INTRODUCTION

Potato (*Solanum tuberosum* L.) belongs to one of three most important edible plants in the world, and is grown on all the continents [Birch et al. 2012]. Potato yields and quality are influenced by numerous agrotechnological, genetic and environmental factors [Escuredo et al. 2018, Trawczyński 2020, Wadas and Dziugieł 2020]. Appropriate tillage to control weeds is one of more important cultivation factors. Destruction of weeds by using a combination of mechanic and chemical practices contributes to increased tuber yields and improved tuber quality, as confirmed in the research by numerous authors [Ilić et al. 2016, Gugała et al. 2018, Barbaś and Sawicka 2020].

In recent years, there has been growing interest and application of various biostimulants in fields under crop plants, including potato, due to many sustainable agriculture-related benefits [Chehade et al. 2018, Nephali et al. 2020, Trawczyński 2020]. Biostimulants stimulate sprouting, development of the rooting system and plant growth [Ertani et al. 2018]. Moreover, they increase the efficiency of chlorophyll synthesis, root development, nutrient uptake from the soil and nutrient metabolism, particularly when the environmental conditions are unfavourable for plant growth and development [Calvo et al. 2014, Popko et al. 2018]. What is more, the products improve the plant resistance systems protecting them against abiotic stress and pathogens [Sharma et al. 2014].
In addition, they are safe for the environment and their application makes it possible to reduce the amount of chemicals utilised in agriculture and plant protection [Radkowski and Radkowska 2013, Du Jardin 2015].

The new regulation (EU) 2019/1009 defines plant bio stimulants as follows: “EU fertilising product the function of which is to stimulate plant nutrition processes independently of the product’s nutrient content with the sole aim of improving one or more of the following characteristics of the plant and/or the plant rhizosphere: (1) nutrient use efficiency, (2) tolerance resistance to (a) biotic stress, (3) quality characteristics, or (4) availability of confined nutrients in the soil or rhizosphere” [Regulation (EU) 2019]. The bio stimulant product number and market are increasing year by year. In 2020, the list of growth stimulants in Poland included 64 products [Ministry of Agriculture and Rural Development 2021]. Thus, the increasing range of bio stimulants introduced into the market and their application in combination with other products prompt an assessment of a wide range of characteristics (physiological, morphological, chemical) of cultivated potato varieties. Potato is one of the most efficient plant species converting the solar energy into human food, both in qualitative and quantitative terms. The chlorophyll content in potato leaves is closely related to the potato content of nitrogen [Ramirez et al. 2014, Gaurav et al. 2019]. Vos and Bom [1993] demonstrated a very strong correlation (r = 0.97) between readings from the SPAD-502 measuring device manufactured by Minolta Camera as well as the nitrogen and chlorophyll concentrations in potato leaf laminae. Moreover, they found that the SPAD readings were closely correlated with the analytical measurements of chlorophyll contents, which ensures a good estimation of the leaf content of these components.

The measurement of chlorophyll SPAD with a measuring device is predominantly used to determine the nitrogen status in crop plants. Many workers have pointed out that, at certain SPAD readings, potato plants are adequately supplied with nitrogen, and yields reach maximum levels. Giletto et al. [2010] and Trawczyński [2019] harvested the maximum tuber yields when the SPAD values ranged from 35 to 40 and from 43.7 to 43.9 units, respectively. Dvořák and Král [2019], who applied black textile mulch while growing potatoes, found a strong correlation (r = 0.6572) between the SPAD values and tuber yield. The authors suggest that, based on the SPAD values, it is possible to predict the potato tuber yield levels as well as yields of its components. Good development of plants is indicative of their good nutrition, normal course of their life processes and, thus, optimum yielding and nutrient accumulation. The purpose of the work was to assess the effect of herbicides and herbicides combined with bio stimulants on the leaf greenness index SPAD, tuber yield and the vitamin C content in tubers.

