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ODDÍL 9. ZEMĚDĚLSKÉ VĚDY

§ 9.1 MODEL OF SOYBEAN VARIETY FOR FOREST-STEPPE CONDITIONS OF UKRAINE (**Biliavska L.H.**, Poltava State Agrarian University, **Prysiazhniuk O.I.**, Institute of Bioenergy Crops and Sugar Beet NAAS, **Diyanova A.O.**, Poltava State Agrarian University)

Purpose. Improve the model of very early ripening soybean variety and determine the peculiarities of the influence of the cultivation conditions on the formation of the major components of its productivity. *Methods.* Field, laboratory, mathematical and statistical. *Results.* The graphic model of productivity of the studied varieties was constructed. It is proved that the characteristics of the productivity are due to the biological peculiarities of a particular variety. It was found that the variability of a trait is defined as the reaction of the genotype to the changing conditions of cultivation and weather conditions of the year. It is shown that among the factors of aggregate influence, the resulting trait is characterized by a stable high impact on the trait to be resulting in the next module. The inverse correlation between the branches in plants and plant height ($r = -0.11$) and nodes on the main stem ($r = -0.20$) was determined. A positive correlation between height of plants and the number of nodes on the main stem ($r = 0.26$) and the attachment height of the lower bean ($r = 0.49$) was established. The number of nodes on the main stem positively correlated with the number of beans ($r = 0.16$). The number of seeds per plant positively and closely correlated with the weight of seed ($r = 0.94$). *Conclusions.* The height of plants is significantly affected by rainfall ($r = 0.60$) and air humidity ($r = 0.65$). A moderate positive correlation between the height of lower bean attachment and precipitation ($r = 0.31$)





and weak with air humidity ($r = 0.11$) was determined. An inverse correlation between the number of branches per plant and air temperature ($r = -0.51$) and precipitation ($r = -0.25$) was established. The number of nodes on the main stem positively correlated with precipitation ($r = 0.28$), air temperature ($r = 0.16$), and humidity ($r = 0.12$). A correlation between the number of beans on plants and air temperature ($r = -0.43$) between the beans was found. Number of seeds per plant negatively correlated with air temperature ($r = -0.33$) and precipitation ($r = 50.25$), and correlated positively with humidity ($r = 0.12$). Air temperature and rainfall affects greatly the weight of seeds ($r = -0.24$, and $r = -0.16$, respectively). The formation of 1000-seed weight is positively affected by the air temperature ($r = 0.18$) and rainfall ($r = 0.19$).

Introduction. For the successful realization of the biological potential of new soybean varieties, it is necessary to formulate knowledge about the existence of the contribution of individual traits to the formation of the crop and its quality. Only the study of the variability of signs in combination with the physiological aspects of their formation makes it possible to develop and implement agrotechnical methods of influencing the plant.

It is believed that the variety model is defined as a kind of scientific standard that describes the combination of plant characteristics necessary to ensure a given level of productivity and quality, resistance to biotic and abiotic environmental conditions, etc. Therefore, in the creation of a new variety, the features of plants that must have certain levels of manifestation are described in a formalized language. Such models can be attributed to the class of descriptive ones, in which, based on the analysis of varietal diversity, a list and values of variability of desired traits for selection are presented.

From a physiological point of view, the variety model can be presented in the form of a photosynthesis balance taking into account respiration and biomass accumulation. Based on such





approaches, balance mathematical models based on Liebig's Law (1840) with Michernich's amendment (1918) were created. However, with such an approach to creating a plant model, quite a lot of questions remain unsolved. It is impossible to reveal the biological compatibility of the features involved in the model and to single out the priorities of individual parameters with an incomplete implementation of the model. It is also difficult to single out the action and interaction of pleiotropic effects and make a holistic overall assessment of the contribution to the yield of new traits.

The concept of an ideal variety model was first mentioned in scientific literature by L. H. Baily (1885) [1]. But in 1935, N. I. Vavilov formulated this concept more clearly in his main theoretical propositions about the starting material for plant breeding [2]. Subsequently, it was supplemented by H. Schmalts, which included 50 parameters. However, the term "idiotype" was not used in his scientific works; it was introduced much later by C. M. Donald [3].

According to V. A. Kumakov, the model should contain a description of growing conditions with proof of the reality of the planned harvest; description of all selectively significant traits, etc. [1]. In a broader sense, an idiotype can be considered a biological model that determines the greatest productivity of a variety under certain environmental conditions [4]. The idiotype is the prototype of the best ideal variety, which is the goal of plant breeding. Also, a model is a scientific prediction that shows what combination of traits plants should have to ensure a given level of productivity and sustainability.

Agriculture is becoming more ecologically oriented, and for a more complete use of the biological potential of plants, the requirements for the diversity of breeding material to obtain adaptive, stably productive varieties are increasing [50]. That is why the focus of selection on resistance to adverse environmental





factors involves a comprehensive assessment of selection material and is of particular importance at the current pace of climate change [51].

There are a number of specific methodological approaches to the creation of models of varieties: breeding, ecological, mathematical, etc. However, in most cases, the variety model is created based on the generalization of knowledge and experience of scientists obtained empirically or experimentally. This ensures obtaining a model of the variety without significant costs, as well as the most complete coverage of the main properties of the variety. However, we should note that insufficiently clear scientific justification leads to insufficient accuracy of the obtained models [10; 11].

Theoretical components of the modern variety model

A new approach to optimizing the construction of variety models is the use of information technologies that can most fully reflect the complexity of the real object, giving higher accuracy of scientific forecast. Therefore, the search for a compromise between complexity and simplicity in the selection of parameters taken into account in the model requires, first of all, professional knowledge in the field of breeding and horticulture of the studied crops. Thus, according to P. P. Litun's method, the space of the module of features in the coordinate system, which reflect the stages of formation of a macro feature in time, can be considered as an elementary unit of the functional space, and the regularities of its structure are used to substantiate the system analysis based on the appropriate methods [12; 13].

Crop yield can be described as the interaction of genetic and environmental factors. If the models are able to simulate the real state of the plants, it means that they can well illustrate the interactions and relationships of the two factors [14; 15; 16]. Computer modeling made it possible to involve factors in numerical calculations much more widely, becoming a tool of historically unprecedented power [17; 18; 19]. Plant models have





been developed as a key to a better understanding of ecological processes, and ecophysiological modeling has become an important area of research in recent decades [20; 21; 22; 23].

Functional models better describe biological processes with a deeper approach to functional relationships. This leads to the formation of so-called model processes or models based on BPMN (Business Process Modeling Notation) processes. Although several intermediate types of models have existed, the structural component has remained largely absent from most general plant models in the past [21; 22; 23]. Around the mid-1990s, the integration of both types of models became more common [25; 26].

Models based on BPMN processes are mainly focused on the prediction of a single functional parameter, i.e. plant growth [17; 18; 19]. In this case, there is no morphological interpretation of plant growth, and this value is a consequence of the passage of various physiological processes within the model, as an attempt to emulate plant metabolism as accurately as possible. The greatest disadvantage of such models is the dependence of certain processes on their spatial position and orientation in the plant and its environment [21].

