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Article

Effect of Tytanit on Selected Physiological Characteristics, Chemical Composition and Production of *Festulolium braunii* (K. Richt.) A. Camus

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Abstract: In intensive and sustainable agriculture, it is not enough to use plant protection products and fertilizers, but it is also important to control plant physiological processes. The aim of this study was to determine the effect of Tytanit on *Festulolium braunii* (K. Richt.) A. Camus dry matter yield, photosynthetic activity and the content of chlorophyll and selected chemical compounds. The pot experiment was conducted in 2019 in a plant breeding room. Four levels of treatment were used: control with no treatment and three stimulant concentrations of 0.02%, 0.04% and 0.06% in the spraying liquid. In particular, the research included the determination of dry weight of plant roots, dry weight of plants, chlorophyll a and b content in leaf blades, maximum and actual efficiency of the leaf photosystem, coefficients of non-photochemical and photochemical fluorescence quenching, and the content of total protein, crude fiber, monosaccharides, crude fat, crude ash, Ca, Mg, P and K in the dry matter of plants. Used in controlled conditions, the stimulant contributed to an increase in most parameter values, increasing photosynthetic activity and the content of chlorophyll a and b, total protein, calcium, magnesium and potassium, but it reduced the amounts of crude fiber.

Keywords: crude ash; crude fat; crude fiber; grass; macro-elements; monosaccharides; protein

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1. Introduction

In intensive and sustainable agriculture, it is not enough to use plant protection products and fertilizers; it is also important to control plant physiological processes. For this purpose, growth stimulants are frequently used [1]. According to Wadas and Kalinowski [2], Tytanit is a liquid mineral growth biostimulant and contains 8.5 g Ti per liter in the form of titanium ascorbate. Hrubý et al. [3] and Samadi [4] demonstrate that titanium positively affects the content of chlorophyll and carotenoids in plants. Additionally, Michalski [5] and Borkowski et al. [6] confirm that this chemical element increases the activity of iron ions, pollen vigor and positively affects the growth and nutrition of plants. According to Hussain et al. [7], it also improves the root architecture of *Glycine max* L. However, Auriga et al. [1] observed a lack of its significant effect on water balance in *Fragaria vesca* L. growing in saline conditions, which indicates that stress might affect the effect of Tytanit. However, according to many studies [2,8–12], it positively affects not only the yield and quality of agricultural crops, but also those of fruit and vegetable plants.

The most common symptom of improper functioning of the metabolism in the plant is growth inhibition resulting from a decrease in respiration or from photosynthetic dysfunctions. Solar radiation in the range of 400–700 nm is called Photosynthetically Active Radiation (PAR). Located in the light-harvesting complex (LHC), photosynthetic pigments (chlorophyll and carotenoids) are responsible for radiation absorption. This antenna complex consists of many chlorophyll and carotenoid molecules linked to proteins. According to Maxwell and Johnson [13], energy from this complex is transferred to the reaction centers of photosystem II and photosystem I (PSII and PSI).

The purpose of chlorophyll fluorescence is to remove excess light energy, and its mechanism is similar to the dissipation of energy as heat. It is therefore a kind of fuse-protecting photosynthetic system component that is sensitive to damage [14]. Although fluorescence is emitted by chloroplasts, it is connected to all life processes occurring inside of the plant. That is why any change in the plant environment causing changes in these processes affects photosynthesis [15]. Any disturbance of its intensity may decrease the yield and quality of plants. The result of chlorophyll fluorescence suggests the possible yield of plants; therefore, in practice it is used instead of the more popular level of photosynthesis and is a highly sensitive indicator of plant reaction [16]. Chlorophyll fluorescence is used in eco physiology and in monitoring plant and ecosystem tolerance to toxins and various stress factors [17]. According to Lyu et al. [18], providing Ti to the plant through leaves or roots in an absorbable form has a positive effect on the yield. This is due to the stimulation of the plant by selected enzymes which stimulate the production of chlorophyll and intensify the photosynthesis process.