MATERIAL AND METHODS

Field experiment and agrotechnological treatments

The field experiment was carried out for three years, from 2012 to 2014, on a farm of the multi-branch company Soleks located in the District of Siedlce, east-central Poland. It was established in a complete block design with a split-plot arrangement, with three replicates. Two factors were examined in the experiment:

- factor I – three medium-early table potato cultivars: Bartek (stem-type cultivar), Gawin (stem-type cultivar) and Honorata (leaf-like cultivar);
- factor II – five methods of herbicide and bio stimulant application: 1. control unit without chemical control, 2. Harrier 295 ZC (linuron + clomazone) at a rate of 2.0 dm³ ha⁻¹, 3. Harrier 295 ZC (linuron + clomazone) at a rate of 2.0 dm³ ha⁻¹ and the Kelpak SL growth regulator (Ecklonia maxima) at a rate of 2.0 dm³ ha⁻¹, 4. Sencor 70 WG (metribuzin) at a rate of 1.0 kg ha⁻¹, 5. Sencor 70 WG (metribuzin) at a rate of 1.0 kg ha⁻¹ and the Asahi SL growth regulator (sodium para-nitrophenol, sodium ortho-nitrophenol, sodium 5-nitroguaiacol) at a rate of 1.0 dm³ ha⁻¹.

Herbicides and bio stimulants were used in accordance with the recommendations of the Institute of Plant Protection of Poland [Plant Protection Recommendations for 2014/15, 2014]. The dates of major agricultural treatments in the experiment are presented in Table 1.

The work of Gugała et al. [2018] presents a detailed description of the treatments applied to units with herbicides and bio stimulants. There were 45 plots in the experiment and the area of each plot was 18.75 m² (that is, 15 plants spaced every 37 cm in five rows, each 67.5 cm apart). Each year, the previous crop was winter wheat. The potato plants were protected against diseases.
and insects following recommendations of the Institute of Plant Protection of Poland [Plant Protection Recommendations for 2014/15, 2014]. During the growing season, the Colorado potato beetle was controlled with the following insecticides: Apacz 50 WG (clothianidin) and Fastac 100 EC (alpha, cypermethrin); the fungicides used against potato blight were as follows: Ridomil Gold MZ 68 WG (metalaxyl-M+mancozeb) and Altima 500 SC (fluazinam).

Leaf greenness index SPAD

The assessment of leaf greenness SPAD (Soil Plant Analysis Development) was conducted using a SPAD-502Plus measuring device (Konica Minolta, INC, Japan). The SPAD-502Plus chlorophyll meter is a small, handy, non-destructive device the readings of which are expressed in nonmetric SPAD units ranging from 0 to 200 [Chlorophyll meter SPAD 502Plus/502DL Plus]. It measures the light absorption by leaves at the wavelengths of 650 and 940 nm. The measurements were taken twice at 10-day intervals, beginning at the stage of full flowering (BBCH 67-68) and after chemical control treatments with herbicides and biostimulants Adamczewski and Matysiak [2011] (Table 2).

Ten individual readings were taken in the second row of each plot starting with the third plant (on a second leaf from the top of the plant). The SPAD readings were taken in the morning between ten and noon on the same plants. Next, the values were recorded and averaged.

Plant height, tuber yield and determination of the vitamin C content

When the potato plants were fully developed, that is at the flowering stage (BBCH 67-68), 10 plants in each plot were analysed at three replicates. Each year, prior to harvest, tubers of randomly selected ten plants were dug out in each unit to determine the yield structure based on the following size fractions: 35 or less, 36–50, 51–60 and 60 mm or more. Total tuber yield comprised the weight of tubers manually harvested from each plot and the weight

