Impact of Nitrogen and Boron Fertilization on Winter Triticale Productivity Parameters

Stanislaw Bielski 1, Kęstutis Romankecas 2,* and Egidijus Šarauskis 3

1 Department of Agrotechnology, Agricultural Production Management and Agribusiness, University of Warmia and Mazury in Olsztyn, Oczapowskiego str. 8, 10-791 Olsztyn, Poland; stanislaw.bielski@uwm.edu.pl
2 Institute of Agroecosystems and Soil Sciences, Vytautas Magnus University, Agriculture Academy, K. Donelaicio str. 58, 44248 Kaunas, Lithuania
3 Institute of Agricultural Engineering and Safety, Vytautas Magnus University, Agriculture Academy, K. Donelaicio str. 58, 44248 Kaunas, Lithuania; egidijus.sarauskis@vdu.lt

* Correspondence: kestutis.romaneckas@vdu.lt; Tel.: +370-656-30044

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Abstract: Research related to fertilization in winter triticale cultivation was limited to macroelements. The effects of boron on triticale (deficiency or toxicity) affecting productivity are still unknown. In 2013–2015, a field experiment was carried out at the Experimental Station in Tomaszkowo near Olsztyn. The objective was to set response of winter triticale variety Pigmej under the influence of various levels of nitrogen (N) and boron (B) fertilization. Five levels of nitrogen fertilization: 0, 40, 80 (50+30), 120 (90+30), and 160 (90+70) kg ha⁻¹ and four levels of boron fertilization: 0, 0.8, 1.6, and 2.4 kg ha⁻¹ were tested. The experiment has demonstrated considerable differences in the grain yield volume and structure under the influence of various weather conditions and different doses of nitrogen. The difference between the highest and lowest grain yield was 1.7 t ha⁻¹—53.6%. The effect of boron application was also manifested as an increase in the winter triticale grain yield and improved yield component structure, but the statistically significant differences were observed only in ears number per 1 m². The highest dose of boron applied in the experiment caused a decrease in the quantity of grain yield and its component parts.

Keywords: Triticosecale; grain yield; yield components; nitrogen; boron

1. Introduction

The cultivation of triticale as a cereal crop is a distinguishing feature of Poland, a leading cereal producer in the European Union. The total area of farmland cropped with triticale in Poland represents around 34% of the total area of triticale production worldwide. Currently, the European agriculture also appreciates this species. Over the past decade, the area sown with triticale has increased by 30%. This definitely is the evidence of the rising position of this species [1]. Triticale is mostly grown for animal feed. However, owing to its high yielding potential and good nutritive properties [2], it raises much interest as a raw food product for the food industry [3–5]. Although triticale can be a useful ingredient in a human diet, as of yet it has secured only a modest position on the food market. The most promising trend for the future of this cereal in the food industry is to investigate the usefulness of triticale grain for baking [3,4,6] and bioenergy production, especially bioethanol [7,8]. Triticale is considered to be an interesting species that can be grown even in unfavorable biotic and abiotic conditions [9,10], even at high salinity [11]. Moreover, it is a species with high genetic potential. In comparison with wheat, triticale varieties are often superior in terms of yields, adjust better to various soil and environmental conditions, and are able to produce a much higher yield of grain [12,13]. Peltonen-Sainio et al. [14]
claim that winter cereals will be grown in northern regions on a much larger area in the near future than at present.

One of the most important agrotechnical factors influencing the yield of grain and enabling farmers to take full advantage of the high production potential of cereals is mineral fertilization, especially nitrogen nutrition [9,15–17]. In intensive plant production, the level of nitrogen fertilization and the date of its application are essential for the attainment of high productivity of plants, supplying good quality yields [18].

Boron is one of the micronutrients that are deficient in soil [19]. According to Herrera-Rodriguez [20], large areas of farmland across the world are characterized by a boron deficit, which inhibits the growth, development, and yielding of major crops. In Poland, the majority of soils are light and acidic. This is conducive to boron deficiencies, because the element is readily soluble in water and therefore easily leached from soil.

