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GRAINS WEIGHT ESTIMATING MODEL ON MAIZE MATURE EARS BASED ON SOME STEMS BIOMETRIC PARAMETERS

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Abstract

The study analyzed different models for estimating seeds production on maize mature ear based on biometric parameters of plants. The biological material was represented by the maize MAS 59 hybrid. In the main growth stage 5 (55-57 BBCH code) stem based diameter (SBD), stem height (SH), stem weight (SW) and stem leaf number (SLN) were determined. At maturity, the weight of the grains (GW) per mature maize ear was determined. Moderate correlations between GW and SH (r = 0.778) and strong correlations between GW with SW (r = 0.819), GW with SBD (r = 0.850) and GW with SLN (r = 0887) were found. The regression analysis led to obtaining polynomial equations of degree 2, which facilitated the estimation of GW according to biometric parameters, in statistical safety conditions (p < 0.05). Based on RMSEP values, it was estimated that the most reliable estimate was obtained based on SLN (RMSEP = 20.80075), compared to SH where RMSEP = 28.13223. Optimal values were calculated for SBD, SH, SW and SLN in relation to GW. 3D and isoquants graphics were obtained for GW distribution according to biometric parameters.

***Key words**: biometric parameters, grains weight estimation, mathematical model, maize, RMSEP.*

INTRODUCTION

Maize is a crop plant of high importance in human nutrition, in industry, as fodder, as ornamental plant etc. (Shiferaw et al., 2011; Shah et al., 2016; Budak and Aydemir, 2018; Capstaff and Miller, 2018; Langner et al., 2019).
The great variety of genotypes, the high ecological plasticity in maize, made it possible to cultivate corn in very varied conditions in terms of soil, climate, relief conditions (Kusmec et al., 2018; Schneider et al., 2020).
At the same time, corn is a plant that responds favorably to various levels of agricultural technologies, both in subsistence conditions and in conditions of high-performance technologies (Gouse, 2012; Lana et al., 2017).
A number of studies have evaluated the behavior of maize genotypes in various climatic conditions (Ramirez-Cabral et al., 2017; Yang et al., 2019), soil fertility (Zhang et al., 2018), and different agricultural practices (Fromme et al., 2019; Zhou et al., 2019).
Physiological indices in crop plants have been studied in relation to various influencing factors such as water (Hernández et al., 2020), soil type and its properties (Moreira et al., 2020), mineral elements (Rawashdeh and Sala, 2014a, 2014b; Căbăroiu et al., 2018, 2019; Abubakar et al., 2019), plant density and mode of reflection in production (Liu et al., 2020), stress factors etc. (Grzesiak et al., 2017; Wang et al., 2019).
Modeling and models are very useful methods and tools in the study of plants, crops and agricultural systems (Antle et al., 2017a, 2017b; Jones et al., 2017). Numerous models, some given by different mathematical expressions, have been found for the study of plants in relation to climatic, technological, mineral elements, stress factors, nutritional status, or to describe its production and quality (Jing et al., 2016; Adnan et al., 2017; Choruma et al., 2019; Liu and Basso, 2020).
In maize crops, different models were also used to analyze, describe and estimate some physiological indices (Schlemmer et al., 2013; Căbăroiu et al., 2018; Zhang et al., 2019), certain fertilization imbalances (Sala et al., 2016), or biomass production (Herbei and Sala, 2016; Tandzi and Mutengwa, 2020).
The present study found models for estimating grains weight in maize mature ears based on some plants biometric parameters determined in intermediate stages of vegetation.

MATERIALS AND METHODS

The study evaluated the safety of some mathematical models that were obtained to estimate grains weight in maize mature ears, based on plant biometric parameters.

The study was carried out in the area of Nădlac Locality, Arad County, Romania, on a chernozem soil type, in the 2018-2019 agricultural year.

The biological material was represented by the maize MAS 59 hybrid. Biometric parameters of the plants were determined in the Inflorescence emergence stage (Main growth stage 5), 55-57 BBCH code.