Table 1. Dates of major agricultural treatments in the experiment

| Parameters                                                                 | 2012               | 2013               | 2014               |
|---------------------------------------------------------------------------|--------------------|--------------------|--------------------|
| Fertilization with phosphorus (44 kg ha⁻¹ P) and potassium (125 kg ha⁻¹ K) and farmyard manure (25 t ha⁻¹) – autumn | 10.11.2011         | 14.11.2012         | 15.11.2013         |
| Nitrogen fertilization 100 kg ha⁻¹ N – spring                            | 27.04.2012         | 06.05.2013         | 21.04.2014         |
| Planting potato tubers                                                  | 30.04.2012         | 08.05.2013         | 23.04.2014         |
| Application Harrier 295 ZC (linuron+clomazone)                          | 10.05.2012         | 18.05.2013         | 02.05.2014         |
| Application Kelpak SL (Ecklonia maxima)                                 | 06.06. and 20.06.2012 | 12.06. and 24.06.2013 | 31.05. and 20.06.2014 |
| Application Sencor 70 WG (metribuzin)                                   | 22.05.2013         | 29.05.2013         | 18.05.2014         |
| Application Asahi SL (sodium para-nitrophenol, sodium ortho-nitrophenol, sodium 5-nitroguaiacol) | 06.06. and 20.06.2012 | 12.06. and 24.06.2013 | 31.05. and 20.06.2014 |
| Date of harvest                                                         | 04.09.2012         | 04.09.2013         | 02.09.2014         |

Table 2. Occurrence of the main development phases of potato cultivars

| Development phases | 2012 | 2013 | 2014 |
|--------------------|------|------|------|
| BBCH scale         | Bartek | Gawin | Honorata | Bartek | Gawin | Honorata | Bartek | Gawin | Honorata |
| Emergence          | beginning 10 | full 12-13 | end 15 | 29.05 | 26.05 | 29.05 | 05.06 | 02.06 | 07.06 | 24.05 | 21.05 | 25.05 |
| Flower buds 51     | 25.06 | 20.06 | 20.06 | 26.06 | 28.06 | 24.06 | 20.06 | 16.06 | 17.06 |
| Flowering          | beginning 60 | full 67-68 | end 69 | 25.06 | 22.06 | 23.06 | 30.06 | 02.07 | 29.06 | 22.06 | 18.06 | 21.06 |
| Yellowing          | beginning 81 | full 95 | end 99 | 20.08 | 17.08 | 17.08 | 18.08 | 16.08 | 18.08 | 09.08 | 09.08 | 14.08 |

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neutral pH (pH in 1 M KCl from 5.60 to 6.35), organic matter 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 potassium content (99.6–149.4 mg kg\(^{-1}\) K), and high magnesium content (50.0–56.0 mg kg\(^{-1}\) Mg).

The weather data are presented in Table 3. On the basis of Sielianinov’s hydrothermal coefficient, the year 2012 was dry, 2013 was optimum and 2014 was relatively dry [Skowera et al. 2014].

In 2012, the average air temperature in April-September was 15.4 °C and was by 0.7 °C higher than the long-term mean for these months. In contrast, precipitation was lower than the long-term value, rendering the growing season unfavourable for potato growth and development.

In 2013, the temperature was higher than the long-term mean and precipitation was by higher than the long-term value as much as 166.1 mm.

**Soil and meteorological conditions**

The soil samples were taken each year before the experiment was set up from the topsoil at a depth of 0–30 cm. The soil was classified as Haplic Luvisol [IUSS Working Group WRB, 2015]. The soil was characterised by slightly acidic to neutral pH (pH in 1 M KCl from 5.60 to 6.35), organic matter 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 potassium content (99.6–149.4 mg kg\(^{-1}\) K), and high magnesium content (50.0–56.0 mg kg\(^{-1}\) Mg).

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**Table 3.** Rainfall, air temperature and the hydrothermal of coefficient Sielianinov during the potato growing season according to the meteorological station in Zawady

