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Marketable Yield of Potato and Its Quantitative Parameters after Application of Herbicides and Biostimulants

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Abstract: Potato (*Solanum tuberosum* L.) is grown in over 160 countries. Weed competition and environmental stressors during the vegetative growth stage significantly impact crop yields. An experiment was conducted from 2012 to 2014 in Poland to assess the effect of herbicides linuron + clomazone (L+CH) and metribuzin (M) as well as herbicides mixed with biostimulants (linuron + clomazone and algae extract of *Ecklonia maxima*—auxins and gibberellins (L+CH+E) and metribuzin + sodium p-nitrophenolate, sodium o-nitrophenolate and sodium 5-nitroguaiacolate (M+S)) on weed infestation, marketable yield and yield components of the following three table potato cultivars: Bartek, Gawin and Honorata. In plots where potato had been treated with herbicides and herbicides mixed with biostimulants, a decline in the fresh matter of weeds was observed, ranging from 72.4% to 96.1%, which was followed by an increase in potato marketable yield (from 27.5% to 61%) and improved parameters of *S. tuberosum* yield components, compared with the control. Linear correlation coefficients indicated that the following characteristics: marketable yield, weight of tubers per plant and average weight per tuber were associated with weed infestation determined prior to potato harvest.

Keywords: components of yield; linuron; clomazone; metribuzin; auxins; gibberellins; sodium p-nitrophenolate; sodium o-nitrophenolate; sodium 5-nitroguaiacolate; *Solanum tuberosum* L.; weed control

1. Introduction

Potato (*Solanum tuberosum* L.) is one of four major agricultural crops (after wheat, maize and rice) grown worldwide as a staple food for humans [1–5]. Potato is propagated vegetatively, which exposes the crop plant to numerous harmful factors (weeds, pests, viral, fungal and bacterial diseases). As a result of reduced soil tillage and simplified harvest, delayed planting dates, natural manuring and continuous cropping, an increase in weed infestation of fields planted to potato has been observed [6–8]. Potato is susceptible to weed infestation as it is grown in widely spaced rows, and its initial growth and development are slow. A decline in potato tuber yield due to segetal vegetation is estimated to range from 20% to 80% [9,10]. Plants growing in fields infested with weeds produce lower yields of, usually, poorer quality. Moreover, they require higher labour input and production costs [11–13]. Ilić et al. [11] showed that in experimental plots with herbicide application, potato yield was by 32% higher in relation to the yield from untreated experimental plots. As a result, there is an increased focus on establishment of effective weed control methods, which may include herbicides, herbicide mixtures, addition of adjuvants, and integration of mechanical and chemical practices [14]. Some researchers suggest that it is possible to improve the competitive ability of a crop plant and increase its yielding by applying biostimulants, either alone or mixed with herbicides [15–19]. Pavlista [15] and Van Oosten et al. [18] claimed that biostimulants stimulate plant growth processes by enhancing their resistance to stress, and promote plant growth and development thus improving plant yield quality and quantity. In potato, biostimulants promote tuber yield, improve tuber biological parameters, and increase potato resistance to unfavorable environmental conditions and pathogens [17]. According to Golian et al. [16], biostimulant application is particularly recommended under stress-inducing conditions such as during prolonged drought, shortage of nutrients in the soil and when applying plant protection agents. The working hypothesis assumed in the present study was that herbicides and biostimulants may contribute to an increase in potato tuber yield, and affect its components. Therefore, the research aimed to assess the impact of herbicides and their mixtures with biostimulants on fresh weight of weeds, marketable yield and components of potato yield (tuber weight per one potato plant, number of tubers, average weight of one potato tuber).

2. Materials and Methods

2.1. Location of the Field Experiment and Agronomic Management

The field experiment was conducted from 2012 to 2014 on a farm of the multi-branch company Soleks located in Wojnów, the District of Siedlce, Mazovian Voivodeship, Poland. It was established in a complete block design with a split-plot arrangement with three replications. The examined factors were:

I—Three cultivars of table potato: Bartek, Gawin and Honorata (Table 1). They are medium-early table potato cultivars producing high yields of very tasty and tasty regularly-shaped tubers which have light yellow flesh.

II—Five treatments of potato plants with herbicides and herbicides mixed with biostimulants:

1. Control object—without herbicides and biostimulants (CO),
2. Linuron + clomazone—Harrier 295 ZC (L+CH),
3. Linuron + clomazone—Harrier 295 ZC and Kelpak SL—extract from the algae *Ecklonia maxima*, auxins and gibberellins (L+CH+E),
4. Metribuzin—Sencor 70 WG (M),
5. Metribuzin—Sencor 70 WG, 70 WG, and Asahi SL—sodium p-nitrophenolate, sodium o-nitrophenolate, sodium 5-nitroguolacolate (M+S) (Table 2).