In the event that the various interactions of plant structural elements, such as their habit, the location of branches and leaves in space, the arrival of light to leaves, the angle of inclination of branches and leaves become more and more important, 3D architecture is required and BPMN models become less productive [24]. Models based on 3D architecture are sometimes also called “virtual plants” and are actually a combination of BPMN with morphological models. Such models help to understand the intensive interactions between the morphological structure of the plant and various physical and biological processes that contribute to its development in space and time [27; 28; 29].

The type of measurements required (e.g. lighting conditions, development of relative humidity) depends on the functionality of





the model and the processes (e.g. photosynthesis, transpiration) to be implemented, which in turn depends on the purpose of the model [25; 26]. Since the accumulation of biomass is synchronized with the scale of plant growth and development, and these phases have certain duration, the course of specific weather conditions should be taken into account during the development of the model [31; 32; 33]. Increasing the number of processes and their complexity in the model can improve the accuracy of the model, but in this case it is necessary to increase the number of measurements due to the increase in the number of parameters [25; 30], measurements are more difficult – to be carried out due to the required accuracy [30], the increased complexity of calibration may require new methods that go beyond the standard setting [34; 35; 36]. Therefore, the complexity of the model should take into account its goals [25; 26].

Several platforms have been developed for grade models, thus L–Studio is the most universally used platform [18; 37]. Programming in L–studio is based on the L–system formalism using the L + C modeling language [38; 39]. VLab is another platform developed by the same L–studio group, but specifically for Linux systems [40]. GroIMP (Interactive Platform for Interacting with Phenological Growth Phases) uses XL, which is an RGG-based programming language specifically designed for modeling plant varieties [41; 42; 43].

Simulation of plant varieties is also possible in other platforms, even if they are not designed specifically for plant simulation. FPSM GreenLab [44] can be implemented in Matlab [45; 46] or Scilab (its open source equivalent). GreenLab applications have also been translated into C++ in Digiplante software [47].

It should also be said that crop yield forecasting models are currently quite widespread and actively exploited. At the same time, forecasting approaches are mainly based on: physical models calibrated using statistical analysis, and machine learning models based on an array of constantly updated data [52].





Thus, under the condition of developing physical models using satellite vegetation indices and climate data, they showed their high efficiency in comparison with machine learning models in terms of forecasting efficiency [52]. Moreover, simpler models can be more effective than complex models if the causal relationships between the most influential factors are well taken into account. Thus, a prime example of this is a simple model for predicting wheat yield by determining the relationship between water use and wheat yield developed by French and Schultz.

M. Meroni and co-authors (2021) studied yield forecasting using machine learning and small data and in turn established the effectiveness of such models [53]. Many other scientists also use machine learning [54; 55]. However, according to other scientists, it is proposed to methodologically form metamodels and integrate data-based and process-based functions into them.

Also, productivity forecasting and modeling of agricultural crops is based on the application of such forecasting systems as WOFOST (WORLD FOOD STUDIES), CropSyst, CERES-Wheat, APSIM, SUBGRO, SUCROS, Patefield and Austin. The common shortcoming of these systems is that they are focused exclusively on the production application of forecasting the yield level of mass-grown crops.

Systems for selection work, although based on well-known principles of building models, are usually a commercial product not intended for wide distribution. And that is why leading scientific breeders are forced to create their own models of varieties based on generally recognized theoretical principles of their construction.

Basic components of the soybean variety model

The creation of models of varieties should be based on the use of modern information technology and computer simulation algorithms of the breeding process.

In essence, the model proposed by us contains two modules of features – component and resulting, which can provide a





quantitative assessment of the specific organization of features of a particular variety, or varieties in general. For the technology of growing soybean varieties, from the point of view of the effectiveness of realizing the biological potential, such models are extremely valuable, because they allow not only to identify signs that can be influenced agrotechnically, but also to answer the question: when and how best to do it. The following general principles must be taken into account for the theoretical justification of the adaptive orientation variety model:

1. Any variety, even the most perfect in terms of many features and properties, forms the maximum yield in certain conditions and zones where the resources of the external environment correspond to the biological optimum of the genotype.

2. In the development of a variety model, an important role should be assigned to the scientific substantiation of the parameters of the manifestation of signs, since plants have clear, genetically determined compensatory properties, thanks to which the worse development of some signs or elements of productivity is compensated by the better development of others, as a result of which the same level of performance can be achieved due to different combinations of subcharacteristics. Knowledge of the genetic patterns of crop formation, relationships and the manifestation of traits that determine productivity brings the process of modeling and forecasting to a scientific basis and contributes to its effectiveness.

3. In the basis of the principles of modeling varieties, the choice of such characteristics, which could be used to predict the productive processes of the plant and their quality, acquires extremely important importance.

Measurements of quantitative parameters of physiological and biochemical processes do not provide reliable information about the properties of the genotype, because they have low heritability from a genetic point of view. Physiological indicators





can serve as background signs; for effective use, it is necessary to deeply study their connections with economic and valuable properties. Morphological features used for visual evaluation of genotypes are characterized by significant staticity and high heritability. The formation of plant morphology is based on its functional activity, which is determined by the genotype. Establishing relationships between plant structural elements and the influence of specific genes is an important part of theoretical selection. Such information will make it possible to program the habit of plants with fairly high accuracy in accordance with the tasks of directed selection.

4. The variety, as a system, must have a specific genetic organization, which is manifested in the specificity of the structural and functional organization of its populations. Therefore, at any stage of work with breeding material, its evaluation, the state of all subsystems of agrophytocenosis, descriptions and evaluations of breeding material as a component of this supersystem should be taken into account.

For each zone, it is necessary to create varieties taking into account the ecological conditions of the region and develop the appropriate parameters of the model of the main indicators for varieties of a specific ecotype [50; 51].

In general, all the quantitative characteristics of plants can be divided into five main groups: mass, fruit productivity, seed productivity, height and indicators of the number of nodes. The optimal productivity of soybean plants can be formed due to the optimal ratio of all elements, structure, because under the limitation of conditions favorable for the development of one of the elements of the plant structure, the individual level of productivity can be compensated by a more complete development of other elements. It is well known that individual elements of productivity are formed at different stages of organogenesis of soybean plants, and therefore different, sometimes contrasting, conditions are necessary





for their optimal development. Those factors that limited the formation of one feature serve as a kind of catalyst for another.

However, in the event of adverse growing conditions or non-compliance with the basic requirements of the technology of growing soybean varieties, one should not place significant hopes on the adaptive potential of plants as a means of forming a high level of productivity. Limits of variability of each individual element of the productivity structure are possible only within certain, genetically determined limits of its plasticity.

