MODELS FOR DESCRIBING THE VARIATION OF MOISTURE IN WHEAT GRAINS DEPENDING ON MINERAL AND FOLIAR FERTILIZATION

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Abstract. The study evaluated the moisture content of wheat grains in relation to mineral nitrogen fertilization and foliar fertilization. The biological material was represented by the Alex wheat cultivar. By mineral fertilization, five nitrogen levels were ensured, in the range 0 - 200 kg a.s. ha⁻¹ (a.s. - active substance). Super Fifty (SF) biofertilizer was applied foliar in six concentrations, ranging from 0 to 5 l ha⁻¹. The combination of the two fertilizing resources resulted in 30 experimental variants, in three repetitions. The moisture content (M, %) of the wheat grains was evaluated, in relation to the applied fertilization. Regression analysis was used to estimate the humidity (M, %) in relation to SF on each nitrogen (N) level. Grains moisture estimation (M, %) was possible in conditions of R² = 0.681, p = 0.043 on the level of nitrogen N0, and in conditions of R² = 0.999, p <0.001 on the other levels of nitrogen fertilization (N50 - N200). According to the calculated prediction error (PE) and the RMSEP statistical parameter, the highest safety in estimating grain moisture relative to SF was at the N150 level, where PE = -0.14, and RMSEP = 0.049163. The variation of moisture (M, %) in relation to N and SF, evaluated on the data set as a whole, was described by an equation of type M (%) = ax² + hy² + cx + dy + ey, in statistical safety conditions, R² = 0.917, p <0.001. A graphical distribution was obtained, in the form of a 3D model and in the form of isoquants of the moisture M (%) variation in relation to N (x-axis) and SF (y-axis). Based on PCA, PC1 explained 42.523% of variance, and PC2 explained 32.781% of variance in relation to N doses, respectively PC1 explained 63.936% of variance, and PC2 explained 23.776% of variance in relation to SF.

Keywords: foliar biostimulator, grains, nitrogen, models, moisture, wheat

INTRODUCTION
Seed moisture has a specific variation in relation to the plant species, the time of analysis (eg intermediate stages of seed formation and maturation, physiological maturity), and is an index and parameter of seed quality.

Seed moisture is important in relation to harvest time and drying conditions (Scariot et al., 2017), for storage stability and content quality indices (Zhang et al., 2010; Suma et al., 2013), for direct consumption or industrial processing (Suma et al., 2013).

Seed moisture was studied regarding the lethal temperature of seeds in relation to natural phenomena (Tangney et al., 2019), the period of rest and germination of seeds (Stanisavljević et al., 2013; Basbouss-Serhal et al., 2016; Zhang et al., 2020), seed viability in relation to storage conditions, or natural conditions (Wen and Cai, 2014; Fennollosa et al., 2020). In relation to the nutrients and the humidity of the substrate, the growth and reproduction of some plant species through seeds was studied (Lee et al., 2017).

The influence of moisture on some physical properties of grains has been evaluated in different species of interest (Irtwange and Igbeka, 2002; Karimi et al., 2009; Tavakoli et al., 2009; Zareiforoush, H. 2009; Aderinlewo et al., 2011; Adinoyi et al., 2017). The influence of moisture on grain processing was also evaluated (Al Sharifi et al., 2019).

In wheat, studies were made on elements of productivity, seed production and quality in relation to fertilization and moisture determination (Mojid et al., 2012; Rawashdeh and Sala, 2014, 2015). Also, in wheat, the importance of grain moisture in relation to harvesting and storage systems was highlighted (Scariot et al., 2017; Belay and Fetene, 2021).

A study on the relationship between storage temperature and relative humidity and seed moisture (seed water content) facilitated the description of the characteristics of the seed water absorption isotherm (Asomaning et al., 2011).

Estimation of grains temperature in relation to influencing factors (eg air temperature) was done in order to ensure proper grain storage conditions (Wang et al., 2020; Azmi et al., 2021).

Moisture was considered as a reporting parameter to ensure proper grain storage conditions (Wang et al., 2020; Azmi et al., 2021).

Due to the importance of grain moisture and the influence on some associated properties (physical, morphological, textural of the seeds) different methods was developed, like the imaging analysis, to study and characterization of the grains in some species (Tahir et al., 2007).

Interest in estimating wheat grain moisture at harvest has been expressed and confirmed by various studies in relation to climatic and technological factors (Uddin et al., 2006; Abdollahpour et al., 2020).