The mechanical practices were also performed in herbicide and biostimulant-treated units and the detailed description of the treatments and analysis of weed infestation were presented in an earlier work of Gugała et al. [8].

Table 1. Potato cultivars and their most important features [20].

Name Cultivars	Year of Registration	Breeding Center	Total Yield (t ha^{-1})	Taste Scale 1–9	Utilisation
Bartek	2003	HZ Zamarte—Poland	50.0–54.4	7.0 very good	frozen, salads, boiled
Gawin	2010	PMHZ Strzekęcin—Poland	44.7–49.2	6.4 good	chips, boiled
Honorata	2012	BöhmNordkartoffelAgrarproduktion OHG—Deutschland	44.1–52.0	6.7 good	chips, boiled

Table 2. Description of herbicides and herbicide mixtures with biostimulants used in the experiment [21].

Trade Name	Herbicides (Active Ingredients)	Rates Product	Manufacturer
Control	without herbicides and biostimulants—mechanical weeding prior to and after the emergence of potato plants		
Harrier 295 ZC	linuron + clomazone	2.0 dm^3 ha^{-1}	Bayer Crop Science S.A.
Harrier 295 ZC and Kelpak SL	linuron + clomazone and extract from algae *Ecklonia maxima*—auxins and gibberellins	2.0 dm^3 ha^{-1} and 2.0 dm^3 ha^{-1}	Bayer Crop Science S.A. and Kelp. Products Ltd.
Sencor 70 WG	metribuzin	1.0 kg ha^{-1}	Bayer Crop Science S.A.
Sencor 70 WG and Asahi SL	metribuzin and sodium p-nitrophenolate, sodium o-nitrophenolate, sodium 5-nitroguolacolate	1.0 kg ha^{-1} and 1.0 dm^3 ha^{-1}	Bayer Crop Science S.A. and Arysta Life Science

The herbicides and their rates were based on the recommendations for plant protection products for the years 2012–2013 issued by the Institute of Plant Protection—National Research Institute in Poznań, and weed species found in the experimental area [21]. The biostimulants Kelpak SL (auxins and gibberellins) and Asahi SL (sodium p-nitrophenolate, sodium o-nitrophenolate, sodium 5-nitroguaiacolate) were selected on the basis of a list of plant nutrients that can be traded on the Polish market, prepared by the Ministry of Agriculture and Rural Development of July 10, 2007 [22]. Rates of herbicides and biostimulants were used with 300 liters of water per hectare. Linuron + clomazone application was made 7–10 days following tuber planting, metribuzin was applied just before potato emergence, and auxins and gibberellins as well as sodium p-nitrophenolate and sodium o-nitrophenolate treatments were made twice—towards the end of emergence and at canopy closure. Each year, the experiment was conducted on soil belonging to Haplic Luvisol (LV-ha) with a texture of sandy loam according to the World Reference Base for Soil Resources (WRB FAO) [23]. The soil in the conducted experiment, was characterized by: 5.60–6.35 pH (in KCl), humus content—15.0–18.7 g kg^{-1}, from high to very high content of available phosphorus (68.6–110 mg kg^{-1} P), medium to very high content of potassium (99.6–149.4 mg kg^{-1} K), high content of magnesium (50.0–56.0 mg kg^{-1} Mg) and low content of iron (465.0–570.5 mg kg^{-1} Fe soil dry matter).

In each year, the previous crop was winter wheat, and in autumn, manure was used at a rate of 25.0 t ha^{-1} and mineral fertilizers (phosphorus and potassium) at the following rates: 44.0 kg ha^{-1} P (in the form of 46% TSP triple superphosphate), 124.5 kg ha^{-1} K (in the form of 60% potassium chloride salt, white granulated). In the spring, nitrogen was used at a rate of 100 kg N per 1 ha (in the form of 34% ammonium salt). Potatoes were planted at a spacing of 67.5 × 37.0 cm in the second week of April and harvested at physiological maturity (phase BBCH 97), based on the scale of Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie, in mid-September [24]. Each potato cultivar was planted in five rows 5.55 m long, with 0.675 m between-row spacing, the between-tuber spacing within the row being 0.37 m. The area of a single plot during planting was 18.75 m^{-2} (5 rows) and until harvest was 15 m^{-2} (4 rows). During the growing season, fungicides were used against the potato blight: Ridomil Gold MZ 68 WG (metalaxyl-M + mancozeb) and Altima 500 SC (fluazinam), Colorado potato beetle was controlled with the insecticides: Fastac 100 EC (alpha, cypermethrin) and Apacz 50 WG (clothianidin).

