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Effect of Herbicide and Biostimulants on Production and Economic Results of Edible Potato

Agnieszka Ginter *, Krystyna Zarzecka and Marek Gugała

Institute of Agriculture and Horticulture, Siedlce University of Natural Sciences and Humanities, Prusa Street 14, 08-110 Siedlce, Poland; krystyna.zarzecka@uph.edu.pl (K.Z.); marek.gugala@uph.edu.pl (M.G.)
* Correspondence: agnieszka.ginter@uph.edu.pl

Abstract: In modern agriculture, preparations qualified as biostimulants are used alongside pesticides. They influence the development of plants and enable a yield-forming effect. An important feature of these preparations is that they are safe for the environment. They can be treated as substitutes for plant protection agents, which is especially important in the era of implementation of the European Green Deal, ordering the reduction of chemicalization of agriculture. The purpose of this paper was to compare the production and economic results of five methods of plantation care in *Solanum tuberosum* cultivation: on the first object (control), mechanical cultivation was used, and on the second, object the herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$), on object three, the herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and the biostimulant PlonoStart (2.0 $dm^3 \cdot ha^{-1}$), on object four, the herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and biostimulant Aminoplant (1.5 $dm^3 \cdot ha^{-1}$), and on object five, the herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and biostimulant Agro-Sorb Folium (4.0 $dm^3 \cdot ha^{-1}$). The research was conducted from 2018 to 2020 at the Agricultural Experimental Station in Zawady, central-eastern Poland. The results were analyzed, on average, for two Polish edible potato cultivars (Malaga and Oberon), and three years of study (2018–2020) were taken into consideration. The experiment was established as a two-factor experiment in three replicates on light soil in a spit-plot arrangement. A beneficial effect of herbicides and biostimulants on the yield and profitability of edible potato production was observed. An average increase of 33.2% in marketable yield was obtained. The gross margin increased by an average of 49.3%. The highest total yield, as compared to the control object, was obtained from object 5, where the herbicide Avatar 293 ZC with biostimulant Agro-Sorb Folium was applied, such as the greatest economic effect was achieved also in object no. 5. Application of this biostimulant was most beneficial.

Keywords: edible potato; plantation protection; yield; production costs; profitability

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1. Introduction

According to the Central Statistical Office, in the year 2020, the area under potato cultivation in Poland is estimated to be about 0.3 million hectares and the harvest is estimated to be about 9.0 million tonnes, which is 40.0% more compared to 2019 [1]. Potatoes are one of the most important crops in the world [2]. In the agriculture of the 21st century, there is a professionalization of potato cultivation technology, which results in an increase in potato yield. The costs of potato protection against weeds are a special kind of direct production cost. Apart from fungicides, herbicides, and insecticides, biostimulants are used more and more frequently. It is estimated that the value of the biostimulant market in the next few years will be increasing; therefore, the utilitarian purpose of scientific research using these preparations should be emphasized. In modern plant cultivation, biostimulants are one of the elements of agrotechnology that in addition to fertilization and plant protection, can positively affect the yield and quality [3]. Potatoes require many treatments, carefully selected according to the condition and degree of weeds, which guarantee the profitability of production. It should be reminded or emphasized that

Solanum tuberosum tubers are rich in vitamin C [4]. Potatoes are low in calories and have high nutritional, dietary, and health value. Potatoes have a beneficial effect on human health [5]. The key element of agrotechnology affecting high yields of good quality is to provide plants with appropriate development conditions thanks to regulators available on the market that affect plant growth, including biostimulants [6] or bacterial vaccines [7]. These products containing bioactive molecules have a beneficial effect on plants and improve their capability to face adverse environmental conditions [8]. An important element in agrotechnics is the maintenance of plantations against weeds. Chemical methods of weed control are more effective than mechanical [9]. The use of plant biostimulants, such as amido acids and micro-organism, could be of great help to farmers [10]. Biostimulants are among the natural preparations that improve the general health, vitality, and growth of plants and protect them against infections. They can be successfully used in both agri- and horticultural crops [11]. The aim of the conducted studies was to compare the production and economic results of five methods of potato plant care in the example of Polish edible cultivars Malaga and Oberon. On the first object (control), mechanical cultivation was used; on the second object, the herbicide Avatar 293 ZC; on object three, the herbicide Avatar 293 ZC and the biostimulant PlonoStart; on object four, the herbicide Avatar 293 ZC and biostimulant Aminoplant; on object five, the herbicide Avatar 293 ZC and biostimulant Agro-Sorb Folium. This paper attempts to highlight the importance of using biostimulants in innovative agricultural agrotechnology by analyzing results, which are very important to potato producers. Both cultivars enjoy exceptionally good and delicate tastes in general culinary types, and for that reason, selection of cultivars for the study should be considered proper from the consumer's point of view, and different ways of plantation care are important for the producer.