The parameter characterizing photosynthetic apparatus in terms of photochemical activity is the maximum photochemical efficiency of PSII (Fv/Fm). For most plants in the stage of full development and in optimal conditions, the value of this parameter can be up to 0.83 [15,19]. In addition, according to Angelini et al. [20], the value of the Fv/Fm parameter depends on the processes occurring in the life of the plant and on varietal characteristics. The literature indicates the possibility of using the maximum photochemical efficiency of PSII as a measure of the impact of stimulants on the physiological condition of crops [1,21–26].

The aim of the present research was to determine the effect of various doses of Tytanit applied to leaves on *Festulolium braunii* (K. Richt.) A. Camus dry matter production and composition, photosynthetic activity and chlorophyll a and b content in leaf blades. In particular, the weight of aboveground plants and roots, the maximum and actual efficiency of the leaf photosystem, the coefficients of non-photochemical and photochemical quenching, and the content of total protein, crude fiber, monosaccharides, crude fat, crude ash, Ca, Mg, P and K in the dry matter of *Festulolium braunii* (K. Richt.) A. Camus were determined.

2. Materials and Methods

2.1. Characteristics of the Research Site

The research with *Festulolium braunii* (K. Richt.) A. Camus grown in pots was carried out in 2019 in the plant breeding room of the Institute of Agriculture and Horticulture of the University of Siedlce. The conditions of the experiment are presented in Table 1.

Table 1. Conditions of the experiment.

Parameter	Value
Air temperature in the light-adapted state	24 ± 2 °C
Air temperature in the dark-adapted state	16 ± 2 °C
Soil moisture	60% of field water capacity
Light intensity	200 µmol m^{-2} s^{-1} (obtained with high-pressure sodium lamps)
Photoperiod	16 h in light

Festulolium braunii (K. Richt.) A. Camus of the Felopa variety is a tall forage grass intended for mowing. It is planted on its own in arable land or in mixtures with legumes for meadow use. Relatively durable and resistant to drought and frost, it can produce high dry matter yields. In the present experiment plants were grown in pots with a height of 300 mm and a bottom diameter of 200 mm, filled with 5 kg of medium soil with light clay grain size from the arable layer (Table 2).

Table 2. Granulation composition of soil material.

Percentage of Earthy Fractions (Diameter in mm)						
1–0.1	**0.1–0.05**	**0.05–0.02**	**0.02–0.06**	**0.06–0.002**	**<0.002**	**Granulometric Group**
48	11	13	9	10	9	gl

Before sowing the plants, samples were taken from pots filled with soil material to assess their physico-chemical properties (Tables 2 and 3). The soil material samples were dried at room temperature to obtain air-dry material and the skeletal parts were separated from the earthy parts by sifting the soil material through a 2 mm diameter sieve. Then, the samples were marked as follows:

- Particle size composition using the Bouyoucos–Casagrande aerometric method, modified by Prószyński;
- pH in a $CaCl_2$ solution with a concentration of 0.02 mol dm^{-3} using the potentiometric method;
- Carbon content in organic compounds using the oxidation titration method;
- Total nitrogen content using the Kiejdahl method;
- Content of available forms of phosphorus—determined spectrophotometrically using the Egner–Riehm method;
- Content of available forms of potassium—determined spectrophotometrically using the Egner–Riehm method;
- Content of available magnesium—determined via the Schachtschabel method using flame atomic absorption spectrometry (FAAS).

Table 3. Chemical composition of soil material.

Parameter	Value
pH	6.80
C_{org} (g kg^{-1} DM)	13.5
N-NO_3 (mg kg^{-1} DM)	1.6
NH_4-N (mg kg^{-1} DM)	60.7
Total content (g kg^{-1} DM)	
P	0.75
K	1.12
Ca	1.80
Mg	1.20
Na	0.15
General forms (mg kg^{-1} DM)	
Fe	4562.80
Mn	156.20
Cu	5.60
Zn	14.50
Content of absorbable forms (mg kg^{-1} DM)	
P–$H_2PO_4^-$	170.00
K–K^+	114.00
Mg–Mg^{2+}	84.00

The soil contained high amounts of available phosphorus and magnesium, while the content of available forms of potassium was moderate. The detailed chemical composition of the soil material is presented in Table 3. Due to the sufficient content of soil plant nutrients, top dressing was not applied.

