MODEL FOR CORN KERNELS WEIGHT ESTIMATING BASED ON MATURE CORN EARS DIMENSIONAL PARAMETERS

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Abstract. *By regression analysis in the present study were obtained models of grain weight prediction based on the dimensional parameters of mature ears of corn. There were randomly sampled 35 mature corn ears of variable sizes, the MAS59 hybrid, the FAO 500 Group. Were determined the parameters: corn ear length (L), base diameter (BD), middle diameter (MD) and tip diameter (TD) of corn ears, total weight of each corn ear (TW), grains weight (GW) and weight of corncobs (CCW). The length of the corn ears (L) recorded values between 12.6 - 20.3 ± 0.32 cm. The diameter at the base of the corn ears (BD) had values between 43.54 - 58.95 ± 0.57 mm; the diameter at the middle of corn ears (MD) had values between 45.34 - 55.78 ± 0.39 mm, and the diameter at the top of corn ears (TD) had values between 38.15 - 49.29 ± 0.41 mm. Total weight of each corn ears (TW) recorded values between 144.9 - 357.2 ± 9.76 g, and the weight of the grains varied between 128.7 - 300.3 ± 8.09 g. Corncobs weight recorded values between 16.2 - 59.9 ± 1.81 g. Given the high level of correlations identified between the studied biometric parameters and the grain weight, multiple linear regression analysis was used to test the possibility and safety of grain weight prediction, based on the biometric parameters of corn ears. A weight estimation equation of the grains was obtained based on all the parameters taken in the study, under conditions of $R^2 = 0.998$, $p << 0.001$. From the regression analysis it was possible to obtain some functions of corn grains weight prediction based on each parameters, under conditions of $R^2 = 0.801$ for parameter L, $R^2 = 0.811$ for parameter BD, $R^2 = 0.590$ for parameter MD, $R^2 = 0.345$ for parameter TD, $R^2 = 0.993$ for parameter TW, and $R^2 = 0.849$ for parameter CcW, respectively.*

Keywords: correlations, grains weight, maize ears, prediction model, regression analysis

INTRODUCTION

Corn is one of the main cereals grown for grains yield or biomass production, for use in human nutrition, animal feed, industrialization (GOVIND et al., 2015; FROMME et al., 2019). Corn is a plant with high ecological plasticity and it is in cultivation in all agricultural areas around the globe, and the productivity of maize has increased mainly through the progress of genetics and cultivation technologies (HAARHOFF and SWANEPOEL, 2018).

The relationship of corn crops has been intensively studied in different agricultural areas in relation to pedoclimatic factors (SINDELAR et al., 2010; HARRISON et al., 2011; Gong et al., 2015), cultivation systems and technologies (VAN ROEKEL and COULTER, 2011; THIERFELDER et al., 2015; HAARHOFF and SWANEPOEL, 2018), nutrition conditions (HAEGELE et al., 2014), stress factors (SADLER et al., 2000; SETTER et al., 2001).

The eco-physiology and morpho-physiology of maize has been studied in relation to different genotypes and their relation to nutrition factors, sunlight reception, photosynthesis process and plant productivity (STEWART et al., 2003; BOMMSMA et al., 2009; VAN ROEKEL and COULTER, 2012; GRICHAR et al., 2018).

Physiological indices such as leaf area, chlorophyll content, foliar thickness, specific weight of foliar surface, were evaluated in relation to different conditions of growth and nutrition in maize (ZIADI et al., 2008; SZCZEPANIAK et al., 2016; ZHAO et al., 2018).

In general, the level of nutrition of the plants is reflected and expressed in the variation of the physiological indices (RAWASHDEH and SALA, 2013, 2014a,b, 2015; JIVAN and

SALA, 2014), being recorded close relationships of interdependence with the elements of productivity and the quality of the production (RAWASHDEH and SALA, 2016).

Biometric parameters of corn ears, such as length, diameter of ears, grains number, grains weight, and yield were evaluated in relation to ecological, technological and nutritional factors (BREDA et al., 2018)

By regression analysis in the present study were obtained models for predicting the weight of the grains based on the values of the dimensional parameters of corn mature ears.