Stem based diameter (SBD) was determined with electronic caliper (± 0.001 mm). The height of the stem (SH) was measured with a ruler (± 0.5 mm); the number of leaves per stem (SLN) was determined by counting. The weight of the stem (SW) and the weight of the grains (GW) were determined by weighing with a technical balance (± 0.05 g).

The ANOVA test was used to evaluate the safety of the experimental data and the presence of variance in the data set. The correlation analysis was performed in order to evaluate the level of interdependence between the analyzed parameters Regression analysis was used to estimate the GW variation in relation to biometric parameters. Based on the regression analysis, models were obtained such as polynomial equations that facilitated the estimation of GW according to biometric parameters of the plants studied.

The statistical safety of the obtained equations and of the results was described by the regression coefficient (R^2), and by p, F-test and RMSEP (Root Mean Square Error of Prediction) parameters, equation (1). For data analysis and graph representation PAST software (Hammer et al., 2001) and Wolfram Alpha software were used.

$$RMSEP = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(y_j - \hat{y}_j\right)^2} \quad (1)$$

RESULTS AND DISCUSSIONS

Based on the measurements and determinations made on the plants and grains at mature ears, the values of the experimental data were obtained: stem base diameter (SBD), stem height (SH), stem weight (SW), stem leaf number (SLN) and grain weight (GW), Table 1. The ANOVA single factor test confirmed the data safety and the presence of the variance in the experimental data set, according to $p << 0.001$, $F > Fcrit$ ($F = 27.1545$, $Fcrit = 5.5639$), for Alpha = 0.001.

Table 1. Values of plant stem biometric parameters and grains weight for maize, MAS 59 hybrid

Sample	SBD	SH	SW	SLN	GW
	(mm)	(cm)	(g)	(no)	(g)
1	24.26	127	665.4	10	276.0
2	12.85	69	121.6	6	153.9
3	19.13	80	282.5	8	201.2
4	25.49	156	812.2	10	280.8
5	23.7	119	560.8	10	294.5
6	26.64	151	816.9	12	302.3
7	26.57	145	816.9	10	251.0
8	26.26	142	743.8	10	289.4
9	12.44	51	115.5	6	218.5
10	21.71	84	361.6	9	256.1
SE	± 1.713	± 1.062	± 9.521	± 0.604	± 5.138

According to the values of the coefficient of variation (CV), there was a higher variation in the stem weight ($CV_{SW} = 54.0385$) and a lower variation in the grain weight parameter ($CV_{GW} = 18.9035$). In the case of the stem height parameter, the coefficient of variation had the value $CV_{SH} = 33.9382$, and SBD and SLN parameters had close values of the coefficient of variation ($CV_{SBD} = 24.7291$; $CV_{SLN} = 21.0105$).

The linear correlation analysis (Pearson) led to the data in Table 2. The analysis of the obtained values highlighted the existence of strong correlations of GW with SBD, SW and SLN and moderate correlations with SH. Also, between the values of the biometric parameters determined in plants, very strong and strong, positive correlations were registered.

Table 2. The values of the correlation coefficient for the studied parameters in maize, the MAS 59 hybrid

	SBD	SH	SW	SLN	GW
SBD		7.94E-05	1.43E-05	1.30E-05	0.00182
SH	0.933		5.84E-08	0.000415	0.008017
SW	0.957	0.989		0.000171	0.003751
SLN	0.958	0.898	0.919		0.00063
GW	0.850	0.778	0.819	0.887	

The relationship between SH and SBD was described by equation (2) in statistical safety conditions according to $R^2 = 0.939$, $p << 0.001$, $F = 54.817$.

$$SH = 0.5148x^2 - 13.53x + 148.2 \quad (2)$$

where: SH - stem hight (cm)
x - SBD - stem based diameter (mm)

