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INFLUENCE OF AGROTECHNICAL PRACTICES AND SOWING TIME IN VARIOUS WEATHER ON SOYBEAN YIELD

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For seed germination and the formation of a good soybean crop, significant reserves of soil moisture are required, which depends on the autumn-winter soil preparation, weather conditions and planting dates. The purpose of this study is to identify the impact of the main tillage technology on its agrophysical properties and conditions for the growth and development of soybean plants. Experimental crop rotation: soybean – winter wheat was carried out under favourable (hydrothermal coefficient 1.46) and dry (hydrothermal coefficient 0.66–0.87) weather conditions. The main tillage was carried out with a stratifier PRSM-5 to a depth of 15–17 cm or a chisel plough PCh-2.5 to a depth of 25–27 cm, with additional pre-sowing or post-sowing rolling with a ring-spur roller KKSH. Sowing was carried out at a depth of 10 cm with stable heating of the soil in three periods: the first at 8–10 °C, the second at 10–12 °C, and the third at 12–14 °C. As a result of evaluating the influence of various factors, it was found that under favourable conditions, the highest seed productivity of soybean plants (1.91–1.96 t·ha^{-1}) was formed after treatment with the stratifier PRSM-5 at the first sowing period and at the second sowing period after chisel ploughing with additional soil compaction. In dry weather conditions, pre-sowing treatment with a stratifier PRSM-5 had an advantage in seed productivity by 7–12% compared to ploughing with a chisel plough PCH-2.5.

Keywords: non-mouldboard tillage; stratifier PRSM-5; chisel plough PCh-2.5; productive moisture; soil structure factor; assimilation leaf area

According to phenological observations (Araji et al., 2018; He et al., 2020; Guo et al., 2022), the length of the growing season of soybean plants is highly dependent on weather conditions. Soybean plants developed well under favourable weather conditions, and the duration of the growing season corresponded to the ripeness group. In dry conditions, the duration of the growing season is significantly reduced (Hatfield and Prueger, 2015; Gobin, 2018; Jumrani and Bhatia, 2018).

Significant moisture reserves are required for seed germination and the formation of a good soybean crop (Etemadi et al., 2019; Shevnikov et al., 2021). The amount of soil moisture at the beginning of the growing season depends on the weather conditions of the autumn-winter period and the agrophysical properties of the soil (Yang et al., 2018; Popolzukhina et al., 2019; Cherenkov at al., 2021). The optimization of soybean growth and development conditions is determined not only by hydrothermal factors, but also by the main technological factors (Ergashev et al., 2020; Siroshtan et al., 2021). An important role in the process of moisture accumulation in the seed layer is played by autumn-winter tillage (Acharya et al., 2019). However, traditional methods of processing soybean crops do not always allow maintaining the necessary reserves of productive moisture at a depth of 10 cm.

Insufficient soil moisture requires improving the technology of growing crops (Kiryushin, 2019; Akhtar et al., 2019; Maslov et al., 2020; Gondal et al., 2021). Agricultural practices aimed at maximizing the preservation of productive moisture in the soil are of particular importance in arid conditions when there is a moisture deficit throughout the entire growing season of soybean plants.

Favourable conditions for soybean plants are observed only with optimal soil density, which allows accumulating

a sufficient amount of productive moisture in the seed layer of the soil (De Moraes et al., 2020; Ferreira et al., 2021; Yue et al., 2021). Excessively loosened soil after ploughing in arid conditions quickly loses moisture, which significantly reduces the density of herbage and further yield (Troyanovskaya et al., 2019; Troyanovskaya et al., 2021). Additional compaction of the topsoil by rolling helps prevent excessive evaporation of soil moisture and create favourable conditions for the growth and development of soybean plants.

The purpose of the study is to reveal the influence of the main tillage technology on its agrophysical properties and conditions for the growth and development of soybean plants in various weather conditions.