MATERIAL AND METHODS

The aim of the study was to found models for predicting the weight of corn grains, based on biometric parameters of corn mature ears.

The biological material was represented by the MAS59 maize hybrid, FAO 500 Group. The study was carried out in the area of Nădlac, Arad County, Romania, on a soil of chernozem type.

35 mature ears of corn, of variable sizes, were taken at random. The following biometric parameters were determined: length of corn ears (L), diameter at the base (BD), middle (MD) and tip (TD) of the corn ears, total weight of each corn ear (TW), weight of grains for each corn ear (GW) and corncob weight (CcW). The length of the corn ears was measured with the ruler, with an accuracy of ± 0.5 mm. The diameter was measured with an electronic caliper with an accuracy of ± 0.001 mm. The weight was determined with a laboratory balance, with an accuracy of ± 0.02 g.

The experimental data obtained on the basis of the measurements made were analyzed with the PAST software (HAMMER et al., 2001) and with the statistical module from EXCEL, Office 2007. The correlation analysis, the ANOVA test, and multiple linear regression analysis (MLR) were used, and as statistical safety parameters the correlation coefficients r and R^2, the parameter p and the sample F were used.

RESULTS AND DISCUSSIONS

Based on the measurements that were made, the length of corn mature ears (L) recorded values between 12.6 - 20.3 ± 0.32 cm. The diameter at the base of corn ears (BD) had values between 43.54 - 58.95 ± 0.57 mm; the diameter at the middle of corn ears (MD) had varied between 45.34 - 55.78 ± 0.39 mm, and the diameter at the top of corn ears (TD) had values between 38.15 - 49.29 ± 0.41 mm. Total weight of each corn ear (TW) recorded values between 144.9 - 357.2 ± 9.76 g, and the weight of the grains, for each corn ear, varied between 128.7 - 300.3 ± 8.09 g. The weight of the corncob recorded values between 16.2 - 59.9 ± 1.81 g. The obtained values for each parameter and case studied are presented in table 1.

The single factor ANOVA test showed the presence of the variance in the experimental data set, and the statistical certainty of the recorded values, table 2.

The correlation analysis led to the values presented in table 3. From the analysis of the respective values were found very high positive correlations between the weight of the grains (GW) and total weight of corn ear (TW), as and between the corncobs weight (CcW) and the total weight of corn ear (TW). High positive correlations were recorded between the length of corn ears (L) and the total weight of each ear (TW), respectively the weight of the grains (GW); between the diameter at the base of ear (BD) and the total weight (TW), respectively the weight of the grains (GW); between the diameter at the middle of ear (MD) and the diameter at the tip of ear (TD), as well as between the weight of the grains (GW) and the weight of corncobs (CcW). Also, moderate or lower correlations between certain parameters studied were recorded, table 3.

Table 1

Biometric data on corn matured ears, the MAS59 hybrid

Sample	L	BD	MD	TD	TW	GW	CcW
1	12.6	54.14	52.96	49.29	225.0	191.5	33.5
2	13.7	47.01	45.34	38.15	144.9	128.7	16.2
3	14.1	52.46	51.95	44.91	183.4	160.0	23.4
4	14.2	46.19	48.67	40.84	160.8	141.4	19.4
5	14.2	52.46	51.77	46.92	199.4	177.6	21.8
6	14.4	50.93	49.51	42.73	178.2	155.6	22.6
7	14.6	43.54	51.22	45.11	198.0	173.0	25.0
8	14.7	51.91	52.33	44.98	214.2	177.1	37.1
9	14.9	48.92	47.58	42.08	172.4	149.7	22.7
10	15.0	54.81	54.55	47.55	237.0	210.2	26.8
11	15.6	51.48	49.54	44.07	217.3	189.7	27.6
12	15.8	50.26	48.41	40.87	186.3	163.5	22.8
13	16.0	55.50	53.89	46.83	241.1	213.8	27.3
14	16.2	53.75	51.89	46.04	215.8	190.1	25.7
15	16.3	51.12	50.16	44.52	209.3	186.3	23.0
16	16.4	50.44	50.32	43.26	214.5	188.5	26.0
17	16.6	55.04	53.49	45.62	242.6	214.4	28.2
18	16.7	54.25	51.30	44.46	242.7	214.5	28.2
19	16.9	52.63	51.20	44.59	241.2	212.4	28.8
20	16.9	53.23	51.39	43.84	233.0	206.2	26.8
21	17.2	53.36	51.57	45.52	261.1	230.0	31.1
22	17.4	57.23	53.25	47.14	318.3	272.7	45.6
23	17.4	52.05	52.05	44.81	250.2	220.9	29.3
24	17.5	53.79	51.17	44.01	270.2	237.5	32.7
25	17.5	53.46	51.14	45.27	249.4	219.2	30.2
26	17.6	55.88	53.24	47.68	305.8	257.3	48.5
27	17.7	56.13	55.73	47.65	301.0	264.7	36.3
28	17.7	55.15	54.90	48.54	294.6	260.8	33.8
29	18.1	56.05	51.78	44.12	266.9	232.3	34.6
30	18.3	56.91	54.75	46.15	300.3	263.4	36.9
31	19.3	55.85	53.62	48.93	349.6	296.8	52.8
32	19.5	58.95	54.68	48.12	357.2	297.3	59.9
33	19.6	58.28	55.78	43.78	351.5	300.3	51.2
34	19.9	56.76	54.00	45.95	349.0	294.0	55.0
35	20.3	55.44	50.78	43.30	316.5	275.4	41.1
SE	±0.32	±0.57	±0.39	±0.41	±9.75	±8.09	±1.81