2.2. Weed Infestation Analysis, Tuber Yield and Its Components

Analysis of fresh weight of weeds in experimental plots just before tuber harvest was performed using the quantitative and weight method when plants entered the stage 97 based on the BBCH scale. The frame was tossed three times diagonally across the ridges and weeds within the frame were collected. Fresh matter weed control efficiency was expressed as percentages in relation to the control where weeds were managed by means of mechanical practices only [25]. The dominant weed species in the experiment were: *Elymus repens*, *Echinochloa crus-galli*, *Chenopodium album*, *Stellaria media*, *Lycopsis arvensis*, *Viola arvensis*. Each year prior to harvest, tubers of ten plants selected at random from each plot were dug to determine the following: tuber number per one plant and tuber weight, and the average weight of one tuber. Total tuber yield consisted of the weight of tubers harvested from the whole plot area and the weight of previously taken samples, both converted to t ha^{-1}. Marketable yield included tubers with the diameter of over 35 mm without external and internal defects [26].

2.3. Statistical Analysis

The data were subjected to analysis of variance (ANOVA Cultivar × Methods × Years) in a factorial arrangement. The significance of the sources of variability was checked using the Fisher-Snedecor test, while the significance of differences between the averages was examined using the Tukey test at the significance level $P \leq 0.05$. Calculations were performed in Excel using the authors' own algorithm based on the split-plot mathematical model. The above statistical procedures are presented in the work by Trętowski and Wójcik [27]. The dependence between weed infestation and yield and yield components was determined, and linear correlation coefficients were calculated.

2.4. Weather Conditions

The humidity-thermal conditions in the study years varied. Air temperature in successive study years was, respectively, 1.0, 0.6 and 0.9 °C higher than the long-term mean. Additionally, in all the study years, the conditions in the months of tuber formation and yield accumulation (July and August) were favorable. Precipitation varied in individual growing seasons. In 2012, rainfall was by 33.0 mm lower than the long-term value but it was evenly distributed. In 2013, precipitation was the highest but unevenly distributed with shortage of rain in August. In 2014, precipitation shortage was recorded in July and it was followed by excessive rainfall in August.

3. Results and Discussion

Various solutions to create the most favorable conditions for crop plant growth and optimal yielding are sought in order to make full use of the biological potential of registered potato cultivars. Favorable conditions may be supported through implementation of successful weed control and application of biostimulants, which may enhance physiological processes counteracting stress conditions [16,28]. Weed fresh matter determined in the study was significantly affected by cultivar, herbicide and biostimulant application, and study year (Table 3).

The highest weed infestation was observed for cv. Gawin, and it was significantly lower for cv. Bartek and Honorata. The herbicide linuron + clomazone contributed to an eight-fold reduction in weed weight, and up to a 25-fold drop when the chemical was mixed with the biostimulant containing auxins and gibberellins compared with the control (Table 3).

Table 3. Fresh weight of weeds in the field cultivated with potato before tuber harvest (g m^{-2}).

Treatments	Cultivars			Years			Mean
	Bartek	Gawin	Honorata	2012	2013	2014	
1. CO*	331.1A	383.3A	310.0A	257.8A	400.0A	366.7A	341.5a
2. L+CH	15.6A	61.2A	48.9A	107.9B	17.8C	0	41.9cd
3. L+CH+E	7.8A	23.8A	8.7A	24.7C	15.6C	0	13.4d
4. M	72.3A	124.4A	85.6A	66.2C	133.3B	82.8B	94.1b
5. M+S	67.6A	88.0A	58.5A	25.1C	118.9B	70.0B	71.3bc
Mean	98.9b	136.2a	102.3b	96.3b	137.1a	103.9b	112.4

* 1. CO—Control; 2. L+CH—Harrier 295 ZC; 3. L+CH+E—Harrier 295 ZC + Kelpak SL; 4. M—Sencor 70 WG; 5. M+S—Sencor 70 WG + Asahi SL. Means followed by the same letters do not differ significantly at $P \leq 0.05$. Means in columns marked with capital letters refer to interactions between the factors. Means in the last column and means in the last row (followed by lowercase) are for treatments, cultivars and years.

A marked efficiency of weed control was observed following an application of linuron + clomazone (87.7%), linuron + clomazone and auxins and gibberellins (96.1%), as well as metribuzin (72.4%), whether it was applied alone on mixed with sodium p-nitrophenolate, sodium o-nitrophenolate and sodium 5-nitroguaiacolate (79.1%) (Table 4).

Table 4. Weed reduction (fresh weight of weeds) in relation to control (%).

