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The Positive Effects of Mechanical and Chemical Treatments with the Application of Biostimulants in the Cultivation of *Solanum tuberosum* L.

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Abstract: The aim of the study was to determine the effect of mechanical and chemical treatments with the application of biostimulants on the effectiveness of weed infestation reduction and potato yielding. A three-year field research study was conducted at the Agricultural Experimental Station Zawady (52°03′ N; 22°33′ E). The field experiment was set up in a split-plot design with three replicates. The first factor was the two edible potato cultivars, and the second was five methods of mechanical and chemical treatments with biostimulants: (1) control object—mechanical weeding, (2) the herbicide Avatar 293 ZC (clomazone + metribuzin), (3) the herbicide Avatar 293 ZC and the biostimulant PlonoStart, (4) the herbicide Avatar 293 ZC and the biostimulant Aminoplant, (5) the herbicide Avatar 293 ZC and the biostimulant Agro-Sorb Folium. Before emergence, the control object was double ridging and single ridging with harrowing and double ridging after emergence. On other objects (2–5) before emergence, two ridgings were applied. The assessment of weed infestation was performed using the quantitative weight method on two dates: about 2 weeks after the application of the herbicide and biostimulants and before the potato tubers harvest. The herbicide and the herbicide with biostimulants applied to the potato crop showed a positive influence in reducing the number and fresh weight of weeds compared to mechanical-only treatments. The highest effectiveness, calculated on the basis of the number and fresh mass of weeds, was found on the fifth object. It was, on average, 70.5 and 71.6% for cultivars, respectively. Research into the use of biostimulants in potato cultivation will continue due to the pro-environmental nature of biostimulants and the importance of this crop. It is certain that the methodology of future field experiments will meet the challenges of sustainable development.

Keywords: biostimulants; cultivars; herbicide; potato; weed reduction; yields

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1. Introduction

Potato ranks fourth in the world's population nutrition (after wheat, rice and corn) and is grown in 80 percent of the world's countries [1,2]. In Poland, it is an important food crop, and the annual consumption of unprocessed (fresh) potatoes and processed potatoes in the 2020/2021 season was 85 kg per capita [3]. The potato yield is determined by many factors, such as soil and climatic conditions, the choice of variety and a complex of agrotechnical treatments, including careful and well-chosen plantation care [4–7]. Weeds are one of the main factors limiting the potato yields. This is favored by: the use of manure combined with intensive fertilization, wide row spacing and slow initial plant growth, which reduce the competitive action of potato plants against weeds, creating ideal conditions for their development [8–10]. The negative impact of weed infestation, expressed in the reduction of the potato tuber yield and the deterioration of tuber quality traits, has been found by many authors. There was a reduction in tuber yields by 32.7% [11], by 61.4–74.0 [12] and by 10.0–50.0% [13–15]. The different variants of mechanical and chemical treatments increased the total yield of potato tubers by 24.7–50% and the marketable yield by 43.7–60.8% compared to the control object [6]. The success of protecting potato fields against weeds with herbicides and achieving a high efficiency is determined by: the proper selection of the preparation for the occurring weed infestation, knowledge of its spectrum of action, the right date of application and the correct technique of treatment. Recommendations for the use of herbicides in potato cultivation (as of 31 January 2022) include 16 active substances [10]. The most effective in weed control are integrated methods involving mechanical treatments with herbicides and the addition of biostimulants. Biostimulants are natural preparations that are safe for human and animal health and do not harm the natural environment. In modern plant cultivation, biostimulants are one of the elements of agrotechnology which, in addition to fertilization and plant protection, can have a positive effect on yield quantity and quality [16,17]. The biostimulants increase the efficiency of nutrient utilization and the tolerance to abiotic stress and improve the quality of crops [18]. The biologically active substances contained in these bio-preparations have a positive effect on plant growth, root system development and potato yield [19–21]. The growth regulators significantly reduced the symptoms of Phytophthora infestans infection and significantly increased the tuber yield [22]. The beneficial effect of biostimulants on the growth and development of plants is not limited only to improving the yield but also neutralizes the damage to crops caused by the active substances of herbicides [23]. The chemical weed control is used in bean cultivation [24,25].