In mid-March, 10 seeds of *Festulolium braunii* (K. Richt.) A. Camus were planted in each pot at a depth of 1 cm. After germination, when leaves developed, a negative selection was carried out, leaving three plants with the largest number of leaves. Variants of the experiment were as follows: control treated with distilled water and plots with 0.02% concentration of Tytanit in the spraying liquid (aqueous solution); 0.04% concentration of Tytanit; 0.06% concentration of Tytanit. Each experimental variant was conducted in three replications. The first spraying was applied at the three-leaf stage and the second at the five-leaf stage. For a single spraying, 25 mL of solution per pot was used.

During plant equipment, the biomass was fractionated into its component parts, i.e., aboveground parts and the root system (washed with water). Then, the dry weight of the aboveground parts and roots was determined using the dryer-weighing method. The plant material was created by grinding leaves, stems and inflorescences collected from one vase. The following characteristics were determined:

- Dry weight of plant roots (g pot^{-1});
- Dry weight of plants (g pot^{-1});
- Chlorophyll a content in leaf blades (mg 100 g^{-1} of fresh weight);
- Chlorophyll b content in leaf blades (mg 100 g^{-1} of fresh weight);
- Maximum photosystem efficiency (F_v/F_m);
- Actual photosystem efficiency ($\Delta F/F_{m'}$);
- Non-photochemical quenching coefficient (qN);
- Photochemical quenching coefficient (qP);
- Content of total protein, crude fiber, monosaccharides, crude fat, crude ash in plant Dry matter (g kg^{-1} DM) in plant dry matter;
- Content of Ca, Mg, P and K in plant dry matter (g kg^{-1} DM).

2.2. Chlorophyll Content Determination

Leaf blades from the third–fourth node of randomly selected shoots were used to determine the content of pigments, with three samples collected from each experimental unit. The content of chlorophyll a and b was determined according to the method of Arnon et al. [27], modified by Lichtenthaler and Wellburn [28]. The optical density of supernatants was determined using the Marcel Mini spectrophotometer with wavelengths of 440, 465 and 663 nm. The content of chlorophyll a and b was calculated according to the formulas provided by Sosnowski and Truba [26].

2.3. Photosynthetic Activity Detppendermination

The photosynthetic activity of plants was determined via the measurement of chlorophyll fluorescence induction, with the PAM 2000, Heinz Walz GmbH, Effeltrich, Germany. All measurements were recorded during the growing season in five replications, using well-developed *Festulolium braunii* (K. Richt.) A. Camus leaves. When taking the measurements, a 2030-B clip holder and a light emitting diode at 650 nm with the standard intensity of 0.15 µmol m^{-2} s^{-1} PAR were used. In the dark-adapted state, leaves were kept in darkness for 15 min.

2.4. Dry Matter Chemical Composition

The content of Ca, Mg, P and K in the dry matter of *Festulolium braunii* (K. Richt.) A. Camus was determined via the ICP-AES method. The content of total protein, crude fiber, monosaccharides, crude fat and crude ash in the dry matter of plants was determined via the NIRS method using the N-NIR Flex 500 (Büchi, Switzerland).

2.5. Statistical Analysis

The data presented in the tables and figures were processed statistically using analysis of variance, and the differences between means were checked via Tukey's HSD test at 0.05.

Means marked with the same letters do not differ significantly. Standard deviation (±SD) was also included in the tables. The Statistica 13-2017.3 software package was used for all calculations.

