Adaptive capacity of sugar beet under herbicide application

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Abstract. The article deals with the results of the research on phytotoxicity exerted by herbicides on plants of various sugar beet hybrids. Treatment with betanal group herbicides ensured high purity of sowing combined with low phytotoxicity for sugar beet plants in the stage with a pair of cotyledon-1 true leaves.The phytotoxicity of the herbicide was 18.0-18.6% relative to the variant with manual weeding. At the initial stages of growth, plants of F hybrids were the most resistant to the negative effects of herbicides F1 Skala, F1 Priliv and F1 Burya. After the second treatment, growth inhibition was observed in the variants using herbicides with an increase in mass deficit. The most resistant to the negative effects of herbicides was hybrid F1 Skala. For hybrids F1 Priliv and F1 Gorizont effect of the chemical stress factor was assessed as the most toxic; the weight of 100 plants increased by only 4.5-4.6% compared to the control hybrid. The phytotoxicity of the herbicide combination for sugar beet plants was significantly reduced (to 12-13%) compared to earlier herbicide treatments. High resistance after three herbicide treatments negative effects of herbicides were noted in hybrid F1 Skala. After the first chemical weeding, the amount of chlorophyll a in the leaves was one and a half times less than after manual weeding. After the second treatment with herbicides, the most intense degradation of pigments in the leaves was observed. After the third treatment in the “third pair of true leaves” phase, the plants’ resistance to chemical herbicides increased slightly.

1 Introduction

Currently, sugar beet plants are cultivated mainly in temperate countries. In the modern system of growing sugar beet plants, an important place is occupied by the protection of crops from weeds with the herbicides application. One of the factors for increasing the productivity of beet fields should be the cultivation of hybrids adapted to the soil and climatic conditions of beet-growing regions and resistant to herbicide stress. Despite the selectivity, sugar beet plants experience stress from the herbicides application, and when the concentration is forced to increase, they experience inhibition [1-7]. The consequences of stress at the biochemical and physiological levels are manifested in changes in the balance of phytohormones, as well as suppression of photosynthetic processes, which, in general, leads to changes in the physiological state of plants and the suffering symptoms

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markers. After such a sharp internal restructuring of plants, an adaptation phase begins, where the plants have to rearrange their biochemistry to overcome the stress state and return homeostasis. Sugar beet plants are most susceptible to stress from herbicides during the early growing stages. Depending on the age of plants, under the influence of herbicides, the growth of sugar beet weight lags behind, and the physiological and biochemical processes of the formation of leaves and root crops are disrupted [8]. When harvesting crops with chemical weeding, there is often a shortage of root crops in plants with well-formed leaves due to incomplete biological ripeness of sugar beet plants. The most prolonged stress on sugar beet plants is caused by inflated rates of herbicide consumption, when they are forced to be used on overgrown weeds at all levels of chemical weeding of the crop. When used systematically, especially in excessive doses, herbicides could accumulate in the environment. Intensification in herbicides application, along with increasing the efficiency of agricultural production, leads to an increase in the chemical load on crop plants and the biocenosis as a whole [9]. Therefore, the current research of phytotoxicity exerted by herbicides on crop plants is of both scientific and practical importance.

2 Materials and methods

Field research was carried out in 2021-2023 on the typical soil of the Middle Volga region - leached medium-loamy chernozem. The tank mixture of herbicides was compiled taking into account the number of weeds, their growing stage, as well as species composition. Sugar beet plants were cultivated in the fallow link of the grain-fallow crop rotation. The predecessor is winter wheat. The seeding rate is 120 thousand pcs/ha. The research was carried out in accordance with the Methodology of field experience in beet growing. Photosynthetic pigments (chlorophyll *a* and *b*) in the leaves were determined by optical density in an extract with 96% ethanol on an SF-46 spectrometer at wavelengths of 649 and 665 nm.

