Adaptivity of leguminous crops in agricultural lands in the south of Central Siberia

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Abstract. To fully use the biological potential of a certain breed, it must fit into the specific environmental conditions, which in each zone differ in their specific characteristics (fertility and agrophysical state of the soil, hydrothermal regimes, insolation indicators, etc.). Knowing the individual reaction (adaptability) of the breed will allow it to be used in specific agrolandscapes, where it will provide maximum returns. The parameters of ecological plasticity, stability and homeostatic index of four soybean breeds and four breeds of field peas under sharply continental conditions in the south of Central Siberia are defined as adaptability criteria. It has been established that the Yakhont pea breed and the Sibiryachka soybean breed are more demanding on high growing conditions. Ruslan and Kemchug pea breeds and SibNIIK 315 and Sibniiskhoz 6 soybean breeds showed a change in yield corresponding to a change in growing conditions. Radomir pea breed and Zaryanitsa soybean breed are recommended to be grown on an extensive background, where they will give maximum returns at a minimum cost. The soybean breeds SibNIIK 315 and Sibniiskhoz 6 and the pea breed Kemchug were distinguished by their homeostatic index. They are characterized by lower yield variability with its high expression. Significant differences in yield stability, both of soybean and pea breeds were not observed, since $F_{05} < F_{0.05}$.

1. Introduction

Cereal legumes in the global structure of sown areas occupy more than 130 million ha [1].

Among legumes, peas have gained great interest as a source of protein, which is necessary for human nutrition and animal feed. Pea seeds contain 20–26 % protein, 22–48 % starch, a lot of carbohydrates, it is rich in vitamins B1, B2, carotene, ascorbic acid, etc. [2, 3].

Pisum sativum L. (Fabaceae), enjoys a worldwide culinary, traditional and medical reputation due to its nutrients [4].

Soy is also a universal culture. It has food, feed and technical value due to its rich and diverse chemical composition: 37–42 % protein, 19–22 % oil, up to 30 % carbohydrates, amino acids, macro-
and microelements and vitamins [5]. Soy and peas accumulate 40–60 kg/ha of nitrogen in the soil and therefore are a good precursor to cereals and other non-leguminous crops [6].

In the south of Central Siberia, which includes the Republic of Khakassia, the area under legumes is still insignificant. So in 2018, seed peas were sown in the Republic on an area of 857 ha with an average yield of 0.81 t/ha. The main areas were occupied by the Rus’ breed.

Soya is not a traditional crop in the crop area in the Republic of Khakassia. Sown areas under this crop in 2018 amounted to 379 hectares. The average yield from the harvested area is 0.55 t/ha. In crops Zolotistaya breed prevailed.

Further deepening of scientific research is associated with an assessment of the search for adaptive properties of varieties, including those included in the state register of selection achievements. When choosing a breed, the positive effect of the “genotype – environment” interaction should be taken into account [7].

To identify the degree of stability and adaptability of the created breeds, the ecological tests are carried out, according to the results of which certain biometric parameters are calculated, proposed to assess the characteristics of the reaction standards of genotypes to the range of test conditions [8].

Adaptive properties of breeds reflect plasticity, stability, as well as homeostaticity [9].

The adaptability property, reflecting the whole diversity of relations with the environment, is characterized by the unity of such opposites as plasticity (variability) and stability. In this regard, the terms of adaptability, environmental plasticity, environmental sustainability can replace and complement each other [10].

Homeostasis is a steady state of an organism with an environment in which the body retains the properties and ability of the normal implementation of vital functions against the backdrop of constantly changing conditions [11].

To evaluate them, it is necessary to identify the genotype of environmental effects; assess the main sources of environmental influences on the value of the trait; evaluate the effectiveness of the interaction of genotypes with environmental factors; to identify the share of influence or the contribution of various factors to the determination of varietal indicators [9, 12].

Therefore, the wider the breeds variety in response to environmental conditions, morphological and biological characteristics, the greater the potential for growth and stabilization of the crop by optimizing the placement of breeds in their corresponding soil-climatic and agrotechnological niches [13]. Which is relevant for the south of Central Siberia.

The purpose of the study is to study the adaptability of pea and soybean breeds in the steppe zone of the south of Central Siberia.