3. Results and Discussion

The results (Figure 1) indicated that Tytanit foliar application significantly affected *Festulolium braunii* (K. Richt.) A. Camus dry matter production. The highest value, on average 24.2% higher than for control units, was recorded for plants treated with 0.04 and 0.06% stimulant concentrations. Compared to the control, the concentration of 0.02% also resulted in a statistically significant increase of 9.91%. The highest amounts of root dry matter (Figure 2) were recorded in plants treated with the lowest concentration of Tytanit, i.e., 0.02%. In response to this amount, dry matter production was on average 12.8% higher than that in units with higher Tytanit concentrations and 23.8% higher than in control units.

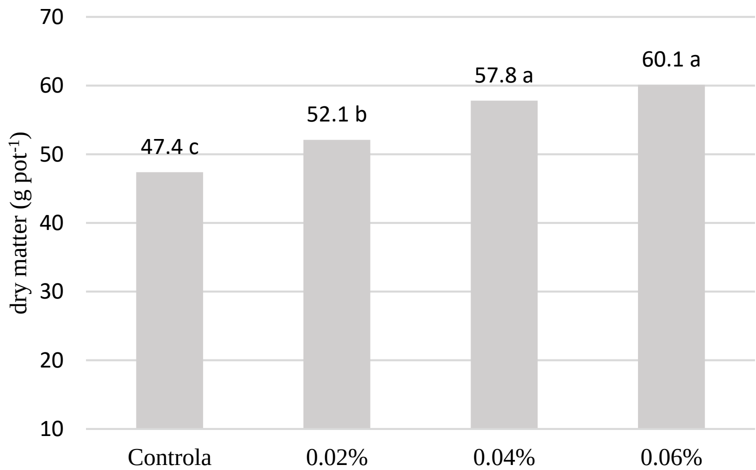

Figure 1. Effect of Tytanit on the amount of *Festulolium braunii* dry matter (g pot^{-1}). Means marked with the same small letters do not differ significantly.

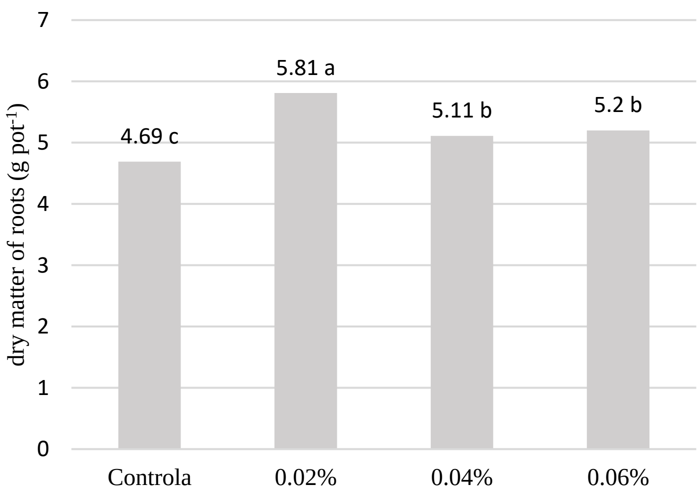

Figure 2. Effect of Tytanit on the amount of *Festulolium braunii* dry matter of roots (g pot^{-1}). Means marked with the same small letters do not differ significantly.

