The models of soybean varieties adapted to dry conditions

V V Tolokonnikov¹, M V Trunova², T S Koshkarova², G M Saenko² and L V Vronskaya¹

¹ All-Russian Research Institute of Irrigated Agriculture, 9 Timiryazev Street, Volgograd, 400002, Russia
² All-Russian Research Institute of Oil Crops, 17 Filatov Street, Krasnodar, 350038, Russia

E-mail: koshkarova_ts@yandex.ru

Abstract. The article presents the analysis of early-ripening and mid-ripening promising and cultivated soybean varieties that received a comprehensive evaluation under irrigation conditions over the past period (2016-2018) of breeding with the increase in atmospheric drought and dry hot wind days to 77 with a long-term average annual indicator of 47 days with a relative humidity of less than 30%. We developed the scientifically based model of highly productive soybean varieties (2021-2023) with a yield of 2.8-3.8 t/ha and the growth season of 105-122 days. The model is based on the established correlations of the main morphological and biological characteristics with the grain productivity of irrigated sowing. The model of soybean varieties reflects characteristics that ensure the responsiveness of plants to watering and resistance to prolonged manifestations of atmospheric drought: a long growth season, low linear plant growth, significant leaf surface area, photosynthetic potential, dry biomass yield, number of plants before harvesting, thousand-seed weight, long-term duration of the “flowering-beans filling” period. The model is complemented by the indicators of high protein and fat content in seeds, as well as their yield from a unit of harvesting area.

1. Introduction
The production of the most important protein-oil soybean crop is closely connected to the breeding and seed growing. In many agricultural zones of the Russian Federation, it is necessary to develop drought-resistant varieties that can slightly reduce grain productivity under increased climate aridization during the soybean growth season and respond to improvement of the conditions of atmospheric water availability with significant increases in yield [1, 2].

It is important to provide the production of this crop under the irrigation in the southern regions with the evaluation of the varieties ability to withstand dry hot wind phenomena that arise due to the rapid decrease in the relative humidity and leading to the decrease in productivity.

The results of any cultivated plant breeding are closely connected to the construction of the future varieties models considering the obtained indicators of highly productive varieties for a given breeding period. In soybean crop, in case of developing models based on traits and characteristics that significantly determine the yield, it is necessary to consider many indicators and dependencies between them under a significant increase in drought.
2. Materials and methods
We prepared the work based on the results of the comprehensive analysis of the most important traits of early and mid-ripening lines, as well as the varieties bred at the research institutes located in the Nizhneje Povolzhje region, cultivated in production, which were developed and evaluated on various backgrounds during the previous breeding period (2006-2018). We estimated the strength of arid phenomena through the analysis of the days’ number with a relative humidity of less than 30% and the testing with a long-term average annual indicator of 47 dry days during the periods of soybean growth and development.

We used a specific technology adopted for each variety, recommended for irrigation conditions with the irrigation regime differentiated by the periods of plant development – 80-80-70% of field moisture capacity and fertilization aimed at obtaining a yield within 3.5 t/ha (N90 P90 K60 of active substance per hectare). The size of the 4-row plots was 12.6 m². We randomized the plot locations and carried out 3 replications. We counted the yield on two middle rows of a plot with a record area of 6.3 m². We carried out the phenological observation during the entire period of soybean development. We evaluated the photosynthesis parameters by the cutting method. We analyzed the productivity structure of genotypes by manually taking apart the trial sheaves, which were harvested as they ripen on an area of 1 m².

3. Results and discussion
The increased number of days with atmospheric drought (more than 55) during the soybean growth season leads to the decrease in yield to 1.5-2 t/ha of grain (2014, 2015, 2017). In years with a less significant number of dry hot wind days (2011, 2016, 2018) during the growth season that were close to the norm (47 days), the yield was 2.5-3.5 t/ha of irrigated sowings.

However, on average, once every three years, there is an increase in air drought up to 77 days, which negatively affects the soybean productivity. In non-irrigated sowings, profitable high yields can be obtained by varying combinations of yield structure indicators. The process of productivity development is closely connected with the nature of photosynthesis in varieties [3] in case of irrigated soybean cultivation, there is the regulation of water supply to plants as the most important factor of life support in this crop, especially in the Nizhneje Povolzhje region.

The long-term research (2016-2018) showed that the high efficiency of soybean production under irrigation conditions depends on the combination of structural elements of productivity, which relate to the growth season (Table 1).