Boron can be applied in long-term and in annual plantations; it is usually supplied in spring or autumn, in the form of solid fertilizers, either to soil or sprayed over foliage, and sometimes even during seed dressing. Plants should have access to this element from germination of maturity [21]. Boron is involved in many processes in the plant, e.g., calcium utilization, cell division, during the generative growth of plants, when the element affects water relations, resistance to diseases, and nitrogen metabolism [22]. Among elements essential for plants, boron is the only element that is absorbed not as an ion but as an uncharged molecule [23].

Boron is essential for plants, and recent studies on the biological role of this element in different metabolic, nutritive, hormonal, and physiological circumstances have provided evidence that boron is also an essential element for humans and animals. There is ongoing research on the influence of this element on metabolism. They prove the formation of disorders in the metabolism of calcium and fluorine in the conditions of the deficiency of this microelement, leading to diseases arthritis, osteoporosis, and brain abnormalities. Boron, which is a micronutrient, is obtained by humans and animals from a daily diet, in amounts depending on its composition [24–26].

The productivity of crops on fields with boron deficit depends on the sources of boron, and on the application schedule and methods. Soil or topdressing fertilization with boron is effective in the improvement of yields and yield quality [27]. The availability of boron is affected by many soil conditions, including: concentration of the soil solution, pH, soil texture, soil moisture, temperature, content of organic matter, and content of aluminum and iron hydroxides [28]. According to Eggert and Wirén [29], boron supply strongly promoted water and nutrient uptake as well as biomass formation. In recent years, both the Polish and international references have failed to provide results of research concerning the effect of boron fertilization on the growth and development of winter triticale. This has encouraged us to conduct an experiment with the winter triticale Pigmej variety, where the following objective was set to identify the production effects—expressed by grain yield volume and structure—under the influence of various levels of nitrogen and boron fertilization. The research hypothesis assumed that the fertilizer factors (nitrogen and boron) would significantly modify the grain yield and its components.

2. Materials and Methods

2.1. Location and Soil Characteristic

In 2013–2015, a field experiment on winter triticale was conducted at the Experimental Station in Tomaszkowo near Olsztyn (N = 53°71’74’’; E = 20°40’62’’). Triticale was grown on proper brown soil, classified as a very good rye complex in the Polish soil taxonomy (Table 1).
Table 1. Soil agrochemical characteristics.

| Specification                  | Vegetative Period |
|--------------------------------|-------------------|
|                                | 2013  | 2014  | 2015  |
| Soil type                      | proper brown soil |
| Soil texture                   | light clay       |
| Soil pH (1 M KCl)              | 5.5    | 5.7   | 6.0   |
| Soil valuation class           | R-IVa  |
| Soil suitability complex       | rye very good    |
| Content of nutrients (mg kg\(^{-1}\) of soil):|         |       |       |
| P                               | 27.4   | 25.8  | 26.5  |
| K                               | 26.7   | 24.9  | 27.2  |
| Mg                              | 4.7    | 5.3   | 5.1   |
| \(N_{\text{min}}\) (0–90 cm)   | 19.4   | 18.5  | 17.2  |
| B                               | 0.73   | 0.75  | 0.74  |

2.2. Experimental Design and Details

A two-factorial experiment was set up according to the random sub block method (split-plot) with four replications. The first order factor was nitrogen fertilization (kg ha\(^{-1}\)): A—0, B—40, C—80 (50 + 30), D—120 (90 + 30), and E—160 (80 + 80). A dose of nitrogen equal 60 kg N ha\(^{-1}\) was applied in early spring (after the plant vegetative growth was resumed—BBCH 27). Higher doses (80, 120, and 160 kg N ha\(^{-1}\)) were split and applied on two dates: at resumed vegetative growth (BBCH 27) and at the 4-internode stage (BBCH 38). Nitrogen in the first dose was applied as CO(NH\(_2\))\(_2\) (46%), and in the second dose as NH\(_4\)NO\(_3\) (34%). The second order factor was composed of boron fertilization: a—0 kg ha\(^{-1}\), b—0.8 kg ha\(^{-1}\), c—1.6 kg ha\(^{-1}\), and d—2.4 kg ha\(^{-1}\).

