INTRODUCTION

The height of wheat plants is a parameter with genetic determination in the first place, but also with a variation in relation to different influencing factors, and it is important in breeding programs (Würschum et al., 2017; Muhammad et al., 2021; Almutairi, 2022). Stem height is an important element that contributes to the architecture of the plants and is related to the biological productivity of the crops, but it is also associated with other aspects of plants status (Muhammad et al., 2021).

The height of wheat plants has been studied in relation to different influencing factors, such as climatic conditions (Bożek et al., 2021; Kronenberg et al., 2021), water regime (Jiang et al. 2020), soil conditions (Hodgkinson et al., 2017; Bazzaz et al., 2018), nutrients and fertilizers (Bhatta et al., 2020; Amjadian et al., 2021; Sarker et al., 2023), facilities provided to plants by azotobacter and mycorrhiza (Lamlon et al., 2023) etc.

Associated with the height of the plants, the morphological structure of the stem, and the phenomenon of plant lodging was studied in relation to various favorable factors for this (Khobra et al., 2019; Shah et al., 2019). Besides the close relationship between the taller height of wheat plants, the resistance structure of the stem and the phenomenon of lodging (Navabi et al., 2006; Niu et al., 2021), a series of factors (climatic, technological - e.g. plant density, the fertilization rate and the state of plant nutrition, water supply, plants health etc.) were studied in relation to the lodging phenomenon (Zhang et al., 2017; Li et al., 2022).

Wheat varieties have different capacities to capitalize the conditions provided by fertilization, and different studies have quantified how the nutrients provided by fertilization influenced the growth of wheat plants, photosynthetic performance, production and certain quality indices (Noureldin et al., 2013; Belete et al., 2018; Kubar et al., 2022). In this context, in different pedoclimatic and technological conditions, fertilization optimization studies in relation to the productivity, yield and quality of wheat production were approached (Sala and Boldea, 2011; Qiu et al., 2022; Luo et al., 2023).

In addition to the direct methods, by measurement, different alternative methods and models have been used to evaluate the wheat crop and the status of the wheat plants, in relation to influencing factors and possible associated effects (Sala et al., 2020; Tao et al., 2020; Wang et al., 2022). In order to describe the variation in the height of wheat plants in relation to influencing factors (e.g. water regime, water stress, fertilizers, etc.), some models were found, in the form of equations, or graphic models, with different utilities in characterizing plant architecture (Jiang et al. 2020; Blanc et al., 2021; Wang et al., 2022).
The present study evaluated the influence of the fertilization rate up to high doses of nitrogen, on plant height (Ph) in six wheat varieties, in deficient climatic conditions, and analyzed different models for estimating the Ph parameter in relation to the applied nitrogen doses.

**MATERIAL AND METHODS**

The research was carried out at the Didactic and Experimental Resort (DER) of the University of Life Sciences "King Mihai I" from Timisoara. Six wheat varieties were cultivated, three with smaller height (C3 – Montecarlo, C4 – Venezio, C5 – Combin), and three with larger height (C1 – PG102, C2 – Falado, C6 – Pitar).

In relation to the purpose of the study, fertilization was done with ammonium nitrate, to ensure variable levels of nitrogen, in the range of 0–280 kg a.s. ha\(^{-1}\) (a.s. – active substance). Fertilizers were applied in the spring, at the end of twinning - the beginning of stem elongation. Aspect from the experiment field, in vegetative stage, is presented in figure 1.

![Figure 1. Aspect from the experiment field (original figure)](image)

The climatic conditions in the area where the experiment was located were deficient in terms of rainfall (the culture was in non-irrigated conditions), and with temperatures above the average value of the area. The values for the climatic conditions are presented in figure 2.

![Figure 2. Climatic conditions for Timisoara, during the study period (Meteoblue)](image)
An appropriate culture technology was used, which facilitated the evolution in good conditions of the vegetation stages until physiological maturity. No phenomena of plants lodging were recorded.

In relation to the purpose of the study, determinations were made regarding the height of the plants (Ph, cm) at the moment of physiological maturity. Plant samples were taken in three repetitions, from each experimental variant. The obtained results were analyzed by appropriate mathematical and statistical methods, in order to quantify the reliability of the data, the presence of variance, the response of the plants to the nitrogen doses, the differences between the variants, the association of the variants in relation to the wheat variety and the nitrogen doses (Hamnet et al., 2001).