2. Methods and materials

An experiment on the environmental testing of peas was carried out in the steppe Shirinsko-Bogradsky district of the East Siberian province. The Shirin steppe covers the steppe, hills, and erosion-hazardous territories. The main soils are southern chernozems and ordinary loamy soils on red rocks. The sum of temperatures above 5 is 2169 °C and above 10–1862 °C, the amount of annual precipitation is 283 mm, including June – 47 mm, July – 68 mm, August – 54 mm. During the cold period, only 10–11 % of precipitation falls. Humidification coefficient calculated according to N.N. Ivanov is equal to 0.71. Experiments on the environmental testing of soybeans were located in the steppe interfluve Abakano-Yenisei agrolandscape region. The lands are foothill-steppe deflation-erosion-hazardous, the relief is gently rugged with ordinary chernozems and leached soils on loams. The sum of temperatures above 5 is 2143 °C and above 10–1807 °, the amount of annual precipitation is 382 mm, including 64 mm in June, 71 in July, 64 in August. Humidification coefficient is 0.97 [15]. Peas are a cold-resistant and precocious crop. Pea seeds in the soil begin to germinate at a temperature of about 2 °C, seedlings tolerate frosts to –5–7 °C. The optimum temperature for the development of the vegetative mass is in the range of 18–22 °C. The study area corresponds to the biology of culture [16].
The restraining factor for soybean cultivation in Siberia is the vegetation period, which is 100-130 days with the sum of active temperatures 1700–2300 ºС; accordingly, cultivation in this zone requires varieties of Siberian selection adapted to the conditions of the south of Central Siberia [17].

Plot allocation is randomized, two-tier. The area of accounting plots is 25 m². The protective strip is 15 m. Repeatability is fourfold.

In the Shirin steppe during the ecological breeding testing of peas, 4 varieties of peas of various morphotypes were used. Radomir breed is leafy and crumbling, Kemchug breed is leafless non-crumbling, Yakhont and Ruslan breeds are leafless (moustached), not crumbling. The test was conducted in 2014–2018 after the wheat as a predecessor.

Ecological test of soybean breeds of Siberian selection passed in Bei steppe: SibNIIK 315, Zaryanitsa, Sibiryachka, and Sibniiskhoz 6.

Processing of black fallow included dump plowing to a depth of 22–25 cm. As weeds appeared, cultivation was carried out. The first cultivation was carried out to a depth of 15 cm, the second – and the subsequent ones to a depth of 8–10 cm. The nailing was carried out in the third decade of April.

Before sowing, cultivation + harrowing to a depth of 5–7 cm, MTZ-80 + KPS-4 + 4 BZSS-1.0.

The processing of the grain predecessor included dump plowing to a depth of 10–12 cm, cultivation to a depth of seed placement. Between pre-sowing treatment, the gap was no more than 4–5 days. Sowing – seeder SN-16 P. Productivity was determined by the method of continuous harvesting with conversion to 14 % humidity.

The indicator of homeostaticity was calculated according to V.V. Hangildin [19]. Ecological plasticity parameters were calculated by the method of S.A. Eberhart and W.A. Russell [20].

3. Results

The productivity of a breed is determined by its yield obtained in various climatic and agrotechnical conditions of most geographical locations and over a large number of years [21].

Based on two-way analysis of variance, the contribution of variability factors (year, breed and their interaction) to the total variability of the yield is determined. This allowed us to obtain a quantitative assessment of the contribution of the studied factors to the formation of crop yields.

The totality of natural factors (the effect of meteorological conditions of the year) is considered as a specific influence of the “year” factor. Having determined the role of this factor, we can characterize the influence of meteorological, soil, and other conditions not taken into account in the experiment on yield formation.

The dominant contribution to the formation of pea and soybean yields was made by the factor “year”. The contribution of this factor to the variability of pea productivity was 85 % and soybean 90 % (Fig. 1). Considering that the set of breeds was not changed in this calculation, the variegation of soil fertility is also limited by the area of the experimental plot and, accordingly, the main variability was due to the “year” factor, which can be considered as variability caused by meteorological conditions of the zone.

![Figure 1. Contribution of factors in yield variability, %: 1 – Breed; 2 – Year; 3 – the interaction of factors «Year x Breed»](image-url)
In general, according to the experiment (on average for 4 varieties), the highest pea yield was obtained in 2017, which amounted to 2.05 t/ha and lower in 2014 and was within 0.78 t/ha (Table 1).

In general, the experience showed the highest soybean yield in 2016 and amounted to 2.01 t/ha and a lower 0.7 t/ha in 2019 (Table 2).