The model of an adaptive and plastic soybean variety for the Forest-Steppe of Ukraine is as follows: yield – > 2.5 t/ha, growing season – about 100 days, plant height – 75–85 cm, height of attachment of the lower bean – from 15 cm, number of nodes per main stem – > 12 pcs., weight of 1000 seeds – 170–180 g, lodging resistance – high, resistance to diseases and pests – high, protein content in seeds – 40–45%, oil content – 22–25%, yield of conditioned seeds – 90%, harvesting index – 0.5–0.6, resistance to drought – high (especially during the period of flowering and filling of beans), resistance to cracking of beans – high.

Biological features of the culture include: photoperiodic neutrality, cold resistance, increased intensity of photosynthesis under moderate intensity of insolation, resistance to increased soil acidity, resistance to short-term drought, increased nitrogen-fixing capacity.

As for the practical implementation of the soybean variety model, the maturity group of soybeans according to the international classification should be taken into account when calculating the dependencies between the main elements of the plant crop structure, since soybean selection is actually aimed at reducing the duration of the growing season within a certain maturity group. Plants of varieties of different maturity groups react differently to changes in the conditions of the growing season, which affects the redistribution of structural features and their contribution to the final productivity of plants [48; 49; 50; 51].





Practical implementation of the model of very early maturing soybean varieties

The quantitative characteristics of very early maturing soybean varieties involved in the modeling and the level of their variation are presented in Table 1. Thus, the total “plant height” of very early maturing soybean varieties is in the range of 70.5-78.4 cm, and the variability of the trait is at the level of the average level of variation. The height of attachment of the lower bean varies from 10.5 to 12.9 cm, and the variation of the trait is significant in Akvamaryn variety, and large in Annushka variety.

The indicator of the number of branches, on average, for the studied varieties was 2 pcs. / plant, however, the lack of trait variability was observed only in the Akvamaryn variety, and in Avantiuryrn variety, the variation is large, in Annushka variety, it is very large.

The parameters of the indicator of the number of nodes in the investigated soybean varieties were at the level of 11.9–13.0 pcs. at weak and moderate levels of variation. It was found that on average, according to the experiment, soybean plants formed 60.1–73.6 pieces of beans with significant variability in Avantiuryrn and Akvamaryn varieties and a large one in Annushka variety.

On soybean plants, from 103.0 to 137.0 pieces of seeds were formed with significant and large (Avantiuryrn, Annushka) variability of the studied indicator.

The variability of seed mass per plant was significant in all varieties, with average values of 14.5–23.5 g.





Table 1

Quantitative traits of very early maturing soybean varieties involved in modeling and their variability, 2007–2013

Indicator	Avantiuryn		Akvamaryn		Annushka	
	average	variability (CV)	average	variability (CV)	average	variability (CV)
Plant height, cm	73.9	13.0	70.5	15.6	78.4	16.6
The height of the attachment of the lower bean, cm	11.4	12.4	10.5	18.4	12.9	26.1
Number of branches, pcs.	2.1	30.2	2.0	0.0	2.1	63.8
Number of nodes, pcs.	13.0	4.1	11.9	3.0	11.9	9.5
Number of beans per plant, pcs.	71.0	16.3	73.6	19.4	60.1	32.4
Number of seeds from a plant, pcs.	137.0	22.2	134.0	19.4	103.0	23.8
Mass of seeds from a plant, g	23.5	19.3	22.1	18.9	14.5	19.5
Weight of 1000 seeds, g	172.9	4.0	166.3	4.2	143.8	8.3

At the same time, the variability of the indicators of the mass of one thousand seeds was weak and moderate for all studied soybean varieties.

In order to obtain the raw data for the construction of models of the realization of soybean productivity in the phenotype, we conducted a correlation analysis. We have highlighted eight indicators that make the greatest total contribution to the variety's productivity feature – seed mass per plant: total number of branches, number of nodes per plant, number of beans per plant, number of seeds per plant, height of attachment of the lower bean, plant height, and weight of 1000 seeds. The first four of them





account for the main share of the total contribution to the trait “seed mass per plant”.

According to the results of the calculations, we built models of manifestation in the phenotype of productivity traits of the investigated soybean varieties. Thus, the basis of the model is the idea of the gradual formation and subsequent manifestation of phenotypic traits in soybean ontogenesis and the correspondence of their manifestation to organogenesis. It is generally accepted that the stages of formation of a quantitative trait in the phenotype also reflect the stages of complication of the genetic system; therefore the connections between the main components of the model are an indicator of the dynamic orderliness of the interaction of the elements of the genetic system.

The model that we have formed is actually built on the basis of two feature modules – the resulting and component ones. For the model, as the resulting features, those elements of the structure are used that have ecologically stable relationships with each other and a high total contribution to the final feature – “mass of seeds per plant”. Such signs can legitimately include “total number of branches”, “number of nodes”, “number of beans per plant”, “number of seeds per plant”. However, as the plants develop, the resulting trait becomes component, with a maximum contribution to the resulting trait of the next block.

Phenotype productivity model of Avantiuryn soybean variety. The diagram (Fig. 1) shows only reliable correlations between the studied features, and where the indicator of the tightness of the correlation is absent, its value is unreliable with a probability of 95%.

According to the results of the analysis, a high inverse relationship was established between the total number of branches and plant height ($r = -0.76$) and a moderate relationship with the number of nodes on the main stem ($r = -0.42$). This type of dependence between the investigated characteristics of very





precocious soybean varieties can be explained by the speed of their development, because 35–40 days pass from the emergence of seedlings to flowering in them, and the total growing season does not exceed 100 days.

Therefore, in fact, very early maturing soybean varieties do not have enough time to branch and form a significant number of branches, that is, the plant either forms good main stem parameters or branches. The obtained data are also confirmed by the high variability of the total number of branches – $C_v=30.2\%$.

Plant height has been proven to have a significant effect on the number of nodes per plant ($r = 0.67$); at the same time, the height of attachment of the lower bean on the plant also depends on the total height of the plants ($r = 0.55$).

The next block of traits is formed by the number of beans per plant and the traits of seed productivity. Thus, the number of beans per plant determines the indicator of the number of seeds per plant, however, these features have a strong correlation ($r = 0.75$). A close negative correlation between the number of seeds per plant and the weight of a thousand seeds was also noted ($r = -0.85$). In our opinion, this is explained not only by the extremely short growing season of very early maturing soybean varieties, but also by the fact that soybean plants are unable to fully form reserve nutrients during the formation of a significant number of seeds. The number of seeds per plant is positively and closely correlated with the mass of seeds per plant: correlation coefficient ($r = 1.0$).

Phenotype productivity model of Akvamaryn soybean variety (Fig. 2).

It was established that the height of the plants affects the number of nodes on the plant ($r = -0.35$), and the height of the attachment of the lower bean on the plant also significantly depends on it ($r = 0.40$). The number of nodes on a plant is a prerequisite for the formation of beans on it, therefore, based on our research, we obtained a correlation between these indicators at



the level ($r = 0.39$). We should note that the greater the number of nodes, the lower the height of the lower bean attachment and vice versa ($r = -0.52$).

The next block of traits is represented by indicators of the number of beans per plant and seed productivity.

