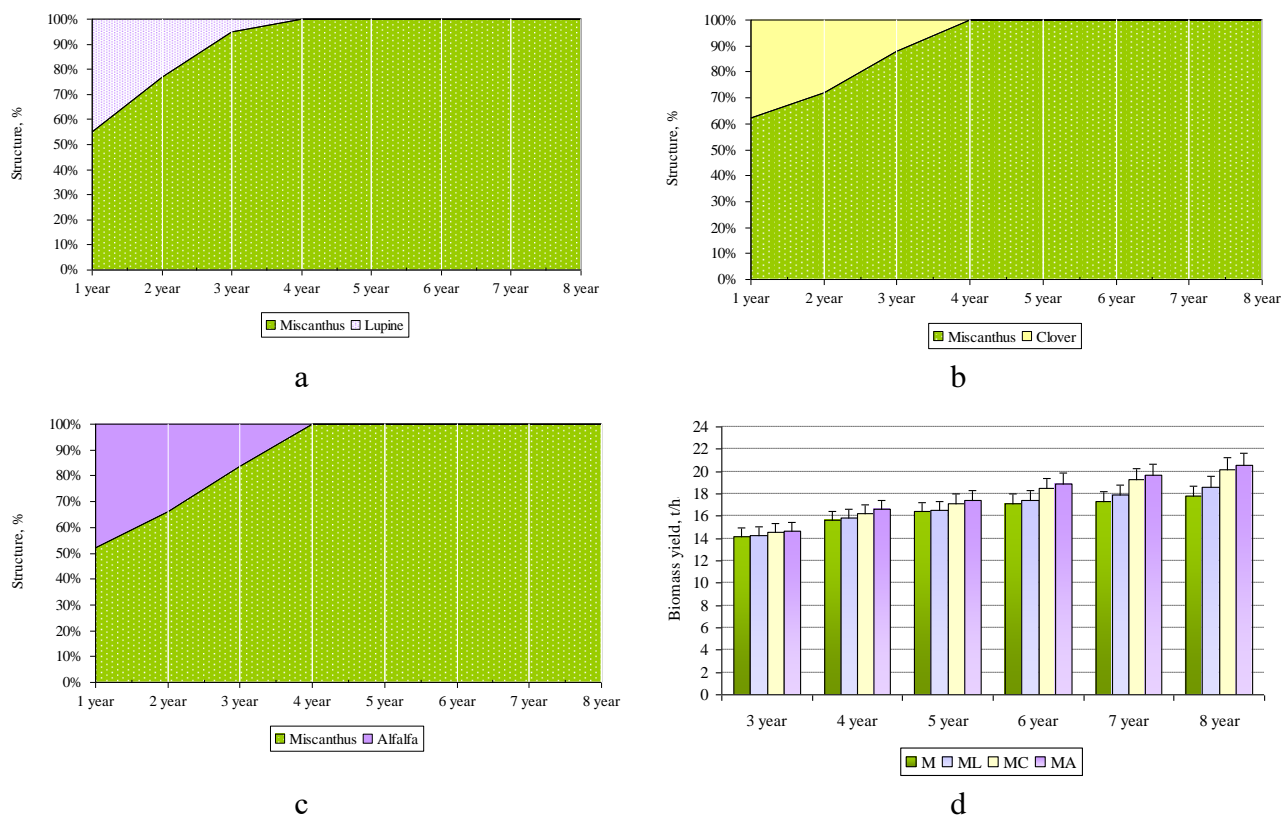
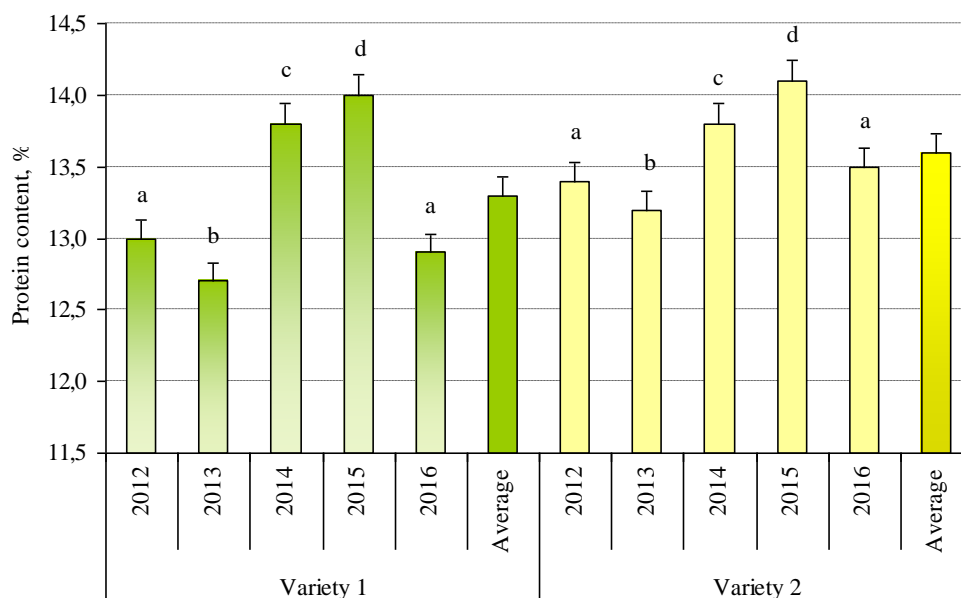