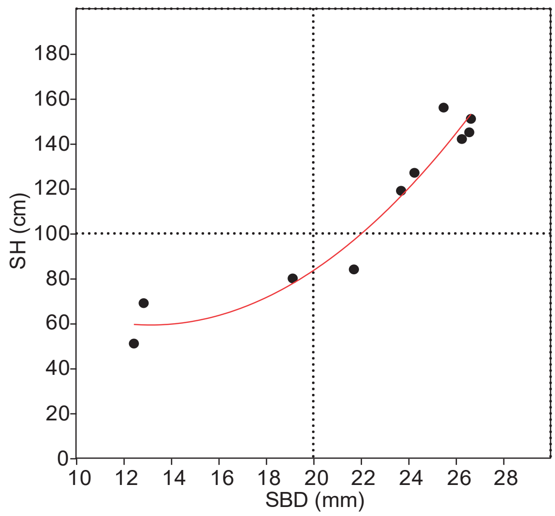

Figure 1. Graphical distribution of SH in relation to SBD in maize, the MAS 59 hybrid

The variation of SW values in relation to SBD were described by equation (3) in statistical safety conditions ($R^2 = 0.976$, $p << 0.001$, $F = 142.89$).

$$SW = 3.619x^2 - 90.76x + 685.7 \quad (3)$$

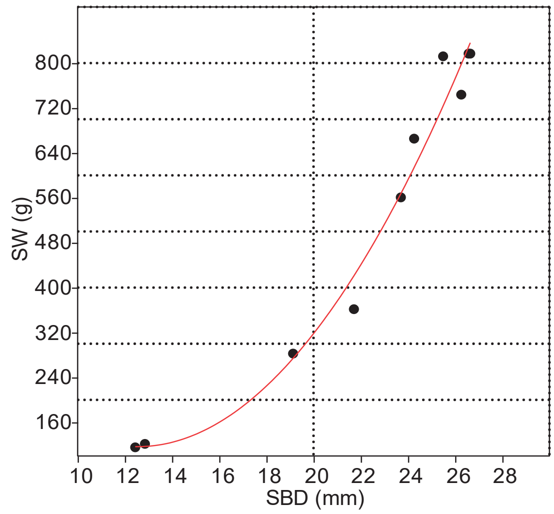

Figure 2. Graphical distribution of SW in relation to SBD in maize, the MAS 59 hybrid

The regression analysis facilitated the obtaining of GW estimation models based on the individual values of the biometric parameters determined in plants, growth stage 55-57 BBCH code.

Models of the type of polynomial equations of degree 2, equations (4) to (7), were obtained which facilitated the estimation of GW in statistical safety conditions, Table 3.

Based on the values of the statistical safety parameters (R^2, p, F-test, and RMSEP), it turned out that SLN provided the safest prediction of GW, compared to the other biometric parameters.

Table 3. GW prediction equations based on biometric parameters of maize plants, the MAS 90 hybrid

Biometric parameter	Equation	Equation number	Statistical safety parameters			
			R^2	p	F-test	RMSEP
SBD	$GW = 0.0982x^2 + 3.655x + 122.6$	(4)	0.725	0.0109	9.2207	23.73994
SH	$GW = -0.004506x^2 + 1.929x + 98.36$	(5)	0.613	0.0358	5.5587	28.13223
SW	$GW = -0.0002905x^2 + 0.4141x + 136$	(6)	0.760	0.0067	11.111	22.15136
SLN	$GW = -0.6818x^2 + 33.85x + 3.038$	(7)	0.788	0.0043	13.07	20.80075

Multiple regression analysis led to the finding of models that facilitated the estimation of grain weight (GW) on maize mature ears according to plant biometric parameters (determined in 55-57 BBCH code), as their simultaneous action. Equations of the type GW=f (x, y) were obtained, where x, y was the biometric parameters, taken in pairs (SBD, SH, SW, SLN). The equations for estimating the grains weight (GW) on maize mature ears were obtained, Eq. (8) to Eq. (11), with different levels of statistical safety (according to $p < 0.05$).