In the countries that provide the main production of this crop of world agriculture (USA, Brazil, Argentina, China, India), the breeding is focused on optimizing the growth season in relation to the area of production sowings concentration, since the soybean varieties develop high productivity only when the full duration of the growth season is used. The Canadian varieties, characterized by the early terms of ripening, do not have significant advantages over the best domestic counterparts in terms of adaptability to the harsh natural conditions of most Russian regions of soybean sowing – both to drought and fall in temperature [4].

The duration of the growth season significantly determines the productivity level in irrigated sowings. Early varieties develop 2.49 t/ha of grain in 105 days, mid-ripening varieties provide 3.32 t/ha of grain for a longer growth period – 122 days.

The changes in the duration of the growth season should not affect the yield size; therefore, it is important to give future soybean varieties the same duration of the growth season as was specific to the previous genotypes of the previous breeding stage [5].

The productivity of the future variety is closely connected to the stages duration of the growth season but not to its total length. There are many varieties that are characterized by similar ripening terms but differing in the rates of passing of its individual periods. The fixation of the restriction of vegetative growth in the plants progeny of the future variety in the irrigated agrocoenosis will help to contain the excessive growth of phytomass before budding, flowering and bean development.
Table 1. The main indicators of highly productive soybean varieties of the previous (2016-2018) and future (2021-2023) breeding stages under irrigation conditions.

| Indicators                                              | Varieties                                                                 |
|---------------------------------------------------------|---------------------------------------------------------------------------|
|                                                          | 2016-2018 early-ripening | mid-ripening | 2021–2023 early-ripening | mid-ripening |
| Productivity, t/ha                                      | 2.5                        | 3.3          | 2.8                        | 3.8          |
| Duration of periods, days:                              |                            |              |                            |              |
| seedlings – beginning of flowering                      | 42.5                       | 47.6         | 39.0                       | 44.0         |
| mass flowering – bean filling                          | 51.5                       | 56.4         | 55.0                       | 60.0         |
| ripening – complete ripeness                           | 11.0                       | 18.0         | 11.0                       | 18.0         |
| seedlings – complete ripeness                          | 105.0                      | 122.0        | 105.0                      | 122.0        |
| Leaf surface area, thousand m²/ha:                      |                            |              |                            |              |
| maximum                                                | 53.2                       | 82.9         | 59.0                       | 90.0         |
| average for the growth season                          | 38.2                       | 58.2         | 40.0                       | 64.0         |
| Photosynthetic potential, million m² × days/ha         | 1.8                        | 2.9          | 2.0                        | 3.1          |
| Photosynthesis net productivity, g/m² day               | 8.4                        | 7.3          | 9.0                        | 8.0          |
| The dry biomass productivity, t/ha                     | 14.2                       | 20.0         | 14.0                       | 22.0         |
| Grain amount in the dry biomass, %                      | 17.5                       | 16.6         | 20.0                       | 19.0         |
| Plant height, m: overall                               | 0.7                        | 0.8          | 0.8                        | 0.8          |
| to lower bean                                          | 0.2                        | 0.1          | 0.15                       | 0.1          |
| The number of plants before harvesting, pcs/m²         | 25.0                       | 38.1         | 26.0                       | 38.0         |
| Seed weight, g: per plant                              | 10.0                       | 8.7          | 10.8                       | 10.0         |
| Thousand seeds                                         | 128.4                      | 120.1        | 140.0                      | 132.0        |
| The average number of grains in one bean, pcs           | 2.1                        | 2.2          | 2.3                        | 2.4          |
| The number per plant, pcs:                             | 77.2                       | 72.3         | 85.0                       | 80.0         |
| beans                                                  | 37.1                       | 33.3         | 41.0                       | 37.0         |
| seeds                                                  | 77.2                       | 72.3         | 85.0                       | 80.0         |
| The content in seeds, % of absolutely dry substance:   |                            |              |                            |              |
| crude protein                                          | 38.6                       | 37.4         | 40.0                       | 40.0         |
| fat                                                     | 18.4                       | 18.5         | 18.0                       | 18.0         |
| Gross yield, t/ha: crude protein                       | 0.8                        | 1.1          | 0.9                        | 1.3          |
| fat                                                     | 0.4                        | 0.5          | 0.4                        | 0.6          |
| crude protein + fat                                     | 1.2                        | 1.5          | 1.4                        | 2.0          |

The initial parental material contains early morphobiotypes (No. 851 and No. 1081), which begin flowering 30–35 days after the mass seedling emergence with a productive mass of one plant of 11-15 g. Their intensive involvement in hybridization gives the opportunity to identify hybrids with the variation in the developing process: by terms of flowering, biomass growth and transition to the reproductive period.