Fig. 3. Variability of the phytocenosis structure during the intercropping cultivation of miscanthus giganteus with legumes: lupine (a), alfalfa (b) clover (c) and biomass yield (d)

At the second stage of the research, the significant impact of weather conditions of the period of grain formation and filling on its quality (protein content) and yield of winter wheat grain has been determined.

The conditions of the period of grain formation and filling have been distinguished: close to optimal (2012 and 2016), arid (2014 and 2015), and wet (2013). This allowed us to fairly analyze their impact on the accumulation of protein content in winter wheat grain (Fig. 4).



Note: different letters show significant differences within each variety.

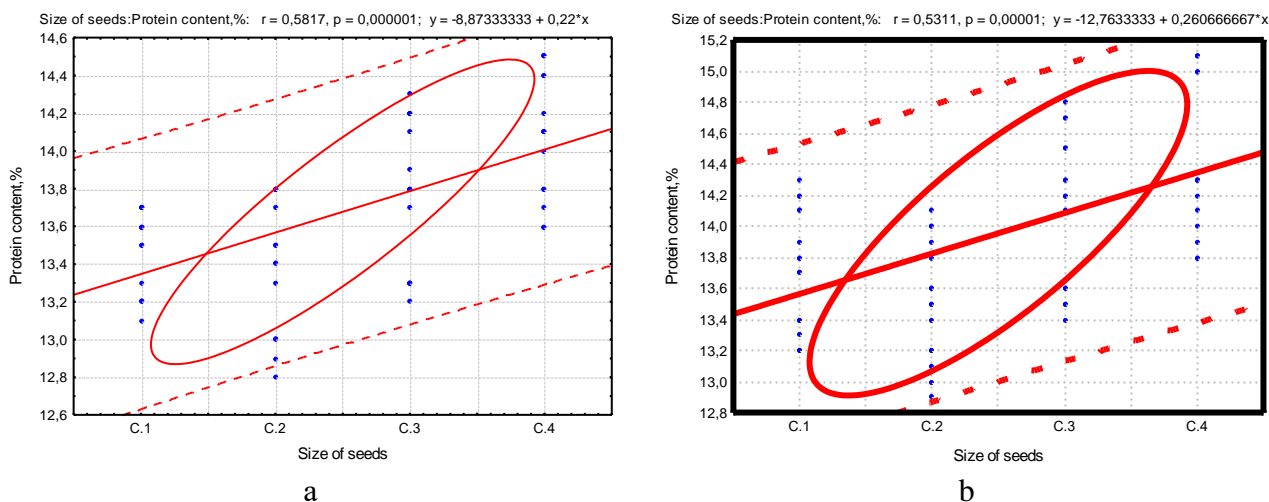
Fig. 4. Protein content in winter wheat grain of Chyhyrynka (variety 1) and Kubus (variety 2) varieties, 2012-2016

A significant amount of precipitation during the period of seed formation and ripening and low average daily air temperature in 2013 reduced the protein content in winter wheat grain of the studied varieties. The lower protein content was found in grain, which was formed in the conditions close to optimal (2012 and 2016). The best grain quality was formed by winter wheat varieties in 2014 and 2015 under the arid and stressful conditions of the period of grain formation and filling.