The values of chlorophyll fluorescence parameters and chlorophyll content (Figures 3 and 4 and Table 4) indicated a various effect of Tytanit on the photosynthetic activity of *Festulolium braunii* (K. Richt.) A. Camus leaves. In response to the stimulant, the content of chlorophyll a and b statistically significantly increased in relation to the control. In response to higher doses of the product (0.04 and 0.06%), chlorophyll a content in leaf blades was on average 29.2% and 16.2% higher than in plants treated with a 0.02% concentration. For chlorophyll b, an increase was not statistically significant, but its content in plants treated with the stimulant was 25.6% higher than in *Festulolium braunii* from the control unit. Chlorophyll a and b are responsible for collecting light and transferring it to photosynthetic reaction centers, and higher content of these pigments might contribute to an increase in photosynthetic activity [29,30]. Likewise, in the present experiment Tytanit increased the amounts of *Festulolium braunii* (K. Richt.) A. Camus chlorophyll pigments and its photosynthetic activity. Studying the effect of Tytanit on chlorophyll content in very early potato cultivars, Wadas and Kalinowski [2] also recorded increased chlorophyll content in the leaves of plants treated with Tytanit. In turn, after triple application of a foliar fertilizer containing titanium ions, Tan and Wang [31] found that potato leaves were dark green, shiny and dense, which was also confirmed in the present research on *Festulolium braunii* (K. Richt.) A. Camus. In addition, according to Radkowski [32] and Kováčik et al. [33], Tytanit increased chlorophyll concentration in the leaves of *Phleum pratense* L., *Triticum aestivum* L. and *Brassica napus* var. *napus*.

Table 4. The effect of Tytanit on the photosynthetic activity of *Festulolium braunii* (K. Richt.) A. Camus leaves.

Characteristics	Tytanit Concentration			
	Control	**0.02%**	**0.04%**	**0.06%**
(F_v/F_m)	0.699 (±0.09) ^{b}	0.780 (±0.09) ^{ab}	0.848 (±0.11) ^{a}	0.833 (±0.11) ^{a}
($\Delta F/F_{m'}$)	0.581 (±0.09) ^{b}	0.708 (±0.11) ^{a}	0.699 (±0.08) ^{a}	0.688 (±0.09) ^{a}
(qP)	0.611 (±0.08) ^{a}	0.627 (±0.10) ^{a}	0.617 (±0.07) ^{a}	0.628 (±0.08) ^{a}
(qN)	0.118 (±0.04) ^{c}	0.134 (±0.05) ^{b}	0.146 (±0.05) ^{a}	0.148 (±0.06) ^{a}

Standard deviation (±SD); maximum photosystem efficiency (F_v/F_m); actual photosystem efficiency ($\Delta F/F_{m'}$); photochemical quenching coefficient (qP); non-photochemical quenching coefficient (qN). Means marked with the same small letters do not differ significantly.

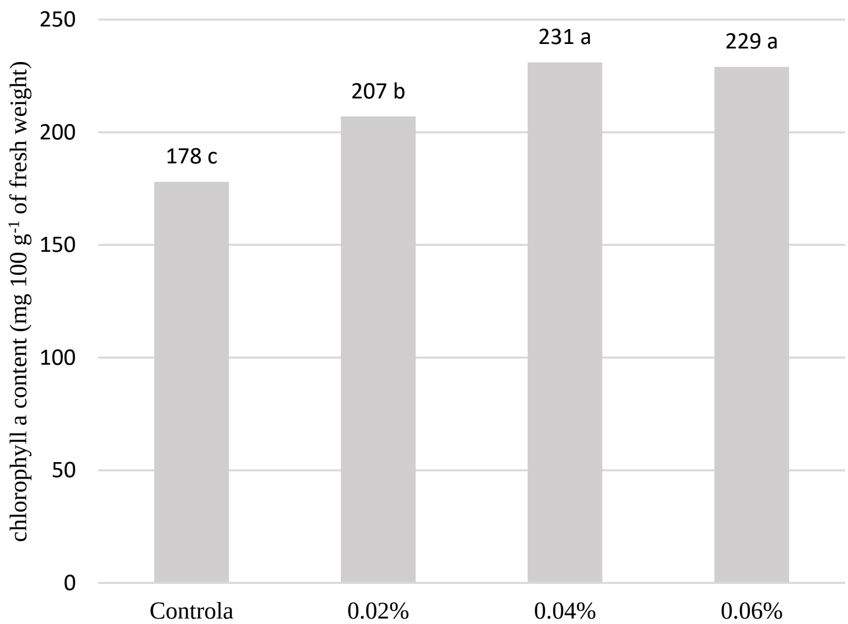

Figure 3. The effect of Tytanit on chlorophyll a content (mg 100 g^{-1} of fresh weight) in *Festulolium braunii* (K. Richt.) A. Camus leaves. Means marked with the same small letters do not differ significantly.