| Year | Month | Rainfall (mm) | Air temperature (°C) | Hydrothermal coefficient \(k^*\) | Evaluation of the month* |
|------|-------|---------------|----------------------|-----------------------------|--------------------------|
| 2012 April | 29.9 | 8.9 | 1.10 | relatively dry |
| May | 53.4 | 14.6 | 1.20 | relatively dry |
| June | 76.2 | 16.3 | 1.60 | optimal |
| July | 43.0 | 20.7 | 0.69 | very dry |
| August | 51.0 | 18.0 | 0.94 | dry |
| September | 11.4 | 14.1 | 0.27 | extremely dry |
| Sum/Average | 264.9 | 15.4 | 0.95 | dry |
| 2013 April | 36.0 | 7.4 | 1.60 | optimal |
| May | 105.9 | 15.3 | 2.30 | humid |
| June | 98.8 | 18.0 | 1.80 | relatively humid |
| July | 91.3 | 19.0 | 1.60 | optimal |
| August | 15.0 | 18.8 | 0.30 | extremely dry |
| September | 94.3 | 11.7 | 2.70 | very humid |
| Sum/Average | 441.3 | 15.0 | 1.60 | optimal |
| 2014 April | 45.0 | 9.8 | 1.50 | optimal |
| May | 92.7 | 13.5 | 2.30 | humid |
| June | 55.4 | 15.4 | 1.20 | relatively dry |
| July | 10.0 | 20.8 | 0.16 | extremely dry |
| August | 105.7 | 18.1 | 1.90 | relatively dry |
| September | 26.3 | 14.1 | 0.62 | very dry |
| Sum/Average | 335.1 | 15.3 | 1.20 | relatively dry |
| Multiyear 1987-2000 | 275.2 | 14.7 | | |

* hydrothermal of coefficient Sielianinov was calculated according to the formula: \(k = 10 \frac{P}{\Sigma t}\), Skowera et al. [2014], where: \(P\) - the sum of the monthly rainfalls in mm, \(\Sigma t\) - monthly total air temperature > 0 °C. Ranges of values of this coefficient were classified as follows: up to 0.4- extremely dry; 0.41–0.7 - very dry; 0.71–1.0 - dry; 1.01–1.3- relatively dry; 1.31–1.6 - optimal; 1.61–2.0 - relatively humid; 2.01–2.5 - humid; 2.51–3.0 - very humid; over 3.0- extremely humid
The meteorological conditions in the growing season 2014 were the most favourable as the air temperature averaged 15.3 °C and precipitation sum reached 335.1 mm. According to Kalbarczyk and Kalbarczyk [2009], the weather conditions which are optimum for plant yielding in Poland consist of the average air temperature from May to September of 15.2 °C and precipitation sum 335 mm and from the stage of flowering to maturing (July and August), potato plant water demand is at its highest. In the study reported here, in 2012, 2013 and 2014, precipitation from July to August was, 94.0, 106.3 and 115.7 mm, respectively.

Statistical analysis

The data obtained in the experiment were analysed statistically using ANOVA. The significance of the sources of variation was tested with the F Fisher-Snedecor test, and the significance of differences between means was checked at the significance level $p \leq 0.05$ using Tukey’s multiple intervals. All calculations were performed in MS Excel using the authors’ own algorithms based on the split-plot mathematical model. The above-mentioned statistical procedures are presented in the work by Trętowski and Wójcik [1991]. The relationships between potato plant height, yield of large tubers, vitamin C content and the leaf greenness index SPAD were also determined by computing linear correlation coefficients.

RESULTS AND DISCUSSION

Leaf greenness index SPAD

The SPAD leaf greenness index determined at the first date averaged 39.71 units and ranged from 34.87 to 43.70 (Tables 4, 5) according to cultivars, methods of herbicide and biostimulant application and atmospheric conditions in the study years. At the second date, SPAD was higher as it averaged 40.64 units and, depending on the experimental factors, ranged from 36.53 to 44.09 units. The values were close to readings reported by Mauromicale et al. [2006], Li et al. [2015], Zarzyńska and Pietraszko [2017] and Trawczyński [2019].

The cultivars grown in the experiment differed significantly in terms of the leaf greenness index. The highest value of the discussed parameter was recorded for cv. Honorata, being significantly lower for cv. Bartek and the lowest for cv. Gawin. The SPAD values which varied according to cultivars have been reported by other authors [Giletto et al. 2010, Zarzyńska and Pietraszko 2017].

In the study reported here, the leaf greenness index values were affected by the methods of herbicide and biostimulant application. These products increased the SPAD parameters compared with control, the highest readings resulting from a combined application of herbicides and biostimulants. A similar response was observed by Dvořák et al. [2016], whereas Wadas and Dziugieł [2020] found no influence of the following biostimulants: Bio-algeen S90,
Kelpak SL and HumiPlant on the SPAD values in potato leaves although they noticed a significant impact of study years on this characteristic. In the research discussed here, there was no influence of weather conditions nor interaction between years and methods of product application on SPAD determined at both dates (Table 5).