The phenological development stages of plants:
BBCH 01-18

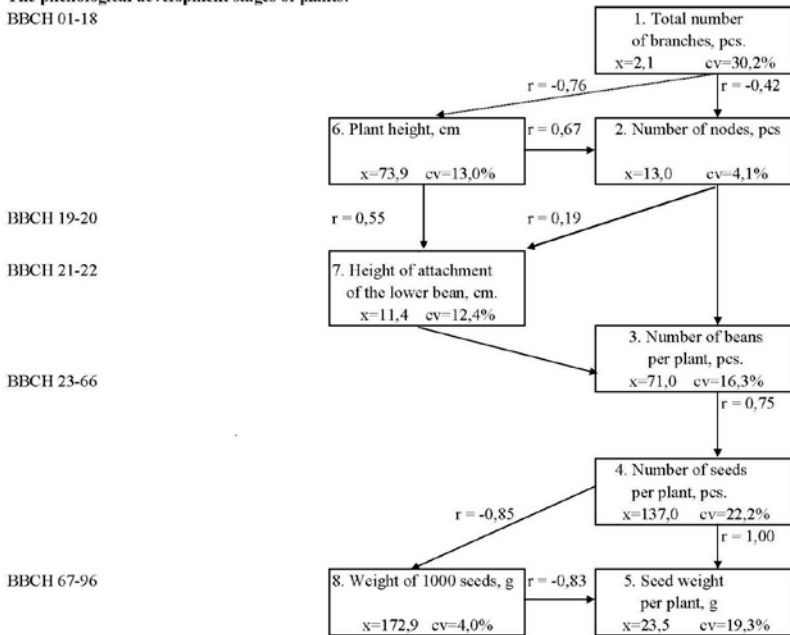


Fig. 1 Phenotype productivity model of Avantiuryrn soybean variety, 2007–2013

Thus, the number of beans per plant determines the number of seeds per plant; these signs have a strong correlation ($r = 0.88$).

A weak inverse relationship between the number of seeds per plant and the mass of a thousand seeds was established ($r = -0.23$). The number of seeds per plant is positively and closely correlated with the mass of seeds per plant, the correlation coefficient is very strong ($r = 0.97$).



The phenological development stages of plants:
BBCH 01-18

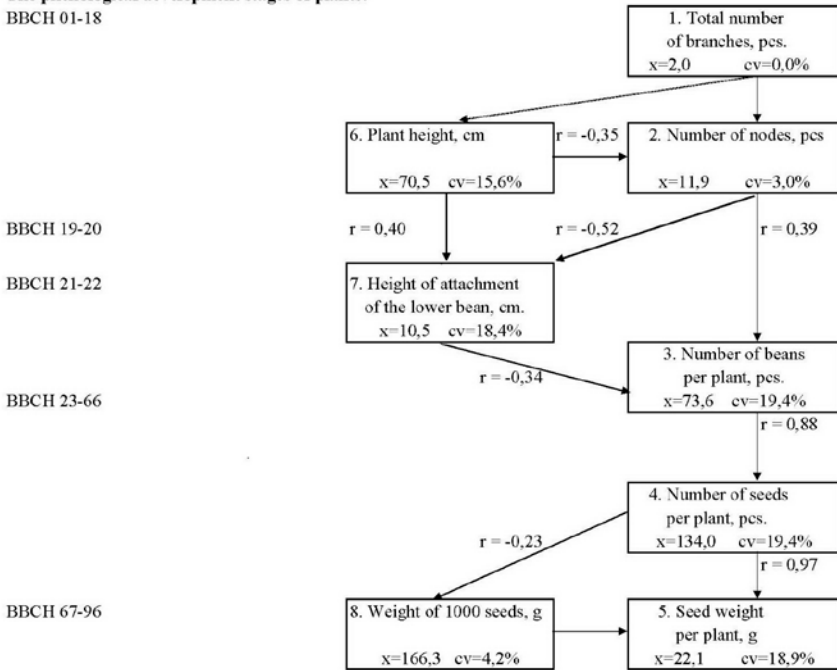


Fig. 2 Phenotype productivity model of Akvamaryn soybean variety, 2007–2013

Productivity model of the phenotype of Annushka soybean variety (Fig. 3). The total number of branches negatively correlates weakly with the number of nodes of the main stem ($r = -0.27$). In addition, it was found that the height of the plants significantly affects the number of nodes per plant ($r = 0.47$). At the same time, the height of attachment of the lower bean on the plant also depends on the total height of the plants ($r = 0.42$). It was established that the number of beans per plant is weakly correlated with the number of seeds per plant ($r = 0.25$). The number of seeds per plant and the weight of a thousand seeds are closely related by an inverse correlation ($r = -0.70$).



The phenological development stages of plants:

BBCH 01-18

BBCH 19-20

BBCH 21-22

BBCH 23-66

BBCH 67-96

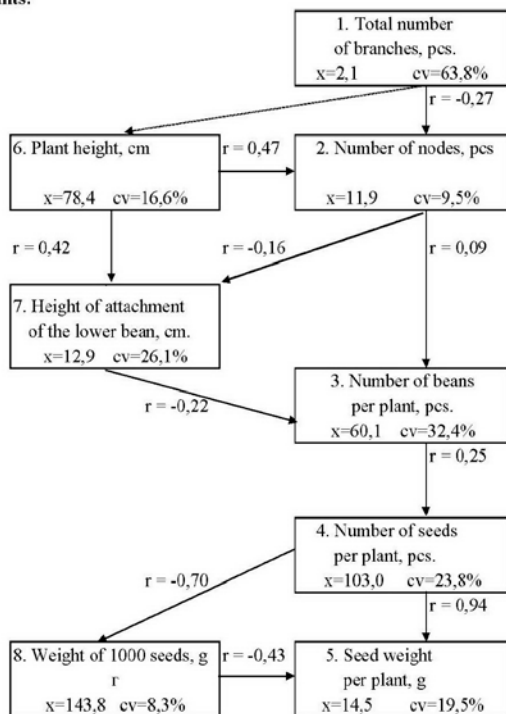


Fig. 3 Phenotype productivity model of Annushka soybean variety, 2007–2013

And the number of seeds per plant is positively and closely correlated with the mass of seeds per plant ($r = 0.94$).

Model for very early maturing soybean varieties (Fig. 4). In addition to the specific consideration of the biological features of the studied soybean varieties and the construction of models of their phenotype productivity based on the parameters of the crop structure, the determination of the parameters of very early maturing varieties remains an interesting aspect.