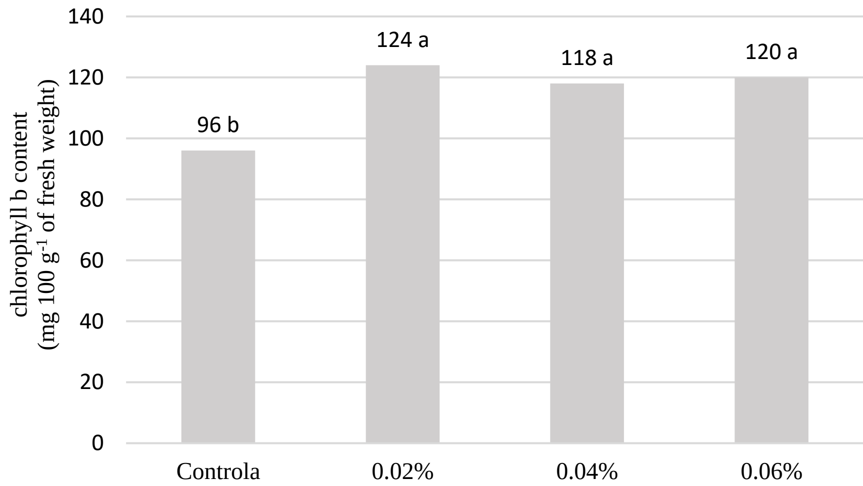

Figure 4. The effect of Tytanit on chlorophyll b content (mg 100 g^{-1} of fresh weight) in *Festulolium braunii* (K. Richt.) A. Camus leaves. Means marked with the same small letters do not differ significantly.

Chlorophyll fluorescence removes excess light energy in a way that is similar to energy dissipation in the form of heat. Thus, it protects photosynthetic apparatus components sensitive to damage. Although fluorescence is emitted by chloroplasts, all life processes in the plant cell are also affected. Therefore, changing environmental conditions will result in changes in the plant's phenology [14]. Fluorescence measurements of *Festulolium braunii* (K. Richt.) A. Camus leaves indicated (Table 4) that Tytanit application affected the maximum and actual efficiency of PSII in a statistically significant way. According to Khaleghi et al. [34] and Laisk et al. [35], increasing the maximum photosystem II efficiency means it activates after dark adaptation, resulting from a lack of photoinhibition in nitrogen-deficient plant cells. Thus, the energy used to transport electrons is not reduced. At the same time, as Nishiyama et al. [36] and Cetner et al. [15] argue, by providing the optimal dose of nitrogen, it is possible to increase the activity of reaction centers in dark-adapted cells. As a result of these activities, the activity of the photosynthetic apparatus and the efficiency of light energy processing can be increased.

According to Chen et al. [37], temperature change is a limiting factor in photosynthesis. Depending on the difference between the optimal and current temperature, different changes happen in photosynthetic machinery. Based on chlorophyll fluorescence measurements, it was found that plants respond to high temperature by decreasing the ratio of reduced electron acceptors to reaction centers, reducing the maximum efficiency of PSII. Similarly, low temperatures affect the efficiency of the photosynthetic apparatus [38].