2. Materials and Methods

The material for the study consisted of tubers of Polish *Solanum tuberosum* cultivars (Malaga and Oberon). Malaga was included in the Polish National List of Agricultural Plant Varieties on 5 March 2013 and Oberon on 9 February 2012 [12]. The field experiment was conducted from 2018 to 2020 at the Agricultural Experimental Station in Zawady of the Siedlce University of Natural Sciences and Humanities. The study was conducted in triplicate using the method of randomized sub-blocks (split-plot). In the calculations, the average values for two cultivars (Malaga and Oberon) and three study years (2018–2020) were taken into account. The forecrop was winter × *Triticale rimpaui*. The soil was analyzed in each year of the study. Differences were recorded in soil pH 5.25–5.42 (in KCl), in organic matter content 20.9–22.3 g·kg^{-1} and in assimilability in macronutrients in the following mg·kg^{-1}: phosphorus-35.2–71.0, potassium-102.1–149.0, and magnesium-36.6–61.0. The applied fertilization level in all plots did not differ. Manure fertilization was applied in the autumn at a rate of 25.0 t·ha^{-1}. Mineral fertilizers were applied at the following rates: phosphorus-44.0 kg·ha^{-1} and potassium-124.5 kg·ha^{-1} and plowed in the autumn, and nitrogen-100.0 kg·ha^{-1} was applied in the spring. Tubers were planted in the third decade of April. Different mechanical-chemical treatments against weeds were applied in the field experiment and compared with the control where only mechanical treatment was applied. Both before and after potato emergence on the control object (1), double edging was performed. Moreover, this treatment in combination with harrowing was performed once before emergence. Herbicide and biostimulants were applied to the remaining objects weeded mechanically and chemically (2–5). Before potato emergence, double harrowing was performed, and immediately after the second one, about 7 days before plant emergence (phase BBCH 00–08), Avatar 293 ZC herbicide was applied (clomazone and metribuzine are active substances of the preparation) at a dose of 1.5 dm^3·ha^{-1}. On plots 3–5, after emergence, different methods of weed control were applied, including three biostimulants applied at two time intervals. On the object 3. apart from the herbicide, PlonoStart 2.0 dm^3·ha^{-1} was applied, the first dose of 1.0 dm^3·ha^{-1} at full emergence (phase BBCH 13–19), and the second 1.0 dm^3·ha^{-1} at the time of 10–50% row cover (phase BBCH 31–35).

On the object 4. biostimulant Aminoplant 1.5 $dm^3 \cdot ha^{-1}$ was applied, the first dose of 1.0 $dm^3 \cdot ha^{-1}$ at the full end of emergence (phase BBCH 13–19), and the second one of 0.5 $dm^3 \cdot ha^{-1}$ at the time of covering the rows in 10–50% (phase BBCH 31–35). On the last research object (object 5), Avatar 293 ZC was also applied, and the biostimulant Agro-Sorb Folium 4.0 $dm^3 \cdot ha^{-1}$. The first and the second dose were applied in the same amounts, i.e., 2.0 $dm^3 \cdot ha^{-1}$ each, at the same plant development stages as in objects 3. and 4. It should be added that the herbicide and the biostimulants were dissolved in 300 dm^3 of water per area unit (per 1 hectare). When selecting the herbicide for the research, the recommendations of the Institute of Plant Protection–National Research Institute were taken into account, and the herbicide was adjusted to the weed infestation status of the plantation. Biostimulant Aminoplant is as follows: contained 9.48% nitrogen, 9.2% amide nitrogen, 11.57% free amino acids, and 87.7% organic matter. Agro-Sorb Folium 2.2% nitrogen, 0.02% manganese, 0.09% zinc, 13.11% total amino acids, of which free 10.66%. PlonoStart is a compilation of minerals with the addition of urea and microorganisms in the form of lactic acidifying bacteria and actinomycetes (Table 1).

