Agroecological techniques for protecting soybean crops from phytopathogens

A G Tishkova

Far Eastern Agriculture Research Institute, Vostochnoe, 680521 Khabarovsk, Russia
E-mail: Betula2717@mail.ru

Abstract. The aim of this research was to study the influence of biofungicides and growth regulators on protecting soybean crops from fungal diseases, allowing the production of environmentally friendly and high-quality products. The main pathogens of soy diseases in the Khabarovsk territory are root rot and leaf-stem infections. The means of protection applied in this study reduced the intensity of development of these diseases. The greatest biological effectiveness against root rot was found when the drugs Zircon, Bisolbifit and Tetramethylthiuram Disulfide (TMTD) with Optimo were used. The use of Zircon, Extrasol and Nutri-Phite with water softener Spartan reduced the infection of soy plants with leaf-stem diseases. With these protection systems, the yield level ranged from 3.62 to 3.88 t/ha.

1. Introduction
Soybean (Glycine max L. (Merr)), the most popular legume crop in the world, is a source of protein and oil [1–4]. Currently, fungal diseases are among the most significant factors that hinder the increase in soybean yields. The greatest crop losses in the region are caused by root rot pathogens, which are mainly fungi of the genus Fusarium, Rhizoctonia and Aphanomyces, Septoria (Septoria glycines Hemmi.), peronospora (Peronospora manshurica [Naum]. Syd), Cercospora (Cercospora sojina Hara. and Cercospora kikuchii T. Matsu. et Tomoyasu) and ascocytta (Ascochyta sojaecola Abramoff) [4–7]. Soy grain processing products are used for food, feed, medical and other purposes [4, 6].

Adaptive technology of soybean cultivation has prioritised the biological method. Biofungicides and growth regulators effectively increase plant resistance to diseases, accelerate plant growth and development, increase yields by 20–30 %, reduce crop losses during storage, promote wound healing when plants are damaged by insects, increase plant resistance to adverse weather conditions, are cost-effective and improve the overall environmental situation [8–10]. Therefore, there is a need to develop environmentally safe systems for protecting crops from fungal diseases. The purpose of this research is to develop methods of adaptive technology to protect soybean plants from phytopathogens and enhance potential soybean productivity.

2. Materials and methods
The research was carried out in 2015–2017 in the crop rotation (grain crop, soybean) of the Department of Selection and Seed Production of Field Crops of the Far Eastern Institute of Agricultural Research, following a field experience method [11]. The soil of the experimental plots is meadow-brown, heavy loam, humus content 4.8 mg /100 g of soil (according to Tyurin); 4.3 mg of
P₂O₅/100 g of soil (according to Kirsanov); and 20 mg/100 g of soil K₂O₅ content (according to Maslov). At the experimental site, soy was sown in early June at the rate of 300,000 Rast./ha (70 kg/ha of seeds) in moist well-cut soil to a depth of 3–4 cm on a profiled surface (140 cm ridges). The area of the assessed plot is 50 m², the repetition is four times and the placement of options in the experiment is randomised. The agricultural equipment is generally accepted for the conditions of the Khabarovsk territory. Records and observations were made according to current methods [12,13]. To determine the biological yield and crop structure, all the assessed plots were cleaned manually, with subsequent analysis in the laboratory. The processing of the obtained data was conducted using dispersion analysis. The final statistical indicator in the method of variance analysis is the least significant difference (LSD). LSD is calculated based on absolute (for soybean yield in tons per 1 ha) and relative (in %) indicators.

The research focused on the following objects: the soybean variety Ivan Karamanov, a chemical grain mordant Tetramethylthiuram Disulfide (TMTD) (tiram, 400 g/l); biological agents Immunocytophyte (arachidonic acid ethyl ether 20 g/kg); Zircon (hydroxycoric acid 0.1 g/l); Bisolbiphite (strain of rhizospheric bacteria Bacillus subtilis H-13, 100 million CFU/ml); Extrasol (strain of rhizospheric bacteria Bacillus subtilis H-13, 100 million CFU/ml); liquid leaf fertilizer Nutri-Phite (phosphorus 28%, P₂O₅ in the form of phosphite = PO₃] and potassium 26% [K₂O]) with water softener Spartan; liquid humic fertilizer; and the chemical fungicide Optimo (pyraclostrobin, 200 g/l).

Drugs were applied by seed treatment (10 l of working solution per 1 ton of seed) and spraying plants during vegetation with a maximum flow of 200 l/ha. In the control version, the seeds were treated with water a day before sowing.

3. Results and Discussion

During the years of research, the hydrothermal conditions differed significantly, which made it possible to study with greater confidence the effect of the drugs on the productive indicators of soy and on the crops’ resulting resistance to pathogens.

During the first growing season of 2015, the agrometeorological conditions were unfavourable to the growth and development of soybean seedlings due to cold and rainy weather. Heat supply during this period was insufficient. The plants lagged in growth, no soy branches were detected, and, in the second half of July, the first flowers formed in the axils of the lower leaves. After the fall of 72.2 mm of precipitation (13–14 July), strong waterlogging of the soil was observed, which led to the waterlogging of the soil, of its upper layer and the lodging of plants. This created a stressful situation for the growth and development of the soy.