The dependence has been established: sowing with seed, grown in the arid conditions allows to obtain progenies with high protein content, and vice versa. This is confirmed by a close correlation for winter wheat variety Chyhyrynka and is expressed by the regression equation $y = -13,55 - 0,18 \times x$, and the variety Kubus ($y = -13,62 - 0,12 \times x$). It has been determined that sowing with small seed increases the protein content in grain, without additional costs, but under the condition of using seed that were formed in the arid conditions.

An inverse moderate correlation ($r = -0.61$) was observed in the interaction of HTC (period of grain formation and filling) and protein content in winter wheat grain of variety Chyhyrynka. A similar dependence was observed in variety Kubus: protein content increases in the arid years of the period of grain formation and filling by HTC, these indicators have a strong inverse correlation $r = -0.66$.

While establishing a correlation between protein content in grain and seed size, it has been determined that these indicators are interdependent at $r = 0.59$ for winter wheat variety Chyhyrynka, and $r = 0.53$ for variety Kubus (Fig. 5).



Note: C.1 – initial sample of winter wheat seed (control), C.2 – large seed of winter wheat, C.3 – medium seed of winter wheat, C.4 – small seed of winter wheat.

Fig. 5. Correlation dependences between protein content and seed size of winter wheat varieties: a – Chyhyrynka variety, b – Kubus variety, 2017–2016

Our studies are consistent with the findings of scientists³³⁵, who developed a new analysis method for quantifying both the gradients of protein concentration and the size distribution of protein bodies in endosperm of wheat plants, grown at two different temperatures (20.0°C or 28.0°C) in the period of seed formation and nutrient-supplied plants. The protein content in wheat grain also varies depending on the fertilizer options: high or low nitrogen content. The authors of the publication found that the increased temperatures during the period of generative development of wheat, on the background of high supply of nitrogen, increases the protein content in grain. This trait, according to the authors³³⁶ can also be used in the selection process.

³³⁵ George P. Savill, Adam Michalski, Stephen J. Powers, Yongfang Wan, Paola Tosi, Peter Buchner1 and Malcolm J. Hawkesford (2018). Temperature and nitrogen supply interact to determine protein distribution gradients in the wheat grain endosperm. *Journal of Experimental Botany*, Vol. 69, No. 12: 3117-3126, doi:10.1093/jxb/ery127.

³³⁶ Pereira Ana Marta, Coimbra Sílvia (2019). Advances in plant reproduction: from gametes to seeds. *Journal of Experimental Botany*, Volume 70, Issue 11: 2933-2936 https://doi.org/10.1093/jxb/erz227.

Grain yield increases while sowing with medium or large seed, which were formed in the optimal or wet years of winter wheat vegetation.

The yield of winter wheat variety Chyhyrynka, sown with large seed, obtained in the arid conditions allowed to increase the yield up to 5.0 t/ha, which is more by 1.1 t/ha than variant 1 (seed mixture), by 0.6 t/ha than variant 2 (small seed), by 0.5 t/ha than variant 3 (medium seed) – Fig. 6.