Chemical protection against diseases consisted of seed dressing with the preparation Baytan Universal 094 FS (active substances: triadimenol + imazalil + fuberidazol), and the application of Input 460 EC in a dose of 1 l ha\(^{-1}\) (spiroxamine + prothioconazol) at the first node stage (BBCH 31). Weeds were controlled in the autumn by spraying the fields with the preparations Dicuran Forte 80 WP in a dose of 1 kg ha\(^{-1}\) (chlorotoluron) and Gold 450 EC in a dose of 1.2 l ha\(^{-1}\) (2,4-D ester + fluroxipir). Phosphorus and potassium fertilization was applied in one dose, prior to sowing, in an amount of 30 kg P ha\(^{-1}\) in the form of triple superphosphate (46%) and 75 kg K ha\(^{-1}\) in the form of potassium salt (60%). Dressed seeds of the winter triticale variety Pigmej were sown to a depth of 3 cm, in rows spaced at 10 cm, and in an amount of 350 germinating kernels per 1 m\(^2\). The variety Pigmej is one of the dwarf forms of winter triticale, and therefore resistant to lodging. This variety is quite resistant to diseases, as well as to sprouting at the ear. In addition, it is recommended for growing, among others in the Warmia and Mazury province due to good frost resistance. The surface area of a plot for harvest was 15 m\(^2\). The yield of grain in kg per plot was determined at the full maturity stage, and then expressed in t ha\(^{-1}\) at 13% grain moisture. Plant samples were taken from an area of 0.25 m\(^2\) in order to determine the yield structure components (number of ears per unit area, number of grains per ear, and 1000-grain weight).

2.3. Statistical Analysis

The results were processed statistically according to analysis of variance (ANOVA), supported by Statistica\(^{\text{®}}\) 13 program (TIBCO Software Inc., Palo Alto, CA, USA). Significance of differences was verified with the Tukey’s test at the level of confidence equal \(p = 0.05\). In order to determine relationships between the dose of applied nitrogen and winter triticale yield components, correlation equations were calculated.
3. Results

3.1. Grain Yield and Meteorological Conditions

Yields of winter triticale were significantly varied during the three-year experiment, and ranged from an average of 4.62 t ha$^{-1}$ in 2014, a year with favorable precipitations and temperatures in autumn and spring (Table 2), through 4.56 in 2013 and 3.82 t ha$^{-1}$ in 2015. The gap between the best years for triticale yields and the worst one was 17.3%.

Table 2. Meteorological conditions in the vegetation period of winter triticale in years 2013–2015, according to Meteorological Station in Tomaszkowo.

| Months | Rainfall (mm) | Temperature (°C) |
|--------|---------------|-----------------|
|        | 2012–13 | 2013–14 | 2014–15 | 1961–2010 | 2012–13 | 2013–14 | 2014–15 | 1961–2010 |
| IX     | 45.7     | 67.5     | 30.8     | 57.1     | 13.5     | 14.1     | 14.5     | 12.6       |
| X      | 68.5     | 29.5     | 21.3     | 46.0     | 7.5      | 8.4      | 9.5      | 7.7        |
| XI     | 45.2     | 14.1     | 21.2     | 47.9     | 4.9      | 3.1      | 4.4      | 2.8        |
| XII    | 11.8     | 25.8     | 56.6     | 36.6     | −3.5     | 2.3      | −0.6     | −1.2       |
| I      | 34.6     | 44.0     | 28.5     | 31.2     | −4.5     | −3.5     | 0.6      | −2.9       |
| II     | 21.3     | 11.4     | 8.8      | 21.9     | −0.8     | 2.0      | 0.3      | −1.3       |
| III    | 14.0     | 55.7     | 46.0     | 28.5     | −4.0     | 5.5      | 4.6      | 1.2        |
| IV     | 22.5     | 26.1     | 23.4     | 34.2     | 6.3      | 9.5      | 7.2      | 7.0        |
| V      | 46.2     | 34.9     | 25.4     | 54.6     | 15.0     | 13.3     | 12.1     | 12.7       |
| VI     | 45.4     | 72.1     | 43.0     | 79.0     | 17.4     | 14.8     | 15.7     | 15.9       |
| VII    | 163.8    | 20.4     | 71.0     | 75.5     | 17.9     | 21.0     | 18.0     | 18.0       |
| Mean/Sum | 519.0 | 401.5 | 376.0 | - | 6.3 | 8.2 | 7.8 | - |