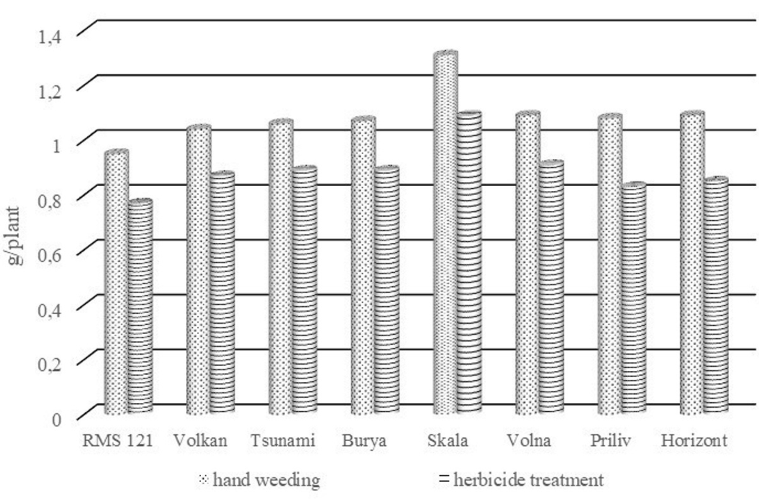
3 Results and Discussion

The first treatment of crops with herbicides was carried out during the phase of full germination of sugar beet plants. Treatment with herbicides of the betanal group ensured high purity of the crop in combination with low phytotoxicity for sugar beet plants in the stage with a pair of cotyledon-1 true leaves, regardless of the number of seedlings of crop plants during chemical weeding. Herbicides had no effect on germination of sugar beet plants lagging behind in time. Examination of the crops showed, that the first herbicide treatment of sugar beet crops brought to a stand the growth and development of weeds, which contributes to the normal development of cultivated plants in the initial phases of their growth. However, herbicides inhibit the growth of plant mass. Sugar beet plants are stressed also after the treatment, “it stops growing and developing.” At this time, adaptation mechanisms to the effects of herbicides are triggered, after which the plants resume active growth. Plant growth begins with a slow and then accelerating process of mass accumulation. Among the hybrids examined, the largest mass of plants in the initial period was characterized by F1 Skala: 6 days after the first treatment with manual weeding, the weight of 1 plant was 1.31 g, which is 38% more than that of hybrid F1 RMS 121 (Figure 1). Plant weight of hybrids F1 Volna and F1 Horizont was also over than that of the hybrid F1 RMS 121 – by 0.14 g, F1 Priliv – by 0.13 g, F1 Burya – by 0.12 g, F1 Tsunami – by 0.11 g, and for the hybrid F1 Vulkan – by 0.09 g. Average daily absolute growth rate of plants in the phase of full germination for the first examining period for hybrid F1 RMC

121 (control) was at the level of 128 g. The examined hybrids could be divided into three groups according to plant growth rate: the first group – hybrids F1 Vulkan, F1 Tsunami and F1 Burya with an absolute average daily growth rate of 140-150 g; the second group – F1 Volna, F1Priliv and F1 Horizont, weight increase by 150-155 g per day; the third group – F1 Skala, whose plants gained weight by more than 180 g per day, which is 46.9% more than the growth rate of the hybrid F1 RMS 121. The plant mass indicator characterizes the intensity of sugar beet plants growth and reflects the degree of influence of a negative factor on the processes of growth and development, which significantly reduces the vegetative mass. The weight of 100 intact sugar beet plants was 108.45 g (Table 1). The phytotoxicity of the herbicide was 18.05-18.57% relative to options with manual weeding.

Table 1. Average daily growth rate of sugar beet plants 6 days after the herbicide treatment.

Hybrid F1	Option	1st treatment	2nd treatment	3rd treatment
RMS 121 (standard)	hand weeding	0.128	1.510	3.850
	herbicide treatment	0.099	1.230	3.490
Volkan	hand weeding	0.143	1.543	4.321
	herbicide treatment	0.115	1.265	3.940
Tsunami	hand weeding	0.146	1.541	4.315
	herbicide treatment	0.118	1.259	3.926
Burya	hand weeding	0.148	1.549	4.337
	herbicide treatment	0.119	1.273	3.968
Skala	hand weeding	0.188	1.568	4.391
	herbicide treatment	0.152	1.293	4.029
Volna	hand weeding	0.151	1.557	4.360
	herbicide treatment	0.122	1.280	3.990
Priliv	hand weeding	0.150	1.553	4.349
	herbicide treatment	0.109	1.276	3.979
Horizont	hand weeding	0.152	1.552	4.346
	herbicide treatment	0.111	1.275	3.976



