Comparison of productivity indicators for the Far Eastern selection of soybean varieties under adverse climatic conditions with different planting dates

T N Fedorova1, K N Dubrovin2 and N A Selezneva1

1 Far Eastern Agricultural Research Institute, Vostochnoe, 680521, Russia
2 Computing Center of the Far Eastern Branch of the Russian Academy of Sciences Khabarovsk, 680000 Russia
E-mail: fedorova.t.92@mail.ru

Abstract. The aim of this study was to determine the relationship between the productivity indicators of soybean varieties of the Far Eastern selection and the climatic conditions of the Russian Far East. We studied the yield, protein content, 1000 seed weight, and the number of beans and seeds per plant, according to the planting date of two varieties: «Batya» and «Khabarovskiy Jubilyar». The duration of the growing season, the sum of temperatures, the amount of precipitation, as well as the Selyaninov Hydrothermal Coefficient were considered as characteristics of the growing season. The period in which the experiment was conducted was unfavorable for the growth and development of soybeans compared with long-term average values. The number of beans per plant, the number of seeds per plant and the yield of «Khabarovskiy Jubilyar» were higher than the corresponding values for «Batya» (the yield of «Khabarovskiy Jubilyar» was 0.8 t/ha higher than «Batya»). Hydrothermal conditions limited the realization of the potential productivity of «Batya», restricting it to 45% of the potential yield. For «Khabarovskiy Jubilyar», this figure was 87%. The relationship between productivity and the length of growth period, as well as hydrothermal characteristics, was established.

1. Introduction
Soybean ranks first in the world in terms of the production of leguminous crops. The USA and Brazil are leaders in soybean production, but Asian countries account for the bulk of soybean consumption. Nowadays, certain soybean varieties have the potential to yield 3–4 t/ha. A combination of several factors, such as genetic qualities and cultivation conditions, including planting dates and methods of sowing, is required to achieve the maximum productivity of soybean varieties [1,2,3].

The optimization of soybean planting dates has been studied in countries such as the USA, Brazil, Argentina and China [4,5]. Studies in China have shown that climate warming significantly affects the phenology of crops [6]. Therefore, the optimization of the sowing date was chosen as a potential strategy for mitigating the effects of climate change [7]. Vavilov et al. found that earlier and later sowing lead to lower yields [8,9]. Minkevich et al. reported higher productivity for early planting dates [10,11]. Early
soybean sowing can stimulate the growth of the vegetative mass of plants; at the same time, late sowing
shortens the duration of both individual phases of growth and development, and the whole growing
period, which, in turn, reduces the accumulation of dry matter and leads to poor separation into
reproductive parts and, ultimately, poor yield [12].

Successful planting of generative organs and seed ripening, especially in adverse environmental
conditions, largely depend on the timely transition to flowering [13]. The most important factors
regulating flowering are daylight hours and the temperature of the surface air layer [14]. According to
various sources, both individual hydrothermal characteristics in different phases of development (the
amount of precipitation, air temperature and soil temperature at sowing), and complex indicators such as
the SHC (Selyaninov Hydrothermal Coefficient), also have an impact on crop productivity indicators [15].

Thus, the study of new highly productive soybean varieties should involve not only comparing the
characteristics of these varieties with each other, but also studying the influence of the planting dates and
temperature characteristics of the phenological phases on the productivity of these varieties. Measures to
mitigate such influences are particularly important for the Far Eastern regions, where climate is
characterized by inconsistency and substantially differs between regions.