The first year was quite beneficial for the growth and development of winter triticale. It was only in July that very abundant rainfall made harvest difficult and caused the sprouting of grain. The second research season 2013/2014 was also favorable to the growth and development of triticale, and the modest rainfall in July allowed a timely harvest of grain. In the third research season, the autumn of 2014 (October and November) was characterized by higher temperatures and rainfall deficit (lower by as much as 97% in comparison with the multi-annual precipitation data), as a result of which the emergent plants were considerably thinned and the plant tillering was weaker. In consequence, the density of stems with panicles was low.

The lowest grain yield of triticale was obtained in the control treatment—without nitrogen fertilization (3.17 t ha$^{-1}$; Table 3).

Table 3. Winter triticale yields (t ha$^{-1}$) depending on nitrogen and boron fertilization.

| Fertilization Rate | nitrogen fertilization (kg ha$^{-1}$) | 2013 | 2014 | 2015 | Mean |
|-------------------|--------------------------------------|------|------|------|------|
| 0                 | 3.57<sup>c</sup>                     | 3.25<sup>d</sup> | 2.67<sup>d</sup> | 3.17<sup>d</sup> |
| 40                | 4.30<sup>c</sup>                     | 4.59<sup>bc</sup> | 3.86<sup>bc</sup> | 4.25<sup>c</sup> |
| 80                | 4.65<sup>b</sup>                     | 5.08<sup>a</sup> | 4.08<sup>d</sup> | 4.57<sup>b</sup> |
| 120               | 5.13<sup>a</sup>                     | 5.08<sup>a</sup> | 4.20<sup>d</sup> | 4.80<sup>a</sup> |
| 160               | 5.17<sup>a</sup>                     | 5.15<sup>a</sup> | 4.28<sup>c</sup> | 4.87<sup>a</sup> |

| Fertilization Rate | boron fertilization (kg ha$^{-1}$) | 2013 | 2014 | 2015 | Mean |
|-------------------|-----------------------------------|------|------|------|------|
| 0                 | 4.51                              | 4.60 | 3.79 | 4.30 |
| 0.8               | 4.36                              | 4.65 | 3.84 | 4.35 |
| 1.6               | 4.67                              | 4.64 | 3.87 | 4.39 |
| 2.4               | 4.52                              | 4.59 | 3.76 | 4.29 |
| mean              | 4.56<sup>a</sup>                 | 4.62<sup>a</sup> | 3.82<sup>b</sup> | -    |

* Different letters significant with α < 0.05.
Nitrogen fertilization caused a distinct increase in grain although it was statistically significant up to the dose of 120 kg N ha\(^{-1}\). The highest grain yield was harvested from the plots fertilized with 160 kg N ha\(^{-1}\), although the difference relative to the yield obtained under the effect of 120 kg N ha\(^{-1}\) was not statistically significant. There was a tendency to increase triticale yields increasing intensity of boron fertilization. The highest boron dose (2.4 kg ha\(^{-1}\)) caused decreased grain yields.