The phenological development stages of plants:
BBCH 01-18

BBCH 19-20

BBCH 21-22

BBCH 23-66

BBCH 67-96

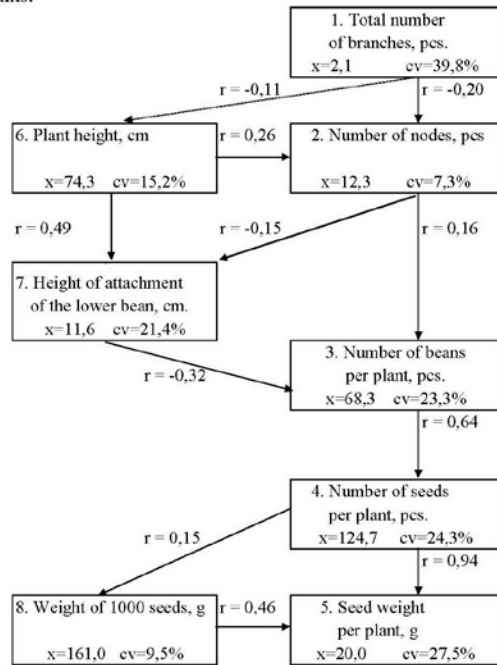


Fig. 4. Phenotype productivity model of very early maturing soybean varieties, 2007-2013

After all, it is the generalization of the knowledge gained that makes it possible not only to compare the features of the formation of certain signs of the structure of the soybean crop, but also to obtain general group features of the realization of the biological potential.

Thus, in general, for very early maturing soybean varieties, it was found that the total number of branches weakly and negatively correlates with plant height ($r = -0.11$) and the number of nodes of the head stem ($r = -0.20$). These results, in fact, confirm that during the rapid period of plant development, they do not have time to form all parameters of the structure well enough. It was found that





the height of the plants affects the number of nodes per plant ($r = 0.26$). At the same time, the height of the attachment of the lower bean also depends on the total height of the plants ($r = 0.49$). Based on our research, it was found that the number of nodes on the main stem was weakly correlated with the number of beans ($r = 0.16$).

It was established that the number of beans per plant affects the number of seeds per plant; these features have a close positive relationship ($r = 0.64$). The number of seeds per plant is positively and closely correlated with the mass of seeds per plant ($r = 0.94$). Growing conditions significantly influenced the growth and development of cultivated plants.

Undoubtedly, their influence on the indicators of phenotypic productivity of very early maturing soybean varieties is also legitimate.

To build the model, we used the biological parameters of very early maturing soybean plants and analyzed the weather conditions of the growing seasons in accordance with the duration of the phenological phases of soybean growth and development in ontogenesis. Thus, if the trait was formed during the period of plant budding, then the course of climatic factors from germination to plant budding was taken into account.

However, one of the mandatory elements of the analysis of the influence of weather conditions on the growth and development of soybean plants was taking into account the vegetative and generative parts of the growing season of soybeans, because it is known: the conditions that occurred at the beginning of the growing season, when the vegetative organs of soybean plants were intensively differentiated, do not have a direct effect on the period of formation of the generative part of the plants. Hence, for the period of growth and development of soybean plants, starting from the laying of the number of beans on the plant until the complete formation of the mass of seeds from the plant, we used the weather data from the second half of the growing season.





Accordingly, for each year of research, the adjustment of the sample of weather conditions was carried out before the calendar dates of the onset of the main phenological phases of growth and development of soybeans, since it was the growth processes of plants that primarily depended on the conditions of the growing season and its favorableness in general for the successful cultivation of the crop.

Fig. 5 shows a model of the phenotype productivity of very early maturing soybean varieties under the influence of weather conditions. Only reliable correlation coefficients are presented, and where there are no lines and, accordingly, indicators, the data are either unreliable, or the coefficients obtained are less than $r = 0.10$, that is, we are talking about a rather weak or almost completely absent connection.

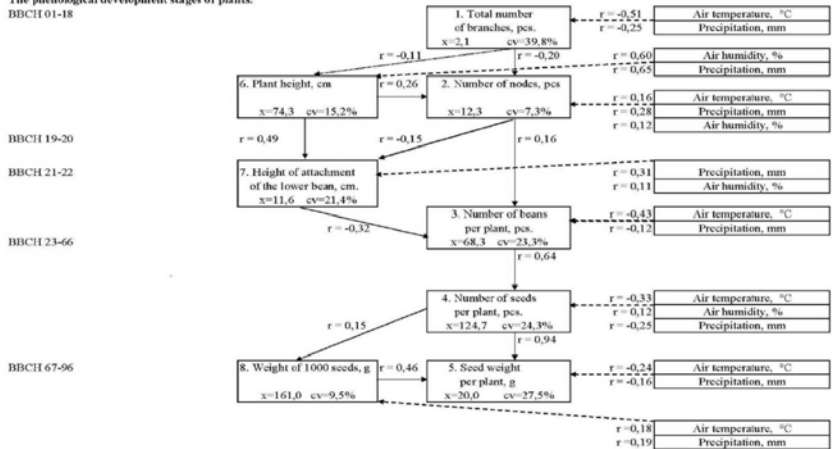
It is worth noting that weather conditions affect the growth and development of soybean plants in a complex and parallel manner with elements of growing technology, soil parameters for providing plants with nutrients and moisture, and other uncontrolled factors. First of all, we studied the direct influence of climatic conditions (rainfall, air humidity, and average daily air temperature) on the phenotypic productivity of the studied soybean varieties, which can explain, in some cases, the low level of correlation between seemingly closely related traits. The results of the research make it possible to highlight certain regularities. Thus, the total number of branches is negatively correlated with air temperature ($r = -0.51$) and the amount of precipitation ($r = -0.25$). This, in fact, means that in the early stages of growth and development of soybean plants there is a certain comfortable range of the course of weather conditions, under which optimal indicators of the structure are formed on the plants. If soybean sowing is carried out according to calendar dates, and not in accordance with the recommendations of breeders, then plants at the beginning of the growing season immediately fall into unfavorable conditions





for their growth and development: high temperatures and a significant amount of precipitation contribute to the formation of a small number of branches per plant.

The phenological development stages of plants:
BBCH 01-18



Phenotype productivity model of very early maturing soybean varieties under the influence of weather conditions, 2007–2013

However, such conditions at the beginning of the soybean growing season

in Ukraine are quite rare. More often there is a lack of precipitation and high air temperatures, or excessive precipitation and low air temperatures: this combination of factors usually causes a decrease in plant branching, which requires the adjustment of further productivity due to the modification of other indicators of soybean productivity.

The height of plants is determined by the influence of the amount of precipitation and air humidity, in addition, both signs have a significant close correlation ($r = 0.60$, $r = 0.65$, respectively). Actually, sufficient air humidity and the amount of precipitation contribute to the increase in the height of soybean





plants due to the better use of other factors, first of all, the activation of photosynthesis and the availability of nutrients in the soil.

We established a weak dependence of the number of nodes per plant with air temperature ($r = 0.16$), amount of precipitation ($r = 0.28$) and air humidity ($r = 0.12$).

Similar dependences were obtained by evaluating the closeness of the connection between weather conditions and the parameters of the height of attachment of the lower bean in very premature soybean plants. Thus, a weak positive correlation of the value of this indicator with the amount of precipitation ($r = 0.31$) and air humidity ($r = 0.11$) was found.

The critical period in the growth and development of soybean plants is the following period – the formation of beans on the plants. The inverse relationship of this sign with air temperature ($r = -0.43$) and amount of precipitation ($r = -0.12$) was established.