The optimization of the leaf surface area has a significant impact on the level of soybean sowings productivity. In the Krasnodar region, the most productive varieties turned out to be those that develop a phytosynthetic surface from 40 to 50 thousand m²/ha in favorable hydrothermal years.

In case of irrigated soybean cultivation, this indicator ranges from 53.2 to 82.9 thousand m²/ha and depends on the duration of the growth season of varieties. The maximum leaf surface area shows a positive correlation with the phytomass yield, which implies the increase in this indicator in valuable breeding genotypes to the level of 59–90 thousand m²/ha.

To this day, Hodson is one of the most productive soybean varieties in the USA. It is characterized
by the ability to develop a significant capacity of the assimilation surface up to 91 thousand m²/ha during the entire growth season, which is typical for this variety under the conditions of the Krasnodar region in years favorable in atmospheric precipitation.

The phytosynthetic potential (PP) is the most important indicator of the process of assimilation of organic matter. The productivity and capacity of the leaf apparatus are closely connected to each other by a direct relation, which is also confirmed by our research results: there is a significant correlation between these traits $r = 0.76$. The genotypes with high PP and yield level (4 t/ha and higher), № 295 (PP - 4.03), № 305 (PP - 4.00), are set to be included in crosses to receive highly productive lines for selection of elite plants, parental to the future varieties.

The photosynthesis net productivity (PNP), which shows the productivity of the photosynthesis process of sowing, is characterized by a low negative correlation ($r = -0.43$) with the yield of varieties dry vegetative mass. The increase in the amount of sowing biomass can lead to the decrease in PNP and, ultimately, yield; therefore, it is necessary to contain the excessive growth of phytomass in the developed varieties and select morphobiotypes with high phytosynthetic activity specific for a particular individual.

The productivity of vegetative mass is closely related to the grain productivity ($r = 0.81$). The early-ripening varieties of the Nizhneje Povolzhje ecological type develop an average of 14.2 t/ha of plant mass, the mid-ripening varieties provide a harvest of 20 t/ha. The varietal composition of the future soybean variety of 2022 should ensure a productivity increase mainly due to the increase in the grain amount in the total biomass, and not only due to the increase in biomass. For this purpose, it is planned to increase the amount of the parental material obtained on the basis of high-yielding soybean varieties crosses, characterized by a high grain mass in the total biomass weight – within 35% and higher.

The indicator “the grain amount in the total biomass” does not have a close correlation with grain productivity ($r = 0.46$). Varieties with both high and low indicators of this trait can be highly productive. The soybean varieties cultivated without irrigation are characterized by high values of this indicator – 40-50%. Under irrigation conditions, soybean develops more significant amount of vegetative mass than on dry land. The levels of this trait should be 19-20% in the varieties of the future breeding period.

The plant height can be considered as an important and one of the essential characteristics for changing the plant architectonics. In our country, the main soybean crop acreage is located on non-irrigated lands. The top-rated varieties are characterized by high linear plant growth – up to 1 m or higher, deep penetration of the root system into the soil, containment of the increase in the total biomass during the growth season and activation of its growth during the reproductive development.

In the countries with a high-intensity soybean production in favorable climates (USA, Brazil, Argentina), the tall plant stand is considered a desirable trait. Under irrigation conditions, the tall plant stand increases the mutual shading of plants, reducing the productivity of the photosynthesis process. Moreover, the long-stemmed plants are prone to lodging due to the increased growth of phytomass and the development of the excessive number of reproductive organs, which do not contribute much to the development of a complete yield. The height of irrigated soybean is not always highly correlated with productivity. The increase in the seed productivity of irrigated soybean sowings can be obtained on the basis of the increase in the number of the main stem internodes, since these traits are very closely connected by correlation dependence ($r = 0.68-0.96$). There is a strong relation between the productivity and the number of beans in a stem node ($r = 0.51-0.7$) based on the research results, we assume that the intensity of linear plant growth in the future varieties should not exceed 0.8 m.

The indicator “the attachment height of lower beans” largely determines the level of sowings harvesting productivity. The bean placement on a plant below 0.15 m from the soil surface contributes to a grain shortage within 20% of the biological yield and even more, depending on the variety and applied agricultural technologies. This indicator is connected with the productivity by a variable negative relation ($r = 0.03-0.78$). There is a sufficiently high correlation between the linear growth of plants and the attachment height of a lower bean ($r = 0.46-0.64$). The optimization of the plants height and their number per unit of sown and harvested area will have a positive effect on the plant productive organs placement level at the distance of at least 0.15 m from the soil surface.