L – length of corn ear, BD – diameter at the base of corn ear; MD – diameter at the middle of corn ear; TD – diameter at the tip of corn ear; TW – total weight of corn ear; GW – grains weight; CcW – corncob weight; SE – Standard Error

Table 2

ANOVA test single factor

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1904881	6	317480.2	385.1331	1.7E-119	3.891333
Within Groups	196192.7	238	824.339			
Total	2101074	244				

Alpha = 0.001

Table 3

Matrix correlation table between the determined biometric parameters

	L	BD	MD	TD	TW	GW	CcW
L		4.86E-06	0.002035	0.13074	1.83E-12	4.20E-13	1.10E-07
BD	0.688		3.55E-08	6.04E-05	3.72E-10	2.53E-10	2.70E-07
MD	0.504	0.779		9.55E-10	1.30E-07	8.54E-08	1.48E-05
TD	0.260	0.625	0.827		0.000205	0.000206	0.000865
TW	0.884	0.837	0.759	0.588		3.28E-37	9.45E-16
GW	0.895	0.841	0.765	0.588	0.997		4.56E-13
CcW	0.761	0.746	0.662	0.538	0.928	0.894	

Given the high level of correlations identified between the studied biometric parameters and the grains weight, multiple linear regression analysis was used to test the possibility and safety of grain weight prediction based on the biometric parameters of the corn ears. Multiple linear regression analysis has facilitated obtaining a function that facilitates the estimation of grains weight, on each corn ear, based on the dimensional parameters taken in the study, the relation (1), under statistical safety conditions ($R^2 = 0.998$, $p << 0.01$).

$$GW = -2.8E-14 - 3.3E-15L + 1.79E-15BD + 3.12E-15MD \\ - 2.6E-15TD + 1TW - 1CcW \qquad (1)$$

where: GW – grains weigth; L – length of corn ear, BD – diameter at the base of corn ear; MD – diameter at the middle of corn ear; TD – diameter at the tip of corn ear; TW – total weight of corn ear; GW – grains weight; CcW – corncob weight

From the regression analysis, the estimation the grains weight for each corn ear was analyzed, on the basis of each dimensional parameter studied. Thus, based on the length of corn ear (L), the weight of the grains was predicted based on a linear equation, relation (2), under conditions of $R^2 = 0.801$. The graphical distribution of the estimated values (GW) in relation to the length of corn ear (L) is presented in figure 1.

$$y = 22.485x - 156.93 \qquad (2)$$

where: y - grains weigth (GW); x - length of corn ear (L)

Based on the diameter at the base of corn ear (BD), the weight of the grains was predicted based on a polynomial equation of degree 2, relation (3), under conditions of $R^2 = 0.811$. The graphical distribution of the estimated values (GW) in relation to the biometric parameter BD, is presented in figure 2.

