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EFFECTS OF SILICATE FERTILIZER ON SEED YIELD IN TIMOTHY-GRASS (*Phleum pratense* L.)

WPŁYW NAWOZU KRZEMOWEGO NA PLON NASION W UPRAWIE TYMOTKI ŁĄKOWEJ (*Phleum pratense* L.)

Abstract: A field experiment was conducted in the years 2012-2014, at the Plant Breeding Station in Polanowice near Krakow (220 m a.s.l.). The aim of the study was to investigate the effect of silicon (Si) on seed yield and quality of timothy-grass (*Phleum pratense* L.) of "Egida" cultivar. A univariate field experiment in randomized block design was repeated four times, and the area of the experimental plots was 10 m^2. The soil on the experimental plots was a loess derived haplic phaeozem of bonitation class I. The experimental factor was spraying with a silicon formulation in the form of Optysil® fertilizer at three doses: 0.2, 0.5 and 0.8 $dm^3 \cdot ha^{-1}$. During the growing season, the plants were evaluated for their height, leaf greenness index (*SPAD*) and general condition. After harvesting, the seed yield and quality were assessed. The study revealed a significant effect of silicon on plant height, general condition and yield and quality of the seeds. The plants treated with silicon showed lower infestation rate with pathogens and pests than the control ones. Foliar fertilization with the highest dose of the silicon formulation (0.8 $dm^3 \cdot ha^{-1}$) caused a significant increase in seed yield as compared with control. The effects were also satisfactory in the plants treated with the formulation at 0.5 $dm^3 \cdot ha^{-1}$. The seeds obtained from silicon-treated plants were bigger, as revealed by the weight of 1000 seeds, and exhibited higher germination ability than the control seeds.

Keywords: timothy-grass (*Phleum pratense* L.), silicon, seed yield, weight of 1000 seeds, germination ability

Introduction

The most common problem of plant production, particularly an intensive one, is dealing with adverse environmental factors that limit the potential of the crops despite implementing all recommended agronomic methods. This may be mitigated by using bio-stimulators, i.e. preparations that stimulate plant processes and trigger the mechanisms that enable plant functioning under stress and increase quantity and quality of yield. The formulations available on the market differ in their mechanisms of action, technological purpose and origin. Silicon is one of the elements that may stimulate plant growth and development and reduce the threat of pathogen and pest infestation [1-5]. This element is

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not among the vital ones, i.e. macronutrients or micronutrients. However, it is present in most plants (particularly monocotyledons) in large quantities comparable with the content of calcium, magnesium, and even phosphate [1, 6-8]. Silicon limits the toxicity of excess manganese and iron, and positively affects the ion balance in plants [9]. It strengthens cell walls and improves plant resistance to fungal diseases and unfavourable conditions, such as low temperature or water shortage [1, 7, 10].

Liquid forms of silicon absorbed by plants are unstable, and they are transformed into water-insoluble gel shortly after synthesis. In practice, silicon-containing fertilizers are often applied in granular form, especially in Asia and South America. The content of absorbable silicon in these fertilizers is very low, and therefore their doses amount to a few tons per hectare. This makes their use cumbersome and in fact limited to the period just before or shortly after sowing [11, 12]. Only the development of liquid formulations containing stabilized silicic acids allowed farmers to use silicon for foliar fertilization. This form of application can be easily combined with using other plant protection products and limits the need for management practices. The effects of silicon on crops such as vegetables, fruit trees and shrubs, rape, wheat, potato, corn and meadow plants have been investigated also in Poland [13, 14]. There are, however, no reports on using this element on seed plantations of forage grasses. Therefore, the aim of this study was to determine the effect of foliar application of silicon preparation on seed yield and quality in timothy-grass (*Phleum pratense* L.) crop.

Materials and methods

The study was conducted in the years 2012-2014, at the Plant Breeding Station in Polanowice near Krakow (220 m a.s.l.), on loess derived haplic phaeozem. Chemical properties of the soil were as follows: pH_{KCl} - 7.1 and absorbable P - 58.0, K - 132.7 and Mg - 44.8 $mg \cdot kg^{-1}$. Annual rainfall in the study period ranged from 434 to 685 mm (Table 1). Mean rainfall during the vegetation period (April-September) was 240-508 mm. Average annual temperature in the study period ranged from 5.4 to 6.1°C, and between April and September from 10.9 to 12.2°C.