Drought strongly inhibits the process of photosynthesis. Water deficiency is becoming a growing problem in agriculture, leading to a significant reduction in yields. It hinders the effective use of the absorbed light energy, which is increasingly dissipated through heat and increased fluorescence. These changes result in visible signs of plant wilting. Hence, the method of measuring chlorophyll fluorescence is used to monitor plants for drought stress [15]. The harmful effect of salts consists in reducing the osmotic potential in soil solution. This leads to difficulties in water uptake and to changes in nutrient uptake. During salt stress, chlorophyll fluorescence monitoring indicates changes in the functioning of PSII, whose ability to capture energy becomes lower. Additionally, an increase in non-photochemical quenching has been found [39]. It can be assumed that, in the present experiment, an increase in photosynthetic parameters such as the maximum (Fv/Fm) and actual (Fv′/Fm′) efficiency of the *Festulolium braunii* leaf photosystem resulted from better nutrition of plant cells with nitrogen after Tytanit application. The maximum efficiency of PSII is an indicator of photochemical activity of the photosynthetic apparatus. During optimal conditions for plant growth, its value should be about 0.85 units [20]. A decrease in this parameter indicates that the plant is undergoing stress, manifested in the form of photoinhibition, while very low values of PSII (0.2–0.3) indicate irreversible changes in its structure. However, according to Maxwell and Johnson [13], this parameter value is not proportional to the intensity of photosynthesis, expressed by CO_2 assimilation or O_2 release. Additionally, Kalajii et al. [40] emphasize that the value of PSII is not sensitive to certain kinds of stress (e.g., drought).

In this present research, the Tytanit stimulant also contributed to increasing the value of the non-photochemical quenching coefficient by 25.4% compared to the control. However, no statistically significant effect of its application on the photochemical quenching coefficient was found, which may be explained by the fact that fluorescence parameters are genetically conditioned [41].

Tytanit had a significant effect on the content of *Festulolium braunii* (K. Richt.) A. Camus organic components (Table 5). The application of its higher concentrations resulted in an increase in total protein content (on average by 14.8%) compared to the control, but the lowest concentration did not affect it. However, higher concentrations of Tytanit decreased the amounts of fiber in the dry matter of plants (on average by 13.9%), and the concentration of 0.06% decreased it by 5.51%. Yet the stimulant did not affect crude fat and crude ash content. Tytanit has a positive effect on the chlorophyll content in the plant and, consequently, on the protein content. According to the literature [42], the leaf greenness index (SPAD) and protein yield are correlated. The above results were confirmed by the research of other authors. Thus, other authors studying the effect of Tytanit doses on the content of organic compounds in the dry matter of meadow plants [43,44] also recorded an increase in protein and sugar amounts and a decrease in crude fiber content.

Table 5. The effect of Tytanit on content (g kg^{-1} DM) on crude protein, crude fiber, monosaccharides, crude fat and crude ash content in *Festulolium braunii* (K. Richt.) A. Camus.

Characteristics	**Tytanit Concentration**			
	Control	**0.02%**	**0.04%**	**0.06%**
Total protein	148 (±17.0) ^{b}	151 (±17.4) ^{b}	169 (±14.6) ^{a}	171 (±18.1) ^{a}
Crude fiber	290 (±16.2) ^{a}	274 (±11.1) ^{b}	249 (±14.9) ^{c}	250 (±14.6) ^{c}
Monosaccharides	66.1 (±8.01) ^{a}	67.4 (±7.74) ^{a}	66.3 (±8.14) ^{a}	67.7 (±9.01) ^{a}
Crude fat	34.7 (±4.13) ^{a}	34.0 (±3.93) ^{a}	34.2 (±4.04) ^{a}	34.9 (±5.11) ^{a}
Crude ash	119 (±8.99) ^{a}	123 (±10.7) ^{a}	120 (±10.0) ^{a}	121 (±10.6) ^{a}

Standard deviation (±SD). Means marked with the same small letters do not differ significantly.

The highest calcium amounts (Table 6) were in plants sprayed with 0.04 and 0.06% concentrations. These values were on average 16.4% higher than those on control units. Plants treated with the lowest dose of the stimulant contained 12.3% more calcium. An increase in calcium content in the dry matter of plants after Tytanit application was confirmed by other authors. Radkowski and Radkowska [11] found that its various doses increased meadow hay calcium content. Its greatest amounts were recorded in plants sprayed with a 0.04% titanium concentration. In the first year, the increase was 79%, with a 133% increase in the second year and 63% in the third year. Wójcik [45] and Skupień and Oszmiański [46] argue that, under the influence of a biostimulator with titanium, the plant is able to accumulate more macro- and microelements in the vegetative and generative parts. The improved nutrition of the plant is caused by a more extensive root system, especially the elongation of the capillaries zone. As a result, the plant rapidly absorbs more nutrients from the soil environment.