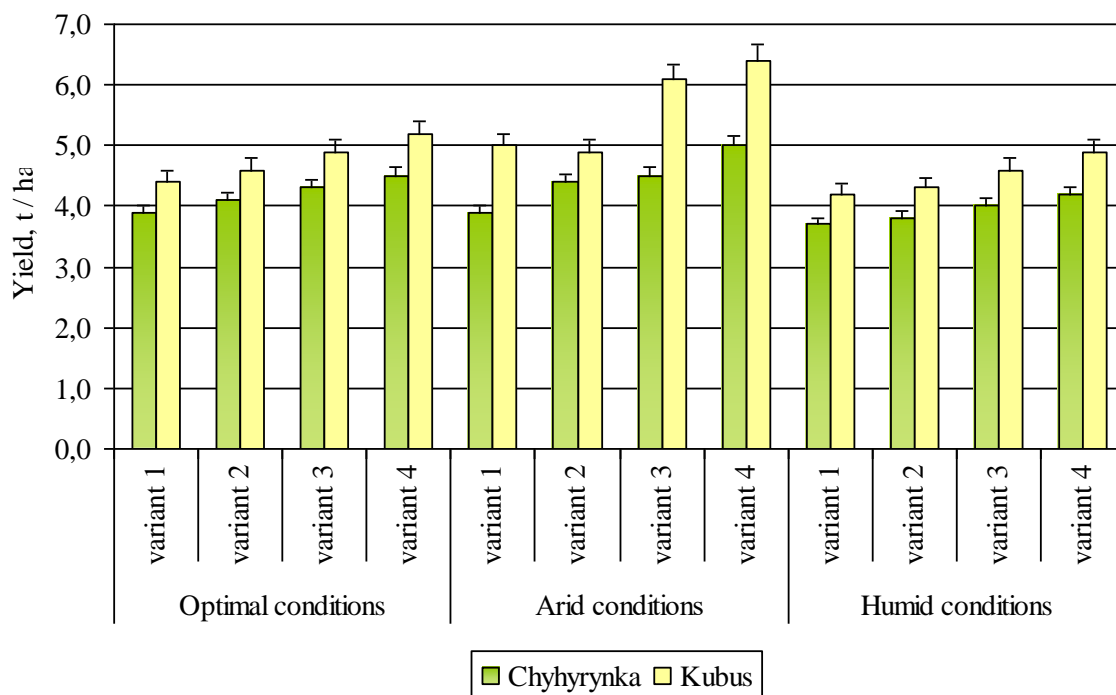


Fig. 6. Grain yield of winter wheat varieties Chyhyrynka and Kubus, 2017–2019

Sowing with a large fraction of seed made it possible to increase the yield of variety Kubus up to 6.4 t/ha, which is more by 1.6 t/ha than variant 1 (seed mixture), by 1.1 t/ha than variant 2 (shallow seed) and by 0.3 t/ha than variant 3 (medium seed).

Sowing with seed, obtained in the arid conditions, in comparison with seed, obtained in the optimal and wet years by HTC, shows a higher coefficient of energy efficiency ($K_{ee} > 2.0$). This indicates the resource conservation in the technology of winter wheat cultivation and reduction of energy costs for the production of grain with high protein content.