1st treatment

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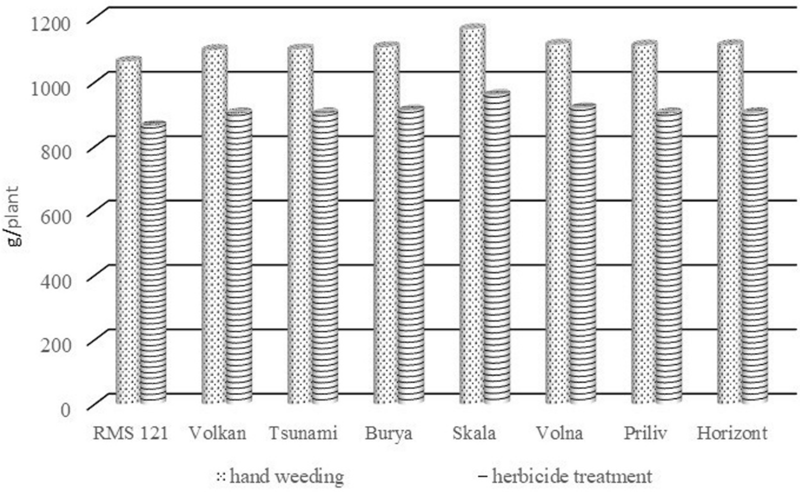
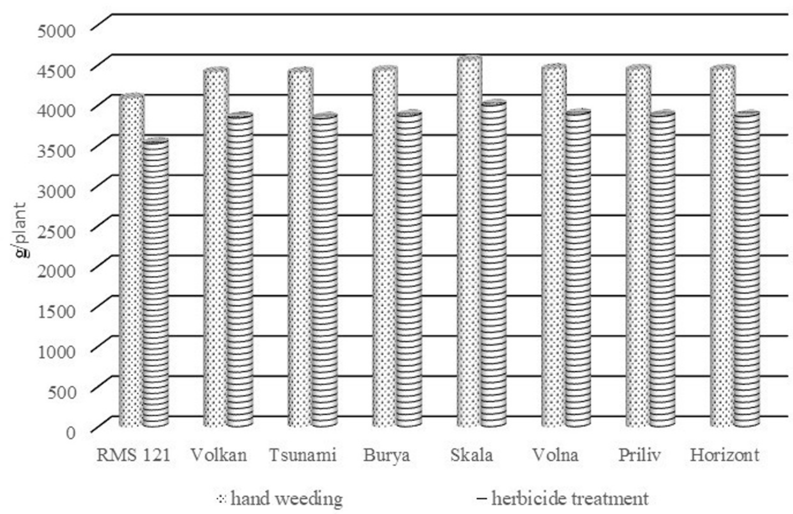


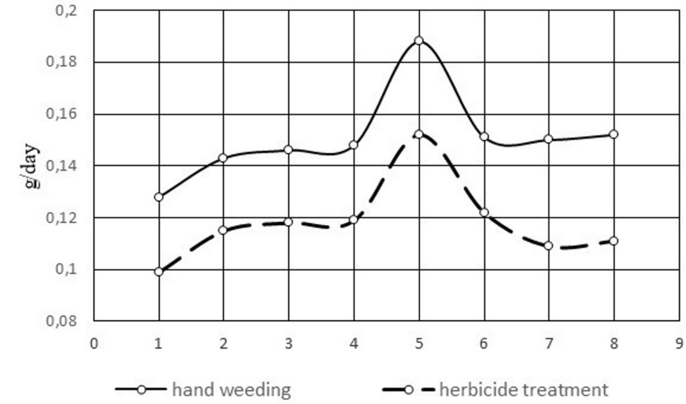
2nd treatment



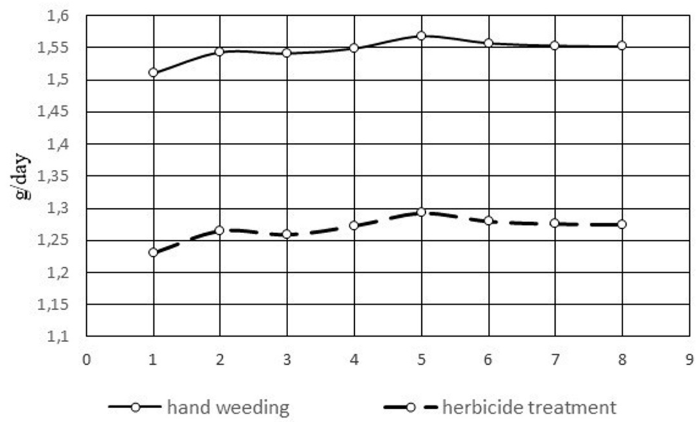
3rd treatment

Fig. 1. Weight of 1 sugar beet plant.