The negative correlation between air temperature and the number of beans per plant can be characterized as moderate ($r = -0.43$). That is, under excessive air temperatures during this period of development, plants of very maturing soybean varieties form a smaller number of beans than under optimal conditions of growth and development. And this indicator has a weak inverse relationship with the amount of precipitation ($r = -0.12$).

By analogy with the previous feature, the number of seeds per plant is negatively correlated with air temperature ($r = -0.33$) and precipitation ($r = -0.25$). Such a relationship can be characterized as moderate and weak, respectively. At the same time, this indicator is positively correlated with air humidity at a weak level of communication ($r = 0.12$). It was established that air temperature ($r = 0.18$) and precipitation ($r = 0.19$) have a positive effect on the formation of the mass of a thousand seeds, but the closeness of the connection at the weak level does not give grounds to consider these factors as the main ones in the formation of this characteristic.





It was studied that the main feature of the productivity of very early maturing soybean varieties – “seed weight per plant” – is influenced by such climatic factors as air temperature ($r = 0.18$) and the amount of precipitation ($r = 0.19$). In fact, excessive air temperatures and excessive rainfall contribute to low plant productivity.

Conclusions. Based on the results of building a graphic model of the productivity of the researched varieties, it was established that the parameters of the productivity characteristics are determined by the biological features of a particular variety. In general, the variability of the trait is determined by the response of the genotype to changes in growing conditions and weather conditions of the year. But among the combined influence of factors, the resulting trait is characterized by a consistently high influence on the trait that is the resulting trait in the next module.

It was determined that for very early maturing soybean varieties, the total number of branches correlates with the height of plants ($r = -0.11$) and the number of nodes of the head stem ($r = -0.20$). The height of the plants affects the number of nodes on the plant ($r = 0.26$), while the height of attachment of the lower bean on the plant also depends on the total height of the plants ($r = 0.49$). The number of nodes on a plant is a prerequisite for the formation of beans on a plant, therefore, based on our research, a correlation between these indicators was obtained at the level ($r = 0.16$). The number of beans per plant affects the number of seeds per plant, and these characteristics have a significant correlation ($r = 0.64$). The number of seeds per plant is positively and closely correlated with the mass of seeds per plant, correlation coefficient ($r = 0.94$).

It was found that the air temperature (significant connection) and the amount of precipitation (weak connection) are negatively correlated with the total number of branches. The height of plants is determined by the influence of the amount of precipitation and air





humidity, and both signs have a significant close correlation. By analogy with height, the number of nodes on soybean plants is positively correlated with air temperature, precipitation and air humidity. A positive correlation was determined between the amount of precipitation (moderate) and air humidity (weak) with the parameters of the height of attachment of the lower bean. The critical period in the growth and development of soybean plants is the period of formation of beans on the plants, and it was established that air temperature and the amount of precipitation are negatively correlated with this feature. The number of seeds per plant is also negatively correlated with air temperature and precipitation, while air humidity is positively correlated with the number of seeds per plant. Air temperature and precipitation have a positive effect on the formation of the mass of a thousand grains, but the tightness of the connection is rather insignificant. The parameters of the weight of seeds from a plant are determined by such climatic factors as air temperature and rainfall. As with the number of beans and the number of seeds per plant, these weather factors are negatively correlated with this indicator.

New soybean varieties must be suitable for cultivation in Ukraine and also must provide high and stable yields. The variety is of decisive importance in modern conditions of effective farming. The foreign and domestic literature sources covered the issues of influence of natural and climatic conditions and the latest varieties on the soybean yields, especially their economic efficiency of cultivation.

The analysis of soybean yield indicators in Ukraine shows its significant fluctuations by years of the research. This is due to the influence of weather and climatic conditions and biotic factors. The dynamics of soybean yields in Poltava region (2002-2018) and HTC during the growing period (April - August) is gradually changing toward the reduction of these indicators. Under the extreme weather conditions (excessive precipitation or their





absence, drought, epiphytotics of diseases), the adapted modern varieties play a decisive role.

As a result of long-term breeding work at Krasnohrad Research Station of the Institute of Grain Management of UAAS (1991–2000) and the Research Field of Poltava State Agrarian Academy (2001–2018), a number of high-yielding, early maturing and environmentally adaptable soybean varieties were created. Breeding work was carried out in quite contrasting soil and climatic conditions. The source and hybrid material, soybean varieties were studied quite thoroughly on dark gray podzolized (pH 5.3-5.5) soils and chernozems (pH 6.2-7.0) in the arid conditions of the Steppe and Forest-steppe of Ukraine.

In Poltava region (left bank Forest-steppe of Ukraine), droughts have often occurred during the growing season recently (Fig. 6). Thus, in 2017, the minimum amount of precipitation during the growing season (April-August) was recorded for the entire period of research (121.1 mm with a long-term average of 268 mm). The data in figure 6 show that of the 16 analyzed in 10 years, the amount of precipitation during the growing season was lower than the long-term average. Increasing rates of soybean production should stimulate breeding activities in Ukraine.

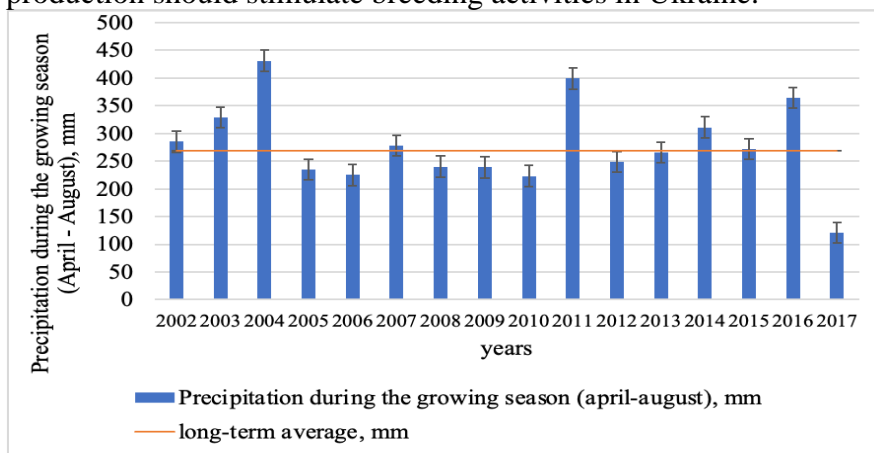


Fig. 6 Dynamics of precipitation during the vegetation period (April-August) in Poltava region, 2002–2017 (according to Poltava Meteorological Centre)





The improvement of soybean varieties is currently taking place against the background of climate change and requires objective assessment of new varieties carried out during the qualification expertise.

Since 1995, Ukraine has become a member of the UPOV (International Union for the Protection of New Varieties of Plants) and officially provided breeders with legal protection for varieties that are subject to intellectual property (the Law of Ukraine About protection of the rights to plant varieties and the Resolution of the Cabinet of Ministers On the Register of Plant Varieties of Ukraine). Since 1991, soybean varieties have been regularly registered in the State Register of Plant Varieties.