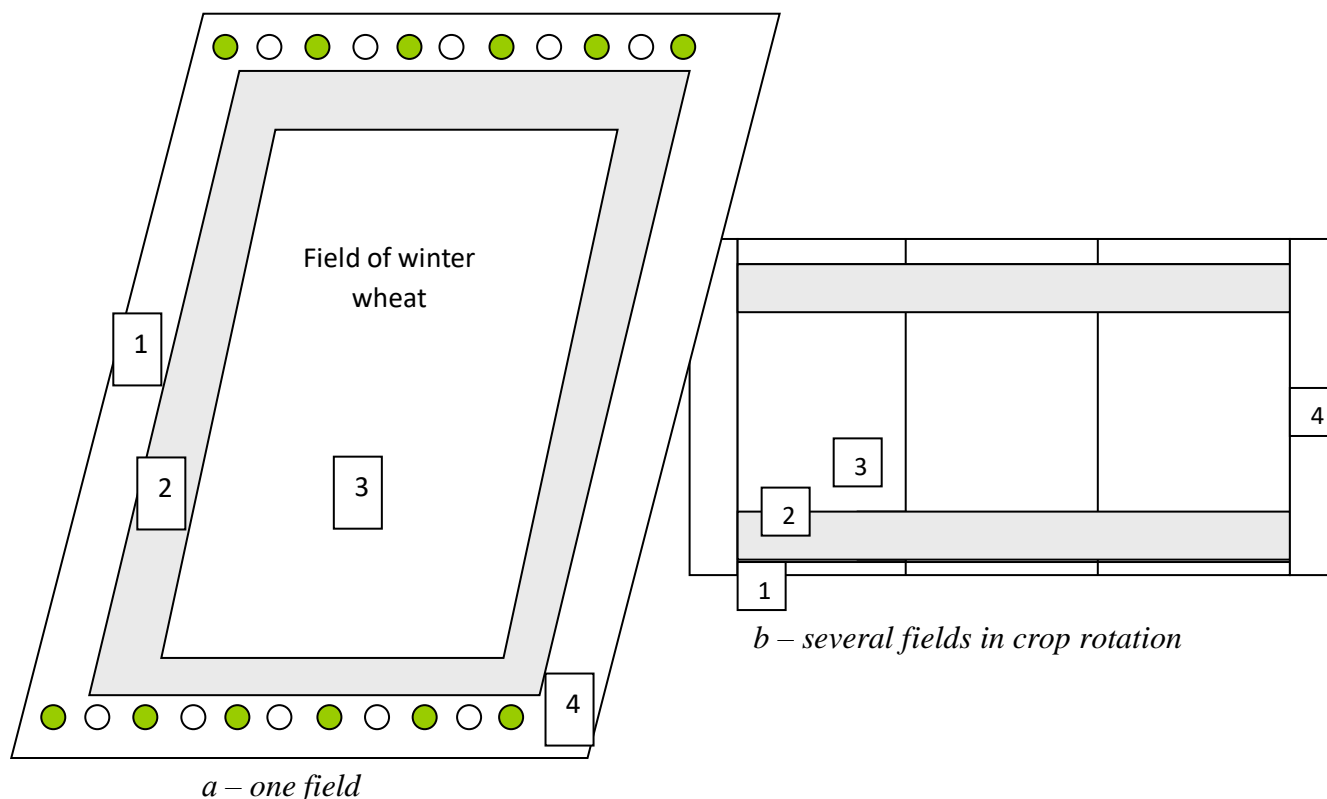
So, according to the results of the second stage of research, we have made preliminary conclusions:

- weather conditions by HTC largely affect grain quality and yield, regardless of the variety origin;
- the conditions of seed formation on maternal plants that correspond to the optimal or arid, and sowing with medium and large seed definitely increase the yield of winter wheat varieties;
- reduction of material and labor resources is achieved by using the optimized technology of winter wheat cultivation: on the basis of sowing with seed obtained in the different conditions and taking into account the size of the seed material.

At the third stage of the research, the structure of sown areas of field and energy crops and the involvement of woody and herbaceous energy crops in the component composition of forest shelter belts have been simulated (Fig. 7).

The innovative model of the structure of sown areas involves the placement of 4 strips of compatible crops of energy crops (legumes are placed in the row-spacings) along the perimeter of the main food crop (winter wheat). The field protective strips with energy crops (sorghum perennial and paulownia) are laid along the perimeter of a field. A semithinly planted forest belt – the bottom and middle layers are occupied by perennial sorghum, sown in wide row-spacings of paulownia (upper layer of forest belt) is obtained. In this case, the maximum result is achieved: the water

regime of the field is improved (due to the retention of snow in winter), and air flows do not blow the topsoil from crop rotation.



a – one field
 Note: 1 – ordinary forest shelter belt, 2 – belt of strip crops of energy crops with legumes, 3 – field of food crop (winter wheat), 4 – shelter belt with energy crops (green circle – perennial sorghum, white circle – paulownia).

Fig. 7. Model of structure of sown areas of industrial crops (food and bioenergy use)

So, perennial sorghum is an “insurance” crop for a constant inflow of raw materials, until the time of obtaining the planned yield (capacity) from the energy plot of miscanthus and switchgrass. Intercropping of legumes and perennial grain crops also makes it possible to obtain an additional product – annual harvest of green mass of clover and alfalfa for animal husbandry. In addition, nitrogen, which is accumulated under strip crops of energy crops, is effectively used by the main component of the phytocenosis – miscanthus and switchgrass plants. The increase of both plant height and stem density – the main quantitative indicators that affect the biomass yield was recorded there. Biomass from the third year of energy plantations usage is used as raw materials for biofuel production.