The amount of productive plant stand is the main factor in the yield development in all agricultural...
plants. It is very important not to allow both excessive thinning and thickening of the irrigated soybean sowings, which contribute to a decrease in yield. The correlation between this trait and the productivity is low ($r = 0.28–0.42$). Due to this, the number of plants before harvesting should be 26-38 pcs/m² in the future varieties with alternative ripening periods.

The seed weight per plant is one of the key factors for developing high yields of soybean on root. The relation of this indicator to the productivity is high and amounts to 0.64-0.96. Nevertheless, the grain productivity of plants before harvesting is a highly variable trait: the coefficient of variation is 26.3-49.4%. Therefore, it is important to pay more attention to the trait that is more constant in such cases, such as “the average number of beans in the internodes of the main stem”, before selecting promising forms from hybrid populations of soybean. In the plant stand of irrigated soybean it is characterized by insignificant variability ($C_v = 11-20\%$) and higher heritability, and it is closely correlated with the grain weight of one plant ($r = 0.51-0.82$). It is planned to select for hybridization the high-yielding (3.5-4.0 t/ha) varieties with high grain productivity (10-15 g) from the working collection of the soybean parent material of V.S. Pustovoit All-Russian Research Institute of Oil Crops: Annushka, Lira, Oressa, Vilana, Slavia, Belgorodskaya 7, Windssoz (France), Line 9084 (Moldova), Sonyachna (Ukraine), Volgogradka 1, Volgogradka 2, VNIIOZ 76, VNIIOZ 31, VNIIOZ 86.

The indicator “thousand-seed weight” is characterized by the insignificant level of the variation coefficient — 3.3-12.1%, and a positive correlation with the seed weight of one plant, which is manifested in an average degree ($r = 0.35-0.45$) and depends on the variety and cultivation conditions. Early-ripening varieties (VNIIOZ 86, VNIIOZ 11, Volgogradka 2) are characterized by a high correlation between seed size and productivity, which manifests itself in plants in years (2005) with the increased intensity of dry hot wind phenomena (from 58 days or more per the soybean growth season) and reaching $r = 0.79-0.93$. In the upcoming breeding period, it is necessary to achieve the increase in thousand-seed weight to 140 g in early-ripening varieties and up to 132 g in mid-ripening varieties, using high-yielding (3-4 t/ha of grain), more plum (150-180 g) and sufficiently early-ripening soybean varieties of the Nizhneje Povolzhje region ecotype (Volgogradka 2, VNIIOZ 86, VNIIOZ 11, Volgogradka 3) with the involvement of divergent varieties and morphobiotypes of different ecological and geographical origin that develop a high grain yield based on their content significant contribution (thousand-seed weight), such as Belosnezhka (Ukraine), Vir K-4562 (the Voronezh region), Vir K-5231 (Romania), Vir K-5075 (Canada).

The traits such as “the number of beans and seeds per plant” are annually highly correlated with the plant grain weight ($r = 0.7-0.9$). However, they are characterized by a very high (33-44%) coefficient of variation, which complicates selection and reduces its efficiency. They should be considered only as an accompanying reference point when selecting elite plants. The formation of 2.8-3.8 t/ha is ensured by the presence of 37-41 beans and 80-85 seeds in them [6].

The goal-oriented work on the development of soybean varieties with a high content of protein and fat in seeds has not yet been as successful in our country as the development of productive, early-ripening, drought-resistant, responsive to irrigation and agricultural techniques varieties [7, 8]. The soybean grain quality is closely related to the conditions of the soybean distribution region. A significant amount of the world soybean production belongs to the southern latitudes, where the length of the growth season, favorable soil and climatic conditions, intensive agroindustrial production contribute to the formation of protein in seeds of 35-45% without a significant decrease in oil content and productivity limitation.

The northering of soybean production in the Russian Federation as a necessary measure to reduce the shortage of domestic raw materials of this crop gives the opportunity to expand domestic production and to obtain soybean grain with a low protein content of 28-34%.

The price of commercial soybean grain and seeds is closely related to the concentration of crude protein in it. By the level of protein content in seeds (38-39%), the released varieties of the All-Russian Research Institute of Irrigated Agriculture breeding fully meet the rigid requirements of the All Union State standard 8056-96 and the US Standard – 38%. In such years as 2003, 2006, 2012, 2013, 2014, 2018, varieties Volgogradka 1, VNIIOZ 31, VNIIOZ 86 accumulated up to 40.5-42.5% of protein in
seeds, and the best breeding forms, such as VNIIOZ 17, had up to 44% of crude protein.