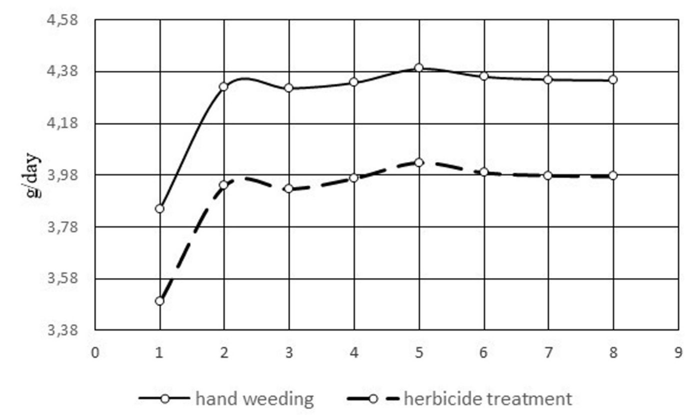
It was identified that the herbicide applied to protect sugar beet plants during the first chemical treatment had a significant inhibitory effect on the biomass growth. The average weight of one plant 6 days after the treatment with the herbicide was 0.88 g. Analysis of plant biometric data showed that the impact of the stress factor, which in this case was the herbicide, on plants of all hybrids turned out to be negative, which was expressed in a decrease in growth rate and how a consequence of a decrease in the rate of mass growth (Figure 2).



1st treatment



2nd treatment



3rd treatment

Fig. 2. daily growth rate of sugar beet plants (1 – F1 RMS 121, 2 – F1 Volkan, 3 – F1 Tsunami, 4 – F1 Burya, 5 – F1 Skala, 6 – F1 Volna, 7 – F1 Priliv, 8 – F1 Horizont).

On the control hybrid F1 RMS 121 phytotoxicity of the herbicide was 18.9%. At the initial stages of their growth, sugar beet plants of F hybrids were the most resistant to the negative effects of herbicides F1 Skala, F1 Priliv and F1 Burya, which resumed active growth successfully after the treatment with the herbicide. In the control hybrid (F1 RMS 121) the decrease in growth rates due to toxic effects was 23.3%. In the hybrids that were most resistant to the negative effects of pesticides, the decrease in the rate of weight growth was 0.028-0.029 g. It was noted that the accumulation of weight during the period of stress occurred due to the growth of successive new leaves, which were least susceptible to the influence of the stress factor.

In the second and third treatments, a herbicide was used in the mixture (Fluoron, VDG, triflusulfuron-methyl 500 g/kg), their application is due to the increased effect of betanal group herbicides on dicotyledonous weeds. The combination of herbicides applied in the second treatment not only contributed to the purifying of crops from weeds (92-99%), but also had a negative effect – phytotoxicity for sugar beets was 18.0-18.5%. In the option without the herbicides application, the largest weight of 100 sugar beet plants was obtained when growing hybrid F1 Skala was 1.166 kg. The hybrid F1 RMS 121, used in this experiment as a control, lagged behind the examined hybrids in mass accumulation by 55-101 g.

In options with the herbicide treatment, growth inhibition was observed with an increase in mass deficit compared to manual weeding, with subsequent adaptation and activation of growth processes that contributed to the restoration of the physiological functions of plants. The most resistant to the negative effects of herbicides was hybrid F1 Skala, whose biomass growth rate was 5.12% higher than the control. The second place in terms of resistance to herbicide stress was for F1 Volna and F1 Burya, the increase in the mass of 100 plants was 5.6-6.4% higher compared to the control F1 RMS 121. For F1 Priliv and F1 Horizont effect of the chemical stress factor was assessed as the most toxic; the weight of 100 plants increased by only 4.5-4.6% compared to the standard hybrid.

The biological effectiveness of the herbicide combination used was high and amounted to 94-95%. At the same time, the phytotoxicity of the herbicide combination for sugar beet plants was eventually reduced (to 12-13%) compared to earlier herbicide treatments.

The weight of 100 sugar beet plants after three herbicide treatments was 3.5-4.5 kg. Without the application of chemical treatments, the greater mass of one plant was observed in hybrid F1 Skala and exceeded the control F1 RMS 121 hybrid by 11.6%. The other hybrids examined in the current research, the intensity of accumulation was slightly lower than in hybrid F1 Skala, and 6 days after the treatment, the weight of one plant was 44.1-44.5 g.

After three herbicide treatments, the differences between the weight of intact and those exposed to the negative effects of chemical stress factors of sugar beet plants were significant, and the ability of plants to withstand the inhibitory effect of herbicides varied depending on the hybrids. Lack of mass accumulation in the standard hybrid F1 RMS 121 was 15.7% compared to manual weeding. High resistance to the negative effects of herbicides was noted in hybrid F1 Skala. Phytotoxicity of herbicides for F1 Burya and F1 Volna was 12.5-12.6%. The hybrids F1 Vulkan, F1 Tsunami, F1 Horizont and F1 Priliv were less resistant – their ability to resume active growth after herbicide stress was estimated at 87.1-87.3%.