Thus, the soybean varieties created by us, registered in Ukraine and recommended for spreading, have duration of vegetation period of 85-120 days. So, the soybean varieties created by breeder L.H Biliavska have the following characteristics and features (Table 2).

Table 2
Soybean varieties which are included in the State Register of Plant Varieties Suitable for Spreading in Ukraine, 1998–2015

Variety	Year of registration	Growing area *	Maturity group	Direction of use
Ametyst	1998	SF	em	grain
Ahat	2000	SF	mm	grain
Artemida	2001	S	mm	grain
Almaz	2007	F	em	grain
Vinni	2010	SF	mm	grain
Vezha	2010	S	mm	grain
Anratsyt	2011	S	em	grain
Aleksandryt	2013	SFP	em	grain
Adamos	2013	SP	em	grain
Avantiuryň	2015	F	em	grain
Akvamaryň	2015	FP	em	grain

Note : * Growing area: S – Steppe, F – Forest-steppe, P – Polissia;

Maturity group: mm – medium-maturing, em – early maturing





The soybean varieties Almaz and Anratsyt were produced at Poltava State Agrarian Academy (2001-2010). The soybean varieties Aleksandryt and Adamos were produced in 2008-2013 and the varieties Avantiuryn and Akvamaryn were produced in 2010-2015.

Here is a brief morphobiological characteristic of these soybean varieties.

Soybean variety Avantiuryn. The variety has passed the state variety trial (2013–2014) and has been listed in the State Register of Plant Varieties Suitable for Spreading in Ukraine since 2015. The approbation group is *agr. Oculata (Mikh.)*. The type of growth is intermediate. The plant has a semi-compressed bush that is 71-90 cm high. (Fig 7). The stem is medium-thick, 7-12 mm, and resistant to lodging. The pubescence is red. The number of internodes is 10-15. The number of branches is 1-3, branching angle is 20-30°. The height of the lower bean attachment is 12–15 cm. The root system is well developed. The leaves are ternate, medium-sized, dark green in color and fall off when the beans mature. The middle leaf is broadly ovate, the top of the middle leaf is rounded, the size of the middle leaf is medium. Inflorescence is a multi-flowered raceme, 5-7 flowers each. The beans are of medium length, slightly curved, with a sharp tip, with 2-3 seeds, light, with sparse pubescence. The grain is medium (0.6 x 0.4 cm), rounded-oval. The main colour of the seed coat is yellow. The seed coat is also sometimes brown with pigmentation of varying intensity. The intensity of the pigmentation on the seed coat can vary depending on the growing conditions. The weight of 1000 seeds is 170–190 g. The protein content is 38%, fat – 22%.



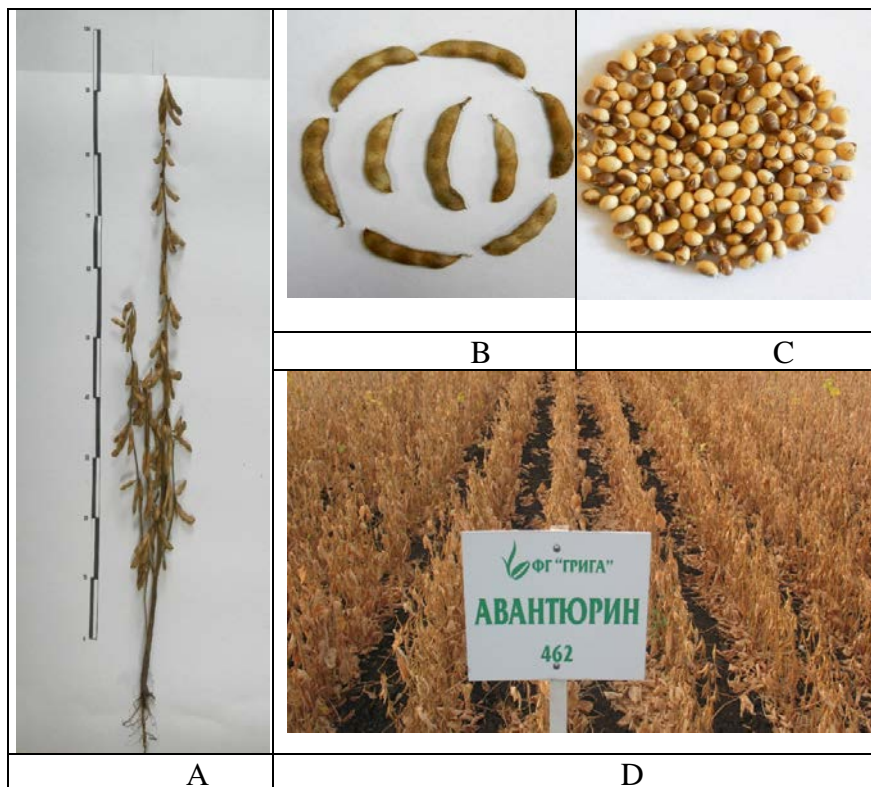


Fig. 7 Variety Avantiuryn: **A** – general view of the plant, **B** – beans, **C** – seed, **D** – plot of variety y

The maturity period is very early. It is a guaranteed predecessor for winter crops. High productivity and seed quality are successfully combined with a short vegetation period. Duration of period from sprouting to flowering is 35-40 days. It has a stable vegetation period of about 100 days in different geographical latitudes. Potential grain yield is 3.0-3.2 t/ha (at a standard moisture content of 14%) under Ukrainian conditions.

It has a neutral photoperiodic reaction which ensures a stable growing season in different climatic zones. It is characterized by an increased adaptability to unfavourable growing conditions,





including cultivation in acidic soils (pH 4.5-5.5). Seeds do not need to be dried. The variety is resistant to bacterial and viral diseases, and slightly damaged by pests. Resistance to lodging and bean cracking is high.

The agricultural technique of the variety Avantiuryn is generally accepted for the conditions of the Forest-steppe and the Steppe of Ukraine. Seeding rate is 550-650 thousand seeds per hectare. Variety responds well to fertilizers and pre-sowing seed inoculation with biological preparations. It is recommended for growing for grain in the Steppe and the Forest-steppe regions of Ukraine. Seed uniformity is 95%.

Under the conditions of the farm “KHOROL-AGRO” Ltd. (Poltava region, Khorol district), it produces 3.0-3.5 t/ha of seeds in productive crops.

According to the qualification expertise of soybean varieties for suitability for spreading in Ukraine, the main results of the research period are provided (Table 3).

Soybean variety Akvamaryn. The variety has passed the state variety trial (2013–2014) and has been listed in the State Register of Plant Varieties Suitable for Spreading in Ukraine in 2015. The approbation group is *agr. Oculata (Mikh.)*. The type of growth is intermediate. The plant has a semi-compressed bush that is 71-90 cm high (fig. 8). The stem is medium-thick, 7-12 mm, and resistant to lodging. The pubescence is grey. The number of internodes is 10-12. The number of branches is 1-3, branching angle is 20-30°. The height of the lower bean attachment is 15 centimeters.