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Wheat is one of the main crop plants, for which many genotypes have been studied in relation to climatic conditions (Heil et al., 2020; Bento et al., 2021; Obembe et al., 2021), soil conditions (He et al., 2014; Nabiollahi et al., 2020), plant nutrition (Guo et al., 2019; Weih et al., 2021), production quality (Zörb et al., 2018; Husenov et al., 2020), fertilization optimization (Sala and Boldea, 2011, Sala et al., 2016), plant protection (Mouron et al., 2016), technology optimization.

The methods of investigation to be used have diversified, from classical, analytical to imaging analyzes, both in terms of plant status, classification and appearance of crops, and in estimating production and quality (Drienovsky et al., 2017a,b; Hughes et al., 2017; Walter et al., 2019; Sala et al., 2020).

The present study analyzed the moisture content of wheat grains in relation to mineral and foliar fertilization, and developed models for estimating grains moisture in relation to applied doses.

MATERIAL AND METHODS

The study evaluated the variation of the moisture of wheat grains, Alex cultivar, in relation to nitrogen (N) fertilization and foliar treatment with the Super Fifty (SF) biofertilizer.

The experiment was organized within the Didactic and Experimental Resort, BUASVM Timisoara, agricultural year 2018-2019, figure 1.

Nitrogen was provided by ammonium nitrate, in doses between 0-200 kg a.s. N ha\(^{-1}\) (a.s. - active substance). The Super Fifty (SF) biofertilizer was applied foliar, in concentrations between 0-5 l ha\(^{-1}\).

The variation of wheat grain moisture (M, %) was evaluated, in relation to the two types of fertilizers (N, SF). Moisture was determined by the non-destructive method.

Regression analysis was used to evaluate the moisture (M, %) variation in relation to the two fertilizer products. To find out the safety of moisture estimating in relation to N and SF and the prediction error (PE) was calculated.

The safety of the equations, models, and distribution of values in relation to the type of analysis applied, was evaluated based on the parameters p, R\(^2\), Coph. corr, and RMSEP, equation (1).

\[
RMSEP = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2}
\]

(1)

The statistical calculation module from EXCEL, the PAST software (Hammer et al., 2001) and the Wolfram Alpha software (2020) were used for data processing and analysis and graphical representations.

RESULTS AND DISCUSSIONS

Values recorded for wheat grain moisture, Alex cultivar, under the influence of mineral fertilization with nitrogen (N) in the range 0-200 kg ha\(^{-1}\) a.s. (ammonium nitrate fertilizer) and the Super Fifty (SF) foliar
biofertilizer in the range 0 - 5 l ha\(^{-1}\), are presented in table 1. The values had a normal distribution.

<table>
<thead>
<tr>
<th>Experimental variant</th>
<th>SF0</th>
<th>SF1</th>
<th>SF2</th>
<th>SF3</th>
<th>SF4</th>
<th>SF5</th>
</tr>
</thead>
<tbody>
<tr>
<td>N0</td>
<td>12.80±0.05</td>
<td>12.90±0.05</td>
<td>12.70±0.05</td>
<td>12.80±0.05</td>
<td>13.00±0.05</td>
<td>12.70±0.05</td>
</tr>
<tr>
<td>N50</td>
<td>12.83±0.07</td>
<td>12.40±0.07</td>
<td>12.60±0.07</td>
<td>12.60±0.07</td>
<td>12.37±0.07</td>
<td>12.60±0.07</td>
</tr>
<tr>
<td>N100</td>
<td>12.60±0.07</td>
<td>12.83±0.07</td>
<td>12.50±0.07</td>
<td>12.60±0.07</td>
<td>12.33±0.07</td>
<td>12.70±0.07</td>
</tr>
<tr>
<td>N150</td>
<td>12.80±0.04</td>
<td>12.70±0.04</td>
<td>12.70±0.04</td>
<td>12.67±0.04</td>
<td>12.70±0.04</td>
<td>12.50±0.04</td>
</tr>
<tr>
<td>N200</td>
<td>12.60±0.05</td>
<td>12.60±0.05</td>
<td>12.43±0.05</td>
<td>12.60±0.05</td>
<td>12.60±0.05</td>
<td>12.80±0.05</td>
</tr>
</tbody>
</table>

**Notes.** N0 to N200 – nitrogen fertilizer variants (0, 50, 100, 150 and 200 kg N ha\(^{-1}\) a.s.); SF0 to SF5 – Super Fifty foliar biofertilizer in different concentration (0, 1, 2, 3, 4 and 5 l ha\(^{-1}\)).

Regression analysis was used to estimate grain moisture (M,%) as a function of SF biofertilizer (l ha\(^{-1}\)), in relation to each N level (kg ha\(^{-1}\)).