2. Materials and methods
A comparative assessment of soybean varieties was carried out in 2019 in the Middle Amur Region (on
the fields of the Far East Agricultural Research Institute). We studied soybean varieties bred by the
Institute «Batya» and «Khabarovskyi Jubilyar». The studies were carried out in a small-plot field
experiment on acid alluvial soils in a field crop rotation in 2018–2019. The humus content was 4.1%, the
soil pH was acidic (pH less than 4.5), hydrolytic acidity was $10^{-12}$ mEq/100 g of soil, and the amount of
exchange bases was $15^{-17}$ mEq/100 g of soil. The soils in the study area are characterized by low
phosphorus availability and high potassium exchange. There were four replicates of each treatment, the
plot area was $4 \text{ m}^2$, and the seeding rate was 40 seeds per $\text{m}^2$. Seeds were sown on six dates: May 9, May
15, May 27, June 5, June 10, and June 17. The variety «Batya» was obtained from the hybridization of
*Glycine ussuriensis* («Midori Sapporo» and «Mivak»). Its average yield under optimal agroecological
conditions is 4.95 t/ha. The potential yield of the variety is more than 6.0 t/ha. The 1000 seed weight
varies widely depending on moisture and mineral availability during germination and is 190–270 g. Seed
protein content is 38.0–42.5%, seed fat content is 19.8%. The growth period lasts 120–130 days [16]. The
variety «Khabarovskyi Jubilyar» was bred from a heterogeneous population, and is one of the Manchu
subspecies of cultivated soybean. Its average yield under optimal agroecological conditions is 4.0 t/ha.
The seeds are medium-sized, and the 1000 seed weight is 170–230 g. The seed protein content is 39–41%,
and the seed fat content is 17%. The growth period lasts 120–135 days.

This study investigated the productivity indicators of these varieties, as well as the characteristics of
the growing season (table 1).

### Table 1. The main indicators of the productivity of soybean varieties and climatic characteristics of the
growing season.

| Indicator          | Variable | Indicator          | Variable | Indicator          | Variable |
|--------------------|----------|--------------------|----------|--------------------|----------|
| Beans per plant, pcs. | $x_1$    | Seed protein content, % | $x_5$    | SHC                | $y_4$    |
| Seeds per plant, pcs. | $x_2$    | Growth period, days | $y_1$    | Soil moisture at sowing, % | $y_5$    |
| 1000 seed weight, g.  | $x_3$    | Total temperature of the surface air layer, °C | $y_2$    | Soil temperature at sowing, °C | $y_6$    |
| Yield, t/ha          | $x_4$    | Rainfall, mm       | $y_3$    | Temperature of the surface air layer at sowing, °C | $y_7$    |
A pairwise comparison of indicators characterizing soybean productivity was carried out using the Scheffe test. For each of the six planting dates of the varieties «Batya» and «Khabarovskiy Jubilyar>, T Scheffe statistics were calculated and compared with T critical. A correlation analysis was performed using rank correlation (Kendall τ) to establish the relationship between the studied indicators. Regression equations were constructed and determination coefficients (R²) were calculated to assess the impact of meteorological factors on soybean productivity indicators.

3. Results
The field experiment revealed that the length of the growth period and the growth phases within this period changed depending on the planting date. Tables 2–3 show the duration of the growth phases of soybean, depending on the planting date.

Table 2. The duration of the growth phases and growing season of variety «Batya» depending on the planting date.

| Planting date | I phase* | II phase | III phase | IV phase | V phase |
|---------------|----------|----------|-----------|----------|---------|
| May 9         | 12       | 44       | 13        | 22       | 52      |
| May 15        | 10       | 42       | 14        | 25       | 46      |
| May 27        | 11       | 33       | 15        | 22       | 54      |
| June 5        | 7        | 35       | 15        | 18       | 57      |
| June 10       | 9        | 29       | 16        | 18       | 58      |
| June 17       | 6        | 27       | 17        | 21       | 53      |

*Germination – phase I (planting to VE); vegetative stages (VE-R1) – phase II; beginning bloom – beginning pod (R1-R3) – phase III; beginning pod – beginning seed (R3-R5) – phase IV; beginning seed – harvesting (R5-harvesting) – phase V.

Table 3. The duration of the growth phases and growing season of variety «Batya» depending on the planting date.

| Planting date | I phase* | II phase | III phase | IV phase | V phase |
|---------------|----------|----------|-----------|----------|---------|
| May 9         | 12       | 46       | 15        | 18       | 51      |
| May 15        | 10       | 44       | 18        | 19       | 45      |
| May 27        | 11       | 38       | 18        | 14       | 53      |
| June 5        | 7        | 37       | 18        | 13       | 56      |
| June 10       | 9        | 32       | 19        | 12       | 57      |
| June 17       | 6        | 30       | 20        | 15       | 52      |

*Germination – phase I (planning to VE); emergence-beginning bloom (VE-R1) – phase II; beginning bloom – beginning pod (R1-R3) – phase III; beginning pod – beginning seed (R3-R5) – phase IV; beginning seed – harvesting (R5-harvesting) – phase V.