The root system is well developed. Leaves are ternate, medium-sized, dark green and fall off when the beans mature. The middle leaf is broadly ovate in shape, the top of the middle leaf is rounded and the size of the middle leaf is medium. The inflorescence is a multi-flowered raceme with 5-7 flowers each.





Table 3.

Results of qualification expertise of the variety Avantiurn for suitability for spreading in Ukraine (according to UIPVE)

Variety, standard	Year	Productivity t/ha	Vegetation period, days	Weight of 1000 seeds, g	Height of plant, cm	Height attachment of the lower bean, cm	Grain quality, %	
							Protein	Fat
Polissia								
st.	2013	1.70	119,1	126.8	65.3	12.4		
Avantiurn	2013	1.61	123.5	166.5	56.3	11.3	38.6	20.7
st.	2014	2.17	114.3	150.9	84.6	14.2		
Avantiurn	2014	2.35	120.0	186.7	73.0	11.1	38.0	20.5
Forest-steppe								
st.	2013	2.19	102.6	138.1	71.4	12.5		
Avantiurn	2013	2.18	108.1	171.2	57.3	11,3	39.5	19.9
st.	2014	2.24	106.8	141.8	71.4	10,9		
Avantiurn	2014	2.33	115.7	167.3	57.7	9.8	37.0	22.0
Steppe								
st.	2013	2.05	96.0	127.3	76.0	9.6		
Avantiurn	2013	1.71	90.8	168.9	55.8	6.3	38.5	21.2
st.	2014	1.70	106.2	143.2	70.7	11.5		
Avantiurn	2014	1.62	108.0	157.5	59.7	8.0	38.1	23.3

The colour of the flower corolla is white. The beans are of medium length, slightly curved, with a sharp tip, with 2-3 seeds, light-coloured, with sparse pubescence. Grain is medium (0.6 x 0.4 cm), rounded-oval. The main colour of the coat is yellow. The seed rumen is red with an eye. Weight of 1000 seeds is 170-180 g. Protein content is 43%, fat is 22%.

It has a neutral photoperiodic reaction, which ensures a stable growing season in different climatic zones. At the time of maturity, it quickly reaches conditioned moisture and does not need to be dried. It is a guaranteed predecessor for winter crops.





This variety successfully combines high productivity and seed quality. Duration of the period from sprouting to flowering is 35 to 40 days. In different geographical latitudes it has a stable vegetation period of about 100 days.

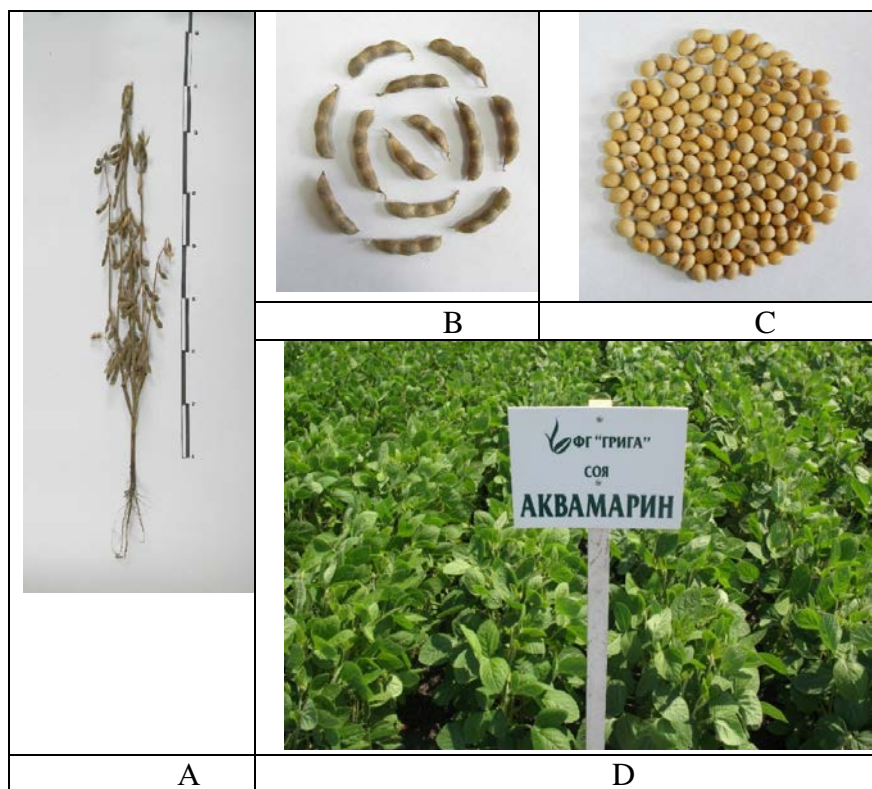


Fig. 8 Variety Akvamaryn: *A* – general view of the plant, *B* – beans, *C* – seed, *D* – plot of variety

The potential grain yield in the Steppe and Forest-steppe of Ukraine is 3.0-3.2 tons / ha. The variety is of grain type. Resistance to lodging and bean cracking is high. The variety is resistant to bacterial and viral diseases, pests damage is weak. Seeding rate is 600-700 thousand seeds per hectare. Variety responds well to





fertilizers and pre-sowing seed inoculation with biological preparations. Characterized by high adaptability to unfavorable growing conditions, including growing in acidic soils (pH 4.5-5.5). Recommended for growing for grain in the Steppe and the Forest-steppe of Ukraine. Seed uniformity is 95%. According to the qualification expertise of soybean varieties for suitability for spreading in Ukraine, the main results of the research period of this variety are provided (Table 4).

Table 4

Results of qualification expertise of the variety Akvamaryn for suitability for spreading in Ukraine (according to UIPVE)

Variety, standard	Year	Productivity t/ha	Vegetation period, days	Weight of 1000 seeds, g	Height of plant, cm	Height of attachment of the lower bean, cm	Grain quality, %	
							Protein	Fat
Polissia								
st.	2013	1.70	119.1	126.8	65.3	12.4		
Akvamaryn	2013	1.76	135.0	157.5	68.5	11.2	40.9	20.2
st.	2014	2.17	114.3	150.9	84.6	14.2		
Akvamaryn	2014	2.34	123.3	148.2	74.0	12.4	40.0	20.0
Forest-steppe								
st.	2013	2.19	102.6	138.1	71.4	12.5		
Akvamaryn	2013	2.23	112.9	166.8	62.6	12.0	41.5	19.8
st.	2014	2.24	106.8	141.8	71.4	10.9		
Akvamaryn	2014	2.37	115.1	162.2	65.6	12.0	38.4	22.1
Steppe								
st.	2013	2.05	96.0	127.3	76.0	9.6		
Akvamaryn	2013	1.63	97.3	146.7	66.5	10.0	40.5	20.8
st.	2014	1.70	106.2	143.2	70.7	11.5		
Akvamaryn	2014	1.65	108.3	148.8	67.0	7.3	39.7	21.7





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