$$y = 0.9689x^2 - 88.483x + 2169.3 \qquad (3)$$

where: y - grains weigth (GW); x – diameter at the base of corn ear (BD)

Based on the diameter at the middle of the corn ear (MD), the weight of the grains was predicted based on a polynomial equation of degree 2, relation (4), but under conditions of low statistical certainty, $R^2 = 0.590$. The graphical distribution of the estimated values (GW) in relation to the MD biometric parameter is presented in figure 3.

$$y = 0.3867x^2 - 23.941x + 415.45 \quad (4)$$

where: y - grain weigth (GW); x – diameter at the middle of corn ear (MD)

Based on the diameter at the tip of corn ear (TD), the weight of the grains was predicted based on a linear equation, relation (5), but without statistical assurance, $R^2 = 0.345$. The graphical distribution of the estimated values (GW) in relation to the biometric parameter TD is shown in figure 4.

$$y = 11.629x - 307.99 \quad (5)$$

where: y - grains weigth (GW); x – diameter at the tip of corn ear (TD)

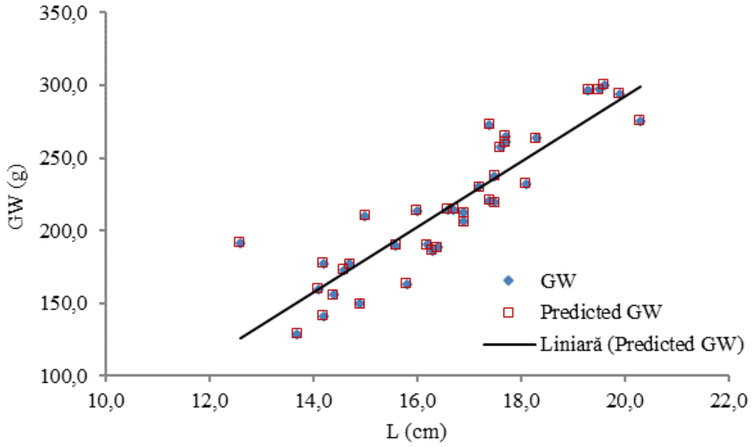

Fig. 1. Graphical distribution of GW values according to the parameter L, for the MAS59 maize hybrid

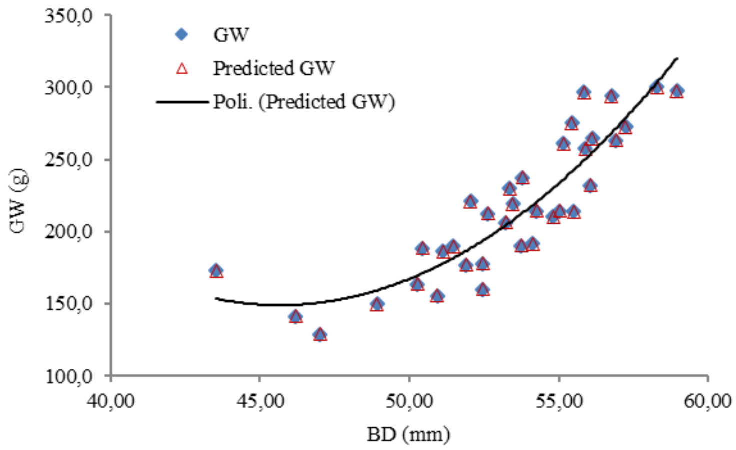

Fig. 2. Graphical distribution of GW values according to the BD parameter, for the MAS59 maize hybrid

Based on the total weight of the corn ear (TW), the weight of the grains was predicted based on a linear equation, relation (6), under conditions of $R^2 = 0.993$. The graphical distribution of the estimated values (GW) in relation to the biometric parameter TW is presented in figure 5.

$$y = 0.8272x + 10.1601 \quad (6)$$

where: y - grain weigth (GW); x – total weight of corn ear (TW)