Table 1

Rainfall and average air temperature at the Plant Breeding Station in Polanowice in the years 2012-2014

Month/Year	**2012**	**2013**	**2014**	**2012-2014**
	Monthly rainfall [mm]			
1	31	63	21	38
2	16	23	23	21
3	5	54	34	31
4	49	21	40	36
5	36	73	76	62
6	88	229	102	140
7	29	27	163	73
8	10	10	117	46
9	28	58	11	32
10	96	9	51	52
11	34	55	26	38
12	12	11	22	15
Total	434	631	685	583
Total April-September	240	417	508	388

Month/Year	**2012**	**2013**	**2014**	**2012-2014**
	Average monthly air temperature [°C]			
1	–2.4	–3.6	–2.8	–2.9
2	–9.6	–2.5	–1.6	–4.6
3	0.6	–2.5	2.6	0.2
4	5.1	4.3	5.1	4.8
5	10.6	11.3	10.3	10.7
6	15.8	15.3	13.7	14.9
7	17.3	16.5	9.6	14.5
8	14.9	15.9	16.7	15.8
9	9.7	8.8	10.1	9.5
10	4.6	5.9	7.3	5.9
11	2.9	3.2	2.9	3.0
12	–4.9	–0.2	–0.2	–1.8
Average	5.4	6.0	6.1	5.8
Average April-September	12.2	12.0	10.9	11.7

The experiment of randomized block design was repeated four times (plots 1.5x6.67 m^2), and included four objects: control (no formulation) and plants sprayed with three different doses, i.e. 0.2, 0.5 and 0.8 $dm^3 \cdot ha^{-1}$ of Optysil®. Optysil® contains 93.6 g of Si per 1 L of the solution, so the actual Si doses were 18.7, 46.8, and 74.9 g $Si \cdot ha^{-1}$. This fertilizer is considered an anti-stress product manufactured by INTERMAG sp. z o.o. in Olkusz. This fertilizer is a mineral growth stimulator, as per the decision of the Ministry of Agriculture and Rural Development No. S-514/15, and it is manufactured by INTERMAG sp. z o.o. in Olkusz.

The first foliar spraying was carried out at stem elongation phase, and the second two weeks later.

The experiment was performed using "Egida" cultivar. This cultivar was registered in the National Register in 2005, and its breeder is Malopolska Breeding Company Krakow.

Soil mineral fertilizers were used at the following doses: pre-sowing 50 kg $N \cdot ha^{-1}$ as ammonium nitrate (NH_4NO_3), 26.2 kg $P_2O_5 \cdot ha^{-1}$ as triple superphosphate ($Ca(H_2PO_4)_2$), and 66.4 kg $K_2O \cdot ha^{-1}$ as 57% potassium salt (KCl). In the years of full utilization, the same doses and forms of K and P fertilizers were used in the fall. Nitrogen fertilization was performed three times. The first dose of 40 kg $N \cdot ha^{-1}$ was applied after seed harvest, the second of 20 kg $N \cdot ha^{-1}$ in the spring at the start of the growing season, and the third of 40 kg $N \cdot ha^{-1}$ at the turn of April and May.

Timothy-grass seeding rate was 4 $kg \cdot ha^{-1}$. The cultivar sown in this experiments was grown without any nurse crop.

To eliminate dicotyledonous weeds, the plants were sprayed with herbicides at the tillering stage. Plots heavily contaminated with dicotyledonous plants were sprayed with Starane 250 *SL* (Dow AgroSciences, Poland) at 0.6 $dm^3 \cdot ha^{-1}$. Monocotyledonous weeds were eliminated at the beginning of September and in the spring at the start of vegetation with Stomp 330 *EC* (BASF, Agro B.V., Wadenswil/Au, Switzerland) at 5 $dm^3 \cdot ha^{-1}$, dissolved in 300 dm^3 of water.