Treatments	Cultivars			Years			Mean
	Bartek	Gawin	Honorata	2012	2013	2014	
1. CO*	0	0	0	0	0	0	0
2. L+CH	95.3	84.0	84.2	58.1	95.5	100.0	87.7
3. L+CH+E	97.6	93.8	97.2	90.4	96.1	100.0	96.1
4. M	78.2	67.5	72.4	74.3	66.7	77.4	72.4
5. M+S	79.6	77.0	81.1	90.3	70.3	80.9	79.1
Mean	87.7	80.6	83.7	78.3	82.2	89.6	-

* 1. CO—Control; 2. L+CH—Harrier 295 ZC; 3. L+CH+E—Harrier 295 ZC + Kelpak SL; 4. M—Sencor 70 WG; 5. M+S—Sencor 70 WG + Asahi SL.

We obtained similar effects of weed control [8] when analyzing the dry weight of weeds. A similar efficiency of herbicides and their mixtures, reaching 96%, has been reported by other authors [3,14,29,30]. Matysiak et al. [30] found that an application of herbicides and herbicides with biostimulants at various rates (MCPA + dicamba, dicamba + triasulfuron, florasulam + 2,4-D) with biostimulants (Kelpak—auxins and gibberellins, Asahi—sodium p-nitrophenolate, sodium o-nitrophenolate, sodium 5-nitroguaiacolate) in wheat reduced the number of weedy species analyzed (*Chenopodium album, Galium aparine, Matricaria indora, Veronica agrestis, Viola arvensis*) by 55%–100% with regard to non-treated control. Research by Golian et al. [16] demonstrated that Asahi SL (sodium p-nitrophenolate, sodium o-nitrophenolate, sodium 5-nitroguaiacolate) mixed with metribuzin and applied to control weeds in carrot did not affect the efficacy of weed control but increased the yield of carrot roots compared with control. In the experiment reported here, there was a significant effect of cultivar, herbicide and biostimulant application as well as weather conditions in the study years on the marketable yield of potato tubers (Tables 5 and 6).

Table 5. Analysis of variance for fresh weight of weeds and the marketable yield of potato tubers and components of potato yield.

Sources of Variation	Fresh Weight of Weeds (g m^{-2})	Marketable Yield of Potato Tubers (t ha^{-1})	Tuber Weight Per One Potato Plant (g)	Tuber Number per one Potato $Plant^{-1}$	Average Weight of One Potato Tuber (g)
Cultivars (C)	**	**	ns	**	**
Treatments (T)	**	**	**	ns	**
Years (Y)	**	**	**	**	**
C × T	ns	ns	ns	ns	ns
C × Y	**	ns	ns	ns	ns
T × Y	**	**	**	**	**
C × T × Y	ns	ns	ns	ns	ns

** Significant at $P \leq 0.05$; ns, non-significant.

Table 6. Marketable yield of potato tubers (t ha^{-1}).

Treatments	Cultivars			Years			Mean
	Bartek	Gawin	Honorata	2012	2013	2014	
1. CO*	23.57A	25.71A	28.06A	28.23E	26.01C	23.08C	25.77d
2. L+CH	29.74A	31.57A	37.28A	35.91D	33.93AB	28.76B	32.87c
3. L+CH+E	33.89A	35.42A	39.87A	44.65BC	33.58B	30.96B	36.40b
4. M	36.14A	35.77A	42.76A	42.17C	35.42A	37.08A	38.22b
5. M+S	38.91A	40.24A	45.28A	48.03A	37.89A	38.50A	41.47a
Mean	32.45b	33.74b	38.65a	39.80a	33.37b	31.68c	34.95

* 1. CO—Control; 2. L+CH—Harrier 295 ZC; 3. L+CH+E—Harrier 295 ZC + Kelpak SL; 4. M—Sencor 70 WG; 5. M+S—Sencor 70 WG + Asahi SL. Means followed by the same letters do not differ significantly at $P \leq 0.05$. Means in columns marked with capital letters refer to interactions between the factors. Means in the last column and means in the last row (followed by lowercase) are for treatments, cultivars and years.

The data indicated that cv. Honorata was the most productive in terms of yield compared with the remaining cultivars. The highest yields were harvested in plots sprayed with the herbicide metribuzin as well as metribuzin and sodium p-nitrophenolate, sodium o-nitrophenolate, sodium 5-nitroguaiacolate (treatments 4 and 5). Additionally, the biostimulant containing auxins and gibberellins mixed with linuron + clomazone had a positive effect, compared with the respective treatment without biostimulant, that is contributed to an increase in tuber yield, compared with the unit where weed control had been achieved by means of mechanical practices only. Linear correlation coefficients indicated that marketable yield was highly associated with weed infestation (Table 7).

Table 7. Significant values of linear correlation coefficients between the fresh weight of weeds and the marketable yield of potato tubers and components of potato yield (means for cultivars and 3 study years).