Our research is completely consistent with the conclusions of other authors³³⁷, and regulatory documents (DBN V.2.4-2-2005)³³⁸, in which the system of biological land reclamation requires compliance of the agro-technological conditions and intercropping of grain crops and shrubs and trees in order to slow down soil erosion³³⁹.

³³⁷ Fedoniuk V. V., Volianskyi V. O., Fedoniuk M. A. (2016). Porivnialnyi ekonomichnyi analiz provedennia rekultyvatsii riznykh vydiv na porushenykh zemliakh [Comparative economic analysis of the reclamation of different species on disturbed lands]. Actual Problems of the Economy, no. 9, pp. 203-212.

³³⁸ ДБН В.2.4-2-2005. Полігони твердих побутових відходів. Основні положення проектування. Затверджено Наказом Держбуду України від 17.06.2005 р. № 101.

³³⁹ Kharyonovskyi A. A., Danylova M. Iu. Rekultyvatsiia zemel v uholnoi promyshlennosti. Vestnyk nauchnoho tsentra po bezopasnosti robot v uholnoi promyshlennosti. 2017. № 3: 72-77.

In the researches³⁴⁰, conducted in the soil and climatic conditions of the Forest-Steppe of Ukraine, the effectiveness of mixed crops of switchgrass and miscanthus in order to increase the yield of dry biomass and energy from the plantation has been substantiated. This cultivation method provides high productivity of biomass, the rational use of energy plantation and saving production costs for harvesting and reduces the lodging of plants in winter. Another method of energy crops cultivation allows to increase productivity and enhance organic matter content in the soil³⁴¹, and the use of phytoremediation will purify the soil with energy crops³⁴².

In addition, intercropping of herbaceous plants and perennials coincides with the agronomic parameters of reclamation, described in a scientific publication³⁴³.

Thus, based on the results of the third stage of research, we have made preliminary conclusions:

- it is quite possible to obtain the main products of field crops (grain) and an additional product – vegetable fodder protein for animal husbandry using an innovative model of the structure of sown areas of industrial crops (food and bioenergy use);

- it is possible to achieve savings of material and labor resources based on the improvement of production processes by optimizing the structure of sown areas on the basis of the updated management of crops.

In general, on the basis of comprehensive field research we have made the following *conclusions*:

1. The study of morphological and biological traits of energy crops identified the best options for intercropping: perennial sorghum and paulownia, alfalfa, lupine and clover grow well in row-spacings of miscanthus and switchgrass, which significantly increases the yield of energy crops biomass.

2. Conditions of seed formation on maternal plants that correspond to the optimal or arid, and sowing with medium and large seed definitely increase the yield of winter wheat varieties. The arid conditions of maternal plants vegetation significantly increase the protein content in grain of the obtained (new progeny) progeny.

3. The model of the structure of sown areas of industrial crops (food and biofuel use) with the involvement of woody and herbaceous energy crops into the component composition of field shelter belts has been developed. The proposed innovative method makes it possible to obtain not only the main products of crops for food (grain), but also additional ones – vegetable raw materials for biofuels and legumes phytomass for animal husbandry. This will not only increase crop yields, but also increase the profitability of agriculture. And this, in turn, helps to achieve savings of material resources and optimize production processes.

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³⁴¹ Kulyk M. I., Kurylo V. L., Kalinichenko O. V., Galytska. M. A. Plant energy resources: agroecological, economic and energy aspects: Monograf / Edited by authors. Poltava: Astraya. 2019: 48-58.

³⁴² Kulyk M. I., Galytska M. A., Samoylik M. S., & I. I. Zhornyk. (2018). Phytoremediation aspects of energy crops use in Ukraine. Agrology, 1(4), 373–381. doi: 10.32819/2617-6106.2018.1402011.

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