The effects of foliar fertilization on chlorophyll content were assessed for each year of the experiment. Leaf greenness index (*SPAD*) was measured with chlorophyll meter Minolta *SPAD 502DL* (Minolta, Osaka, Japan) in the upper leaves. The measurements were performed on each plot and included thirty fully developed leaves.

Plant height was assessed at anthesis (June) with a measuring tape.

Timothy-grass lodging, infestation with diseases and pest damage injury were evaluated using a nine grade scale, where 1° represented the worst condition and 9° corresponded to the optimum of an investigated trait.

The seeds were harvested in the third decade of July and the first days of August, with a plot combine Wintersteiger *NM-ELITE* (Wintersteiger AG Ried, Austria). After the harvest, the plots were cleared of straw of crop residue. After threshing, the seeds were cleaned and dried to achieve moisture content of 14%.

Weight of 1000 seeds and germination ability were determined individually for each plot in the samples collected after threshing, drying and cleaning. Germination ability was evaluated after 10 days with Jacobsen's germination apparatus (Laborset, Poland) according to PN-/R-65950 standard [15].

The results were subjected to an analysis of variance, and the significance of differences between means was determined with Duncan test, using Statistica 10 PL software.

Results

Leaf greenness index (*SPAD*) was variable and depending on the fertilizing variant, developmental stage and year of study ranged from 36.4 to 46.2 (Table 2). Plants fertilized with 46.8 and 74.9 g of $Si \cdot ha^{-1}$ had similar chlorophyll content that was significantly higher ($p \leq 0.05$) than that in the plants fertilized with 18.7 g of $Si \cdot ha^{-1}$ and control ones. Leaf greenness index was the highest at anthesis. Changes in this parameter followed a similar pattern at all developmental stages. The lowest *SPAD* values were determined for control plants.

Table 2

Leaf greenness index (*SPAD*) of timothy-grass “Egida” cv. at different developmental stages depending on Si dose (3-year average)

Si dose [g·ha^{-1}]	**Developmental stage**			
	Stem elongation	**Heading**	**Flowering**	**Milky Ripeness**
Control	36.8 (±0.7) ^{b}	38.4 (±0.8) ^{b}	39.3 (±0.7) ^{b}	36.4 (±0.7) ^{b}
Si (18.7 g)	37.4 (±0.8) ^{b}	38.9 (±0.9) ^{b}	42.1 (±0.6) ^{b}	37.2 (±0.8) ^{b}
Si (46.8 g)	38.9 (±0.9) ^{a}	41.9 (±0.7) ^{a}	44.8 (±0.9) ^{a}	38.3 (±0.6) ^{a}
Si (74.9 g)	40.0 (±0.7) ^{a}	42.7 (±0.7) ^{a}	46.2 (±0.7) ^{a}	40.2 (±0.9) ^{a}
Standard deviation	0.8	0.8	0.7	0.8
Variation coefficient [%]	3.8	5.3	7.1	4.3

a, *b* - values marked with different letters are significantly different ($p \leq 0.05$)

Depending on the year of the experiment and Si fertilizer dose, the height of the generative shoots ranged between 92.8 and 104.3 cm (Table 3). The shortest shoots were found in the control and in the plants fertilized with 18.7 g of $Si \cdot ha^{-1}$. The plants fertilized with higher doses of Si had significantly ($p \leq 0.05$) longer shoots than the control ones. The highest variability ($V = 4.0\%$) was observed for the year 2012, in which the lowest rainfall per growing season was recorded (240 mm).

Timothy-grass plants were particularly susceptible to stem rust (*Puccinia graminis var. phlei-pratensis*) in the second and third year of study (Table 4). The greatest variability ($V = 18.8\%$) in this aspect was recorded in the third year, characterized also by the most abundant rainfall in the growing season (508 mm). In 2012, no effects of Si fertilization on infestation rate were observed, while in 2013 and 2014 the plants fertilized with higher doses of Si were more resistant to stem rust than the control ones.