At the level of N0, the estimation of grain moisture (M,%) was described by equation (2), in conditions of low statistical safety (R\(^2\) = 0.681, p = 0.043).

\[
M = 0x + 3.494y
\]  
(2)

where:  
M – grains moisture (%);  
\(x\) – N doses (kg ha\(^{-1}\));  
\(y\) – SF doses (l ha\(^{-1}\))

At different nitrogen levels, under the conditions of the studied doses (N50 - N200), the estimation of grain moisture (M,%) in relation to the SF product (studied concentrations), was described in statistical safety conditions (R\(^2\) = 0.999, p <0.001); equation (3) for level N50; equation (4) for level N100; equation (5) for level N150; and equation (6) for level N200.

\[
M = 0 + 0.2531x - 0.0362y
\]  
(3)

\[
M = 0 + 0.1266x - 0.02571y
\]  
(4)

\[
M = 0 + 0.0852x - 0.04381y
\]  
(5)

\[
M = 0 + 0.626x + 0.03333y
\]  
(6)

where:  
M – grains moisture (%);  
\(x\) – N doses (kg ha\(^{-1}\));  
\(y\) – SF doses (l ha\(^{-1}\))

In order to evaluate the safety of the grains moisture prediction(M, %) by the equations found (equations (2) - (6)), the prediction error (PE) was calculated in relation to SF (PE) on each level of N, and the results are presented in table 2. Average values of the prediction error (PE) are graphically represented in figure 2.

For the evaluation of the grain moisture prediction safety (M,%) in relation to SF on each level of N, the RMSEP statistical parameter was calculated, according to equation (1), and the values are presented in table 2. From the analysis of the data of PE and RMSEP values obtained, in relation to each level N, it was found that the most reliable prediction of grain moisture M (%) in relation to SF was recorded at level N150, where PE = -0.14, and RMSEP = 0.049163.

The moisture variation (M,%) was analyzed on the entire data series, in relation to the overall values of the fertilizers used (N, kg ha\(^{-1}\) and SF, l ha\(^{-1}\)), and the equation (7) resulted in statistical safety conditions (0.917, p <0.001). The graphic distribution is represented in figure 3 in the form of a 3D model, respectively in figure 4 in the form of isoquants.
Table 2. Grains moisture prediction error (PE) and RMSEP statistical parameter values, in relation to SF and N, Alex wheat cultivar

<table>
<thead>
<tr>
<th>Fertilizers variants</th>
<th>Prediction Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N0</td>
</tr>
<tr>
<td>SF0</td>
<td>-12.80</td>
</tr>
<tr>
<td>SF1</td>
<td>-9.41</td>
</tr>
<tr>
<td>SF2</td>
<td>-5.71</td>
</tr>
<tr>
<td>SF3</td>
<td>-2.32</td>
</tr>
<tr>
<td>SF4</td>
<td>0.98</td>
</tr>
<tr>
<td>SF5</td>
<td>-4.77</td>
</tr>
<tr>
<td>PE (mean)</td>
<td>-4.08</td>
</tr>
<tr>
<td>RMSEP</td>
<td>7.23439</td>
</tr>
</tbody>
</table>

Notes. N0 to N200 – nitrogen fertilizer variants (0, 50, 100, 150 and 200 kg N ha\(^{-1}\) a.s.); SF0 to SF5 – Super Fifty foliar biofertilizer concentration (0, 1, 2, 3, 4 and 5 l ha\(^{-1}\)) PE – prediction error.

Figure 2. Graphical representation of the average values of the prediction error (PE) for M (%) in relation to SF and N

The optimal values for N and SF, in relation to the grains moisture (M,%) were calculated and resulted in the values \(x_{\text{opt}} = 120.975\) kg ha\(^{-1}\) N a.s. (active substance), respectively \(y_{\text{opt}} = 2.964\) l ha\(^{-1}\) (SF).

\[
M = ax^2 + by^2 + cx + dy + exy + f
\]  \hspace{1cm} (7)

where:  
M - wheat grains moisture (%);  
x – N – nitrogen doses, kg ha\(^{-1}\);  
y – SF – Super Fifty, l ha\(^{-1}\);  
a, b, c, d, e, f – coefficients of the equation (7);  
a= -0.0002794;  
b= -0.5336723;  
c= 0.1189940;  
d= 5.2608458;  
e= -0.0173403;  
f= 0

PCA led to the diagram in figure 5. According to PCA, PC1 explained 42.523% of variance, and PC2 explained 32.781% of variance, in relation to N doses.
Figure 3. 3D model of humidity variation (M,%) of wheat grains, Alex cultivar, under the influence of N (x-axis), and SF (y-axis)

Figure 4. Model in the isoquants form of humidity variation (M,%) of wheat grains, Alex cultivar, under the influence of N (x-axis), and SF (y-axis)

Figure 5. PCA diagram in relation to N doses (N as biplot)
In relation to the SF leaf biofertilizer, PCA led to the diagram in Figure 6. PC1 explained 63.936% of variance, and PC2 explained 23.776% of variance, in relation to SF concentration.