It was hypothesized that herbicide and herbicide with various biostimulants would effectively reduce weed infestation, which would benefit potato yields. The purpose of the study was to analyze whether the use of mechanical and chemical treatments with the application of biostimulants will effectively reduce weeds in edible potatoes. Biostimulants have a positive effect on plant development, and they enable a yield-forming effect. An important feature of them is that they are safe for the environment. From the point of view of the European Green Deal guidelines for reducing chemical use, the research carried out is of great cognitive value.

2. Materials and Methods

2.1. Experimental and Agronomic Management

The experiment was conducted on a field owned by the Siedlce University of Natural Sciences and Humanities in Siedlce, at the Agricultural Experimental Station Zawady (Figure 1), Masovian Voivodship, Poland (52°03′ N; 22°33′ E), from 2018 to 2020.

The experiment was established in a complete block design with a split-plot arrangement with three replications. The first-order factors were potato cultivars, Oberon and Malaga (Table 1). The description of the potato cultivars was made based on Nowacki [26].

Table 1. Description of potato cultivars.

Cultivar	Registration Year	Maturity	Breeding Center	Total Yield $t \cdot ha^{-1}$	Content of Starch %	Utilization
Oberon	2012	medium early	Potato Breeding Zamarte—Poland	53.1	13.5	boiled baked
Malaga	2013	medium early	Potato Breeding Zamarte—Poland	56.7	15.0	boiled

The second-order factors were five methods of mechanical and chemical treatments with biostimulants (Table 2). The description of the preparations used in the experiment was made according to the List of Fertilizers and Plant Conditioners 2022, The Register of Plant Products [27]. The herbicide Avatar 293 ZC is a product intended for use by professional users according to the Register of Plant Protection Products authorized by the authorization of the Minister of Agriculture and Rural Development on 9 December 2022 (authorization number R-23/2014). The herbicide is for agricultural use in potato [28].

Figure 1. Location of the experiment.

Table 2. Description of the preparations used in the experiment and their application doses ($dm^3 \cdot ha^{-1}$).

N_o	Preparations	Characteristic	Doses ($dm^3 \cdot ha^{-1}$) and Dates (Scale BBCH) 00–08	13–19	31–35	Manufacturer
1.	Control object	only mechanical weeding				
2.	Avatar 293 ZC	herbicide—clomazone 60 g + metribuzin 233 g	1.5	-	-	FMC Corporation—USA
3.	Avatar 293 ZC + PlonoStart	clomazone 60 g + metribuzin 233 g biostimulant—content: N_{tot}—16.4%, K_2O—0.75%, CaO—0.07%, MgO—0.02%, S—941 $mg \cdot kg^{-1}$, lactic acid bacteria, actinomycetes	1.5 -	- 1.0	- 1.0	FMC Corporation—USA Implementation and Innovation Enterprise Andrzej Bogdanowicz—Poland
4.	Avatar 293 ZC + Aminoplant	clomazone 60 g + metribuzin 233 g, biostimulant—content: N_{tot}—9.48%, N_{org}—9.2%, N-NH_4—0.88%, C_{org}—25%, free amino acids—11.57%, organic matter—87.7%	1.5 -	- 1.0	- 0.5	FMC Corporation—USA ISARO Company—Italy
5.	Avatar 293 ZC + Agro-Sorb Folium	clomazone 60 g + metribuzin 233 g, biostimulant—content: N_{tot}—2.2%, B—0.02%, Mn—0.05%, Zn—0.09%, total amino acids—13.11%, free amino acids—10.66%	1.5 -	- 2.0	- 2.0	FMC Corporation—USA, BIOPHARMA-COTECH Company—Poland

The agronomic treatments were carried out on the basis of plant protection recommendations according to the Institute of Plant Protection—National Research Institute [29]. 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 $dm^3 \cdot ha^{-1}$. On plots 3–5, after emergence, different methods of weed control were applied, including three biostimulants applied at two time intervals. On object 3, apart from the herbicide, PlonoStart 2.0 $dm^3 \cdot ha^{-1}$ was applied; the first dose was 1.0 $dm^3 \cdot ha^{-1}$ at full emergence (phase BBCH 13–19), and the second was 1.0 $dm^3 \cdot ha^{-1}$ at the time of 10–50% row cover (phase BBCH 31–35). On object 4, the biostimulant Aminoplant 1.5 $dm^3 \cdot ha^{-1}$ was applied; the first dose was 1.0 $dm^3 \cdot ha^{-1}$ at the full end of emergence (phase BBCH 13–19), and the second one was 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, along with 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 for 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 followed. The potato tubers were planted manually in late April at a spacing of 67.5 × 40 cm and were harvested at the full physiological maturity of tubers in the first and second decade of September (phase BBCH 97–99) [25]. The seed potatoes were the base material, bred by the breeder, of class E—that is, the elite, highest class. This is in line with European Union requirements. The size of a single plot for the harvest was 12.96 m^2. The protection of the plants against pests and diseases was carried out in accordance with the recommendations of the Institute of Plant Protection, National Research Institute, and the principles of Good Agricultural Practice [30].