Material and methods

The studies were carried out in 2018–2020 years on the experimental field of Kharkiv National Agrarian University. V. V. Dokuchaev. The total sown area was 128.8 m^2. Each experimental area was 48.3 m^2. The experiment used the soybean – winter wheat crop rotation. The experiments were repeated three times. Soybean seeds of the Feya variety were sown in a wide-row way with a row spacing of 70 cm. The seeding rate was 500,000 viable seeds per hectare. Sowing was carried out at a depth of 10 cm with stable heating of the soil in three periods: the first at 8–10 °C, the second at 10–12 °C, and the third at 12–14 °C.

The soil cover of the research areas is a typical slightly eroded low-humus heavy loamy chernozem on carbonate loess. Agrochemical indicators of the soil:

- pH of salt extract 6.45–7.0;
- total humus content in the upper soil layer 5.5%;
- the content of nitrate nitrogen 2–3 mg per 100 g of soil;
- mobile phosphorus content (according to Chirikov) 10.2 mg per 100 g of soil;
- the content of exchangeable potassium (according to Surikov) 179 mg per 1 kg of soil.

As a result of the experiment, a comparison was made of non-mouldboard tillage with various methods of basic tillage. Efficiency was evaluated against the background of chemical measures (Lancaster – 2.0 $l \cdot ha^{-1}$ for pre-sowing cultivation) using rolling before and after sowing.

The main factor hindering the growth of soybean seed productivity is moisture availability. The moisture availability content of the soil can be indirectly estimated through the hydrothermal coefficient (the ratio of the amount of precipitation to the amount of evaporated moisture). The weather conditions during the years of the research were different, which made it possible to comprehensively characterize the effect of agrotechnical measures and sowing dates on the productivity of soybean plants. The growing season for moisture in 2020 was favourable. The hydrothermal coefficient for the growing season (May–September) was 1.46. In 2019, the hydrothermal coefficient of the growing season was 0.87, which is characterized as a dry year. In 2018, the hydrothermal coefficient from May to September was only 0.66, which is typical for an extremely dry year.



Fig. 1 Electronic moisture soil meter MC-7828 SOIL

The critical period for soybean plants is the flowering phase – the formation of beans. In the experimental plot in the second half of the summer of 2018–2020, difficult weather conditions were observed. The air temperature in July and August increased significantly, and the amount of precipitation was several times less than the annual average. Relative air humidity for 14–16 days per month was less than 30%. The hydrothermal coefficient in July 2018 was 0.13, and in August it was 0.56. In 2019, the hydrothermal coefficient was 0.26 in July and 0.75 in August. Difficult weather conditions have negatively affected the realization of soybean potential.

Before sowing soybeans, soil moisture was measured using an electronic moisture meter MC-7828 SOIL (Fig. 1).

The MC-7828 SOIL moisture meter has a 320 mm probe. It measures soil moisture in the range from 0 to 80%, with an error of ±0.5%. The liquid crystal screen has a colour indication in addition to digital humidity values. A green screen corresponds to dry soil, a yellow screen corresponds to moderately moist soil, a red screen corresponds to extreme soil moisture. The digital device allows calculating the average value. In the experiment, at least 5 measurements were taken in different places of the field.

Experimental studies were carried out using three different tillage units: a stratifier PRSM-5, a chisel plough PCh-2.5, and a ring-spur roller KKSH.

The trailed stratifier PRSM-5 (Fig. 2) is a universal tillage unit designed for pre-sowing and main surface tillage (Syromyatnikov et al., 2021; Syromyatnikov et al., 2022a).