The hydrothermal conditions in 2016 were close to the long-term average, but they were not evenly distributed during the growing season. In June, the amplitude of fluctuations between day and night air temperatures was 16.5–20.5°C. A sharp drop in night air temperatures was noted in late June, which negatively impacted on the soybean plants’ rate of development, as the heat was insufficient. Due to difficult weather conditions in May (16 days with rain intensity from 0.2 to 23 mm), the top layer of soil was compacted, making it difficult to prepare. Hence, sowing was carried out only on 6 June, so the interphase period of ‘sowing full shoots’ was two days longer than in 2015. However, in general, the duration of the growing season in 2016 was two days less than in 2015, since it was reduced by late sowing periods.

The agro-climatic conditions in 2017 were favourable for the seed germination, emergence, growth and development of soybean plants. In late July, the weather grew colder, with daytime air temperatures dropping to 17°C and soil temperatures to 8°C, and heavy precipitation caused excessive soil moisture. The formation and maturation of the crop took place with sufficient provision of heat and moisture to the plants.

Root rot infects soybean plants in the germination phase through the root system and then colonises the vascular and cortical tissues of the plant, preventing the movement of nutrients [14]. The annual development of root rot in the Khabarovsk territory is observed in 80–100% of plants with an intensity
of up to 20% on average and up to 40% maximum. In the experiment during the bean formation phase, the maximum degree of root rot development in the control variant, as averaged over three years, was more than 40%. The soybeans were protected most effectively with the application of Zircon, Bisolbifit and TMTD with Optimo, with a biological efficiency of 33%, 29.8% and 28.8%, respectively.

It is known that hydrothermal conditions, especially precipitation, serve as a ‘trigger’ for the mass development of leaf-stem infections. During the years that this research was conducted, favourable weather conditions occurred for the development of peronosporosis and Septoria on soy plants; the first signs of leaf-stem infections appeared in early August. Mass development occurred from late August to early September. During this period, the degree of development of peronosporosis and Septoria were more than 20% and approximately 19%, respectively, averaged over three years. The best protective properties against leaf-stem diseases were exhibited plants prepared with Zircon, Extrasol and Nutri-Phite with water softener Spartan. In these variants, the intensity of peronosporosis and Septoria development decreased by 38.0–44.7% and 32.8–47.6%, respectively.

Table 1. Impact of protective measures on soybean yield indicators, t/ha, average over three years.

| Variant | Weight of 1000 seed, g | Biological yield, t/ha | Increase in control, t/ha |
|---------|-----------------------|------------------------|--------------------------|
| 1. Control (without treatments) | 164.5 | 2.68 | 0.00 |
| 2. Reference – TMTD | 166.7 | 2.86 | 0.18 |
| 3. TMTD + Immunocytophyte | 172.1 | 3.12 | 0.44 |
| 4. Immunocytophyte | 169.7 | 3.02 | 0.34 |
| 5. Nutri-Phite with water softener Spartan | 175.2 | 3.62 | 0.94 |
| 6. Zircon | 173.6 | 3.88 | 1.20 |
| 7. Bisolbiphite | 170.1 | 3.18 | 0.50 |
| 8. Extrasol | 179.6 | 3.71 | 1.03 |
| 9. Liquid humic fertilizer | 172.6 | 3.13 | 0.45 |
| 10. TMTD + Optimo | 177.4 | 3.48 | 0.80 |
| LSD 0.5 | 12.9 | 0.42 |  

The studied means of protection combined fungicidal properties with growth-regulating and antistressful activity, which had a positive effect on the structural elements of yield and productivity (table 1). Analysis of the soybean variety’s productive qualities in various hydrothermal conditions showed that a significant increase in yield, compared to the untreated plants, was obtained using the following drugs: Zircon at 1.2 t/ha, Extrasol at 1.03 t/ha and Nutri-Phite with water softener Spartan at 0.94 t/ha.

4. Conclusion
In the hydrothermal conditions of the Khabarovsk territory, the studied means of protection, combining fungicidal properties with growth-regulating and antistress activity, positively enhanced the productive qualities of the Ivan Karamanov soybean variety. The most effective approaches in the fight against root rot were treating seeds pre-sowing and subsequently crops in the flowering phase with Zircon and Bisolbiphite, as well as treating seeds with TMTD and vegetating plants with Optimo in the flowering phase. The biological efficiency was 33%, 29.8% and 28.8%, respectively.

Concerning the development of Septoria and peronosporosis, the most effective approach was the pre-sowing seed treatment and processing soy plants in the flowering phase with Zircon and Extrasol. The treatment of seeds and vegetating plants with Zircon, Nutri-Phite with water softener Spartan and Extrasol caused a significant increase in soybean yield compared to the control crop, with the yield levels increasing by 44.8%, 38.4% and 35.1%, respectively, in relation to the control variant.
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