Although each biometric parameter of the plants is important, still from the multiple regression analysis were found certain pairs of parameters that facilitated the estimation of GW in high statistical safety conditions according to ANOVA test (both in general terms of the equations and for each parameter in part; p<0.05). Thus, high statistical safety was obtained for the analysis in combination of parameters SBD with SLN, and SH with SW, respectively.

The estimation of GW based on SBD (stem base diameter) and SLN (stem leaf number) was described by equation (8) in general statistical safety conditions (R^2 = 0.996, p << 0.001, F = 804.0272). Also for each term of equation (8) was recorded statistical certainty, according to the p values obtained (p = 0.0355 for x^2, p = 0.0093 for y^2, p = 0.0040 for x, p = 0.00164 for y, and p = 0.0150 for xy, respectively, where x - SBD, and y - SLN).

$$GW = ax^2 + by^2 + cx + dy + exy + f \quad (8)$$

where: GW - grain weight in maize mature ear;
x - SBD - stem based diameter (mm);
y - SLN - stem leaf number;
a, b, c, d, e, f - the equation (8) coefficients;
a = -5.54621410449098;
b = -60.4859095649374;
c = -122.475929977058;
d = 303.038174731417;
e = 39.3402740721637;
f = 0.

The 3D graphical distribution of GW values in relation to SBD (x-axis) and SLN (y-axis) is presented in Figure 3. Based on the values of the coefficients of equation (8), the optimal values for SBD (x = 14.0657) and SLN (y = 7.0792) were obtained, and the graphical representation in the form of isoquants is presented in Figure 4.

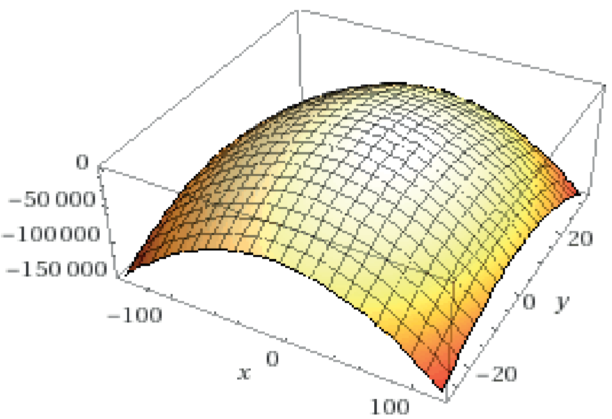

Figure 3. 3D graphical representation of the variation of the GW value in relation to SBD (*x*-axis) and SLN (*y*-axis)

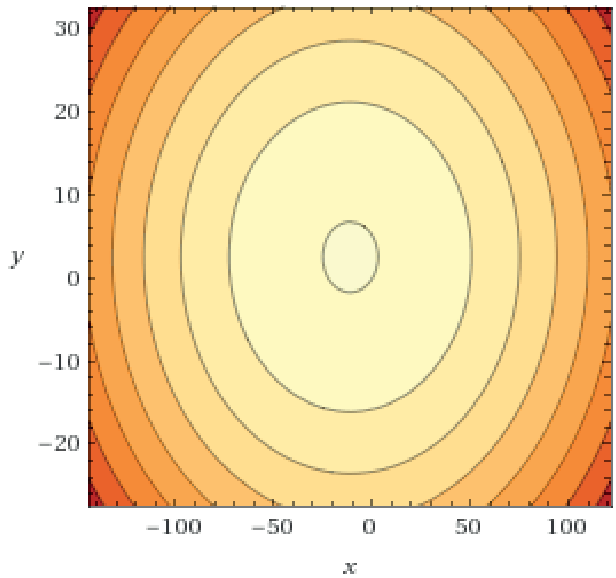

Figure 4. Graphical representation in the form of isoquants of the distribution of GW values according to SBD (*x*-axis) and SLN (*y*-axis)