These indicators of the soybean grain quality are characterized by weak correlation with the productivity of irrigated soybean (r = 0.10–0.14). That is why there is a high probability of developing a productive and at the same time high-protein soybean variety in the conditions of the Nizhneje Povolzhje region. Our collection contains a number of high-protein varieties and forms, these are varieties Maria (Ukraine), Harovinton (Canada) and samples A 937 (the Amur region), Herb 606 (Romania), CH 1470-20-1 (Belarus), Volzhana (the Volgograd region), Bystritsa (the Krasnodar region). Their usage in the breeding process will give the opportunity to increase the range of the new parental material variability in terms of the protein content in seeds, increase the likelihood of availability of the selection of high-protein genotypes and accelerate the development of productively valuable varieties of a new formation – with the average protein content of 40-45%.

The process of accumulation of protein and fat in seeds is interrelated with a significantly high negative correlation (r = - 0.62–0.76). This points to the development of two directions of breeding of this crop: grain protein and grain oil. The increase in the efficiency of the breeding process for the quality of soybean grain and obtaining an optimally high level of productivity can be achieved by using the criteria for selecting genotypes of such value not according to the data on the absolute content of crude protein and fat in the grain but by their yield from a unit of harvesting area. The strong correlations between the gross yield of protein, fat and productivity (r = 0.87–0.92) revealed during the research will give opportunity to obtain the protein yield of 0.96-1.31 t/ha, of fat – 0.43-0.52 t/ha in the future soybean varieties of 2021-2023 reproduction.

4. Conclusion
The comprehensive research on the study of the correlations between the structure elements of productivity in irrigated sowings with the intensification of dry hot wind phenomena of the local climate have shown the necessity to cultivate several soybean ideotypes (ideal types) with different periods of guaranteed ripening, the possibility of the fullest use of the bioclimatic potential for the regular need of industrial processing enterprises for raw soybean. We determined the morphobiological traits and characteristics of plants closely related to the grain productivity of irrigated soybean sowings, such as the growth season, the area of the assimilating surface, phytosynthetic potential, the productivity of dry vegetative mass, the grain content in the total phytomass, and the amount of the productive plant stand. The combined set of important economic indicators, recommended as a scientifically based model, will contribute to the breeding of varieties responsive to irrigation and adapted to dry hot winds. This will increase the yield of early-ripening varieties up to 2.8 t/ha, mid-ripening varieties – up to 3.8 t/ha and will provide a high level of profitability of soybean production under irrigation conditions – up to 150% and more.

References
[1] Borisenko I B, Ovchinnikov A S, Meznikova M V, Fomin S D, Bocharnikov V S, Rogachev A F and Ulybina E I 2019 Resource-saving method of chemical treatment of tilled crops Conf. on Innovations in Agricultural and Rural Development IOP Conf. Series: Earth and Environmental Science 341
[2] Pleskachev Yu N, Semina N I and Antonnikova S E 2013 Innovative approaches in sunflower Proc. of the Nizhnevolzhsky Agrouniversity Complex: Science and Higher Professional Education 4(32) 36-41
[3] Seferova I V and Bulakh P P 2019 Results of testing soybean accessions at the Far East experiment station of VIR in 1990-2017 Proc. on Applied Botany, Genetics and Breeding 180(4) 59-65
[4] Pleskachev Yu N, Voronov S I and Grabov R S 2020 Improvement of the system of basic tillage in the cultivation of spring barley Proc. of the Nizhnevolzhsky Agrouniversity Complex: Science and Higher Professional Education 1(57) 88-95
[5] Nekrasov A Y 2020 Soybean: Sources from the VIR collection of genetic resources Proc. on
Applied Botany, Genetics and Breeding 181(1) 48-52

[6] Tolokonnikov V V, Cancer G P, Koshkarova T S, Ivy N M and Kozhukhov I V 2018 Varietal responsiveness of soybean irrigation regime Proc. of the Nizhnevolszhsky Agrouniversity Complex: Science and Higher Professional Education 3(51) 128-133.

[7] Jha P K, Kumar S N, Ines A V M 2018 Responses of soybean to water stress and supplemental irrigation in upper Indo-Gangetic plain: Field experiment and modeling approach Field Crops Research 219 76-86

[8] Montoya F, Garcia C, Pintos F, Otero A 2017 Effects of irrigation regime on the growth and yield of irrigated soybean in temperate humid climatic conditions Agricultural Water Management 193 30-45