Table 1. Herbicide and herbicide with biostimulants–description.

Trade Name	Active Substance/Chemical Combination	Dose	Usage
1. Control object	Mechanical care	-	-
2. Herbicide Avatar 293 ZC	Clomazone and metribuzine	1.5 $dm^3 \cdot ha^{-1}$	BBCCH 00-08
3. Herbicide Avatar 293 ZC and PlonoStart	Clomazone and metribuzune and N_{total}-16.4%, K_2O-0.75%, Cao-0.07%, MnO-0.02%, S-941 $mg \cdot kg^{-1}$, lactic acid bacteria, actinomycetes	1.5 $dm^3 \cdot ha^{-1}$ and 2.0 $dm^3 \cdot ha^{-1}$	BBCCH 13-19 and BBCCH 31-35
4. Herbicide Avatar 293 ZC and Aminoplant	Clomazone and metribuzine and N_{total}-9.48%, N-9.2%, N_NH_4-0.88%, $C_{organic}$-25%, free amino acids-11.57%, organic matter-87.7%	1.5 $dm^3 \cdot ha^{-1}$ and 1.5 $dm^3 \cdot ha^{-1}$	BBCCH 13-19 and BBCCH 31-35
5. Herbicide Avatar 293 ZC and Agro-Sorb Folium	Clomazone and mteribuzine and N_{total}-2.2%, B-0.02%, Mn-0.05%, Zn-0.09%, tatal aminoacids-13.11%, free amino acids-10.66%	1.5 $dm^3 \cdot ha^{-1}$ and 4.0 $dm^3 \cdot ha^{-1}$	BBCCH 13-19 and BBCCH 31-35

During the vegetation period the following insecticides were used: Actara 25 WG (htiametoxam)—0.08 $kg \cdot ha^{-1}$, Decis Mega 50 EW (deltamethrin) 0.15 $dm^3 \cdot ha^{-1}$, Karate Zeon 050 CS (lambda-cyhalothrin) 0.25 $dm^3 \cdot ha^{-1}$, Proteus 110 OD-0.4 $dm^3 \cdot ha^{-1}$ (thiachloprid, deltamethrin) and fungicides: Ridomil Gold MZ 68 WG (metalaxyl-M and mencozeb-2.0 $kg \cdot ha^{-1}$) and Dithane Neo Tec 75 WG (mencozeb)-2.5 $kg \cdot ha^{-1}$. In the first decade of September tubers were harvested and their weight from each plot was determined, and then the yield per 1 hectare was calculated. Moreover, the sample of tubers was taken (10 kilos) to determine the yield structure. Just before potato harvest, each plot was randomly sampled (10 potato plants were dug). Tubers with diameters $\geq$35 mm and without external and internal defects were considered marketable yield. Marketable quality traits important in the preparation of goods for trade (packaging) include tuber size [13]. Defective tubers with visible external defects, potatoes with internal defects, and tubers below 35 mm were qualified as by-product yield. The cost and production values were calculated based on current prices from each year of the study. The group of production effects included the total, marketable, and by-product yield, while the gross margin was the economic effect according to the methodology presented in the paper by Zię tara [14]. Gross margin (without subsidies) is the value of production less direct costs. Production value is the sum of primary and secondary production and direct costs are those which are incurred for its production. The income category chosen is of fundamental importance in cost accounting on European Union farms.

The results of the three-year study were subjected to analysis of variance and the significance of differences between the means was determined by the Tukey test at the significance level of $p \leq 0.05$.

3. Results and Discussion

3.1. Production Results

For each agricultural producer, one of the most important production effects of cultivated crops is the yield level achieved. Field experiments have shown that edible potato protection methods significantly affected the total, marketable, and by-product yields of edible potato tubers (Table 2).