The trailed stratifier PRSM-5 has its own chassis [2]. A rotor [3] is mounted on the frame [1], the knives of which crumble and feed the soil onto the separating grate [4]. As a result of separation, the soil is differentiated by structural composition. By combing, the stratifier PRSM-5 removes

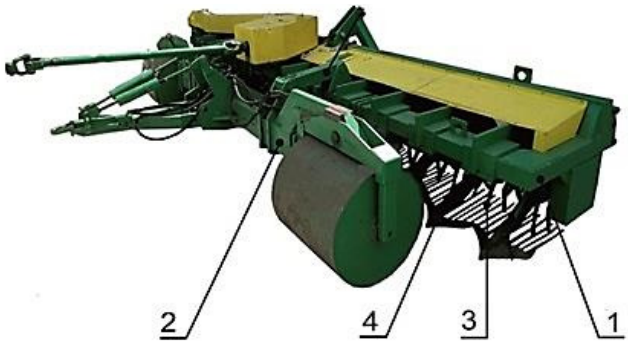


Fig. 2 Trailed stratifier PRSM-5
Source: Syromyatnikov et al., 2021

weeds from the soil along with the root system. Weeds thrown to the surface form a mulching layer. The stratifier PRSM-5 improves the physical and mechanical properties of the soil at a depth of up to 18 cm (Blednykh et al., 2015; Syromyatnikov et al., 2022 b).

The mounted chisel plough PCh-2.5 (Fig. 3) is designed for non-mouldboard tillage instead of ploughing, as well as for deep loosening of the soil along mouldboard and non-mouldboard backgrounds (Nunes et al., 2019, Katayama et al., 2018).

The main working bodies of the PCh-2.5 chisel plough are flat-cut rippers [2], mounted on the frame [1]. In the process of deep loosening with the PCh-2.5 chisel plough, the cultivated soil layer becomes looser and saturated with oxygen.

The ring-spur roller KKSH (Fig. 4) is designed for soil compaction before and after sowing in all soil and climatic zones, except for the zone of mountain farming.

The KKSH-6 skating rink is equipped with a chassis [3] fixed on the frame [2]. The skating rink section of steel ring-spur rings [1] acts as a working tool. The roller is aggregated with the tractors of traction class 1.4–2.0. Its design allows safe transportation on public roads due to the possibility of transferring it to the long-distance transport position using a hydraulic cylinder [4].

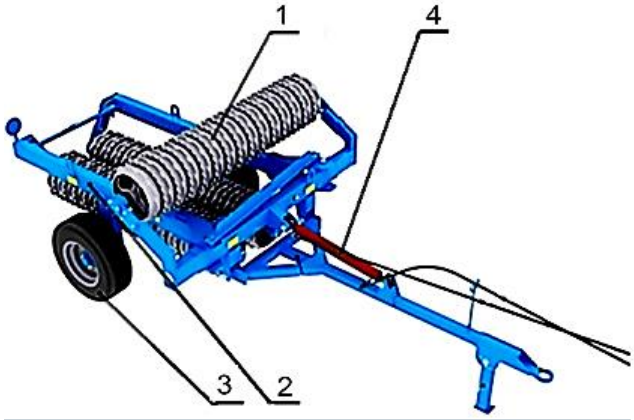


Fig. 4 Ring-spur roller KKSH-6 for soil compaction

Pre-sowing rolling is carried out to retain moisture in the soil, crush large clods of earth and partially level the field surface. Rolling the soil before sowing breaks up large clods of earth and compacts too loose soil (Kokieva et al., 2021). This operation reduces the slippage of the seeder support wheels, which increases the uniformity of sowing and stabilizes the depth of seed placement (Jia et al., 2016; Liu et al., 2022). Post-sowing rolling is carried out for additional moisture retention and ensuring the contact of seeds with the soil. Such contact creates favourable conditions for obtaining earlier and friendly seed germination, which increases yields even in arid regions (Acquah and Chen, 2022).

Soil density was measured after tillage. Density was measured as penetration resistance using a conical GPS penetrometer (Fig. 5). The device is equipped with a depth measurement sensor, which allows obtaining the law of change in the resistance to penetration into the soil in depth. The working body of the penetrometer is a polished steel cone with a base diameter of 12.83 mm and an apex angle of 30°. It allows taking measurements at a depth of up to 45 cm.