In the summer of 2019, extreme conditions for crops developed in the south of the Khabarovsk Territory. Soybean development was accompanied by heavy rainfall. Precipitation in the 2019 growing season was 804.4 mm, compared with an average annual norm of 507 mm. As a result, the soil was over moistened.

In 2019, there was an increase in the productivity of soybean planted at a later date (its growing season was distinguished by more favorable conditions). The duration of phase I was significantly affected by the soil temperature and moisture at sowing [17]. The minimum temperature at seed sowing on the first three dates was 11–17 °C, which led to emergence after 10–12 days. The shift in the planting dates to June
reduced the duration of phase I, as the soil had warmed to 20–28 °C and moisture levels were more suitable (not overabundant). There were no obvious varietal differences in the duration of this phase. The field germination rate in 2019 was 84% for «Batya» and 90% for «Khabarovskiy Jubilyar».

«Batya» was 3–6 days ahead of «Khabarovskiy Jubilyar» in development, as the sum of the temperatures in phase 2 was 592–731 °C for «Batya», and 667–777 °C for «Khabarovskiy Jubilyar». The amount of precipitation in the specified period was in the range of 64–132 mm. Under the prevailing hydrothermal conditions, the duration of phase 2 varied from 27 to 44 days for «Batya» and from 30 to 46 days for «Khabarovskiy Jubilyar».

The soybean growing season in 2019 was characterized by high levels of moisture (SHC varied from 3.1 to 3.2) with a sum of temperatures of 2128.8–2694.2 °C and a total precipitation of 646.2–876.0 mm. Later planting dates reduced the growth period. For the first planting date, the growth period was 152 days, and at the latest date, it was 113 days. A shortening of the growth period negatively affected crop yields. The soybean varieties «Batya» and «Khabarovskiy Jubilyar» had the lowest yields when sown on the last planting date.

Table 4 presents the statistical analysis of the main indicators characterizing the productivity of the two studied soybean varieties, depending on the planting date. The least variable indicators for both varieties were \(x_3\) and \(x_5\). The greatest variation was in \(x_1\) and \(x_4\) for «Batya», and \(x_1\) and \(x_2\) for «Khabarovskiy Jubilyar». Important indicators of soybean productivity are the number of beans and seeds per plant. The largest number of seeds per plant in the variety «Batya» was observed for the fourth planting date, and for «Khabarovskiy Jubilyar» for the second planting date. This indicator varied slightly for «Batya» (V = 3.4%), and the variability for «Khabarovskiy Jubilyar» was 13.7%. The average yield of «Batya» was 45% of its potential (6 t/ha), and for «Khabarovskiy Jubilyar» it was 87%, with a potential of 4 t/ha.

**Table 4.** Statistical processing of the main productivity indicators for soybean varieties «Batya» and «Khabarovskiy Jubilyar» at different planting dates.

| Planting date | \(x_1\) | \(x_2\) | \(x_3\) | \(x_4\) | \(x_5\) |
|---------------|--------|--------|--------|--------|--------|
| **«Batya»**   |        |        |        |        |        |
| May 9         | 18     | 30.5   | 218    | 2.76   | 40.7   |
| May 15        | 17     | 31.0   | 214    | 2.83   | 37.4   |
| May 27        | 16     | 31.2   | 224    | 2.95   | 39.3   |
| June 5        | 17     | 33.3   | 220    | 3.05   | 39.9   |
| June 10       | 16     | 31.0   | 216    | 2.54   | 39.6   |
| June 17       | 14     | 30.5   | 210    | 2.30   | 38.2   |
| \(\bar{x}\)   | 16.3   | 31.3   | 217    | 2.7    | 39.2   |
| \(\sigma\)    | 1.4    | 1.1    | 5      | 0.3    | 1.2    |
| V, %          | 8.4    | 3.4    | 2.2    | 10.0   | 3.0    |
| \(\Delta \bar{x}\) | 1.4 | 1.1 | 5 | 0.3 | 1.2 |
| **«Khabarovskiy Jubilyar»** |        |        |        |        |        |
| May 9         | 29     | 49.2   | 186    | 3.73   | 35.9   |
| May 15        | 27     | 52.7   | 184    | 3.93   | 37.4   |
| May 27        | 24     | 48.4   | 184    | 3.61   | 36.6   |
| June 5        | 23     | 45.3   | 190    | 3.46   | 38.8   |
| June 10       | 21     | 45.0   | 186    | 3.38   | 37.7   |
The correlation analysis revealed the dependence of productivity on the length of the growth period and hydrothermal conditions (table 5). The degree of their influence on «Batya» and «Khabarovskiy Jubilyar» differed. The optimal ratio between yield and environmental factors was achieved by «Khabarovskiy Jubilyar», with a correlation coefficient of 0.87. Its higher resistance to the deterioration of agrometeorological factors was noted. In limited hydrothermal conditions «Batya» is not able to realize its productive potential. A significant increase in productivity is observed when environmental factors are optimized.