**Potato plant height, yield of large tubers and the vitamin C content in potato tubers**

Potato plant height, yield of large tubers and the vitamin C content were significantly affected by methods of herbicide and biostimulant application as well as cultivars, weather conditions having an effect on plant height only (Tables 6, 7).

### Table 5. Leaf greenness index SPAD depending on weather conditions during the study years

| Methods of herbicides and biostimulants application | Years | Mean value |
|----------------------------------------------------|-------|------------|
|                                                     | 2012  | 2013       | 2014       |
| **Leaf greenness index – SPAD I**                  |       |            |            |
| 1. Control object                                  | 36.99A| 38.03A     | 38.70A     | 37.91d     |
| 2. Harrier 295 ZC                                  | 39.09A| 38.57A     | 39.80A     | 39.15c     |
| 3. Harrier 295 ZC + Kelpak SL                      | 40.16A| 39.23A     | 40.61A     | 40.09b     |
| 4. Sencor 70 WG                                    | 39.79A| 39.23A     | 41.51A     | 40.18b     |
| 5. Sencor 70 WG + Asahi SL                         | 40.93A| 40.81A     | 42.30A     | 41.35a     |
| Mean                                               | 39.39a| 39.17a     | 40.58a     | 39.71      |
| **Leaf greenness index – SPAD II**                 |       |            |            |
| 1. Control object                                  | 37.31A| 40.04A     | 40.26A     | 39.20d     |
| 2. Harrier 295 ZC                                  | 38.67A| 40.60A     | 41.03A     | 40.10c     |
| 3. Harrier 295 ZC + Kelpak SL                      | 40.44A| 41.49A     | 41.60A     | 41.18b     |
| 4. Sencor 70 WG                                    | 39.53A| 41.21A     | 41.77A     | 40.84bc    |
| 5. Sencor 70 WG + Asahi SL                         | 41.53A| 41.82A     | 42.45A     | 41.93a     |
| Mean                                               | 39.50a| 41.00a     | 41.42a     | 40.64      |

Means followed by the same letters do not differ significantly at P≤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 methods and years.

### Table 6. Plant height, yield of tubers and vitamin C content in potato depending on cultivar

| Methods of herbicides and biostimulants application | Cultivars | Mean value |
|----------------------------------------------------|-----------|------------|
|                                                     | Bartek    | Gawin      | Honorata  |
| **Potato plant height (cm)**                        |           |            |           |
| 1. Control object                                  | 56.02A    | 63.04A     | 61.57A    | 60.21d    |
| 2. Harrier 295 ZC                                  | 58.44A    | 65.09A     | 65.02A    | 62.85c    |
| 3. Harrier 295 ZC + Kelpak SL                      | 62.47A    | 71.76A     | 69.03A    | 67.76ab   |
| 4. Sencor 70 WG                                    | 60.32A    | 70.11A     | 66.50A    | 65.64bc   |
| 5. Sencor 70 WG + Asahi SL                         | 65.89A    | 74.42A     | 70.69A    | 70.32a    |
| Mean                                               | 60.63b    | 68.88a     | 66.56a    | 65.36     |
| **Yield of large tubers (diameter over 50 mm) (t ha⁻¹)** |       |            |            |
| 1. Control object                                  | 21.51E    | 16.31C     | 20.79D    | 19.54d    |
| 2. Harrier 295 ZC                                  | 25.78D    | 23.54B     | 25.68C    | 25.00c    |
| 3. Harrier 295 ZC + Kelpak SL                      | 27.16C    | 24.03B     | 28.38B    | 26.52b    |
| 4. Sencor 70 WG                                    | 29.52B    | 26.09A     | 33.33A    | 29.65a    |
| 5. Sencor 70 WG + Asahi SL                         | 32.33A    | 27.39A     | 32.47A    | 30.73a    |
| Mean                                               | 27.26a    | 23.47b     | 28.13a    | 26.29     |
| **Vitamin C content of fresh matter (mg kg⁻¹)**    |           |            |            |
| 1. Control object                                  | 199.5     | 193.7      | 200.7     | 197.9c    |
| 2. Harrier 295 ZC                                  | 203.4     | 195.8      | 202.6     | 200.6b    |
| 3. Harrier 295 ZC + Kelpak SL                      | 205.0     | 197.0      | 203.9     | 202.0a    |
| 4. Sencor 70 WG                                    | 202.0     | 195.6      | 204.2     | 200.6b    |
| 5. Sencor 70 WG + Asahi SL                         | 203.2     | 199.1      | 206.4     | 202.9a    |
| Mean                                               | 202.7a    | 196.2b     | 203.5a    | 200.8     |