2.2. Assessment of Weed Infestation and Potato Yields

The analysis of weed infestation was conducted using the quantitative weight method on two terms: about 2 weeks after the application of herbicide and biostimulants (before the row closing of the potato) and at the end of potato vegetation (before the potato tubers harvest). The observations were carried out on a surface of 0.5 m^{-2}, determined by a frame measuring 33.4 × 150 cm. The frame was randomly thrown into three places on each plot, diagonally through the ridges. The fresh weight of weeds and the number weeds were determined [31]. The weed control efficacy (the number of weeds and the fresh weight of weeds) was expressed as a percentage compared to the control object. During the harvest, tubers of ten plants selected at random from each plot were dug to determinate the tuber yield and its structure according to the fraction: <3.5, 3.5−5.0, 5.0−6.0, >6.0 cm in diameter. The trade fraction tuber yield was the yield of the fraction larger than 3.5 cm in diameter and the yield of tubers larger than 5.0 cm in diameter, and it was then converted into t ha^{-1} [32].

2.3. Statistical Analysis

The results of the study were statistically tested with an analysis of variance. The significance of the sources of variability was tested with the Fisher–Snedecor F test, and the significance of differences between the compared means was assessed with Tukey's test at $p \leq 0.05$. The dependence between weed infestation and yields was determined, and linear correlation coefficients were calculated according to Trętowski and Wójcik [33] and according to Badowski, Domaradzki et al. [34].

3. Results and Discussion

In reducing weeds in potato fields, there is a need for a solution to ensure the effective destruction of weeds, the proper development of the crop and good yielding. The mechanical treatments are often ineffective, the use of herbicides causes abiotic stress related to the metabolism of the plant. In contrast, many authors have shown that biostimulants improve plant resistance to various types of stresses [35,36]. The use of herbicides and biostimulants stimulates the physiological activity of the plant and decreases the risk of a decrease in herbicide efficacy under unfavorable environmental conditions [23]. The study showed that the treatments used in the experiment produced different herbicidal effects during the early potato growing season (Table 3).

Table 3. Weed number reduction (%) in relation to the control object before the row closing of the potato (mean for the years 2018–2020).

Mechanical and Chemical Treatments with Biostimulants	Cultivars		Mean
	Oberon	**Malaga**	
Weed number reduction%			
1. Control object—mechanical weeding	0	0	0
2. Herbicide Avatar 293 ZC	46.6	47.5	47.1
3. Herbicide Avatar 293 ZC + biostimulant PlonoStart	55.0	61.7	59.6
4. Herbicide Avatar 293 ZC + biostimulant Aminoplant	50.7	54.9	51.8
5. Herbicide Avatar 293 ZC + biostimulant Agro-Sorb Folium	67.3	69.9	67.5
Mean for 2–5	54.9	58.5	57.9
Weed fresh mass reduction%			
1. Control object—mechanical weeding	0	0	0
2. Herbicide Avatar 293 ZC	44.9	39.5	42.4
3. Herbicide Avatar 293 ZC + biostimulant PlonoStart	71.8	66.7	59.0
4. Herbicide Avatar 293 ZC + biostimulant Aminoplant	66.1	51.4	58.1
5. Herbicide Avatar 293 ZC + biostimulant Agro-Sorb Folium	76.5	70.2	73.1
Mean for 2–5	64.8	57.0	60.7

The highest efficacy, calculated on the basis of the number and fresh weight of weeds, was found on the 5th object which tended to the emergence of potato plants mechanically and, just before emergence, was applied with the Avatar 293 ZC herbicide and, after emergence, twice with the Agro-Sorb Folium biostimulant (Table 3). The average for the varieties and years of testing was 67.5 and 73.1%, respectively. The other biostimulants (PlonoStart and Aminoplant) applied with the herbicide gave a better weed-killing effect than the single herbicide alone. Before harvesting the potato tubers, the percentage of the weed number reduction ranged from 35.9 to 71.6, and the fresh weight of weeds ranged from 48.6 to 71.6, compared to the control facility (Table 4).