Index	Marketable Yield of Potato Tubers (t ha^{-1})	Tuber Weight per one Potato Plant (g)	Tuber Number per one Potato $Plant^{-1}$	Average Weight of one Potato Tuber (g)
Fresh weight of weeds (t ha^{-1})	−0.769**	-	-	-
Fresh weight of weeds (g m^{-2})	-	−0.687**	+0.098ns	−0.633**

** Significant at $P \leq 0.05$; ns, non-significant.

A similar relationship has been reported by Gugała and Zarzecka [31] as well as Ilić et al. [11]. Pavlista [15] demonstrated an increase in potato tuber yield following an application of various rates of the growth regulator Auxigro (4-aminobutyric acid and L-glutamate) at different dates. Additionally, Mystkowska [32] observed an increase in the tuber yield of potato treated with Kelpak SL (auxins and gibberellins), Tytanit (titanium), Green OK (humic substances) and Brunatne Bio Złoto (auxins and cytokinins). Other authors [30,33] claimed that the biostimulants sodium p-nitrophenolate, sodium o-nitrophenolate, sodium 5-nitroguaiacolate and auxins and gibberellins contributed to an increase in yield as well as certain qualitative and quantitative characteristics of spring wheat, potato and winter oilseed rape. According to Wierzbowska et al. [17], the effect of growth regulators was influenced by weather conditions, and the applied biostimulants (Asahi SL—sodium p-nitrophenolate, sodium o-nitrophenolate, sodium 5-nitroguaiacolate; Bio-Algeen S90—extract from seawater brown algae; Kelpak SL—auxins and gibberellins) considerably increased tuber yield (by respectively 7.6%, 16.3% and 24.7%) only in the second year of experimentation when both the precipitation and temperature were lower during the growing season.

The weight of tubers per potato plant was influenced by product application treatments, as well as differences across study years (Tables 5 and 8). The number of tubers produced by one plant was dependent upon cultivar and study years (Tables 5 and 9), and the average weight of one tuber depended on the cultivar, herbicide and biostimulant application as well as study years (Tables 5 and 10).

Table 8. Tuber weight per one potato plant (g).

Treatments	Cultivars			Years			Mean
	Bartek	Gawin	Honorata	2012	2013	2014	
1. CO*	831.3A	799.4A	829.2A	922.2B	831.0A	706.7B	820.0d
2. L+CH	885.6A	855.5A	930.9A	1012.2B	875.4A	784.4B	890.7cd
3. L+CH+E	964.0A	943.4A	985.2A	1175.6A	893.7A	823.3B	964.2bc
4. M	1001.9A	972.7A	1041.3A	1152.2A	900.6A	963.1A	1005.3ab
5. M+S	1036.3A	1005.7A	1111.2A	1237.8A	908.3A	1007.1A	1051.1a
Mean	943.8a	915.3a	979.6a	1100.0a	881.8b	856.9b	946.2

* 1. CO—Control; 2. L+CH—Harrier 295 ZC; 3. L+CH+E—Harrier 295 ZC + Kelpak SL; 4. M—Sencor 70 WG; 5. M+S—Sencor 70 WG + Asahi SL. Means followed by the same letters do not differ significantly at $P \leq 0.05$. Means in columns marked with capital letters refer to interactions between the factors. Means in the last column and means in the last row (followed by lowercase) are for treatments, cultivars and years.

Table 9. Tuber number per one potato plant.

Treatments	Cultivars			Years			Mean
	Bartek	Gawin	Honorata	2012	2013	2014	
1. CO*	9.5A	10.6A	9.7A	11.1B	9.1A	9.6A	9.9a
2. L+CH	9.3A	10.2A	9.9A	11.9AB	8.5A	9.1AB	9.8a
3. L+CH+E	9.5A	10.0A	9.8A	12.7A	8.0A	8.6AB	9.8a
4. M	9.4A	9.9A	9.6A	12.6A	7.9AB	8.4AB	9.6a
5. M+S	9.3A	9.7A	9.5A	12.8A	7.5B	8.2B	9.5a
Mean	9.4b	10.1a	9.7ab	12.2a	8.2b	8.8b	9.7

* 1. CO—Control; 2. L+CH—Harrier 295 ZC; 3. L+CH+E—Harrier 295 ZC + Kelpak SL; 4. M—Sencor 70 WG; 5. M+S—Sencor 70 WG + Asahi SL. Means followed by the same letters do not differ significantly at $P \leq 0.05$. Means in columns marked with capital letters refer to interactions between the factors. Means in the last row (followed by lowercase) are for cultivars and years.

Table 10. Average weight of one potato tuber (g).