RESULTS AND DISCUSSIONS

The wheat varieties studied showed variable height, as a specific genetic and morphological trait. Associated with nitrogen fertilization, within each variety, the variation in plant height was recorded, in relation to the dose and the specific way in which each variety used the provided nutrition. The experimental data, average values, and the values of standard errors (SE) calculated in relation to each variety and dose of fertilizers, are presented in table 1. The varieties C3, C4 and C5 presented a lower height, and the varieties C1, C2 and C6 presented a high height. The highest values for plant height were recorded for the C6 variety (77.67±1.20 cm, at the N240 dose). The ANOVA test confirmed the presence of variance in the data set, under statistical safety conditions (Alpha=0.001), and the values resulting from the test are presented in table 2.

Table 1. Plant height in relation to wheat variety and nitrogen doses

<table>
<thead>
<tr>
<th>Trials</th>
<th>N0</th>
<th>N40</th>
<th>N80</th>
<th>N120</th>
<th>N160</th>
<th>N200</th>
<th>N240</th>
<th>N280</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>63.67±1.45</td>
<td>64.33±2.40</td>
<td>67.33±1.45</td>
<td>68.00±1.73</td>
<td>68.67±1.76</td>
<td>73.00±1.15</td>
<td>68.00±0.58</td>
<td>67.33±1.76</td>
</tr>
<tr>
<td>C2</td>
<td>62.33±0.88</td>
<td>65.00±1.53</td>
<td>65.33±1.76</td>
<td>69.33±0.67</td>
<td>73.67±2.33</td>
<td>69.67±1.76</td>
<td>69.67±2.03</td>
<td>67.33±2.73</td>
</tr>
<tr>
<td>C3</td>
<td>56.67±1.20</td>
<td>59.00±1.15</td>
<td>59.00±1.53</td>
<td>60.33±2.60</td>
<td>63.00±1.15</td>
<td>63.67±1.45</td>
<td>61.67±2.73</td>
<td>61.33±3.18</td>
</tr>
<tr>
<td>C4</td>
<td>54.00±2.08</td>
<td>56.00±0.58</td>
<td>59.33±2.96</td>
<td>60.00±1.73</td>
<td>60.33±0.33</td>
<td>62.67±3.18</td>
<td>61.67±0.88</td>
<td>61.33±2.85</td>
</tr>
<tr>
<td>C5</td>
<td>59.00±0.58</td>
<td>60.33±1.76</td>
<td>62.33±0.88</td>
<td>63.67±1.45</td>
<td>64.33±1.45</td>
<td>70.00±1.15</td>
<td>68.00±3.61</td>
<td>66.67±1.45</td>
</tr>
<tr>
<td>C6</td>
<td>67.33±1.76</td>
<td>67.67±0.881</td>
<td>68.33±1.86</td>
<td>68.67±1.20</td>
<td>74.00±1.53</td>
<td>75.00±0.58</td>
<td>77.67±1.20</td>
<td>74.67±1.20</td>
</tr>
</tbody>
</table>

Table 2. Results of the ANOVA test

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rows</td>
<td>2778.701</td>
<td>17</td>
<td>163.453</td>
<td>17.88647</td>
<td>3.58E-25</td>
<td>2.670868</td>
</tr>
<tr>
<td>Columns</td>
<td>1076.16</td>
<td>7</td>
<td>153.7371</td>
<td>16.82326</td>
<td>2.69E-15</td>
<td>3.769544</td>
</tr>
<tr>
<td>Error</td>
<td>1087.465</td>
<td>119</td>
<td>9.138364</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4942.326</td>
<td>143</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The data series, related to each wheat variety, regarding the values for the height of the wheat plants (Ph), in relation to the applied fertilization, presented a normal distribution, according to the histograms in figure 3.