In stress conditions caused by the influence of herbicides, the main link in the formation of biomass, and as a consequence – the crop yield, is photosynthesis and its intensity. Cultivated plants, despite the selectivity of modern herbicides, experience their negative effects, appearing during the growing season is a decrease in the intensity of photosynthesis processes. The content and ratio of different forms of pigments in chloroplasts could be observed as one of the indicators of their photochemical activity [10]. The effect of many xenobiotics on higher plants could lead to degradation of pigments, which affects the quantitative and qualitative content of pigments in plants.

It was found that the herbicide treatment had a negative effect on pigment synthesis. Thus, after the first chemical weeding, the amount of basic chlorophyll a in the leaves was, on average, one and a half times less than after manual weeding (Table 2). A decrease in chlorophyll b was also noted. During this phase of growth and development of sugar beet plants, the ratio of chlorophyll *a* to chlorophyll *b* with the herbicide treatment was 2.4, whereas with manual treatment it was more optimal – 2.7.

Table 2. Dynamics of chlorophyll under various methods of weed control.

Hybrid F1	Option	1st treatment		2nd treatment		3rd treatment	
		a	*b*	*a*	*b*	*a*	*b*
RMS 121 (standard)	hand weeding	0.639	0.239	0.583	0.331	0.785	0.595
	herbicide treatment	0.418	0.156	0.155	0.094	0.308	0.279
Volkan	hand weeding	0.925	0.346	0.844	0.478	1.136	0.861
	herbicide treatment	0.605	0.226	0.224	0.136	0.446	0.404
Tsunami	hand weeding	0.701	0.262	0.639	0.363	0.861	0.653
	herbicide treatment	0.459	0.171	0.170	0.103	0.338	0.306
Burya	hand weeding	0.650	0.243	0.592	0.336	0.797	0.604
	herbicide treatment	0.425	0.158	0.158	0.095	0.313	0.284
Skala	hand weeding	0.812	0.303	0.740	0.420	0.997	0.755
	herbicide treatment	0.531	0.198	0.197	0.119	0.392	0.355
Volna	hand weeding	0.660	0.247	0.601	0.341	0.810	0.614
	herbicide treatment	0.432	0.161	0.160	0.097	0,318	0.288
Priliv	hand weeding	0.755	0.282	0.688	0.390	0.926	0.702
	herbicide treatment	0.494	0.184	0.183	0.111	0.364	0.330
Horizont	hand weeding	0.839	0.314	0.765	0.434	1.030	0.781
	herbicide treatment	0.549	0.205	0.203	0.123	0.405	0.366

After the second treatment, a slight decrease in the accumulation of photosynthetic pigments was noted with all methods of combating the weed component. Compared to the first treatment, the amount of chlorophyll *a* decreased on average in hybrids by 9.6%, and chlorophyll *b* by 2.7%. During this phase of growth of the sugar beet plant under stress conditions caused by the action of herbicides, the most intense degradation of pigments in the leaves was noted. Thus, after the chemical weeding, the accumulation of chlorophyll *a* was 3.8 times less than during manual weeding. Chlorophyll *b* turned out to be slightly more stable, the amount of which decreased by 3.5 times under conditions of chemical stress. In all hybrids, during manual weeding, more chlorophyll *a* accumulated relative to chlorophyll *b* (ratio 1.76:1), whereas with the herbicide treatment it was 1.61:1. This could indirectly indicate a greater activity of the photosynthesis process without the herbicide treatment.

The gained results showed that after the third treatment in the "third pair of true leaves" stage, the accumulation of photosynthetic pigments in the leaves increased significantly compared to the previous determination. Plant resistance to chemical herbicides increased slightly during this growth phase. Thus, compared to manual weeding, the content of chlorophyll *a* in the leaves decreased only by 2.5 times, and chlorophyll *b* by 2.1 times. When treated with herbicides, the ratio of chlorophyll *a* to chlorophyll *b* became narrower (1.10: 1) compared to manual weeding, and on a herbicide-free background it was 1.32:1.

4 Conclusion

Thus, the inhibition of weight gained in sugar beet hybrids largely depended on the stage of the plants and the herbicide application on them. The negative reaction of sugar beet plants to herbicides applied at regulated application rates is the most significant in the cotyledon phase – the first pair of true leaves, and with an increase in the mass of cultivated plants, the negative effect of herbicides decreases. The phytotoxicity of herbicides for the plants of the examined hybrids was noted to various extents. The duration of plant depression was shorter in F1 Skala and F1 Volna. After three herbicide treatments, the largest weight of one plant was observed in F1 Skala and F1 Volna.

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