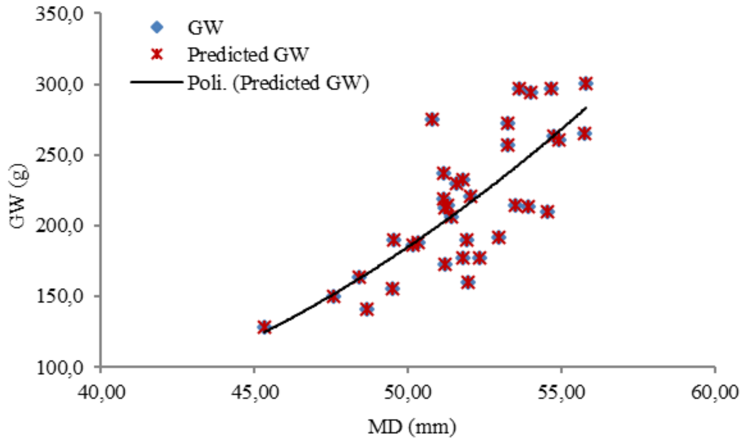

Fig. 3. Graphical distribution of GW values according to the MD parameter, for the MAS59 maize hybrid

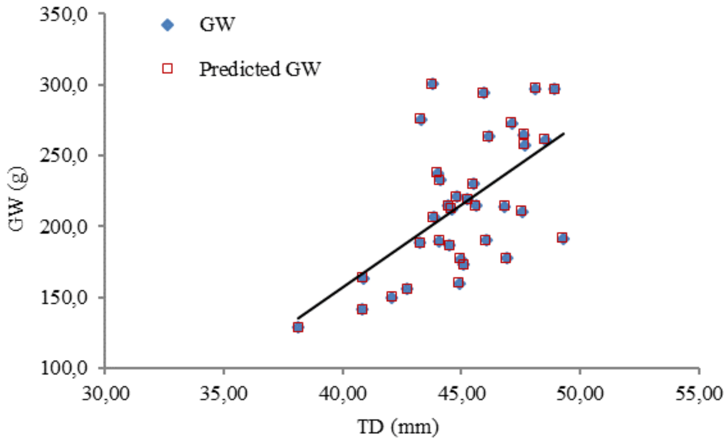

Fig. 4. Graphical distribution of GW values according to the TD parameter for the MAS59 maize hybrid

Based on the weight of the corncob (CcW), the weight of the grains was predicted based on a polynomial equation of degree 2, relation (7), under conditions of R^2 = 0.849. The graphical distribution of the estimated values (GW) in relation to the biometric parameter CcW, is shown in figure 6.

$$y = -0.0858x^2 + 10.452x + 22.507 \quad (6)$$

where: y - grains weigth (GW); x – corncob weihgt (CcW).

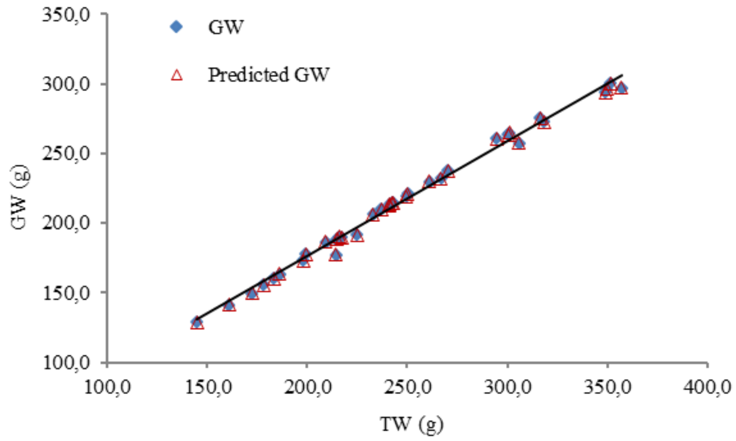

Fig. 5. Graphical distribution of GW values according to the TW parameter for the MAS59 maize hybrid