Table 6. The effect of Tytanit on *Festulolium braunii* (K. Richt.) A. Camus calcium, magnesium, phosphorus, and potassium content (g kg^{-1} DM).

Mineral	Tytanit Concentration			
	Control	0.02%	0.04%	0.06%
Ca	18.6 (±1.79) [c]	20.9 (±1.87) [b]	21.6 (±2.14) [a]	21.7 (±2.43) [a]
Mg	2.31 (±0.82) [b]	2.49 (±0.85) [b]	3.18 (±0.88) [a]	3.14 (±0.91) [a]
K	17.1 (±1.01) [b]	17.7 (±1.04) [b]	19.9 (±2.10) [a]	17.8 (±1.44) [b]
P	3.49 (±0.81) [a]	3.72 (±0.89) [a]	3.61 (±0.94) [a]	3.70 (±0.96) [a]

Standard deviation (±SD). Means marked with the same small letters do not differ significantly.

Statistical analysis also showed a significant effect of the stimulant on magnesium and potassium content in *Festulolium braunii* (K. Richt.) A. Camus. The magnesium content was significantly higher relative to the control (on average by 36.7%) in plants treated with 0.04 and 0.06% concentrations of the stimulant. The effect of Tytanit on an increase of magnesium accumulation in plants was also noted by Radkowski and Radkowska [11] and Kleiber and Markiewicz [47]. In tomato cultivation, the highest magnesium content was in leaves sprayed with a liquid containing 960 g Ti ha^{-1}. However, a low dose of 80 g Ti ha^{-1} lowered magnesium content relative to the control. In turn, Kalembasa et al. [48] recorded its highest content in the blades and petioles of celery treated with 1.0, 1.2 and 2.4% concentrations of Tytanit, but its concentration of 3.6% and very low amounts did not affect magnesium content relative to the control. In turn, potassium content in the dry matter of *Festulolium braunii* (K. Richt.) A. Camus was the lowest on units treated with 0.04% stimulant solution. This increase averaged 13.4% relative to the control and to plants treated with other doses. In turn, Kleiber and Markiewicz [47] found no significant effect of Tytanit doses on potassium content in tomato fruits. Radkowski and Radkowska [11] reported that foliar application of Tytanit at a concentration of 0.04% resulted in the largest increase in the content of all macroelements in the dry matter of meadow plants. This difference compared to the control was 28% for phosphorus, 78% for potassium, 80% for calcium and 81% for magnesium. A higher concentration of the product (0.08%) reduced macronutrient content compared to a concentration of 0.04, and in some cases even compared to a concentration of 0.02%. In this present experiment, Tytanit doses did not affect phosphorus content, which remained typical (average 3.63 g kg^{-1} DM). However, some authors [47,49] observed an increase in phosphorus content in vegetables treated with titanium.

4. Conclusions

1. The highest production of *Festulolium braunii* (K. Richt.) A. Camus dry matter was recorded in response to 0.04 and 0.06% Tytanit concentrations. However, all concentrations positively affected the development of the plant root system. Tytanit also increased the concentration of chlorophyll pigments in leaf blades.
2. Tytanit applied to green parts improved its photosynthetic activity. The stimulant increased the maximum (Fv/Fm) and actual (Fv′/Fm′) efficiency of PSII and the non-photochemical quenching coefficient (qN).
3. Tytanit affected the content of organic compounds and macroelements in the dry matter of plants in various ways. Its higher concentrations increased the amounts of total protein and decreased the content of crude fiber. An increase in calcium, magnesium and potassium content was also noted. Tytanit did not affect the content of monosaccharides, crude fat, crude ash or phosphorus.

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