Table 4. Weed number reduction (%) in relation to the control object before the potato tubers harvest (mean for years 2018–2020).

Mechanical and Chemical Treatments with Biostimulants	Cultivars		Mean
	Oberon	**Malaga**	
Weed number reduction in %			
1. Control object—mechanical weeding	0	0	0
2. Herbicide Avatar 293 ZC	35.1	36.5	35.9
3. Herbicide Avatar 293 ZC + biostimulant PlonoStart	60.8	60.8	60.8
4. Herbicide Avatar 293 ZC + biostimulant Aminoplant	50.2	55.1	53.1
5. Herbicide Avatar 293 ZC + biostimulant Agro-Sorb Folium	75.4	66.9	70.5
Mean for 2–5	55.4	54.8	55.1
Weed fresh mass reduction in %			
1. Control object—mechanical weeding	0	0	0
2. Herbicide Avatar 293 ZC	50.5	45.5	48.6
3. Herbicide Avatar 293 ZC + biostimulant PlonoStart	63.3	60.2	62.1
4. Herbicide Avatar 293 ZC + biostimulant Aminoplant	52.8	51.1	52.2
5. Herbicide Avatar 293 ZC + biostimulant Agro-Sorb Folium	73.6	68.4	71.6
Mean for 2–5	60.1	56.3	58.6

The highest effectiveness was recorded after the application of the herbicide Avatar 293 ZC and the biostimulant Agro-Sorb Folium. At the same time, the Oberon cultivar was more competitive against weeds than the Malaga cultivar. Gugala et al. found a high efficacy in reducing the fresh weight of weeds by using herbicides and herbicides alone, followed by biostimulants [12]. The variant in which the Harrier 295 ZC herbicide was applied, followed by the Kelpak SL bioregulator twice, proved to be the most effective in reducing weeds, both before the rows were shortened and before the potato tubers were harvested. Additionally, Baranowska et al. [13] showed that the percentage of weed destruction after the application of the Avatar 293 ZC herbicide and the Avatar 293 ZC herbicide and the biostimulant and GreenOK Universal—PRO (at the beginning and end of the vegetation) was, respectively, 85.0 and 86.8% (object 5—only herbicide Avatar 293 ZC) and 83.0 and 84.1% (object 4—herbicide Avatar 293 ZC and biostimulant GreenOK Uniwersal—PRO). Domaradzki et al. [37], for most weed species, found no effect of the herbicide application method (with or without a biostimulant) on the final efficiency of their destruction. However, they noted that the addition of the biostimulants Asahi SL and Kelpak SL to the herbicide mixture at a dose of 50% provided an increase in the destruction efficiency of POLAV (*Polygonum aviculare* L.). Kieloch and Marczewska-Kolasa [38] found that the herbicidal effectiveness of the tested mixtures of herbicides with growth regulators in spring barley depended on the weather patterns in the years of the study, the weed infestation and the timing of the spray. In the 2015 season, a high herbicidal efficacy (91–98%) was obtained on the tested objects. Species moderately susceptible to the tested herbicides were weakly destroyed when herbicide mixtures with growth regulators were applied at a later date at the BBCH 31 scale. The treatments used in the experiment significantly differentiated the tuber yield of the commercial fraction and the yield of large potato tubers (Table 5). Both the single herbicide and the herbicide with biostimulants, as a result of removing weed competition, increased labeled tuber yields by 3.92–10.63 and 4.50–10.46 t·ha^{-1} compared to the control object.

Table 5. Yields of potato tubers in t·ha^{-1} (mean for the years 2018–2020).