Treatments	Cultivars			Years			Mean
	Bartek	Gawin	Honorata	2012	2013	2014	
1. CO*	87.9A	77.3A	85.9A	81.7B	93.2C	76.2C	83.7d
2. L+CH	95.4A	84.3A	97.3A	84.7A	104.1BC	88.1BC	92.3c
3. L+CH+E	102.4A	93.6A	108.3A	94.4A	113.1AB	96.9B	101.5b
4. M	109.5A	99.3A	117.4A	93.7A	115.6AB	117.0A	108.8ab
5. M+S	113.9A	104.9A	122.9A	95.8A	122.9A	123.1A	113.9a
Mean	101.8a	91.9b	106.4a	90.0b	109.8a	100.3a	100.0

* 1. CO—Control; 2. L+CH—Harrier 295 ZC; 3. L+CH+E—Harrier 295 ZC + Kelpak SL; 4. M—Sencor 70 WG; 5. M+S—Sencor 70 WG + Asahi SL. Means followed by the same letters do not differ significantly at $P \leq 0.05$. Means in columns marked with capital letters refer to interactions between the factors. Means in the last column and means in the last row (followed by lowercase) are for treatments, cultivars and years.

The highest tuber weight and average weight of one tuber were recorded for plots sprayed with metribuzin (treatment 4), being by 22% and 30% respectively higher than the control, and after metribuzin was mixed with sodium p-nitrophenolate, sodium o-nitrophenolate, sodium 5-nitroguaiacolate (treatment 5), being by 28% and 36% higher compared with the control. Additionally, a mixture of auxins and gibberellins and linuron + clomazone positively influenced the discussed characteristics. Linear correlation coefficients confirmed a significant association between tuber weight per one potato plant and average weight of one potato tuber, and fresh weight of weeds determined prior to potato tuber harvest (Table 7). Ilić et al. [11] showed that the number of tubers from one plant significantly depended on the number of weeds per unit area. Decrease of weed infestation led to significant increase in number of tubers per plant. This study also showed that the average number of tubers per plant achieved in experimental plots with herbicide treatment was by 40% higher compared with the number of tubers in non-treated experimental plots, the difference being highly significant. The unit efficiency of potato plants (weight and number of tubers per one plant and the average weight of one tuber) was also affected by cultivars, weather conditions in which the experiment was conducted and an interaction of herbicides and biostimulant application methods with study years. Ahmadi Lahijani et al. [19] demonstrated that growth regulators significantly affected tuber yield per plant and mean tuber weight compared with the control. Following an application of BAP (6-BenzylAminoPurine) +ABA (Abscisic Acid), yield per plant of cv. Agria increased by 20%, and the average weight of one tuber increased by 28% compared with the control. An application of only ABA increased yield per plant of cv. Fontane by 21%. Differences between cultivars in terms of total yield, marketable yield and tuber yield components as well as the effect of study years on the above-mentioned characteristics have been reported by other authors [32,34,35]. Mystkowska [32], who compared three cultivars, found that the highest yield was produced by Jelly (on average, 51.05 t·ha^{-1}) compared with Tajfun (42.6 t ha^{-1}) and Honorata (40.9 t ha^{-1}); also, the superlative yield was obtained in the year with the highest precipitation. Sanli et al. [34] demonstrated that tuber number per plant, marketable tuber yield and total tuber were significantly affected by the weather conditions in the years of experimentation. Merga and Dechassa [35] examined eight cultivars and found the highest marketable and total yields for cv. Bubu (39.4 t ha^{-1}), and the lowest for cv. Jarso (20.89 t ha^{-1}). In their study, the highest number of tubers per plant was produced by cv. Badasa. An interaction of the tested cultivars with herbicide and biostimulant application was confirmed. Wierzbowska et al. [17] demonstrated that, in the second study year (with lower precipitation and temperature during the growing season compared with the remaining years), Asahi SL (sodium p-nitrophenolate, sodium o-nitrophenolate, sodium 5-nitroguaiacolate), Bio-Algeen S90 (extract from seawater brown algae) and Kelpak SL (auxins and gibberellins) increased tuber yields of cv. Satina by 14.7%, 14.7% and 18.3% respectively; Bio-Algeen S90 (extract from seawater brown algae) and Kelpak SL (auxins and gibberellins) increased tuber yields of cv. Volumia by 16.2% and 24.7% respectively, and Kelpak SL (auxins and gibberellins) contributed to such a response in cv. Irga and Sylvana, the respective increases being 14.6% and 37.8%.