The calculated regression equation between the dose of nitrogen and grain yield, which is a second-degree curve, shows that the maximum yield of grain in a field experiment with the Pigmej variety can be achieved at 141 kg ha\(^{-1}\) N (Figure 1).

![Figure 1](image)

**Figure 1.** Regression curve of grain yield (y) of winter triticale cv. Pigmej depending on nitrogen fertilization dose (x).

3.2. Ears Number per 1 m\(^2\)

The number of ears per 1 m\(^2\) depended on the year of the experiment. The highest value of this trait was noted in 2013 (Table 4).

| Fertilization Rate | Years          | Mean  |
|-------------------|----------------|-------|
|                   | 2013           | 2014  | 2015  |     |
|                   | nitrogen fertilization (kg ha\(^{-1}\)) |       |       |     |
| 0                 | 448\(^{de}\)   | 434\(^{e}\) | 398\(^{g}\) | 427\(^{e}\) |
| 40                | 461\(^{d}\)    | 472\(^{d}\) | 417\(^{f}\) | 450\(^{d}\) |
| 80                | 495\(^{c}\)    | 489\(^{c}\) | 430\(^{e}\) | 472\(^{c}\) |
| 120               | 512\(^{b}\)    | 505\(^{b}\) | 442\(^{de}\) | 486\(^{b}\) |
| 160               | 546\(^{a}\)    | 537\(^{a}\) | 450\(^{de}\) | 511\(^{a}\) |
| boron fertilization (kg ha\(^{-1}\)) |       |       |       |     |
| 0.8               | 496           | 489   | 429   | 471\(^{a}\) |
| 1.6               | 501           | 492   | 433   | 475\(^{a}\) |
| 2.4               | 486           | 484   | 422   | 464\(^{b}\) |
| mean              | 493\(^{a}\)   | 487\(^{a}\) | 427\(^{b}\) | -    |

* Different letters significant with \(\alpha < 0.05\).
A significantly smaller number of ears (by 11.2%) per unit area was recorded in 2015. Nitrogen fertilization significantly differentiated the number of productive ears before harvest per unit area. Their smallest number was observed in the control treatment (without nitrogen). The highest increase in this trait occurred under the influence of nitrogen fertilization with the dose of 40 kg N ha\(^{-1}\) (an increase by 4.6% relative to the control). A significant increase in the number of productive ears took place up to the dose of 160 kg N ha\(^{-1}\) (higher by 10% than in the control). The significant higher ears number per 1 m\(^2\) of triticale was obtained from objects with boron fertilization in a dose of 0.8 and 1.6 kg ha\(^{-1}\). Application of the highest in experiment boron dose caused a significant decrease in the ears number (2.3%).

3.3. Number of Grains per Ear

The highest number of grains per ear in the cultivated winter triticale was recorded in 2015, when it was significantly higher than noted in 2013 and 2014 (Table 5).

**Table 5.** Grain number per one ear of winter triticale depending on nitrogen and boron fertilization.

| Fertilization Rate | Years       | Mean  |
|--------------------|-------------|-------|
|                    | 2013 | 2014 | 2015 |       |
| nitrogen fertilization (kg ha\(^{-1}\)) |
| 0      | 21.2\(^{b}\) | 20.1\(^{a}\) | 23.1\(^{f}\) | 21.4\(^{b}\) |
| 40     | 25.3\(^{c}\) | 27.8\(^{d}\) | 29.6\(^{b}\) | 27.6\(^{a}\) |
| 80     | 26.8 | 27.5\(^{d}\) | 30.2\(^{a}\) | 28.1\(^{a}\) |
| 120    | 27.8\(^{d}\) | 28.1\(^{c}\) | 30.5\(^{a}\) | 28.8\(^{a}\) |
| 160    | 28.1\(^{c}\) | 28.3\(^{c}\) | 30.5\(^{a}\) | 29.0\(^{a}\) |
| boron fertilization (kg ha\(^{-1}\)) |
| 0      | 25.8 | 26.3 | 28.7 | 26.9 |
| 0.8    | 25.9 | 26.4 | 28.9 | 27.1 |
| 1.6    | 26.0 | 26.5 | 28.9 | 27.1 |
| 2.4    | 25.7 | 26.2 | 28.6 | 26.8 |
| mean   | 25.8\(^{a}\) | 26.4\(^{b}\) | 28.8\(^{c}\) | - |

* Different letters significant with \(\alpha < 0.05\).