Table 2. Potato yield on average for two cultivars (Malaga and Oberon) and three study years (2018–2020).

Methods of Application Herbicide with Biostimulants	Yield Potato ($t \cdot ha^{-1}$)		
	Total	**Marketable**	**By-Product**
1. Control object—mechanical weeding	31.2c	24.4d	6.8a
2. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$)	34.7b	29.3c	5.4b
3. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and PlonoStart (2.0 $dm^3 \cdot ha^{-1}$)	37.8ab	33.2b	4.6bc
4. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and Aminoplant (1.5 $dm^3 \cdot ha^{-1}$)	36.1b	31.0bc	5.1bc
5. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and Agro-Sorb Folium (4.0 $dm^3 \cdot ha^{-1}$)	40.7a	36.5a	4.2c
Average for objects 2–5	37.3	32.5	4.8
NIR statistic $p \leq 0.05$	3.2	2.8	0.9

Means (standard error) followed by different letters are significantly different within the analysed variable ($p \leq 0.05$).

The highest total yield, as compared to the control object, was obtained from object 5, where the herbicide Avatar 293 ZC with biostimulant Agro-Sorb Folium was applied. The analysis of variance showed that it was significantly higher than in objects 2 and 4 and did not differ significantly from object 3. The total yield from objects 2, 3, and 4 was smaller but totally differentiated. The highest marketable yield from object 5 differed significantly from the yield from the control object as well as from the yields of the other objects. The lowest by-product yield was obtained after herbicide application with Agro-Sorb Folium (object 5). Its differences were found to be significant as compared with the yields obtained on objects 1 and 2. The by-product yields from objects 2–4 did not differ significantly. Obtaining an increasing share of marketable yield in the total yield that meets the requirements of consumers is a desirable production effect for any market-oriented producer (Figure 1).

The positive effect of biostimulants in plant breeding is the subject of scientific studies. Biostimulant BrownBio Gold significantly increased the total yield and proportion of large tubers of edible potatoes compared to the control object [15]. Under the influence of the tested biostimulators Krzemian and Naturamin Plus, a significant increase in potato yield was obtained [16]. Biostimulators positively influence the increase in the yield of oilseed rape [17]. Biostimulants allow increasing the efficiency of the use of production factors and reducing the negative impact on the environment [18]. Aminoacidic biostimulants are one of the new proposals for increasing yield efficiency [19]. In spite of the fact that plant protection is not a yield-creating factor but only limits the negative impact of agrophages, the results of experiments allow confirming that in combination with biostimulants it is possible to obtain a positive production effect. Application of biostimulants increased potato shoot [20]. Biostimulants play an important role in modern agricultural management [21]. Agronomic practices should be improved. For example, nutrient management and foliar application of plant growth regulators can be used during prolonged droughts [22]. Bearing in mind that droughts in Poland have been recurring more and more frequently in recent years, research using preparations that mitigate the negative impact on their development under such weather conditions is of particular importance.

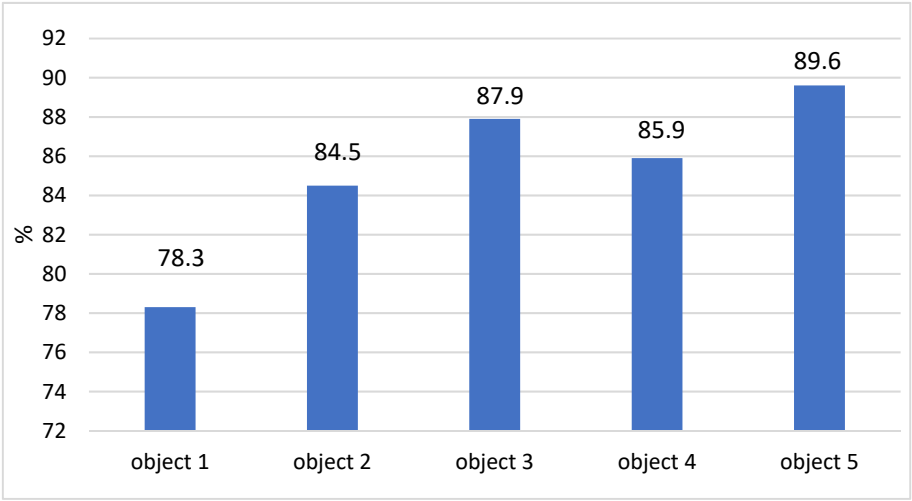

Figure 1. Share (%) of the marketable yield in the total yield on average for two cultivars (Malaga and Oberon) and three study years (2018–2020).