The yield of plants depends on the photosynthetic properties of plants. It is the ability to absorb and accumulate

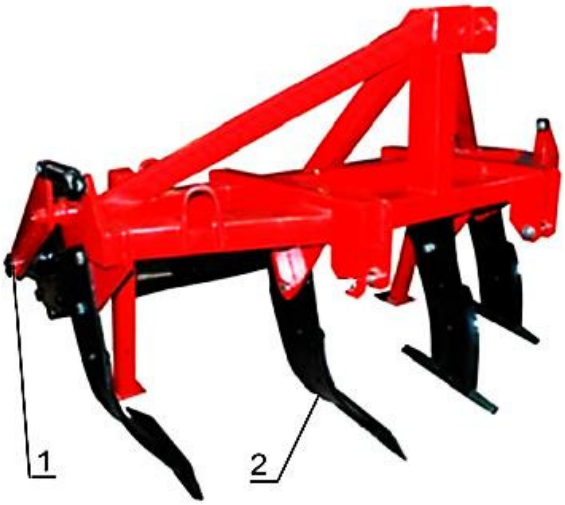


Fig. 3 Mounted chisel plough PCh-2.5



Fig. 5 Measuring penetration resistance force with a cone penetrometer

solar radiation. The assimilating leaf area was determined by recalculating the shape and size of the leaves using the factors (Belyshkina et al., 2020).

Results and discussion

The results of experimental studies confirmed the dependence of the density of the seed layer of the soil and the yield of soybeans on the method of the main processing.

Before sowing, the soil density indicators after treatment with the stratifier PRSM-5 were less than those after chisel treatment (Table 1). With increasing depth, the density indicators increased.

The density of the upper soil layer at a depth of 0–10 cm after treatment with the stratifier PRSM-5 was 0.95 g·cm^{-3}, which is 9% less than after chisel ploughing. On average, at the entire depth of the main tillage (0–30 cm), the density of the soil after the stratifier PRSM-5 was 4.5% less compared to ploughing with the chisel plough PCH-2.5.

This is due to the fundamentally different effects of the working bodies. The working bodies of the chisel plough PCh-2.5 acted on the soil only in the vertical plane. The result of such tillage was vertical narrow unloosened strips in the form of closed ridges, alternating with more intense and slight soil refinement. Between these loosened strips, the soil was additionally compacted due to lateral pressure. Thus, during chisel cultivation, there was a large unevenness in the density of the soil arable layer.

When removing the soil from the lower layers to the surface layers, the stratifier PRSM-5 crushes it evenly. This has a fruitful effect on the deeper layers of the soil. After treatment with the stratifier PRSM-5, in the upper soil layer at a depth of 0–10 cm, 71.8% of fractions 0.25–7 mm in size, the most valuable from an agronomic point of view, were observed. The amount of lumpy fraction and dust was insignificant. The coefficient of structure in the layer of 0–10 cm was 2.56, and during chisel processing, the coefficient of structure was 2.21 (Table 2).

In the soil layer at a depth of 10–20 cm, when treated with the stratifier PRSM-5, it was 70%, and when chiselled, it was 67%. The coefficient of structure in the layer of 20–30 cm treated with the stratifier PRSM-5 was 2.21, and with the chisel loosening it was 2.06. With increasing depth, the amount of agronomically valuable fraction (0.25–7 mm) decreased by an average of 4% for both types of treatment. Thus, tillage with the stratifier PRSM-5 provided the best structural structure of the soil in comparison with ploughing with the chisel plough PCh-2.5. The coefficient of soil structure when ploughing with the stratifier PRSM-5 is 12% higher than when ploughing with the chisel plough PCh-2.5.