The estimation of GW based on SH (stem height) and SW (stem weight) was described by equation (9) in general statistical safety conditions, according to R^2 = 0.996, p << 0.001, F = 846.4896. Also for each term of equation (9) statistic safety was recorded, according to the p values obtained (p << 0.001 for x^2, p << 0.001 for y^2, p << 0.001 for x, p = 0.000224 for y, p < <0.001 for xy).

$$GW = ax^2 + by^2 + cx + dy + exy + f \quad (9)$$

where: GW - grain weight in maize mature ear;
x - SH - stem height (cm);
y - SW - stem weight (g);
a, b, c, d, e, f - the equation (9) coefficients;
a = -0.184741346834375;
b = -0.00453570586772057;
c = 11.7082990067731;
d = -1.59048298832375;
e = 0.0572027400268204;
f = 0.

The 3D graphical distribution of the GW variation in relation to SH and SW is presented in Figure 5. Based on the values of the coefficients of equation (9), the optimal values for SH (*x* = 191.399 cm) and SW (*y* = 1031.601 g) in relation to GW were obtained, and the graphical representation in the form of isoquants is presented in Figure 6.

The estimation of GW based on SBD and SW was described by equation (10) in general conditions of statistical safety of the equation ($R^2 = 0.992$, $p << 0.001$, $F = 409.1736$).

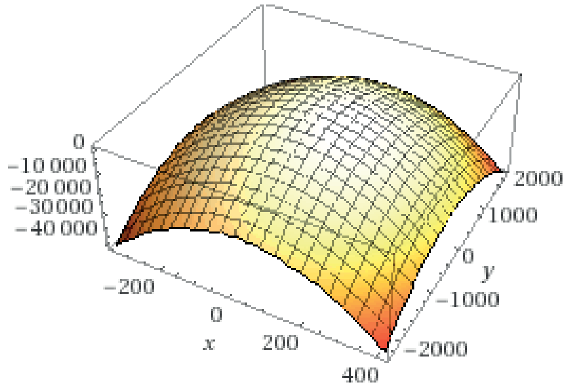

Figure 5. 3D graphical representation of the variation of GW values in relation to SH (*x*-axis) and SW (*y*-axis)

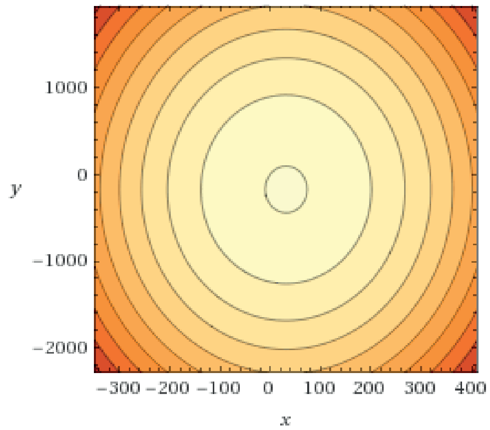

Figure 6. Graphical representation in the form of isoquants of the GW distribution according to SH (*x*-axis) and SW (*y*-axis)

Within the parameters of the equation (10) statistical safety was registered only for the stem based diameter (SBD), respectively $p = 0.00164$ for x and $p = 0.03707$ for x^2.

$$GW = ax^2 + by^2 + cx + dy + exy + f \qquad (10)$$

where: GW - grain weight in maize mature ear;
x - SBD - stem based diameter (mm);
y - SW - stem weight (g);
a, b, c, d, e, f - the equation (10) coefficients;
a = -1.44630575467533;
b = -0.00114731028912421;
c = 28.5990692292411;
d = -0.346527674314089;
e = 0.0732732499500045;
f = 0.

From the analysis of the 3D distribution of GW values in relation to SBD and SW it was found that at a small variation of SW (*y* axis), a very important role in defining GW was given by SBD (*x* axis), Figure 7. In relation to the two independent variables (x, y) for obtaining the optimal value of GW, the values $x_{opt} = 31.717$ mm, respectively $y_{opt} = 861.803$ g were obtained. The graphical distribution in the form of isoquants for the variation GW in relation to SBD and SW is presented in Figure 8.