The number of grains per ear in winter triticale was differentiated by the applied nitrogen fertilization. A significant increase in the number of grains per ear continued up to the nitrogen dose of 40 kg N ha\(^{-1}\), and above this amount the said increase was small and the difference was statistically insignificant. Our research shows that more grain number per one ear winter triticale was recorded from objects with boron fertilized but was not a significant difference.

3.4. Weight of 1000 Grains

The weight of 1000 grains of winter triticale was significantly varied between the years of the experiment. The largest grains were harvested in the third year with a kernel weighing on average 40.9 g, whereas the smallest grains were produced in 2013 with 36.7 g on average (Table 6).

With respect to nitrogen fertilization, it needs to be underlined that the smallest 1000 grain weight was achieved by triticale grown in the control treatment, without fertilization (36.4 g). Even the smallest dose of nitrogen (40 kg ha\(^{-1}\)) caused a significant rise in this trait’s value (10.2%). Triticale plants fertilized with this amount of nitrogen produced grains with the highest 1000 grain weight (40.1 g). Increasing the fertilizing nitrogen doses caused a so-called post-fertilization diminution of grains and a tendency towards a decrease in the weight of 1000 grains. However, a significant decline in this trait occurred at the second highest (120 kg N ha\(^{-1}\)) dose of nitrogen. When raised to 160 kg ha\(^{-1}\), it caused another significant decrease relative to the impact of the dose of 120 kg N ha\(^{-1}\).
Table 6. Weight of 1000 grains (g) of winter triticale depending on nitrogen and boron fertilization.

| Fertilization Rate | 2013 | 2014 | 2015 | Mean  |
|-------------------|------|------|------|-------|
| nitrogen fertilization (kg ha\(^{-1}\)) |      |      |      |       |
| 0                 | 35.1\(^a\)* | 36.8\(^d\) | 39.1\(^a\) | 36.4\(^d\) |
| 40                | 37.4\(^c\) | 40.7\(^ab\) | 42.1\(^a\) | 40.1\(^a\) |
| 80                | 38.2\(^bc\) | 39.4\(^b\) | 41.7\(^a\) | 39.8\(^a\) |
| 120               | 37.0\(^c\) | 38.3\(^bc\) | 41.1\(^a\) | 38.8\(^b\) |
| 160               | 36.5\(^cd\) | 36.8\(^cd\) | 40.4\(^ab\) | 37.7\(^c\) |
| boron fertilization (kg ha\(^{-1}\)) |      |      |      |       |
| 0                 | 36.7  | 37.9  | 40.8  | 38.5  |
| 0.8               | 36.8  | 38.1  | 40.9  | 38.6  |
| 1.6               | 36.9  | 38.2  | 41.1  | 38.7  |
| 2.4               | 36.5  | 38.1  | 40.8  | 38.4  |
| mean              | 36.7\(^c\) | 38.1\(^b\) | 40.9\(^a\) | -     |

* Different letters significant with \(\alpha < 0.05\).

3.5. Correlations Between Yield and Yield Related Traits

Table 7 shows the correlation coefficients between the grain yield and its components. Significant positive correlations were observed between yield and grain number in ear, yield and ears number per 1 m\(^2\), 1000 grain weight and grain number in ears, grain number in ear and ears number per 1 m\(^2\).