Table 3

The height of generative shoots in timothy-grass [cm]

Si dose $[g \cdot ha^{-1}]$	**Year of utilization**			**Mean**
	2012	**2013**	**2014**	
Control	92.8 (±2.5) ^{b}	98.8 (±2.4) ^{b}	96.8 (±2.6) ^{b}	96.2 ^{b}
Si (18.7 g)	94.2 (±3.3) ^{ab}	101.6 (±4.3) ^{ab}	99.8 (±3.8) ^{b}	98.5 ^{b}
Si (46.8 g)	96.4 (±3.8) ^{a}	103.8 (±4.7) ^{a}	101.4 (±3.5) ^{a}	100.5 ^{a}
Si (74.9 g)	101.5 (±3.9) ^{a}	104.3 (±4.8) ^{a}	102.5 (±4.7) ^{a}	102.7 ^{a}
Standard deviation	3.4	4.0	3.7	3.7
Variation coefficient [%]	4.0	2.5	2.5	2.8

a, *b* - values marked with different letters are significantly different ($p \leq 0.05$)

Table 4

Timothy-grass infestation with stem rust (*Puccinia graminis var. phlei-pratensis*) in nine grade scale

Si dose $[g \cdot ha^{-1}]$	**Year of utilization**			**Mean**
	2012	**2013**	**2014**	
Control	8.5 (±0.3) ^{a}	6.3 (±0.7) ^{b}	6.0 (±0.4) ^{b}	7.0 ^{b}
Si (18.7 g)	8.6 (±0.3) ^{a}	7.2 (±0.5) ^{ab}	6.5 (±0.3) ^{b}	7.4 ^{ab}
Si (46.8 g)	9.0 (±0.0) ^{a}	8.7 (±0.3) ^{a}	8.6 (±0.2) ^{a}	8.8 ^{a}
Si (74.9 g)	9.0 (±0.0) ^{a}	8.8 (±0.1) ^{a}	8.7 (±0.2) ^{a}	8.8 ^{a}
Standard deviation	0.1	0.4	0.3	0.3
Variation coefficient [%]	3.0	15.6	18.8	12.0

1° - the worst condition, 9° - optimum condition

The investigated plants exhibited also variable resistance to powdery mildew (*Erysiphe graminis* DC.), depending on the year and Si fertilization dose. In the second and third year the infestation rate was much higher and the effects of Si treatment more visible (Table 5). The plants fertilized with higher doses of Si were significantly ($p \leq 0.05$) more resistant than the control ones. The greatest variability was observed for the second and third year of timothy-grass crop utilization (V = 17.0 and 19.4%, respectively).

Table 5

Infestation of timothy-grass with powdery mildew (*Erysiphe graminis* DC.) in nine grade scale

Si dose $[g \cdot ha^{-1}]$	**Year of utilization**			**Mean**
	2012	**2013**	**2014**	
Control	8.5 (±0.3) ^{a}	6.0 (±0.3) ^{b}	6.0 (±0.2) ^{b}	6.9 ^{b}
Si (18.7 g)	8.7 (±0.2) ^{a}	7.0 (±0.2) ^{ab}	6.2 (±0.3) ^{b}	7.3 ^{ab}
Si (46.8 g)	9.0 (±0.0) ^{a}	8.5 (±0.1) ^{a}	8.5 (±0.1) ^{a}	8.7 ^{a}
Si (74.9 g)	9.0 (±0.0) ^{a}	8.7 (±0.1) ^{a}	8.6 (±0.1) ^{a}	8.8 ^{a}
Standard deviation	0.1	0.2	0.2	0.2
Variation coefficient [%]	2.8	17.0	19.4	12.2

1° - the worst condition, 9° - optimum condition

Stem elongation stage in the first year of the study was marked with the presence of *Amaurosoma flavipes* Fall. (Table 6). The plants fertilized with higher doses of Si were significantly ($p \leq 0.05$) more resistant than the control ones. Variability of this parameter was the greatest in the first year of the study ($V = 20.6\%$).