The main tillage method significantly influenced not only the agrophysical properties of the soil, but also the amount of soil moisture accumulation. The reserves of productive moisture in the upper soil layer at a depth of

Table 1 Density (g·cm^{-3}) of soil before sowing soybeans depending on the method of main cultivation and the depth of the surface layer

Soil cultivation method	Depth (cm)	2018	2019	2020	Mean
Processing with a stratifier PRSM-5 at 15–17 cm	0–10	0.94	0.96	0.96	0.95
	10–20	1.06	0.98	1.14	1.06
	20–30	1.15	1.01	1.15	1.10
	0–30	1.05	0.98	1.08	1.04
Ploughing with a chisel plough PCh-2.5 at 25–27 cm	0–10	1.01	1.01	1.10	1.04
	10–20	1.11	1.02	1.15	1.09
	20–30	1.19	1.04	1.16	1.13
	0–30	1.10	1.02	1.14	1.09

Table 2 Indicators of agronomically valuable soil fraction (0.25–7 mm) depending on the method of main processing

Soil cultivation method	Depth (cm)	2018	2019	2020	Mean	Soil structure factor
Processing with a stratifier PRSM-5 at 15–17 cm	0–10	71.0%	74.3%	70.0%	71.8%	2.56
	10–20	67.9%	72.0%	69.1%	69.7%	2.31
	20–30	67.0%	71.8%	67.4%	68.7%	2.21
	0–30	68.7%	72.7%	68.8%	70.1%	2.36
Ploughing with a chisel plough PCh-2.5 at 25–27 cm	0–10	68.4%	70.3%	68.3%	69.0%	2.21
	10–20	66.7%	66.2%	69.5%	67.5%	2.06
	20–30	65.9%	64.5%	68.8%	66.4%	1.98
	0–30	67.0%	67.0%	68.9%	67.6%	2.08

0–10 cm before sowing in areas treated with the stratifier PRSM-5 were 13.6–14.0 mm, and during chisel ploughing, they were 11.3–12.0 mm. The amount of accumulated soil moisture before sowing in the upper layer is 14–16% more after treatment with the stratifier PRSM-5 than after chisel ploughing. Differences in moisture reserves are associated with an increase in the porosity of this layer as a result of the mixing of crop residues with the soil. Moisture reserves in a meter layer of soil after treatment with the stratifier PRSM-5 were 128–144 mm, and after chisel treatment, 123–142 mm. At the end of the growing season, the reserves of productive moisture decreased significantly. In the phase of full ripeness of soybeans after treatment with the stratifier PRSM-5, they were 57 mm, and after chisel treatment – 69 mm. Hence, it can be concluded that the reserves of productive moisture were used more rationally during chisel pre-sowing tillage.

Rolling the soil before sowing ensured the accumulation of moisture in the zone of seeding due to its capillary pulling from the lower layers of the soil. This agrotechnical technique ensured uniform placement of seeds during sowing and their closer contact with the soil. Improving moisture supply during sowing contributed to obtaining friendly seedlings.

The use of rolling after sowing with soil moistening led to a decrease in the density of soybean plants. This is explained by the fact that soybean plants, during germination, bring their cotyledons to the soil surface and, at high soil density, the sprouts break and die. Thus, rolling the soil before sowing seeds provided the best results, and after sowing, it led to a decrease in the density and productivity of soybean plants.

The observations made during the "sowing-shooting" period showed that the methods of sowing did not affect the emergence of seedlings. In this case, the main role was played by the amount of moisture in the seed layer and the thermal regime during this period.

The passage of development phases by soybean plants depended on the above factors and weather conditions during the growing season. In the presence of precipitation and a decrease in air temperature, the phases of plant development were lengthened, and the duration of the growing season increased. Under favourable weather conditions, the onset of full ripeness was noted on the 125th day of vegetation, and under dry conditions, due to the reduction of interphase periods, on the 115th day.

The analysis of biometric indicators at the time of soybean flowering showed that the height of plants changed depending on agricultural practices. The timing of sowing is of decisive importance in the technology of growing crops and largely determines the further growth and development of plants (Luiz et al., 2020; Oserbaeva and Kunakbayev, 2021). The comparison was carried out at three terms of soybean planting, determined by the soil temperature at a depth of 10 cm. The first sowing was carried out at a soil temperature of 8–10 °C, the second (additional sowing) was carried out at a soil temperature of 10–12 °C, and the third additional sowing at a soil temperature of 12–14 °C.