Table 7. Correlation coefficients between grain yield and its components (significant level (\(p\))/correlation coefficient (r)).

| Traits                  | Yield       | 1000 Grain Weight | Grain Number in Ears | Ears Number per 1 m\(^2\) |
|-------------------------|-------------|-------------------|----------------------|--------------------------|
| Yield                   | 1.00        | \(p = 0.012/-0.842\) | \(p = 0.000/0.5596\)* | \(p = 0.000/0.8316\)* |
| 1000 grain weight       | 1.00        | \(1.00\)          | \(p = 0.000/0.6957\)* | \(p = 0.019/-0.1515\)* |
| Grain number in ears    |             |                   | \(1.00\)             | \(p =0.019/0.2877\)*    |
| Ears number per 1 m\(^2\)|             |                   |                      | \(1.00\)                |

* Significant at 0.05.

4. Discussion

4.1. Grain Yield

In a previous study by Bielski [30], the maximum nitrogen fertilization with a dose of 150 kg ha\(^{-1}\) caused a significant increase in the grain yield of the winter triticale Gniewko variety. In another experiment conducted by Bielski and Falkowski [31], where the Twingo variety was tested, the highest dose of nitrogen (150 kg ha\(^{-1}\)) caused an increase in grain yield relative to the dose of 120 kg ha\(^{-1}\), yet the differences were not statistically significant. Triticale is capable of using very high doses of nitrogen, even 180 kg ha\(^{-1}\) [32]. According to Lestingi et al. [15], an application of 50 kg N ha\(^{-1}\) in comparison with the dose of 100 kg N ha\(^{-1}\) is a good compromise as it combines a relatively small input with good grain and protein yields, good grain quality parameters, as well as being ecofriendly. The year × nitrogen fertilization interaction shows that the highest triticale grain yield was achieved in 2013 when the nitrogen dose applied was 160 kg ha\(^{-1}\). In a study by Alaru et al. [33], the strongest effect on the yield volume and structure was produced by the years of the experiment, followed by the cultivar and then the division of the nitrogen fertilization dose. This supports the earlier studies conducted by other authors, who reported that the yield volume and quality of triticale depended not only on fertilization but also on the weather conditions [34,35]. Biberdžić et al. [12] mention the weather as one of the most important factors affecting the yield of grain.
Boron fertilization did not differentiate significantly the volume of winter triticale grain yield (Table 3). In the years of the study, there occurred a tendency towards higher grain yields under the influence of higher boron doses. However, the highest dose of this element (2.4 kg ha\(^{-1}\)) decreased the grain yield. This response of winter triticale to boron fertilization was noted in each year. On average for a growing season, triticale without boron fertilization yielded by 0.04 t ha\(^{-1}\) lower (1.2\%) than when supplied a dose of 0.8 kg B ha\(^{-1}\). Similarly, the dose of 1.6 kg B ha\(^{-1}\) raised the grain yield by 0.04 t ha\(^{-1}\) (0.9\%) compared with the plots fertilized with 0.8 kg B ha\(^{-1}\).

Due to the lack of publications providing the latest results of boron fertilization on winter triticale yield and yield components, the authors will confront their data with reports on wheat, a species, which is a maternal form of triticale. The results of our researches prove the higher nutritional needs of winter triticale varieties than boron reported in the literature. Boron is an essential micronutrient for plants, needed to achieve proper growth. Disorders in the development of plants may be caused by both deficit and excess of boron [36]. Ahmad et al. [27] report that boron fertilization can enhance the yield volume and quality. Ahmad et al. [27] recommend to use boron in a dose up to 2.5 kg ha\(^{-1}\), so as to prevent or correct boron deficit in major crops. Debnath et al. [37] obtained the highest wheat grain yield from plots fertilized with nitrogen in a dose of 120 kg ha\(^{-1}\) and 2 kg B ha\(^{-1}\). Fakir et al. [38] as well as Thakur and Mukhopadhyay [39] noted a significant rise in wheat grain yield under the influence of boron fertilization. Iqbal et al. [40] concluded that the addition of boron to a seed dressing mixture ensured earlier and more uniform germination of seeds.