4. Conclusions

Herbicides and herbicide + biostimulant mixtures applied in potato cultivation contributed to an increase in marketable tuber yields, ranging from 27.5% to 61% compared with mechanical weed control, due to removal of competition with weeds and improved utilization of crop plant yield-formation potential. The biostimulants containing auxins and gibberellins as well as sodium p-nitrophenolate, sodium o-nitrophenolate and sodium 5-nitroguaiacolate mixed with herbicides insignificantly reduced weed weight and increased potato tuber yields by 10.7% and 8.5% (treatments 3,5), and increased the average weight of one tuber (treatment 3) compared with herbicide treatments. Correlation coefficients confirmed a strong association of marketable yield, tuber biomass per one plant and average weight of one tuber with weed infestation. Integration of mechanical and chemical practices as well as biostimulant application increases weed control efficiency and positively affects potato yield performance.

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References

1. Hussain, Z.; Munsif, F.; Marwat, K.B.; Ali, K.; Afridi, R.A.; Bibi, S. Studies on efficacy of different herbicides against weeds in potato crop in Peshawar. *Pak. J. Bot.* **2013**, *45*, 487–491.
2. Halterman, G.; Guenthner, J.; Collinge, S.; Butler, N.; Douches, D. Biotech potatoes in the 21st century: 20 years since the first Biotech potato. *Am. J. Potato Res.* **2016**, *93*, 1–20. [CrossRef]
3. Kebede, G.; Sharma, J.J.; Dechassa, N. Evaluation of chemical and cultural methods of weed management in potato (*Solanum tuberosum* L.) in Gishe District, North Shewa, Ethiopia. *J. Nat. Sci. Res.* **2016**, *6*, 28–47.
4. Al-Hamed, S.A.; Wahby, M.F.; Aboukarima, A.M.; El Marazky, M.S. Effect of soil and water characteristics on yield and properties of 'Spunta' potatoes. *Chil. J. Agric. Res.* **2017**, *77*, 250–256. [CrossRef]
5. Haider, M.W.; Ayyub, C.M.; Malik, A.U.; Ahmad, R. Plant growth regulators and electric current break tuber dormancy by modulating antioxidant activities of potato. *Pak. J. Agric. Sci.* **2019**, *56*, 867–877. [CrossRef]
6. Hamouz, K.; Hamouzová, K.; Holec, J.; Tyšer, L. Impact of site-specific weed management in winter crops on weed populations. *Plant Soil Environ.* **2014**, *60*, 27–35. [CrossRef]
7. Hussain, Z.; Khan, M.A.; Ilyas, M.; Luqmani Khan, I.A. Non-chemical weed management in potato at higher elevations. *Appl. Ecol. Environ. Res.* **2016**, *14*, 67–76. [CrossRef]