Figure 3. The distribution histograms of values, Ph parameter, for the wheat varieties studied

The analysis of the data series (average values) in relation to the doses of fertilizers, showed a close relationship between the considered parameter (Ph) and the applied fertilization, according to the graphic
diagram in figure 4, and the correlation coefficient values obtained (\( r=0.994 \) for the variety C1; \( r=0.980 \) for variety C2; \( r=0.984 \) for variety C3; \( r=0.979 \) for variety C4; \( r=0.985 \) for variety C5; \( r=0.983 \) for variety C6).

\[ \text{Figure 4. Graphical representation of the data series distribution for the wheat varieties studied, Ph parameter} \]

The PCA led to the diagram in figure 5, in which the groups of average values related to the six varieties of wheat studied were positioned differently in relation to the applied fertilization, based on the recorded values of the Ph parameter. PC1 explained 92.498% of variance, and PC2 explained 4.134% of variance. The varieties C1, C2 and C6 presented a position associated with the nitrogen doses applied, and the varieties C3, C4 and C5 presented an independent position.

\[ \text{Figure 5. PCA diagram, with the distribution of the wheat varieties studied in relation to the fertilization variants} \]

The CA analysis on the average values regarding Ph in the six wheat varieties, led to the dendrogram in figure 6, in which the variants were associated based on similarity in relation to the height of the plants, from the perspective of the wheat varieties (Coph.corr.=0.732), and from the perspective of fertilization variants (Coph.corr.=0.727). Figure 6 also shows the matrix of Ph values based on which the variants were associated.
With lower values for the Ph parameter, the varieties (C3,C4) were associated. The C6 variety was positioned in an independent position, with the highest values for Ph. Within a subcluster (C1,C2,C5), the other three varieties with intermediate values were associated. From the perspective of fertilization, the formation of two clusters was found, one cluster that included the variants (N0,N40) and (N80,N120), and the second cluster that included the variants (((N240,N280), N200),N160).

In relation to the Ph parameter, high levels of similarity were recorded in the case of the C3 and C4 varieties, and in relation to the fertilization variants, high similarity was recorded between the N240 and N280 variants.

The ranking classification analysis of the wheat varieties studied based on the values recorded for Ph, in relation to the nitrogen doses, led to the diagram in figure 7.

The response of wheat plants to fertilization with increasing doses of nitrogen was analyzed, based on the considered parameter, namely plant height (Ph). The variation of Ph in relation to N was described by equation (1), according to $R^2=0.793$, $p=0.074$ (variety C1), by equation (2), according to $R^2=0.841$, $p=0.044$ (variety C2), by equation (3), according to $R^2=0.898$, $p=0.018$ (variety C3), by equation (4), according to $R^2=0.960$, $p<0.001$ (variety C4), by equation (5), according to $R^2=0.909$, $p=0.014$ (variety C5), by equation (6), according to $R^2=0.923$, $p=0.009$. 

![Figure 6. Cluster diagram regarding the association of variants by category, wheat varieties and nitrogen doses](image)

![Figure 7. Scaling dendrogram regarding the ranking of the wheat varieties studied, based on the Ph values](image)
R²=0.943, p=0.0058 (variety C6). The graphic representation of Ph values and regression curves, according to equations (1) to (6), are presented in figure 8.

\[ \begin{align*}
\text{Ph}_{(C1)} & = -1.359E - 0.06x^3 + 0.0003659x^2 + 0.01588x + 63.59 \\
\text{Ph}_{(C2)} & = -1.253E - 0.06x^3 + 0.0002371x^2 + 0.04836x + 62.24 \\
\text{Ph}_{(C3)} & = -8.456E - 07x^3 + 0.0002138x^2 + 0.02101x + 56.96 \\
\text{Ph}_{(C4)} & = 0.0001587x^2 + 0.07124x + 53.89 \\
\text{Ph}_{(C5)} & = -1.591E - 06x^3 + 0.0005606x^2 - 0.005403x + 59.33 \\
\text{Ph}_{(C6)} & = -2.419E - 06x^3 + 0.001001x^2 - 0.06454x + 67.85
\end{align*} \]  

where: \( x \) – nitrogen doses (kg ha\(^{-1}\) N a.s.)

![Figure 8. Graphic representation of the response curves regarding Ph in relation to fertilization for wheat varieties studied](image)

The wheat varieties studied have differentiated use of nitrogen fertilization, quantified based on the considered parameter (Ph, cm). In the Falado wheat variety (C2), the highest value for plant height was recorded (Ph=73.67±2.33 cm) at the dose of 160 kg ha\(^{-1}\) N a.s. At the dose of 200 kg ha\(^{-1}\) N a.s., the highest value of the Ph parameter was recorded in the PG102 variety (C1, Ph=73.00±1.15 cm), in the Montecarlo variety (C3, Ph=63.67±1.45 cm), in the Venezio variety (C4, Ph=62.67±3.18 cm), and the Combin variety (C5, Ph=70.00±1.15 cm).