Means followed by the same letters do not differ significantly at P≤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 methods and cultivars.
The tallest plants were recorded for cv. Gawin, cv. Bartek being the lowest. The highest large tuber yield and vitamin C content were found for cv. Honorata. They were lower for cv. Bartek and significantly lowest for cv. Gawin. The cultivar-related differences for the discussed characteristics have been confirmed by other authors [Esecuredo et al. 2018, Gugała et al. 2018, Ierna and Mauromicale 2019, Trawczyński 2019].

Herbicides applied alone or in combination with biostimulants contributed to an increase in plant height, yield of large tubers and the vitamin C concentration compared with control. The tallest potato plants and the highest vitamin C content in tubers were observed after a combined application of herbicides and biostimulants, the highest yield being harvested following spraying with Sencor and Sencor+Asahi SL. A positive effect of chemical control methods on tuber yield was reported by Barbaś and Sawicka [2020] and Gugała et al. [2018] whereas Ahmadi Lahijani et al. [2018], Trawczyński [2020] and Wadas and Dziugiel [2020] observed a positive influence of biostimulants on tuber yields, yield structure and elements of chemical composition, including vitamin C. Barbaś and Sawicka [2015] found increased vitamin C contents, compared with control tubers, following spraying of the crop with the herbicide Sencor 70 WG in combination with Titus 25 WG, Fusilade Forte 150 EC and Apyros 75 WG.

The weather conditions during the growing season significantly influenced plant height only (Table 7). The tallest plants grew in 2012 and the lowest in 2013. It was also observed that, in terms of yield and vitamin C accumulation, precipitation and thermal conditions which were the closest to optimum prevailed in 2014, which is consistent with the findings of long-term research by Kalbarczyk and Kalbarczyk [2009]. Linear correlation coefficients confirmed that the leaf greenness index SPAD at both determination dates was strongly associated with plant height and large tuber yield of all the cultivars (Table 8).

The vitamin C content was significantly correlated with SPAD I (the first date) for cv. Honorata, and SPAD II (the second date) for cv. Gawin and Honorata. Similar relationships were reported by other authors. Tang et al. [2018] found that SPAD was positively correlated with the Solanum tuberosum plant height under thermal stress conditions, Dvořák and Král [2019] observed a strong correlation of SPAD with tuber yield and weight.

### Table 7. Plant height, yield of tubers and vitamin C content in potato tubers depending on weather conditions during the study years