Mechanical and Chemical Treatments with Biostimulants	Cultivars		Mean
	Oberon	Malaga	
Trade fraction tuber yield			
1. Control object—mechanical weeding	32.06	25.67	28.87
2. Herbicide Avatar 293 ZC	34.81	30.77	32.79
3. Herbicide Avatar 293 ZC + biostimulant PlonoStart	39.48	33.26	36.37
4. Herbicide Avatar 293 ZC + biostimulant Aminoplant	37.13	31.72	34.42
5. Herbicide Avatar 293 ZC + biostimulant Agro-Sorb Folium	42.57	36.42	39.50
Mean for 2–5	37.21	31.57	34.39
Lowest Significant Difference$_{0.05}$: cultivars = 2.00; treatments = 3.09; cultivars x treatments = n.s.			
Yield of large potato tubers			
1. Control object—mechanical weeding	13.17	15.03	14.10
2. Herbicide Avatar 293 ZC	16.93	20.26	18.60
3. Herbicide Avatar 293 ZC + biostimulant PlonoStart	24.31	21.14	22.73
4. Herbicide Avatar 293 ZC + biostimulant Aminoplant	19.75	20.27	20.01
5. Herbicide Avatar 293 ZC + biostimulant Agro-Sorb Folium	26.19	22.93	24.56
Mean for 2–5	20.07	19.93	20.00
Lowest Significant Difference: LSD$_{(0.05)}$: cultivars = n.s.; treatments = 1.85; cultivars x treatments = 2.85			

n.s.—non-significant differences.

The highest tuber yield of the trade fraction (on average for the two cultivars Oberon and Malaga and the three study years 2018–2020) was characteristic of object 5: the herbicide Avatar 293 ZC combined with the biostimulant Agro-Sorb Folium (Figure 2). The highest yield of large tubers (Figure 3) of potato was also recorded with this method of weed control in potato plantation (object 5).

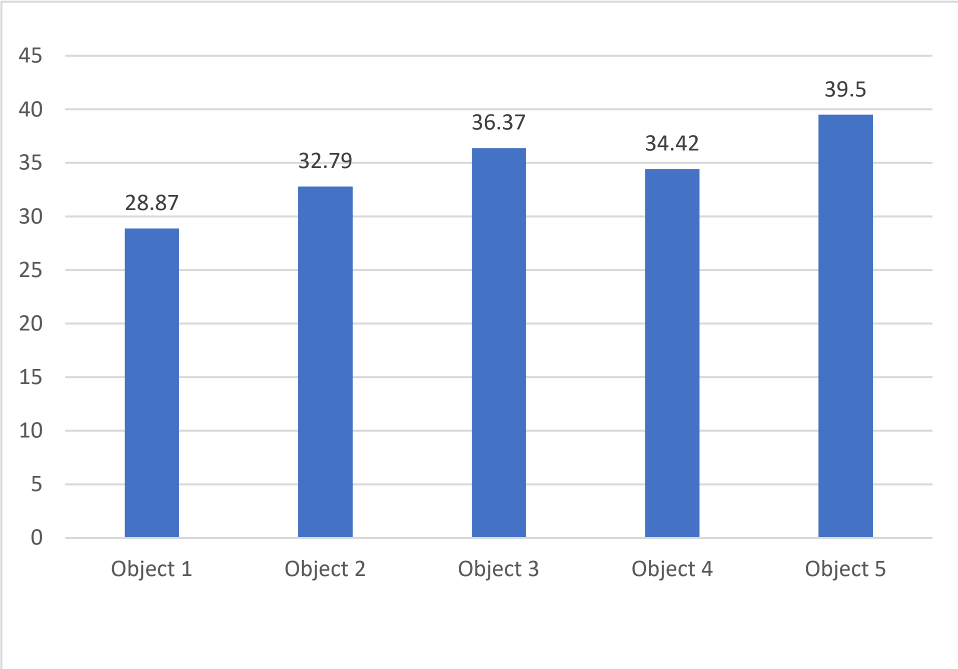

Figure 2. Trade fraction tuber yield t·ha^{-1} (on average for two cultivars Oberon and Malaga and three study years 2018-2020).