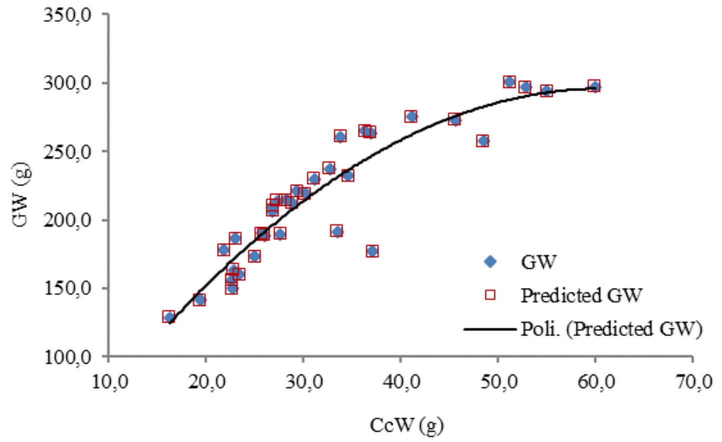

Fig. 6. Graphical distribution of GW values according to the CcW parameter for the MAS59 maize hybrid

The estimation of production in agricultural crops is of practical interest for evaluating the relationship of crops with pedoclimatic conditions; for evaluating the relationship of plants with the fertilization system, mineral elements, and stress factors; and for extrapolation and estimation of production at the surface unit, as well as for organizing the harvesting, transport and storage process. In relation to the scale of analysis, very useful in this regard is the imaging approach for large areas (HERBEI and SALA, 2015, 2016; FERNANDEZ-ORDOÑEZ and SORIA-RUIZ, 2017; FIEUZAL et al., 2017; LEROUX et al., 2019). The estimation of physiological indices and the grains weight based on biometric parameters on corn ears has been performed in other studies, in relation to mineral fertilization with NPK and Lithovit (PRISECARU and SALA, 2017a,b), or in relation to nitrogen and silicon treatments (CĂBĂROIU et al., 2018a,b). Also, corn production was estimated based on pedoclimatic factors (REIDSMA et al., 2009; LIU et al., 2017), plant nutrition status (OSBORNE et al., 2002a; SHARMA and BALI, 2018), stress factors (OSBORNE et al., 2002b; RAES et al., 2006), or genetic material (PRESTERL et al., 2003; DUARTE et al., 2005; ANDRIOLI and SENTELHAS, 2009).

Some researchers have studied the optimization of the fertilization in corn crop under conditions of limited fertilizing resources, or for finding technical and economic solutions that will determine and motivate the farmers to apply a balanced fertilization (BOLDEA et al., 2015; SALA et al., 2019). Also some studies of optimization of fertilizer doses, reflected in the elements of productivity and production were carried out in different pedoclimatic, technological or economic conditions (SALA and BOLDEA, 2011; SALA et al., 2015) due to the need to optimize agricultural technologies.

In the context of the referenced bibliographic sources, the results of the present study are fitting, and they can be useful for practical purpose of evaluating the weight of the grains at the level of corn ears and estimating the production of grains in the corn crop based on biometric parameters in individual corn ear and plant.

CONCLUSIONS

The regression analysis has facilitated the obtaining of some models in the form of linear and polynomial equations of degree 2, for predicting the weight of the grains, based on the values of the biometric parameters of the corn mature ears, MAS59 hybrid.

Models in the form of linear equations were obtained for the prediction of grains weight according to the length of the corn ears (L), the diameter at the tip of the corn ear (TD), and total weight of the each corn ear (TW). Models of the type of polynomial equations of degree 2 were obtained for predicting the weight of the grains depending on the diameter at the base of the corn ear (BD), the diameter at the middle of the corn ear (MD) and the weight of the corncob (CcW), respectively.

The model with the highest degree of confidence for estimating the weight of the grains was obtained based on the parameter TW ($R^2 = 0.993$).

REFERENCES

ANDRIOLI K.G., SENTELHAS P.C. 2009. Brazilian maize genotypes sensitivity to water deficit estimated through a simple crop yield model. Pesquisa Agropecuária Brasileira 44(7): 653-660.

BOLDEA M., SALA F., RAWASHDEH H., LUCHIAN D. 2015. Evaluation of agricultural yield in relation to the doses of mineral fertilizers. Journal of Central European Agriculture 16(2): 149-161.

BOMMSMA C.R., SANTINI J.B., TOLLENAAR M., VYN T.J. 2009. Maize morphophysiological responses to intense crowding and low nitrogen availability: an analysis and review. Agronomy Journal 101(6): 1426-1452.