| Methods of herbicides and biostimulants application | Years          | Mean value |
|-----------------------------------------------------|---------------|------------|
|                                                     | 2012          | 2013       | 2014       |
| Potato plant height (cm)                            |               |            |            |
| 1. Control object                                   | 62.53A        | 56.80A     | 61.27A     | 60.21d     |
| 2. Harrier 295 ZC                                    | 64.09A        | 61.20A     | 63.27A     | 62.85c     |
| 3. Harrier 295 ZC + Kelpak SL                        | 69.66A        | 65.30A     | 68.33A     | 67.76ab    |
| 4. Sencor 70 WG                                      | 67.33A        | 63.00A     | 66.60A     | 65.64bc    |
| 5. Sencor 70 WG + Asahi SL                           | 74.06A        | 66.50A     | 70.40A     | 70.32a     |
| Mean                                                 | 67.53a        | 62.60b     | 65.96a     | 65.36      |
| Yield of large tubers (diameter over 50 mm) (t ha⁻¹) |               |            |            |
| 1. Control object                                    | 16.50C        | 20.01C     | 22.11C     | 19.54d     |
| 2. Harrier 295 ZC                                    | 24.59B        | 25.66B     | 24.75B     | 25.00c     |
| 3. Harrier 295 ZC + Kelpak SL                        | 29.00A        | 26.51B     | 24.06B     | 26.52b     |
| 4. Sencor 70 WG                                      | 29.58A        | 27.96B     | 31.40A     | 29.65a     |
| 5. Sencor 70 WG + Asahi SL                           | 30.94A        | 30.81A     | 30.43A     | 30.73a     |
| Mean                                                 | 26.12a        | 26.19a     | 26.55a     | 26.29      |
| Vitamin C content of fresh matter (mg kg⁻¹)         |               |            |            |
| 1. Control object                                    | 195.3A        | 198.6A     | 199.9A     | 197.9c     |
| 2. Harrier 295 ZC                                    | 199.5A        | 201.3A     | 201.0A     | 200.6b     |
| 3. Harrier 295 ZC + Kelpak SL                        | 200.8A        | 203.5A     | 201.7A     | 202.0a     |
| 4. Sencor 70 WG                                      | 197.7A        | 201.8A     | 202.3A     | 200.6b     |
| 5. Sencor 70 WG + Asahi SL                           | 199.6A        | 204.0A     | 205.2A     | 202.9a     |
| Mean                                                 | 198.6a        | 201.8a     | 202.0a     | 200.8      |

Means followed by the same letters do not differ significantly at P≤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 methods and years.
of tubers with the diameter 55–60 mm. Mauromicale et al. [2006] reported highly significant correlations of the chlorophyll content with tuber yield \( r = 0.992 \) and plant dry matter yield \( r = 0.969 \). Wadas and Kalinowski [2017] demonstrated that, in cv. Lord, the correlation between the leaf greenness index SPAD and tuber weight was stronger following an application of the Tytanit® biostimulant compared with non-treated control. The role of a chlorophyll meter and the possibility of its application are also stressed by other authors who point out strong correlations between readings obtained using a SPAD-502 chlorophyll meter and an N-tester in the examinations of various crop plant species [Pacewicz and Gregorczyk 2009, Zhu et al. 2012].

**CONCLUSIONS**

The findings of this study showed that herbicides and herbicides combined with biostimulants contributed to an increase in the leaf greenness index SPAD determined by a Konica Minolta SPAD-502Plus measuring device, plant height, yield of tubers and the vitamin C content in tubers. Strong correlation associations between SPAD and the determined characteristics (potato plant height, yield of large tubers and the vitamin C content) confirm a positive effect of the applied products and, simultaneously, they suggest SPAD may be a good indicator of normal plant development. Thus, the device measuring SPAD, as a non-invasive tool, may have a wider range of applications in integrated and precision agriculture.

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### Table 8. Plant height, yield of tubers and vitamin C content in potato tubers depending on weather conditions during the study years

| Index                             | Cultivars | Potato plant height (cm) | Yield of large tubers (t ha⁻¹) | Vitamin C content in of fresh matter (mg kg⁻¹) |
|-----------------------------------|-----------|--------------------------|-------------------------------|-----------------------------------------------|
| Leaf greenness index              |           |                          |                               |                                               |
| – SPAD I term                     | Bartek    | 0.9678**                 | 0.8802**                      | 0.5826ns                                      |
|                                  | Gawin     | 0.9593**                 | 0.9186**                      | 0.8765ns                                      |
|                                  | Honorata  | 0.9617**                 | 0.9526**                      | 0.9492**                                      |
| Leaf greenness index              |           |                          |                               |                                               |
| – SPAD II term                    | Bartek    | 0.9747**                 | 0.9757**                      | 0.6215ns                                      |
|                                  | Gawin     | 0.9916**                 | 0.9413**                      | 0.9244**                                      |
|                                  | Honorata  | 0.9852**                 | 0.9844**                      | 0.9838**                                      |

** Significant at P≤0.05; ns - non-significant
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