3.2. Economic Results

The use of these preparations generates higher production costs, which directly affect the profitability of agricultural production. The highest cost of plantation protection in comparison with other objects was recorded in the case of the 5th object (Figure 2). They amounted to almost 427 euros per hectare.

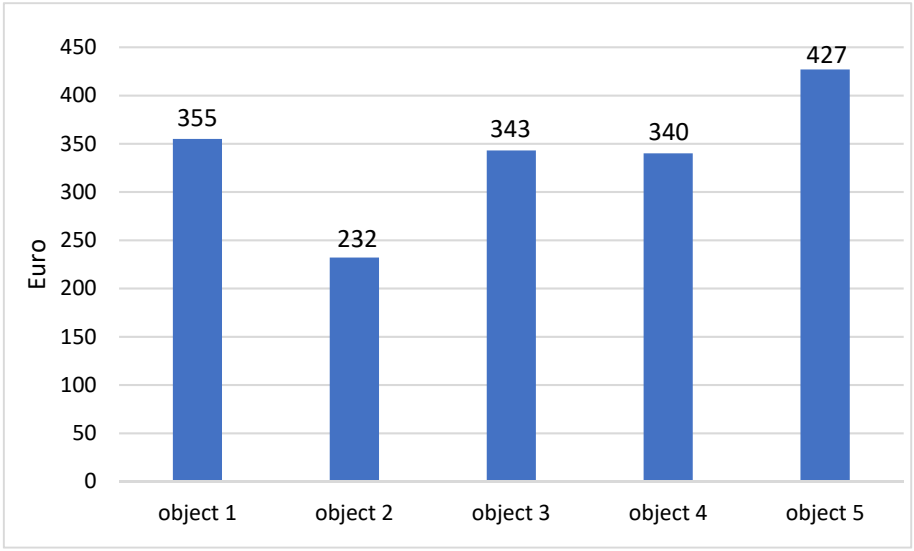

Figure 2. Potato protection costs (Euro·ha^{-1}) on average for two cultivars (Malaga and Oberon) and three study years (2018–2020).

The costs of plantation protection against weeds are the basic type of direct cost of plant production, including potato production. In agricultural economics, direct costs are distinguished by a criterion referred to as the place where the costs arise. Cost accounting is a system providing information about costs [23]. It is indispensable in every farming unit [24]. Production costs belong to the basic economic categories in an agricultural holding [25]. Their level should be the subject of analysis, but also of planning and control.

The cost of plantation protection was determined mainly by the cost of applied biostimulants, herbicides, and treatments [26]. The cost of potato protection against weeds depends mainly on the number of mechanical and chemical means as well as on the prices of herbicides and biostimulants.

Analyzing the direct costs (Table 3) of edible potato production, it was found that the purchase of certified seed potatoes accounted for the largest share, ranging from 32.8% (object 5) to 34.7% (object 2). Seeds and fertilizers were the main part of edible potato production costs [27]. The use of qualified seed material in agriculture determines the obtaining of a higher yield with better quality parameters [28]. In the structure of the costs incurred, the costs of seed potatoes had the largest share (34.5%), natural fertilizers (11.9%), then the costs of plant pesticides (6.1%), and mineral fertilizers (5.6%) [29]. A characteristic feature of root crop cultivation is its high labor intensity, which, however, largely depends on applied technologies [30]. The major cost was labor cost [31].

Table 3. Direct cost structure (%) of potato production on average for two cultivars (Malaga and Oberon) and three study years (2018–2020).