8. Gugała, M.; Zarzecka, K.; Dołęga, H.; Sikorska, A. Weed Infestation and Yielding of Potato under Conditions of Varied Use of Herbicides and Bio-Stimulants. *J. Ecol. Eng.* **2018**, *19*, 191–196. [CrossRef]
9. Boydston, R.A. Potato and Weed Response to Postemergence-Applied Halosulfuron, Rimsulfuron, and EPTC. *Weed Technol.* **2007**, *21*, 465–469. [CrossRef]
10. Fernandez-Quintanilla, C.; Quadranti, M.; Kudsk, P.; Bárberi, P. Which future for weed science? *Weed Res.* **2008**, *48*, 297–301. [CrossRef]
11. Ilić, O.; Nikolić, L.; Ilin, Ž.; Mišković, A.; Vujasinović, V.; Kukić, B. Effect of cultural practices on weeds community in function of potato yield. *Acta Sci. Pol. Hortorum Cultus* **2016**, *15*, 31–43.
12. Mehring, G.H.; Stenger, J.E.; Hatterman-Valenti, H.M. Weed control with cover crops in irrigated potatoes. *Agronomy* **2016**, *6*, 3. [CrossRef]
13. Kołodziejczyk, M.; Antonkiewicz, J.; Kulig, B. Effect of living mulches and conventional methods of weed control on weed occurrence and nutrient uptake in potato. *Int. J. Plant Prod.* **2017**, *11*, 275–284.
14. Siblani, W.; Haidar, M. Reduced rates of metribuzin and time of hilling controlled weeds in potato. *Am. J. Plant Sci.* **2017**, *8*, 3207–3217. [CrossRef]
15. Pavlista, A.D. Growth regulators increased yield of Atlantic potato. *Am. J. Potato Res.* **2011**, *88*, 479–484. [CrossRef]
16. Golian, J.; Anyszka, Z.; Kohut, M. The assessment of herbicides application with biostimulants and adjuvants in carrot (*Daucus carota* L.). *Prog. Plant Prot.* **2014**, *54*, 167–173. (In Polish) [CrossRef]
17. Wierzbowska, J.; Cwalina-Ambroziak, B.; Głosek-Sobieraj, M.; Sienkiewicz, S. Effect of biostimulators on yield and selected chemical properties of potato tubers. *J. Elem.* **2015**, *20*, 757–768. [CrossRef]
18. Van Oosten, M.J.; Pepe, O.; De Pascale, S.; Silletti, S.; Maggio, A. The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. *Chem. Biol. Technol. Agric.* **2017**, *4*, 1–12. [CrossRef]
19. Ahmadi Lahijani, M.J.; Kafi1, M.; Nezami, A.; Nabati, J.; Erwin, J. Effect of 6-Benzylaminopurine and Abscisic Acid on Gas Exchange, Biochemical Traits, and Minituber Production of Two Potato Cultivars (*Solanum tuberosum* L.). *J. Agric. Sci. Technol.* **2018**, *20*, 129–139.
20. Nowacki, W. *Characteristic of Native Potato Cultivars Register*; XV Plant Breeding Acclimatization Institute-National Research Institute: Section Jadwisin, Poland, 2012; pp. 1–43. (In Polish)
21. *Plant Protection Recommendations for 2014/15*; Institute of Plant Protection−National Research Institute: Poznań, Poland, 2014. (In Polish)
22. List of Fertilizers and Plant Conditioners. List of Other Measures to be Used in the Protection of Agricultural Plants. Available online: http://www.gov.pl/web/rolnictwo/wykaz-nawozow-i-srodkow-wspomagajacych-uprawe-roslin and www.abcochronyroslin.pl/uploads/program_other/inne_wykaz (accessed on 21 February 2020). (In Polish).
23. WRB FAO World Reference Base for Soil Resources. In *International Soil Classification System for Naming Soils and Creating Legends for Soil*; World Soil Resources Reports No. 106; Field Experiment; FAO: Rome, Italy, 2014; Available online: http://www.fao.org (accessed on 21 February 2020).
24. Adamczewski, K.; Matysiak, K. *Compendium of Growth Stage Identification Keys for Mono- and Dicotyledonous Plants Extended BBCH Scale*; Institute of Plant Protection−National Research Institute: Poznań, Poland, 2011; pp. 1–132. (In Polish)
25. Roztropowicz, S. *Methodology of Observation, Measurements and Sampling in Agricultural Experiments with Potatoes*; Plant Breeding and Acclimatization Institute: Section Jadwisin, Poland, 1999; pp. 1–50. (In Polish)
26. *Regulation of the Minister of Agriculture and Rural Development 29, (2003) on Detailed Requirements for Commercial Quality of Potatoes; Dz. U. 2003 No 194, item 1900*; ISAP—Internet System of Legal Acts: Warsaw, Poland, 2003; pp. 13086–13088. Available online: http://prawo.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20031941900 (accessed on 4 February 2020). (In Polish)
27. Trętowski, J.; Wójcik, R. *Methodology of Agricultural Experiments*; Wyższa Szkoła Rolniczo-Pedagogiczna: Siedlce, Poland, 1991; pp. 331–334. (In Polish)
28. Gawrońska, H.; Przybysz, A.; Szalacha, E.; Słowiński, A. Physiological and molecular mode of action of Asahi SL biostimulator under optimal and stress conditions. In *Biostimulators in Modern Agriculture-General Aspects*; Gawrońska, H., Ed.; Wieś Jutra: Warsaw, Poland, 2008; pp. 54–76.
29. Ivany, J.A. Acetic acid for weed control in potatoes. *Can. J. Plant Sci.* **2010**, *90*, 537–542. [CrossRef]
30. Matysiak, K.; Miziniak, W.; Kaczmarek, S.; Kierzek, R. Herbicides with natural and synthetic biostimulants in spring wheat. *Ciência Rural* **2018**, *48*, 1–10. [CrossRef]

31. Gugała, M.; Zarzecka, K. Relationship between potato yield and the degree of weed infestation. *Afr. J. Agric. Res.* **2013**, *8*, 5752–5758. [CrossRef]
32. Mystkowska, I. Biostimulators as a factor affecting the yield of edible potato. *Acta Agrophys.* **2018**, *25*, 307–315. [CrossRef]
33. Matysiak, K.; Adamczewski, K.; Kaczmarek, S. Influence of biostimulator Asahi SL on yielding and selected quantitative and qualitative traits of some agricultural plants cultivated in the conditions of Wielkopolska. *Prog. Plant Prot.* **2011**, *51*, 1849–1857. (In Polish)
34. Sanli, A.; Karadogan, T.; Tonguc, M. Effects of leonardite applications on yield and some quality parameters of potatoes (*Solanum tuberosum* L.). *Turk. J. Field Crops* **2013**, *18*, 20–26.
35. Merga, B.; Dechassa, N. Growth and productivity of different potato cultivars. *J. Agric. Sci.* **2019**, *11*, 528–534. [CrossRef]