In our study, a decrease in grain yield and its component traits noticed on plots with the highest boron dose is most probably a consequence of its excessive amount supplied to winter triticale, which therefore produced a toxic effect. Similar tendencies associated with boron fertilization were noted by Debnath et al. [41] and Zare et al. [42]. Matula [28] claims that the gap between boron deficit and toxicity to plants is extremely narrow. Any change in the concentration of boron may considerably affect the growth and development of plants.

4.2. Ears Number per 1 m\(^2\)

The most important factor influencing the volume of yield is the ears number per unit area [43]. In another study by Bielski [30], significant differences in the number of ears per unit area were also noted depending on the research year. However, nitrogen fertilization did not have a significant effect on this property. The author only noted a tendency towards a higher number of ears in response to nitrogen fertilization. Similar research results concerning this characteristic were also reported by Bielski and Falkowski [31].

4.3. Number of Grains per Ear

In a study by Lalević and Biberdžić [44], an increase in this trait appeared up to the dose of 90 kg N ha\(^{-1}\), and 120 kg N ha\(^{-1}\) resulted in a lower number of grains per ear. In earlier studies reported by Bielski [30] as well as by Bielski and Falkowski [31], both on winter triticale, years of the research had no influence on the value of this trait. However, these authors noted a significantly greater number of grains per ear only when the nitrogen dose applied reached 90 kg N ha\(^{-1}\).

4.4. Weight of 1000 Grains

Dekić et al. [17] observed that the influence of nitrogen fertilization on grain yield and 1000 grain weight was highly significant statistically. Likewise, the effect of the interaction between years of the research and nitrogen fertilization on the weight of 1000 grains was substantial. According to Gerdzhikova [45], the highest dose of nitrogen, i.e., 180 kg ha\(^{-1}\), caused a statistically significant decrease in the weight of 1000 grains relative to the treatment where the nitrogen dose equaled 120 kg ha\(^{-1}\). Different impact of nitrogen fertilization on the weight of 1000 grains is reported by Lalević and Biberdžić [44]. All the winter triticale varieties tested by these authors (Odisej, Kg-20, Trijumf, Rtanj, and Tango) responded to higher doses of nitrogen by raising the weight of 1000 grains.
A positive effect of boron fertilization was also noted with respect to basic yield structure components but same as for yield volume only to the dose of 1.6 kg ha$^{-1}$. The boron fertilization treatment with 2.4 kg ha$^{-1}$ caused a trend towards a lower density of ear per unit area, lower number of grains per ear and lower 1000 grain weight.

Many researchers have noted a positive effect of boron on yield and yield structure. Most often, it was manifested as a significantly higher weight of 1000 grains [37,38,46], number of grains per ear [22] and wheat plant density [47].

4.5. Correlations between Yield and Yield Related Traits

Other authors have found that seed yield had positive and significant correlation with number of spikes 1 m$^{-2}$ [42], grain number in ear [41,42], and 1000 grain weight [41,48]. Dekić et al. [17] reported that winter triticale grain yield was highly correlated with the weight of 1000 grains (in 3 research years, respectively $r = 0.71$, 0.52, and 0.54).

5. Conclusions

Winter triticale grain yield volume was strongly dependent on weather conditions during the study years and on nitrogen fertilization. Winter triticale grain volume was significantly positively correlated with number of ear per unit area (0.8316), grain number in ears (0.5596), and significantly negatively correlated with the weight of 1000 grains (~0.842). Boron fertilization had a positive effect on yield and yield structure, but the statistically significant differences were observed only in ears number per 1 m$^2$. The highest boron dose in the experiment (2.4 kg ha$^{-1}$) caused a decrease in the yield and lower values of yield component traits. The regression equation between doses of nitrogen and grain productivity, which is a second degree curve, shows that the maximum grain productivity in a field experiment with the variety Pigmej can be obtained at a dose of 141 kg ha$^{-1}$ N.

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