BREDA C.C., TAVANTI R.F.R., FREDDI O.S., TAVANTI T.R., PIEDADE A.R., MAHL D., GUERRINI I.A., TRABALLI R.C. 2018. Nutritional status and productive components of maize fertilized with sewage sludge. Journal of Agricultural Science 10(6): 86-98.

CĂBĂROIU G., RUJESCU C.I., SALA F. 2018a. Model of productivity elements variation in maize under the influence of silicon treatment. Lucrări Științifice Management Agricol Seria I, 20(3): 18-25.

CĂBĂROIU G., RUJESCU C.I., SALA F. 2018b. Model of physiological indices variation in maize under silicon influence. Lucrări Științifice Management Agricol Seria I, 20(3): 26-32.

DUARTE A.P., MASON S.C., JACKSON D.S., KIEHL C. 2005. Grain quality of Brazilian maize genotypes as influenced by nitrogen level. Crop Science 45(5): 1958-1964.

FERNANDEZ-ORDOÑEZ I.M., SORIA-RUIZ J. 2017. Maize crop yield estimation with remote sensing and empirical models. 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS).

FIEUZAL R., MARAIS SICRE C., BAUP F. 2017. Estimation of corn yield using multi-temporal optical and radar satellite data and artificial neural networks. International Journal of Applied Earth Observation and Geoinformation 57: 14-23.

FROMME D.D., SPIVEY T.A., GRICHAR W.J. 2019. Agronomic response of corn (*Zea mays* L.) hybrids to plant populations. International Journal of Agronomy 2019: Article ID 3589768, 8 pages.

GONG F., WU X., ZHANG H., CHEN Y., WANG W. 2015. Making better maize plants for sustainable grain production in a changing climate. Frontiers in Plant Science 6: 835.

GOVIND K.C., KARKI T.B., SHRESTHA J., ACHHAMI B.B. 2015. Status and prospects of maize research in Nepal. Journal of Maize Research and Development 1(1): 1-9.

GRICHAR W.J., JANAK T.W. 2018. Corn (*Zea mays* L.) response to hybrid, row spacing, and plant populations in the Blacklands of Central Texas. Journal of Advances in Agriculture 8(1): 1214-1223.

HAARHOFF S.J., SWANEPOEL P.A. 2018. Plant population and maize grain yield: a global systematic review of rainfed trials. Crop Science 58(5): 1819-1829.

HAEGELE J.W., BECKER R.J., HENNINGER A.S., BELOW F.E. 2014. Row arrangement, phosphorus fertility, and hybrid contributions to managing increased plant density of maize. Agronomy Journal 106(5): 1838-1846.

HAMMER Ø., HARPER D.A.T., RYAN P.D. 2001. PAST: paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4(1): 1-9.

HARRISON L., MICHAELSON J., FUNK C., HUSAK G. 2011. Effect of temperature changes on maize production in Mozambique. Climate Research 46(3): 211-222.

HERBEI M.V., SALA F. 2016. Biomass prediction model in maize based on satellite images. AIP Conference Proceedings 1738: 350009-1 – 350009-4.

HERBEI M.V., SALA F. 2015. Use landsat image to evaluate vegetation stage in sunflower crops. AgroLife Scientific Journal 4(1): 79-86.

JIVAN C., SALA F. 2014. Relationship between tree nutritional status and apple quality. Horticultural Science 41(1): 1-9.

LEROUX L., CASTETS M., BARON C., ESCORIHUELA M.-J., BÉGUÉ A., SEEN D.L. 2019. Maize yield estimation in West Africa from crop process-induced combinations of multi-domain remote sensing indices. European Journal of Agronomy 108: 11-26.

LIU B., CHEN X., MENG Q., YANG H., VAN WART J. 2017. Estimating maize yield potential and yield gap with agro-climatic zones in China—Distinguish irrigated and rainfed conditions. Agricultural and Forest Meteorology 2019: 108-117.

OSBORNE S.L., SCHEPERS J.S., FRANCIS D.D., SCHLEMMER M.R. 2002a. Detection of phosphorus and nitrogen deficiencies in corn using spectral radiance measurements. Agronomy Journal 94(6): 1215-1221.

OSBORNE S.L., SCHEPERS J.S., FRANCIS D.D., SCHLEMMER M.R. 2002b. Use of spectral radiance to estimate in-season biomass and grain yield in nitrogen- and water-stressed corn. Crop Science 42(1): 165-171.