In the case of the Pitar variety (C6), the highest value for plant height was recorded at the dose of 240 kg ha\(^{-1}\) N a.s. (Ph=77.67±1.20 cm).

Plant height in relation to fertilization has been evaluated in other studies, and high statistical confidence levels have been reported for the estimation of this plant parameter in relation to different varieties and doses of fertilizers. Variation of plant height, tillers length, morphological parameters (e.g. leaf, ear parameters) in wheat in relation to nitrogen, or nitrogen in combination with other nutrients or fertilizers (e.g. P, K, microelements, organic fertilizer), were evaluated in different genotypes and in different culture conditions (Ibtida, 2010; Jan et al., 2013; Sharma et al., 2016; Kabato et al., 2022). Mohamed et al. (2019) communicated variable values for the height of wheat plants in relation to different types of organic and mineral fertilization, and found values for plant height between 74.00 – 79.67 cm, with statistical safety (LSD = 0.61). The increase in wheat plant height in relation to mineral fertilizers was reported by Amjadian et al. (2021), with values of 90-95 cm and a good tolerance to certain pathogens. Lamlom et al. (2023) communicated the differential growth of wheat plants in relation to different types of fertilizers used, and recorded values for plant height of 100 cm (p≤0.05) in conditions of azotobacter and mycorriza, and plant height of 93 cm in conditions of organic fertilizers.

In conditions of this study, equations (1) to (6), obtained through regression analysis, described the variation of plant height in relation to the dose of fertilizer applied. Similar behavior regarding the variation of the studied parameter was recorded in C3 and C4 varieties. The highest level of statistical certainty in the
description of the variation of the Ph parameter in relation to the doses of N was recorded in the case of the C4 variety, with a polynomial equation of degree 2, equation (4) ($R^2=0.960$, $p<0.001$), followed by variety C6, with a polynomial equation of degree 3, equation (6) ($R^2=0.943$, $p=0.0058$).

In the climatic conditions specific to the vegetation period of the wheat varieties studied, with an accentuated deficit of precipitation, especially in the months of May (third decade) and June, there were no plant lodging phenomena recorded in any of the varieties studied, on the fertilization variants (especially at high doses of fertilizer).

CONCLUSIONS

Fertilization with increasing doses of nitrogen, in the tested interval, generated a differentiated variation in the height of the plants in the six varieties of wheat studied, in accordance with the genetic specificity of each of them to capitalize on the fertilizers and vegetation conditions.

Classified in two categories, as the height of the plants, the increase in the height of the plants was in accordance with the doses of nitrogen applied, but with a variable rate of response. According to the PCA, the wheat varieties with a smaller height (C3, C4, C5) showed relative independence from the applied mineral fertilization, while the varieties with a larger height showed an association with the nitrogen doses. Based on PCA, PC1 explained 92.498% of variance, and PC2 explained 4.134% of variance. The cluster analysis led to obtaining a classification based on the similarity of the values recorded for the studied parameter (Ph), in relation to the wheat varieties (Coph.corr.=0.732), and in relation to the doses of nitrogen (Coph.corr.=0.727). A ranking was obtained for the studied wheat varieties, in relation to the Ph parameter, and the distances between the neighboring positions occupied by the studied wheat varieties. Polynomial equations of the 2nd and 3rd degree described the variation of Ph in relation to the doses of N, under conditions of statistical safety.

Although the level of N doses reached up to 280 kg a.s. ha$^{-1}$, based on the climatic conditions of 2022, the phenomenon of plant lodging was not recorded.

ACKNOWLEDGMENTS

The authors thank the Didactic and Experimental Resort of the University of Life Sciences "King Mihai I" from Timisoara for the facilitation of this study.

REFERENCES

1. Almutairi M.M. - Genetic parameters estimation for some wild wheat species and their F1 hybrids grown in different regions of Saudi Arabia. Saudi Journal of Biological Sciences, 2022, 29(1), 521-525.
Management, 2020, 232, 106066.
20. Meteoblue - https://www.meteoblue.com (accessed on the date: 23.03.2023)