After treatment with the stratifier PRSM-5, the soybean plants of the first sowing period had a height of 1.2–1.7 cm more than the plants of the second and third sowing periods. Pre-sowing and post-sowing rolling additionally reduced the height of plants by another 1.7–2.3 cm.

The formation of plant height and density during chisel processing was fundamentally different. During chisel ploughing, more than 60% of crop residues remained on the soil surface. These residues mixed with the soil, which led to an increase in the number of cracks and some loss of moisture. At the first sowing term, pre-sowing rolling ensured plant density, as in the case of treatment with the stratifier PRSM-5. However, seedlings appeared 3–4 days later, which was reflected in the height of plants. The height of soybean plants during flowering with chisel pre-sowing treatment without rolling was 4.2 cm less than with stratification.

When preparing the soil with the chisel plough PCH-2.5, rolling is an expedient agricultural technique. Rolling before and after sowing provided better soil compaction after ploughing. Seedlings in areas with chisel ploughing with pre-sowing and post-sowing rolling appeared at the same time as in areas treated with the stratifier PRSM-5. The height and density of standing plants of the first sowing period during chisel ploughing with rolling was higher than during the main treatment with the stratifier PRSM-5. At the second sowing period, when the soil warmed up to 10–12 °C, there were no differences in height and seedling density between the variants. At the third sowing period with soil warming up to 12–14 °C, rolling during chisel ploughing contributed to a decrease in plant height by 1.9 cm.

The main quantitative indicator of the photosynthetic activity of sowing is the area of the assimilation leaf surface of the herbage (Board and Tan, 1995). Leaf surface area depends on weather conditions, main processing methods and rolling time (Table 3).

Under favourable moisture conditions in the first half of the growing season, soybean crops of the first period during the main processing with the stratifier PRSM-5 formed a leaf surface by 8–9% more than ploughing with

Table 3 Assimilation leaf area (thousand $m^2 \cdot ha^{-1}$) of soybean crops depending on growing conditions

Soil cultivation method	Roller soil compaction	Dry weather (2019)			Favourable weather (2020)		
		first sowing	second sowing	third sowing	first sowing	second sowing	third sowing
Processing with the stratifier PRSM-5 at 15–17 cm	no	26.7	30.7	28.6	42.2	42.6	41.6
	yes	30.4	29.8	27.4	43.1	42.9	43.2
Ploughing with the chisel plough PCh-2.5 at 25–27 cm	no	25.9	25.6	25.0	38.3	42.4	42.8
	yes	26.3	26.5	26.0	39.7	41.9	43.7

Table 4 Soybean yield (t·ha^{-1}) depending on the main processing method and sowing time

Soil cultivation method	Roller soil compaction	Dry weather (2019)			Favourable weather (2020)		
		first sowing	second sowing	third sowing	first sowing	second sowing	third sowing
Processing with the stratifier PRSM-5 at 15–17 cm	no	1.12	1.18	1,15	1.91	1.77	1.71
	yes	1.14	1.14	1,15	1.78	1.75	1.68
Ploughing with the chisel plough PCh-2.5 at 25–27 cm	no	1.04	1.03	1,02	1.80	1.96	1.70
	yes	1.05	1.05	1.03	1.76	1.81	1.66

the chisel plough PCh-2.5. At the second sowing period, soybean crops formed almost the same assimilation surface (42.4–42.6 thousand m^2·ha^{-1}) when treated with the stratifier PRSM-5 and when ploughing with the chisel plough PCh-2.5. At the third sowing term, the assimilation surface of soybean crops when ploughing with the chisel plough PCH-2.5 was higher by 1–2% than when treated with the stratifier PRSM-5. Thus, in favourable weather conditions, treatment with the stratifier PRSM-5 made it possible to obtain a large assimilation leaf area of soybean crops during the first sowing period, while ploughing with the chisel plough PCh-2.5 provided the advantage of the third sowing period.