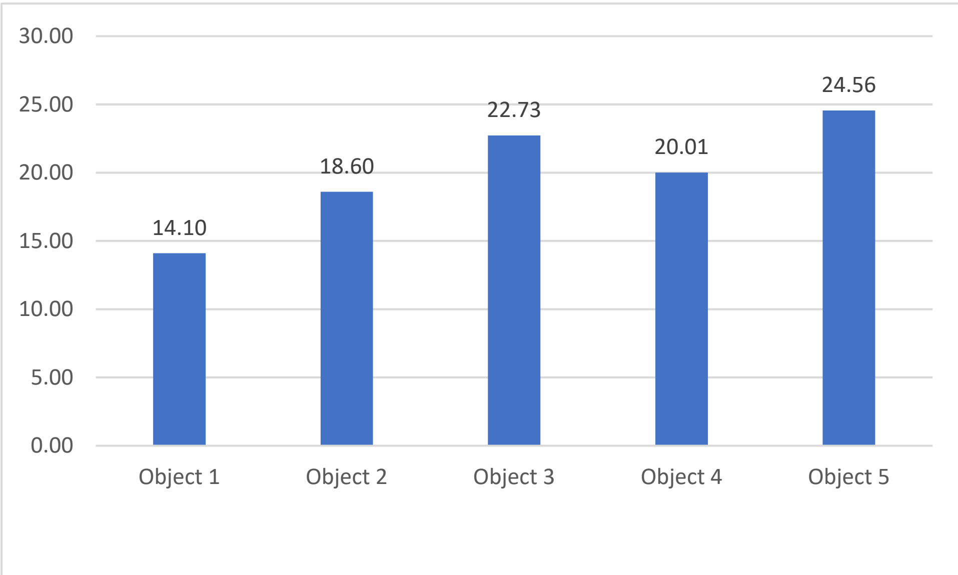

Figure 3. Yield of large potato tubers t·ha^{-1} (on average for two cultivars Oberon and Malaga and three study years 2018–2020).

Kołodziejczyk and Gwóźdż [21], after the application of the biostimulant Asahi SL, reported an increase in the marketable yield of 6.8 t·ha^{-1}. Gugała et al. [12] found that, in plots sprayed with a herbicide or a herbicide and a biostimulant, the average yield of potato tubers was 13.6 to 33.2% higher compared to the control object protected only mechanically. The highest yield was obtained from plots that were sprayed with the herbicide metribuzin and the biostimulant Asahi SL. The high yield-protective effect of herbicides as a result of limited weed competition was obtained by Barbaś and Sawicka [6]. The mechanical-chemical treatment increased the total yield by 24.7–50.0% and the marketable yield by

43.7–60.8% compared to the control object. The positive effect of biostimulants on the yield potential of crop plants has been shown by many researchers [39–41]. The cultivars grown in our study differed only in trade fraction tuber yield. A significantly higher yield was produced by the Oberon cultivar than by Malaga. The effect of the cultivar on potato tuber yields is confirmed by studies of other authors [5,20,22].

The calculated linear correlation coefficients showed that the trade fraction tuber yield and the yield of large potato tubers were strongly correlated with the number and fresh weight of weeds determined at the beginning and end of the growing season (Table 6).

Table 6. Significant values of linear correlation coefficients between the weed number and the weight and yields of potato tubers (mean for the 3 years 2018–2020 and the cultivars Oberon and Malaga).

Indices of Weediness	Trade Fraction Tuber Yield $t \cdot ha^{-1}$	Yield of Large Potato Tubers $t \cdot ha^{-1}$
Number of weeds per 1 m^2 before row closing	−0.9269	−0.9484
Weed fresh mass in t per 1 ha before row closing	−0.9438	−0.9692
Number of weeds per 1 m^2 before the harvest of tubers	−0.9375	−0.9588
Weed fresh mass in t per 1 ha before the harvest of tubers	−0.9654	−0.9798

The determined tuber yields depended more strongly on the fresh weight of the weeds than on the number of weeds. In addition, the relationship was stronger with weed infestation occurring before the potato was harvested than that before compacting the crop rows. A significant relationship between weediness was found by Gugała and Zarzecka [42], Mondani et al. [43] and Barbaś and Sawicka [6].

4. Conclusions

The herbicide and the herbicide with biostimulants applied to the potato crop showed a greater effectiveness in reducing the number and fresh weight of weeds compared to mechanical-only treatments. The highest efficiency in reducing weed competition before harvesting potato tubers was recorded after the application of the Avatar 293 ZC herbicide and the Agro-Sorb Folium biostimulant and was 70.5% (weed reduction number) and 71.6% (weed fresh mass reduction). The Agro-Sorb Folium biostimulant had the most positive effect on the potato plant, which may have been due to the chemical composition of this preparation. As a result, it had a positive effect on the potato's development and its competitiveness with weeds. The potato plants were strengthened through the use of this biostimulant. As a result of the removal of weed competition, significantly higher yields were harvested from mechanically and chemically tended objects with the application of biostimulants compared to those from the control object. The research carried out is in line with the idea of sustainable development. They popularize environmentally friendly farming practices, and they emphasize the importance of measures for improving the environment due to the nature of using biostimulants. These preparations contain non-toxic substances of natural or synthetic origin, making them safe for humans, plants and nature.

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