There is no sufficient reason to compare the productivity of peas and soybeans over the years, since field experiments were carried out in various geographical locations with a distance of about 270 km. Accordingly, the soil and climatic conditions of the zones had significant differences.

Pea breeding differences determined yield by only 5% in the field experiment. According to the results of four years of testing, the most fruitful breed was Kemchug (1.58 t/ha). Yakhont and Ruslan breeds showed yields of 1.4 and 1.38 t/ha, respectively (Table 1).

Genotypic differences in soybean breeds only 6% influenced the formation of productivity. In general, according to the experiment, varietal differences between the varieties SibNIIK 315, Sibiryachka and Sibniiskh 6 were within the range of NSR0.5. The yield of these varieties ranged from 1.28 t/ha (Sibniiskh 6) to 1.32 t/ha (SibNIIK 315) (Table 2).

A specific “year × breed” interaction was noted, which contributed to the total variability of pea yields of about 10% and soybeans – 4% (Fig. 1). The “year × breed” interaction indicates the individual response of the breeds to growing conditions. If we compare the yield of breeds by year, it can be noted that their rank varies. So, in 2014, the highest yield was observed in Radomir breed, in 2015 and 2017 – in the Kemchug breed, in 2016 – in the Yakhont and Ruslan breeds, in 2018 – in the Radomir breed.

Accordingly, there are no clear patterns of yield variability by year and in soybean varieties. In 2015, the Sibiryachka had the highest yield in experience; in 2016 – SibNIIK 315 and Sibiryachka, in 2017 – SibNIIK 315 and Sibniiskh 6, in 2018 – Sibniiskh 6, in 2019 – Sibiryachka and Sibniiskh 6.

It should be noted that the average yield of sown peas of 4 varieties for 5 years of testing was 1.41 t/ha and soybean –1.24 t/ha. Given the high value of leguminous crops at a given yield loss, it is advisable to cultivate them in the test zones. Since the cost of soybean cultivation pays off with a yield of 0.5 t/ha, this crop is less than others in the risk zone due to low productivity [22].

The introduction of breeds with increased adaptability in production allows us to stabilize the average yield in the region over the years. And accordingly, it is necessary to have a clear predicted value of the individual reaction of breeds to varying conditions of plant growth.

### Table 1. Yield of peas in the field experiment, t/ha

| Breeds    | 2014 | 2015 | Years | 2016 | 2017 | 2018 | 2019 | bi   | σ²d | Hom  |
|-----------|------|------|-------|------|------|------|------|------|-----|------|
| Kemchug   | 0.8  | 1.4  | 1.8   | 2.4  | 1.5  | 1.09 | 0.03 | 4.30 |
| Radomir   | 0.9  | 0.9  | 1.0   | 1.8  | 1.8  | 0.59 | 0.18 | 3.41 |
| Yakhont   | 0.7  | 1.0  | 2.1   | 2.1  | 1.1  | 1.2  | 0.07 | 2.97 |
| Ruslan    | 0.7  | 0.9  | 2.1   | 1.9  | 1.3  | 1.12 | 0.06 | 3.12 |
| Ij        | -0.63| -0.36| 0.34  | 0.64 | 0.01 |      |      |      |

HCP05 «breed» factor – 0.04 t/ha; «year» factor – 0.05 t/ha; «year × breed» interaction – 0.01 t/ha.

### Table 2. Yield of soybeans in the field experiment, t/ha

| Breeds      | 2015 | 2016 | Years | 2017 | 2018 | 2019 | bi   | σ²d | Hom  |
|-------------|------|------|-------|------|------|------|------|-----|------|
| SibNIIK 315 | 1.4  | 2.3  | 1.0   | 1.3  | 0.6  | 1.05 | 0.04 | 3.65|
| Zaryanitsa  | 0.9  | 1.7  | 0.9   | 1.1  | 0.6  | 0.63 | 0.05 | 2.64|
| Sibiryachka | 1.7  | 2.3  | 0.7   | 1.0  | 0.8  | 1.27 | 0.29 | 2.48|
| Sibniiskh 6 | 1.2  | 2.0  | 1.0   | 1.4  | 0.8  | 1.05 | 0.17 | 3.56|
| Ij          | 0.15 | 0.93 | 0.47  | -0.47| -0.17| -0.44|      |      |

HCP05 «breed» factor – 0.08 t/ha; «year» factor – 0.08 t/ha; «year × breed» interaction – 0.01 t/ha.
S.A. Eberhart, and W.A. Russell proposed a method for calculating adaptability using two parameters: a linear regression coefficient (bi) and dispersion (σ²d). The first shows the response of the genotype to the improvement of growing conditions, and the second characterizes the stability of the breed in various environmental conditions [20].