Cost Type	Methods of Application Herbicide with Biostimulants				
	1. Control Object	**2. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$)**	**3. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and PlonoStart (2.0 $dm^3 \cdot ha^{-1}$)**	**4. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and Aminoplant (1.5 $dm^3 \cdot ha^{-1}$)**	**5. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and Agro-Sorb Folium (4.0 $dm^3 \cdot ha^{-1}$)**
Seed potatoes	33.5	34.7	33.6	33.7	32.8
Natural fertilizer–manure	12.5	12.9	12.6	12.6	12.3
Mineral feritilzers	8.8	9.1	8.9	8.9	8.7
Plant protecion products and biostimulants	4.9	6.7	6.9	6.9	9.1
Human work	9.2	8.7	8.7	8.8	8.0
Equipment operation	31.1	27.9	29.2	29.1	29.1
Total direct costs	100.0	100.0	100.0	100.0	100.0

Direct costs are the costs that can be precisely assigned to the produced output. The highest value of potato production, constituting the sum of the main and side production, was found in object 5. (Table 4). In comparison with the control object, it was higher by about 30.0%.

Table 4. Potato production value and gross margin (Euro·ha^{-1}) on average for two cultivars (Malaga and Oberon) and three study years (2018–2020).

Specification	Methods of Application Herbicide with Biostimulants				
	1. Control Object	**2. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$)**	**3. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and PlonoStart (2.0 $dm^3 \cdot ha^{-1}$)**	**4. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and Aminoplant (1.5 $dm^3 \cdot ha^{-1}$)**	**5. Herbicide Avatar 293 ZC (1.5 $dm^3 \cdot ha^{-1}$) and Agro-Sorb Folium (4.0 $dm^3 \cdot ha^{-1}$)**
Marketable yield value	3893	4672	5294	4947	5811
By-product yield value	1079	856	730	808	674
Total production value	4972	5528	6024	5755	6485
Gross margin	2013	2671	3075	2809	3467

The calculated gross margin showed the profitability of edible potato production. The obtained values from particular ways of herbicide and herbicide application with biostimulants, as compared to the control object, reflected the economic justification of their use. The greatest economic effect was achieved in object no. 5—the application of Avatar 293 ZC herbicide with Agro-Sorb Folium biostimulant. A smaller gross margin (by 12.0%) was obtained as a result of the application of Avatar 293 ZC with the biostimulant PlonoStart (object 3). Application of herbicide with Aminoplant biostimulant (object 4) generated production profitability at the level of 2809 Euro ha^{-1}. The profitability of edible potato production is analyzed in scientific works. Despite relatively high costs incurred for potato protection against weeds, the combination of herbicide with biostimulants was profitable [26]. The profitability of edible potato production was generally high [32]. The calculated gross margin indicates that Bellarosa edible potato cultivation in 2015–2016 was profitable [33]. Proper allocation of inputs and available resources increased the profitability of potato cultivation [34]. Studies of edible potatoes prove that their cultivation is profitable; it is at a relatively high level [35]. The profitability analysis of potato cultivation indicated that potatoes were an attractive crop [36]. The field experiment conducted is an incentive for agricultural producers to produce edible potatoes. As research shows, it is a profitable crop, and combining chemical control with biostimulants is conducive to increasing it.

4. Conclusions

Research conducted at the Agricultural Experimental Station in Zawady at the Siedlce University of Life Sciences and Humanities on the effectiveness of plant protection inputs allowed for the following conclusions: Herbicide application with biostimulants had a positive effect on the production results of edible potatoes. It was observed that the total yield increased from 31.2 t to 40.7 $t \cdot ha^{-1}$ and the share of marketable yield in the total yield increased from 78.3% to 89.6%. The cost of edible potato protection, depending on the method of herbicide application with biostimulants varied. The highest costs were incurred on object no. 5, where Avatar 293 ZC was applied with biostimulant Agro-Sorb Folium. The calculated gross margin indicated that the application of Avatar 293 ZC herbicide with biostimulants was cost-effective, and the combination with Agro-Sorb Folium was the most economical. Along with fungicides, herbicides, and insecticides, biostimulants should be a permanent part of agricultural crop technology and can be viewed as a yield-enhancing agent. In a food potato plantation, their combination with weed control should be recommended.

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