Table 6

Damage of timothy-grass inflicted by *Amaurosoma flavipes* Fall. in nine grade scale

Si dose [g·ha^{-1}]	**Year of utilization**			**Mean**
	2012	**2013**	**2014**	
Control	6.0 (±0.3) ^{b}	8.7 (±0.3) ^{a}	8.8 (±0.3) ^{a}	7.9 ^{ab}
Si (18.7 g)	6.3 (±0.2) ^{b}	8.8 (±0.2) ^{a}	8.8 (±0.4) ^{a}	8.0 ^{ab}
Si (46.8 g)	8.7 (±0.1) ^{a}	8.9 (±0.1) ^{a}	9.0 (±0.0) ^{a}	8.9 ^{a}
Si (74.9 g)	8.9 (±0.0) ^{a}	9.0 (±0.0) ^{a}	9.0 (±0.0) ^{a}	9.0 ^{a}
Standard deviation	0.2	0.2	0.2	0.2
Variation coefficient [%]	20.6	1.5	1.3	7.0

1° - the worst condition, 9° - optimum condition

Lodging of timothy-grass plants depended on environmental conditions, mostly rainfall intensity and silicon application (Table 7). Considerable lodging was observed in the control plants in the second and third year of utilization. It was less pronounced in the plants fertilized with 46.8 and 74.9 g of Si·ha^{-1}. Silicon application at a dose of 74.9 g of Si·ha^{-1} reduced lodging by 35.4 and 23.4% in the second and third year, respectively, as compared to the control.

Table 7

Lodging of timothy-grass plants in nine grade scale

Si dose [g·ha^{-1}]	**Year of utilization**			**Mean**
	2012	**2013**	**2014**	
Control	8.5 (±0.3) ^{a}	6.5 (±0.3) ^{b}	6.4 (±0.3) ^{b}	7.1 ^{b}
Si (18.7 g)	8.6 (±0.1) ^{a}	7.0 (±0.4) ^{b}	6.6 (±0.4) ^{b}	7.4 ^{b}
Si (46.8 g)	8.8 (±0.0) ^{a}	8.6 (±0.3) ^{a}	7.2 (±0.5) ^{a}	8.2 ^{a}
Si (74.9 g)	9.0 (±0.0) ^{a}	8.8 (±0.2) ^{a}	7.9 (±0.4) ^{a}	8.6 ^{a}
Standard deviation	0.2	0.3	0.5	0.3
Variation coefficient [%]	2.5	14.9	9.6	8.7

a, b - values marked with different letters are significantly different ($p \leq 0.05$)
1° - the worst condition, 9° - optimum condition

Table 8

Seed yield in timothy-grass [kg·ha^{-1}]

Si dose [g·ha^{-1}]	**Year of utilization**			**Mean**
	2012	**2013**	**2014**	
Control	479 (±19) ^{b}	702 (±22) ^{b}	606(±24) ^{b}	596^{b}
Si (18.7 g)	500 (±16) ^{ab}	705 (±35) ^{b}	610 (±37) ^{ab}	605^{b}
Si (46.8 g)	532(±15) ^{a}	739(±28) ^{a}	640(±23) ^{a}	637^{a}
Si (74.9 g)	548(±21) ^{a}	746 (±19) ^{a}	680(±26) ^{a}	658^{a}
Standard deviation	18	26	28	24
Variation coefficient [%]	5.9	2.6	5.4	4.6

a, b - values marked with different letters are significantly different ($p \leq 0.05$)

Seed yield depended on experimental variant and year of the study and ranged from 479 to 746 kg·ha^{-1} (Table 8). Analysis of the seed yield for all three years of the study revealed that silicon fertilization at the doses of 46.8 and 74.9 g of Si·ha^{-1} caused a significant increase ($p \leq 0.05$) in this parameter as compared with control plants. Yield increment in the plants fertilized with 74.9 g of $Si \cdot ha^{-1}$ was 14.2% in the first year, 6.3% in the second year, and 12.2% in the third year. In the plants fertilized with 46.8 g of $Si \cdot ha^{-1}$, the seed yield increment was 10.9, 5.2, and 5.6% for the first, second, and third year, respectively, as compared with control.

Mean germination ability of timothy-grass for three years of the study (2012-2014) ranged from 88 to 96% (Table 9). Application of silicon at a dose of 74.9 g of $Si \cdot ha^{-1}$ improved germination ability by 6.8% in the first year of the study and by 6.7% in the second and third year, as compared with control. Fertilization with 46.8 g of $Si \cdot ha^{-1}$ caused 5.7, 5.6 and 5.6% increase in this parameter, respectively for the first, second, and third year of the experiment.