Under arid conditions, the leaf surface area of crops was obtained on average by 35–40% less than under favourable weather conditions. Pre-sowing treatment with the stratifier PRSM-5 provided an advantage of 5–10% compared to ploughing with the chisel plough PCh-2.5. High temperatures in dry years contributed to an increase in the level of harmfulness of the acacia moth over the entire growing season of plants. In crops of the first sowing period, up to 8% of damaged seed was observed when treated with the stratifier PRSM-5 and 12–13% when chisel tillage. In crops of the second and third sowing periods, seed damage increased to 16–21%.

Under favourable moisture conditions (hydrothermal coefficient 1.45) and treatment with the stratifier PRSM-5, the best productivity (yield 1.91 t·ha^{-1}) of soybean plants was observed with stable heating of the soil to 8–10 °C (first sowing). Plants were characterized by a large number of branches, which contributed to the growth of beans and seeds from one plant. With chisel tillage, the highest productivity (yield of 1.96 t·ha^{-1}) was recorded during the second additional sowing with a soil warming temperature of 10–12 °C (Table 4).

Conclusion

Pre-sowing tillage with the help of the stratifier PRSM-5 provides a 4.5% lower density with ploughing with the chisel plough PCH-2.5 at the entire depth of the arable layer. After treatment with the stratifier PRSM-5 in the upper soil layer (depth 1–10 cm), a greater (by 4%) amount of agronomically valuable soil fraction (0.25–7 mm in size) was observed than after ploughing with a chisel plough PCh-2.5. In addition, during chisel processing, there was a large unevenness in the density of the soil arable layer. The coefficient of soil structure when ploughing with the chisel plough PCH-2.5 is 12% less than when ploughing with the stratifier PRSM-5.

The amount of accumulated soil moisture before sowing in the upper layer (0–10 cm) was 14–16% more after treatment with the stratifier PRSM-5 than after chisel ploughing. However, after the growing season, the ratio of productive moisture reserves decreased, which indicates a more rational use of productive moisture reserves during chisel pre-sowing tillage.

An analysis of the effect of rolling on the agrotechnical properties of the soil revealed the feasibility of using it only for chisel tillage.

An analysis was made of the timing of sowing and agrotechnical methods of tillage for the biometric parameters of soybean plants. Soybean plants of the first sowing period (soil temperature 8–10 °C) had a height of 1.2–1.7 cm more than plants of the second (soil temperature 10–12 °C) and third (soil temperature 12–14 °C) sowing terms after the main treatment with the stratifier PRSM-5. Additional rolling of the soil reduced the height of plants by another 1.7–2.3 cm. During chisel ploughing and additional pre-sowing and post-sowing soil rolling, soybean plants of the first sowing period had a height greater than when treated with the stratifier PRSM-5. At the second sowing period, there were no differences in the height and density of seedlings. At the third sowing term, plant height after chisel ploughing was 1.9 cm lower than after stratification.

Under favourable weather conditions (hydrothermal coefficient 1.46), treatment with the stratifier PRSM-5 made it possible to obtain a large assimilation leaf area of soybean crops during the first sowing period, while ploughing with the chisel plough PCh-2.5 provided an advantage for the third sowing period. The highest seed productivity (1.91–1.96 t·ha^{-1}) of soybean plants was formed after treatment with the stratifier PRSM-5 at the first sowing period and at the second sowing period after chisel ploughing with additional soil compaction.

Under dry weather conditions (hydrothermal coefficient 0.66–0.87), the leaf surface area of crops was obtained on average by 35–40% less than under favourable weather conditions. At the same time, pre-sowing treatment with the stratifier PRSM-5 had an advantage in assimilation area by 5–10% and seed productivity of 7–12% compared to ploughing with the chisel plough PCh-2.5.

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