Based on two-way analysis of variance, the fact of a significant “genotype × environment” interaction was established at a 5% significance level for both pea and soybeans, which allows the calculation of the linear regression coefficient (bi) and dispersion (σ²d).

Indices of environmental conditions (Ij) allow us to characterize the conditions for growing crops (Tables 1, 2).

The most favorable conditions for the formation of a pea crop were in 2017 (Ij = + 0.64) and unfavourable – in 2014 (–0.63) (Table 1).

2016 was more favorable for the formation of soybean productivity (Ij = + 0.93) and less favorable – 2017 and 2019 (Ij = – 0.47 and 0.44) (Table 2).

The pea breed Yakhont is more demanding on high growing conditions (bi > 1), so it increases the grain yield by 1.20 t/ha, while increasing the level of productivity in the experiment by 1 t/ha. In Ruslan and Kemchug breeds, the change in yield was consistent with the change in growing conditions (bi within 1). Radomir cultivar is recommended to be grown on an extensive background (bi <1), where it will give maximum returns with minimum costs.

Soybean breeds of Siberian breeding also had a different reaction to changing growing conditions. Sibiryachka breed is more demanding on high growing conditions (bi = 1.27), so it increases the grain yield by 1.27 t/ha, while increasing the level of productivity in the experiment by 1 t/ha. In cultivars SibNIIK 315 and Sibniiskhоз 6, the change in yield was consistent with the change in growing conditions (bi = 1.05). Zaryanitsa breed is recommended to be grown against an extensive background (bi = 0.63), where it will give maximum returns with minimum costs.

Significant differences in yield stability (σ²d) during the study years were not noted in the set of breeds of peas and soybeans, since F<sub>ϕ</sub> < F<sub>05</sub>.

In terms of homeostaticity, the pea breed Kemchug (Hom = 4.3) and the soybean breeds SibNIIK 315 and Sibniiskhоз 6 (Hom = 3.65 and 3.56, respectively) were distinguished. These breeds are characterized by lower yield variability with its high expression.

### 4. Conclusion

To obtain data on the share of genotype and environmental factors in the formation of pea and soybean crops, we decomposed ecological (phenotypic) variability into its components. Based on the two-way analysis of variance, the variance components are determined, i.e., the parts of the general variance attributable to the genotypic effect, the season effect of the year, and the effects of the interaction of the studied factors (breed, year). The dominant influence of the factor “year” is established, which indicates its decisive role in the formation of productivity. The materials presented indicate extreme instability in the productivity of peas and soybeans in the steppe conditions of southern central Siberia. In general, the experience of the differences between the extreme options can be more than 2.6 times for peas and 2.9 times for soy. It should be noted that in favorable years for the formation of crop productivity they have a fairly high yield potential, which was within 2 t/ha.

Accordingly, to reduce the influence of the “year” factor on the formation of soybean and pea productivity, it is necessary to more widely introduce adaptive breeds and technologies for growing crops.

Based on field experience, it is not possible to identify any morphotype of peas by yield. The traditional form of peas, that is, leaflet and crumbling, was represented in the sample by the Radomir breed, which showed an average yield of 1.28 t/ha over the years. Kemchug breed (leafy, non-crumbling) had a higher average yield, which amounted to 1.58 t/ha. The group of leafless (moustached) non-shedding forms was represented by Yakhont and Ruslan breeds, which formed an average yield of 1.4 and 1.38 t/ha.
It should be noted that leafless plants mate with a mustache in a ball of interwoven antennae, forming an elastic frame, which provides higher resistance to lodging and cleaning by direct combining [23, 24].

Breeds of peas that are resistant to lodging and easily amenable to mechanized harvesting lead to an increase in sown areas of peas without a significant increase in grain yield per hectare of harvested area [25].

To stabilize yields in the steppe conditions of the south of Central Siberia, it is necessary to include breeding in the technology of growing a culture taking into account their homeostaticity. Environmental plasticity parameters are the basis for the selection of breeds for different levels of intensification of agriculture.

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