Table 9

Germination ability in timothy-grass [%]

Si dose [g·ha^{-1}]	**Year of utilization**			**Mean**
	2012	**2013**	**2014**	
Control	88.1 (±3.3) ^{b}	90.2 (±3.3) ^{b}	89.3 (±3.7) ^{b}	89.2 ^{b}
Si (18.7 g)	90.3 (±2.9) ^{b}	91.3 (±2.5) ^{b}	90.3 (±3.3) ^{b}	90.7 ^{b}
Si (46.8 g)	93.6 (±3.0) ^{a}	95.5 (±4.7) ^{a}	94.6 (±3.6) ^{a}	94.6 ^{a}
Si (74.9 g)	94.7 (±3.8) ^{a}	96.2 (±3.9) ^{a}	95.4 (±4.1) ^{a}	95.5 ^{a}
Standard deviation	3.3	3.6	3.7	3.5
Variation coefficient [%]	3.3	3.2	3.3	3.3

a, b - values marked with different letters are significantly different ($p \leq 0.05$)

Average weight of 1000 seeds for three years of the study ranged from 0.461 to 0.532 g (Table 10). Foliar fertilization with silicon increased the weight of 1000 seeds irrespective of Si concentration. However, significant differences ($p \leq 0.05$) were observed between seeds collected from the plants fertilized with 46.8 and 74.9 g of $Si \cdot ha^{-1}$. In the plants treated with 74.9 g of $Si \cdot ha^{-1}$ the increase in this parameter was 14.8% in the first, 9.2% in the second, and 11.0% in the third year, as compared with control.

Table 10

Weight of 1000 seeds [g]

Si dose [g·ha^{-1}]	**Year of utilization**			**Mean**
	2012	**2013**	**2014**	
Control	0.461 (±0.025) ^{b}	0.487 (±0.025) ^{b}	0.473 (±0.018) ^{b}	0.474^{b}
Si (18.7 g)	0.469 (±0.024) ^{b}	0.498 (±0.028) ^{b}	0.487 (±0.022) ^{b}	0.485^{b}
Si (46.8 g)	0.507 (±0.019) ^{a}	0.526 (±0.029) ^{a}	0.494 (±0.024) ^{a}	0.509^{a}
Si (74.9 g)	0.529 (±0.028) ^{a}	0.532 (±0.026) ^{a}	0.525 (±0.029) ^{a}	0.529^{a}
Standard deviation	0.024	0.027	0.023	0.025
Variation coefficient [%]	6.5	4.3	4.4	5.1

a, b - values marked with different letters are significantly different ($p \leq 0.05$)

Discussion

Crops are exposed to variable and often extreme climatic conditions. Among them, drought and high temperature cause especially intense abiotic stress. Silicon improves plant tolerance to drought by increasing their water absorption, thus enhancing dry matter production and general productivity. Moreover, silicon limits oxidative damage to functional molecules and improves plant antioxidant properties [16]. Numerous studies have shown a positive effect of silicon on crop yield [1-5]. In our study, foliar application of silicon improved seed yield throughout the growing season, and was particularly visible in the first year characterized also by the smallest rainfall amount per growing season. Ahmad et al. [17], who investigated the role of silicon in fertilization of wheat (*Triticum aestivum* L.) under different soil humidity conditions, reported that silicon application considerably improved plant biomass, height and ear weight. Also, the study of silicon fertilization under water shortage published by Hattori et al. [18] showed that Si reduced a decrease in dry matter in drought-exposed sorghum but did not affect dry matter production in humid conditions. Si fertilization improved also root growth, allowed for maintaining photosynthesis rate and for increasing stomatal conductance in comparison with non-fertilized plants. Gao et al. [19] found that the use of silicon increased water flow rate in the vessels, thus limiting transpiration rate and improving water management in plants. The work of Ahman et al. [20] and Ning et al. [21] showed a positive effect of Si fertilization on the production of rice straw, and similar results were published by Ahman et al. [17], Surapornpiboom et al. [22] and Sacala [23]. They found silicon responsible for controlling stomata functionality, photosynthesis, and water management, and consequently for more intense vegetative growth and greater production of straw. An experiment conducted by Wattanapayapkul et al. [24] and Cuong et al. [25] in rice indicated that silicon fertilization improved yield mainly by means of increasing the number of inflorescences per m^2 and the amount of filled grain.