Cluster analysis, Two-way led to the diagram in Figure 7, in which the variants were associated on the basis of similarity (Euclidean distances), in conditions of statistical safety (Coph. Corr. = 0.714. In relation to N, it was found the association of the variants in two distinct clusters, and in relation to SF the SF4 variant was positioned separately, and the other variants were grouped within a sub-cluster.

Figure 6. PCA diagram in relation to SF concentration (SF as biplot)

Figure 7. Two-way cluster analysis diagram regarding the association of variants in relation to N and SF
In order to quantify the level of similarity of the variants, the values of Similarity and Distance Indices (SDI), were calculated. In relation to nitrogen doses (N), the highest level of similarity was recorded between variants N100 and N200 (SDI = 0.37510), table 3.

In relation to the SF biostimulator, the highest level of similarity was registered between the SF2 and SF3 variants (SDI = 0.22316), table 4.

<table>
<thead>
<tr>
<th>N0</th>
<th>N50</th>
<th>N100</th>
<th>N150</th>
<th>N200</th>
</tr>
</thead>
<tbody>
<tr>
<td>N0</td>
<td>0.84131</td>
<td>0.75750</td>
<td>0.43232</td>
<td>0.64257</td>
</tr>
<tr>
<td>N50</td>
<td>0.84131</td>
<td>0.50931</td>
<td>0.47403</td>
<td>0.46336</td>
</tr>
<tr>
<td>N100</td>
<td>0.75750</td>
<td>0.50931</td>
<td>0.52792</td>
<td>0.37510</td>
</tr>
<tr>
<td>N150</td>
<td>0.43232</td>
<td>0.47403</td>
<td>0.52792</td>
<td>0.47728</td>
</tr>
<tr>
<td>N200</td>
<td>0.64257</td>
<td>0.46336</td>
<td>0.37510</td>
<td>0.47728</td>
</tr>
</tbody>
</table>

Table 3. SDI values in relation to N doses, Alex wheat cultivar

<table>
<thead>
<tr>
<th>SF0</th>
<th>SF1</th>
<th>SF2</th>
<th>SF3</th>
<th>SF4</th>
<th>SF5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF0</td>
<td>0.50774</td>
<td>0.33437</td>
<td>0.26420</td>
<td>0.57836</td>
<td>0.45044</td>
</tr>
<tr>
<td>SF1</td>
<td>0.33437</td>
<td>0.46669</td>
<td>0.32218</td>
<td>0.51078</td>
<td>0.42059</td>
</tr>
<tr>
<td>SF2</td>
<td>0.26420</td>
<td>0.32218</td>
<td>0.22316</td>
<td>0.44800</td>
<td>0.46573</td>
</tr>
<tr>
<td>SF3</td>
<td>0.57836</td>
<td>0.51078</td>
<td>0.44800</td>
<td>0.40829</td>
<td>0.29816</td>
</tr>
<tr>
<td>SF4</td>
<td>0.45044</td>
<td>0.42059</td>
<td>0.46573</td>
<td>0.29816</td>
<td>0.59983</td>
</tr>
</tbody>
</table>

Table 4. SDI values in relation to the SF biostimulator, Alex wheat cultivar

CONCLUSIONS
The moisture content of wheat grains, Alex cultivar, recorded a specific variation in relation to the doses of nitrogen (N, ammonium nitrate), 0 - 200 kg ha⁻¹, and the concentrations of the Super Fifty (SF) foliar biofertilizer, in the range 1 - 5 l ha⁻¹, studied.

The regression analysis facilitated the finding of some equations, as models for estimating M (%) in relation to N and SF, in statistical safety conditions. 3D and isoquants graphic models showed the variation of moisture (M, %) in relation to N and SF.

The approached model can be adapted for other wheat genotypes, or agricultural crops, in relation to different influencing factors.

The results obtained are of scientific and practical importance in order to estimate the moisture content of wheat grains for decisions on harvesting and post-harvest production management.

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BIBLIOGRAPHY