### Table 5. Correlation coefficients between soybean quality indicators and hydrothermal characteristics during the growing season.

|       | \(y_1\) | \(y_2\) | \(y_3\) | \(y_4\) | \(y_5\) | \(y_6\) | \(y_7\) |
|-------|----------|----------|----------|----------|----------|----------|----------|
| \(x_1\) | 0.79* | 0.79 | 0.50 | 0.00 | -0.07 | -0.36 | 0.00 |
| \(x_2\) | 0.07 | 0.07 | 0.33 | -0.41 | 0.33 | 0.33 | 0.41 |
| \(x_3\) | 0.33 | 0.33 | 0.33 | -0.83 | 0.33 | 0.07 | 0.14 |
| \(x_4\) | 0.20 | 0.20 | 0.47 | -0.41 | 0.20 | 0.20 | 0.28 |
| \(x_5\) | 0.20 | 0.20 | -0.07 | -0.41 | 0.47 | 0.20 | 0.00 |

* Significant values were marked bold.

Regression equations were constructed to quantify the most variable characteristics for the two varieties. The number of beans per plant for «Batya» and «Khabarovskiy Jubilyar» are respectively described by equations (1) and (2):

\[
x_1 = 6.55 + 0.074 \cdot y_1 \\
x_1 = -8.09 + 0.24 \cdot y_1
\]

The number of beans per plant was directly related to the length of the growth period. The determination coefficient for the regression models (1) and (2) was 0.68 and 0.98, respectively. Equation 3 describes the dependence of yield on the length of the growth period for «Khabarovskiy Jubilyar» (**R^2** = 0.76):

\[
x_4 = 4.51 + 0.23 \cdot y_1
\]

Equations 4 («Batya») and 5 («Khabarovskiy Jubilyar») describe the relationship between the mass of 1000 seeds and the climatic characteristics of the growing season: rainfall and SHC (**R^2** is 0.95 and 0.66,
respectively):

\[ x_3 = 574.6 - 120.96 \cdot y_4 + 0.029 \cdot y_3 \]  
\[ x_3 = 212.6 - 0.033 \cdot y_3 \]  

4. Conclusions

The influence of the sowing period on the productivity characteristics of two soybean varieties («Batya» and «Khabarovskiy Jubilyar») was studied. The studied varieties reacted differently to the hydrothermal conditions of the growing season. Based on the results, the optimal planting dates should be selected in order to achieve the maximum potential productivity of soybean varieties. Differences in the varieties «Batya» and «Khabarovskiy Jubilyar» in terms of productivity in adverse hydrothermal conditions were revealed: the yield of «Khabarovskiy Jubilyar» is on average 0.8 t/ha higher than that of «Batya». The relationship between productivity and the duration of the growing season, as well as hydrothermal characteristics, was determined. Regression equations were constructed, in which the length of growth period, amount of rainfall and the SHC of the growth period are included as independent variables. Hydrothermal conditions significantly limited the realization of the potential productivity of «Batya», which only achieved 45% of its potential. The same value for «Khabarovskiy Jubilyar» was 87%. Therefore, it can be assumed that this variety is better adapted to adverse conditions.

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