Silicon application reduced also plant lodging. Wattanapayapkul et al. [24] concluded that, based on the knowledge of physiological function of silica in rice, silicon might be expected to improve mechanical resistance of leaf epidermal cells. Moreover, the leaves maintained in upright position do not cast shadows on each other and photosynthesis efficiency is increased. It was found that rice fertilized with silicon was more resistant to lodging [26]. Si application improved also phosphorus absorption, thus enhancing bioavailability of calcium and potassium that help to strengthen the plants and reduce lodging. Silicon is accumulated in the shoot at up to 10% of dry weight, and more than 90% of this element is present in the form of silica gel [6]. Silica gel is deposited on the cell wall of epidermal cells of leaves, stems, and hulls, forming a silica-cuticle double layer and a silica-cellulose double layer [27, 28]. The studies conducted in rice showed that silicon increased strength and rigidity of cell walls, thereby improving plant resistance to diseases, pests and lodging [6, 29]. Si fertilization resulted in a rise in leaf chlorophyll content that indicated increased nitrogen content. These two factors accompanied by sufficient availability of other macronutrients enhance the overall yield. In this work, SPAD index was higher in the plants treated with Si than in the control ones. Furthermore, differences in this parameter were observed depending on the time of measurement, as its values were the highest at the flowering stage. Ranganathan et al. [30] reported that treating rice plants with silicone restored chlorophyll content (SPAD value) and the efficiency of photosystem II in pest-infected rice leaves. Silicon has been found to stimulate photosynthesis, increase tissue strength and reduce transpiration rate [6]. The work of Xie et al. [31] suggested that silicon-based fertilizers increased chlorophyll content, net photosynthesis (P_n), and stomatal conductance (g_s) in maize leaves but reduced transpiration rate (E) and intercellular carbon dioxide concentration (C_i). Similar results were reported for other plant species [32, 33]. Gong et al. [34] reported that silicon treatment increased the amount of photosynthetic pigments and soluble plant proteins during drought. Another study by Li et al. [35] showed that Si fertilization increased net photosynthesis rate, chlorophyll content, the activity of superoxide dismutase (*SOD*), peroxidase (*POD*), catalase (*CAT*), ascorbate peroxidase (*APX*), and restrained the increase of leaf plasma membrane permeability.

In this study, Si-treated timothy-grass was more resistant to stem rust (*Puccinia graminis var. phlei-pratensis*), powdery mildew (*Erysiphe graminis* DC.), and *Amaurosoma flavipes* Fall. These results confirm the outcomes of many studies conducted in other plant species claiming positive effects of silicon fertilization on plant resistance against numerous pathogens. Silicon shortage makes plants more susceptible to insect feeding, fungal diseases and pathogen attack that adversely affect crop yield and quality [20]. The study of Rodgers-Gray and Shaw [36] proved that *Si* fertilized wheat was less susceptible to powdery mildew (*Blumeria graminis*), septoria (*Phaeosphaeria nodorum* and *Mycosphaerella graminicola*), and eyespot (*Oculimacula yallundae*). A beneficial effect of silicon treatment in the form of greater resistance of rice was reported for stalk rot (*Leptosphaeria salvinii*), rice blast (*Magnaporthe grisea*), fusarium wilt (*Fusarium*), tan spot (*Cochliobolus miyabeanus*), melting seedlings (*Thanatephorus cucumeris*), and leaf spots (*Monographella albescens*) [5, 6].

Fertilization with silicon improves plant defense mechanisms, e.g. by means of accumulation of lignins, phenolic compounds, and phytoalexins [1, 37].