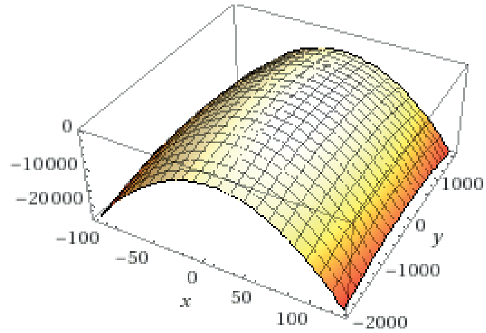

Figure 7. 3D graphical distribution of GW values in relation to SBD (*x*-axis) and SW (*y*-axis)

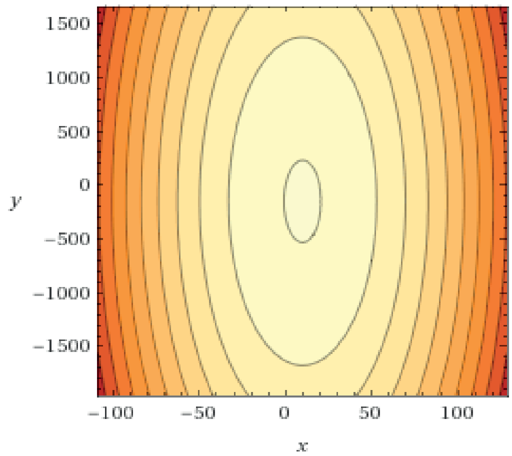

Figure 8. Graphical distribution in the form of isoquants of GW values in relation to SBD (*x*-axis) and SW (*y*-axis)

The estimation of GW based on SW and SLN was given by equation (11) under general conditions of statistical safety, according to $R^2 = 0.994$, $p << 0.001$, $F = 512.8562$. However, within the parameters of the equation, statistical safety was recorded only for x (SW, $p = 0.01298$). From the analysis of the 3D distribution of GW values in relation to SW and SLN, a small variation of SW (*x*-axis) was found, and a very important role in defining GW was given by SLN (*y*-axis), Figure 9.

$$GW = ax^2 + by^2 + cx + dy + exy + f \qquad (11)$$

where: GW - grain weight in maize mature ear;
x - SBD - stem based diameter (mm);

y - SW - stem weight (g);
a, b, c, d, e, f - the equation (11) coefficients;
a = -0.000704285832822687;
b = -5.85197982516811;
c = -0.205824441634237;
d = 57.9863038463908;
e = 0.111342770989778;
f = 0.

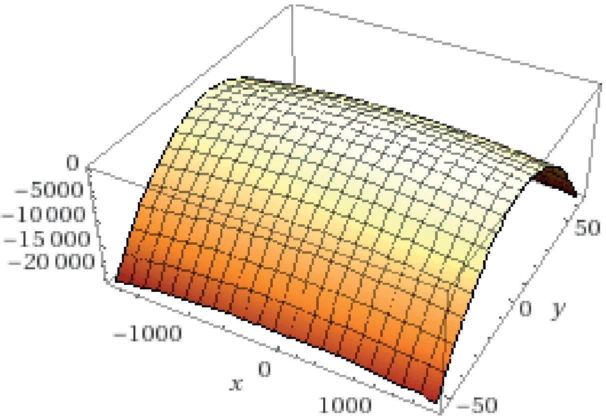

Figure 9. 3D graphical distribution of GW values in relation to SW (*x*-axis) and SLN (*y*-axis)

In relation to the two independent variables (x, y) for achieving the optimal value of GW, the values x_{opt} = 989.909 g (SW), and y_{opt} = 14.37 (SLN) respectively, were obtained. Under the given conditions, for the optimal GW, SW should have the optimal value of 989.909 g, and under the experimental conditions maximum values for SW of 816.9 g were recorded, with a difference of 173.009 g. This could be achieved through better supply of water and plant nutrients. The graphical distribution in the form of isoquants for the GW variation in relation to SW (x-axis) and SLN (axis 4) is presented in Figure 10.