In their literature review on silicon role in plants, Fauteux et al. [3] concluded that this element not only participated in structural and physiological processes but also affected plant resistance to fungal pathogens. Studies in epidermal cells revealed that in Si fertilized plants the defense mechanisms were stimulated by a production of phenolic compounds, callose, or methylaconitate (phytoalexin) [38-41]. Guével et al. [42] reported that foliar fertilization with Si limited infestation with powdery mildew but they did not explain the mechanism behind it. Other experiments showed that fertilization with silicon inhibited the development of powdery mildew in cucumber and it was associated with increased activity of catalase, peroxidase, and ascorbic dehydrogenase [43]. Silicate fertilizers were also found to prevent powdery mildew development in other species [38, 42, 44, 45]. Resende et al. [46] found that fertilization of ice lettuce plants 20 days after transplanting them into the ground with Si at a dose of 2.0 or 2.7 $dm^3 \cdot ha^{-1}$ improved their yield and postharvest durability. Cherif and Belanger [47] reported that fertilizing cucumber crop with a silicon containing preparation protected the leaves against *Sphaerotheca juliginea*, and the roots against *Pythium ultimum*. Pathogen-infected cucumbers may produce about 30% higher yield when fertilized with silicon than control infected plants [48]. Silicon was also shown to reduce crop damage inflicted by insects. This effect was observed for many species, such as insect borers (*Chilo suppresalis*), yellow borers (*Scirpophaga incertulas*), rice chlorops (*Chlorops oryzae*), rice leafhopper (*Nephotettix bipunctatus cinticeps*), brown leafhoppers (*Nilaparvata lugens*), weavers spider mites (*Tetranychus* spp.), or mites [5]. Silica containing leaves are stiffer and therefore less attractive to animals [49]. Cotterill et al. [50] and Hunt et al. [51] showed that Si-fertilized grasses were less eagerly fed on by wild rabbits and locusts than non-fertilized ones.

Our study showed a beneficial effects of silicon application on the germination ability and weight of 1000 seeds. These results are concurrent with those published by Ahmad et al. [20], Cuong et al. [25] and Khaing et al. [52] indicating positive influence of Si fertilization on the weight of 1000 seeds in rice, and are at variance with the reports of Ghanbari-Malidareh [53]. Abro et al. [54] and Ghanbari-Malidareh [53] claimed that Si application significantly reduced the amount of empty (sterile) grains in the ear. This might be associated with proper plant nutrition, optimum metabolic activity and lower susceptibility to stress. Similar findings were published by Mauad et al. [55], who concluded that by limiting diseases and improving stress tolerance silicon contributed to enhancing yield quality. Janas and Borkowski [56], who sprayed lettuce plants with 0.2% potassium Alkalin supplemented with 1.1% Si, reported a significant increase in the weight of 1000 seeds and germination ability. Control non-fertilized seeds were commonly attacked by fungi of *Alternaria and Septoria* genera, and this indicated a positive effect of silicon on seed condition. However, the research by Segalin et al. [57] revealed that foliar application of silicon did not affect either yield or physiological quality of wheat seeds of different cultivars.

Conclusions

The results of the field experiment performed in a seed plantation showed the beneficial effect of using the silicon additives (46.8 and 74.9 g $\mathrm{Si \cdot ha^{-1}}$) on agricultural characteristics of timothy grass cv. Egida. During the study, relative chlorophyll content, expressed as the leaf greenness index (*SPAD*) was found to increase during the growth period as well as yield of timothy seeds, germination capacity and weight of 1000 seeds. The increase in yield and the improvement of seed quality in silicon-fertilized plots resulted from lower level of infestation with stem rust (*Puccinia graminis var. phlei-pratensis*) and powdery mildew (*Erysiphe graminis* DC.), and from damage caused by timothy fly (*Amaurosoma flavipes* Fall.). Higher incidence of seed fly infestation was found in the control plot, which caused a significant decrease in seed yield.

The increasingly widespread use in agricultural practice, and the expanding range of plant growth enhancers and biostimulators requires concurrent research on their efficiency and optimal application techniques. The observed improvement in some growth and yield characteristics of timothy grass in the seed plantation in response to foliar application of silicon additives confirms the appropriateness of using them in this crop while showing the need for further research concerning the effect of silicon additives on the development and yielding of other species of feed grasses in seed plantations.

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