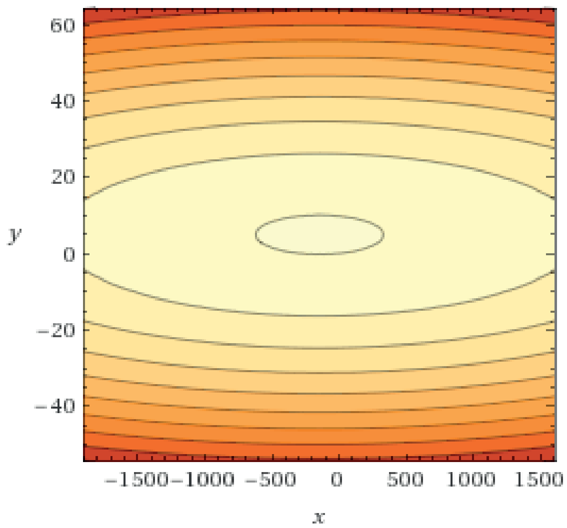

Figure 10. Graphical distribution in the form of isoquants of GW in relation to SW (*x*-axis) and SLN (*y*-axis)

The obtained models, of the type of polynomial equations of degree 2, equations (4) to (7), facilitated the estimation of grain weight on maize mature ears, based on biometric parameters of plants determined in stage 55-57 BBCH code. Models such as eq. (8) to eq. (11) facilitated the description of GW variation according to plants biometric parameters under conditions of simultaneous action, and also facilitated the obtaining of optimal values for the studied parameters, in order to ensure GW_{optim}.

Physiological indices and biometric parameters of maize plants are important elements to ensuring productivity, production and quality and have been studied primarily in relation to genetic variation and breeding in maize (Lorenz et al., 2010; Hassan et al., 2018). Also physiological indices, biometric parameters and quality indices in corn were studied in relation to climatic conditions, soil conditions, mineral elements, plants nutritional status (Valadabadi and Farahani, 2010; Ciampitti and Vyn, 2012; Prisecaru and Sala, 2017; Căbăroiu et al., 2019).

The importance of methods and models for estimating and predicting production of plants of agricultural interest has been highlighted in various studies, due to their importance for obtaining accurate agricultural statistics, evaluation of agricultural practices, adjustment of technology elements, decisions in regarding the capitalization of agricultural production (Sala and Boldea, 2011; Popescu, 2018; Popescu et al., 2018; Tendzi and Mutengwa, 2020).

Based on Chl (chlorophyll content) FB (fresh biomass), and NDBR indices, Herbei and Sala (2016) obtained a model for estimating the production of biomass in silage maize in very high statistical safety conditions (R^2 = 0.986, p <0.01). High level of statistical safety (R^2 = 0.7) in estimating grain production in maize in relation to nitrogen fertilization was reported by Vergara-Díaz et al. (2016). Various models for estimating maize production in relation to biometric indices and parameters of plants, cobs, as well as in relation to the NDVI index were also presented by Tendzi and Mutengwa (2020).

The results obtained and communicated by this study are in the general context of approaching the models for estimating production at the main plants of agricultural interest, in order to provide solutions for improving technologies and optimizing production.

CONCLUSIONS

By regression analysis were obtained models for estimating grain weight in mature maize ears based on biometric parameters of plants determined in the Main growth stage 5 (55-57 BBCH code).

The optimal values of the biometric parameters in relation to the optimal GW were determined, and this can contribute to the optimization of some elements of technology in order to manage the production of maize grains.

The obtained models allow the estimation of maize grain production from early vegetation stages, so that the information generated can be the basis for decisions on the destination of the maize crop, and of the grains or biomass productions.

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