PRESTERL T., SEITZ G., LANDBECK M., THIEMT E.M., SCHMIDT W., GEIGER H.H. 2003. Improving nitrogen-use efficiency in European maize. Crop Science 43(4): 1259-1265.

PRISECARU G., SALA F. 2017a. Response model of vegetation parameters and yield in maize under the influence of Lithovit fertilizer. AIP Conference Proceedings 1863: 430005

PRISECARU G., SALA F. 2017b. Variation of biometric parameters in corn cobs under the influence of nitrogen fertilization. AIP Conference Proceedings 1863: 430006.

RAES D., GEERTS S., KIPKORIR E., WELLENS J., SAHLI A. 2006. Simulation of yield decline as a result of water stress with a robust soil water balance model. Agricultural Water Management 81(3): 335-357.

REIDSMA P., EWERT F., BOOGAARD H., VAN DIEPEN K. 2009. Regional crop modelling in Europe: The impact of climatic conditions and farm characteristics on maize yields. Agricultural Systems 100(1-3): 51-60.

RAWASHDEH H., SALA F. 2015. Foliar application with iron as a vital factor of wheat crop growth, yield quantity and quality: a review. International Journal of Agricultural Policy and Research 3(9): 368-376.

RAWASHDEH H., SALA F. 2014a. Influence of iron foliar fertilization on some growth and physiological parameters of wheat at two growth stages. Scientific Papers. Series A. Agronomy 17: 306-309.

RAWASHDEH H., SALA F. 2014b. Foliar application of boron on some yield components and grain yield of wheat. Academic Research Journal of Agricultural Science and Research 2(7): 97-101.

RAWASHDEH H.M., SALA F. 2013. The effect of foliar application of iron and boron on early growth parameters of wheat (*Triticum aestivum* L.). Research Journal of Agricultural Science 45(1): 21-26.

SADLER E.J., BAUER P.J., BUSSCHER W.J., MILLEN J.A. 2000. Site-specific analysis of a drought corn crop: II: water use and stress. Agronomy Journal 92(3): 403-410.

SALA F., RUJESCU C., FEHER A. 2019. Assessment model for the imbalance in N and PK fertilization for maize: Case study for the Western part of Romania. Romanian Agricultural Research 36: 1-11.

SALA F., BOLDEA M. 2011. On the optimization of the doses of chemical fertilizers for crops. AIP Conference Proceedings 1389: 1297-1300.

SALA F., BOLDEA M., RAWASHDEH H., NEMET I. 2015. Mathematical model for determining the optimal doses of mineral fertilizers for wheat crops. Pakistan Journal of Agricultural Sciences 52(3): 609-617.

SINDELAR A.J., ROOZEBOOM K.L., GORDON W.B., HEER W.F. 2010. Corn response to delayed planting in the central great plains. Agronomy Journal 102: 530-536.

STEWART D.W., COSTA C., DWYER L.M., SMITH D.L., HAMILTON R.I., MA B.L. 2003. Canopy structure, light interception, and photosynthesis in maize. Agronomy Journal 95(6): 1465-1474.

SHARMA L.K., BALI S.K. 2018. A review of methods to improve nitrogen use efficiency in agriculture. Sustainability 10: 51.

SETTER T.L., FLANNIGAN B.A., MELKONIAN J. 2001. Loss of kernel set due to water deficit and shade in maize. Crop Science 41: 1530-1540.

SZCZEPANIAK W., GRZEBISZ W., POTARZYCKI J., ŁUKOWIAK R., PRZYGOCKA-CYNA K. 2016. The magnesium and calcium mineral status of maize at physiological maturity as a tool for an evaluation of yield forming conditions. Journal of Elementology 21(3): 881-897.

THIERFELDER C., MATEMBA-MUTASA R., RUSINAMHODZI L. 2015. Yield response of maize (*Zea mays* L.) to conservation agriculture cropping system in southern Africa. Soil Tillage Research 146: 230-242.

VAN ROEKEL R.J., COULTER J.A. 2012. Agronomic responses of corn hybrids to row width and plant density. Agronomy Journal 104(3): 612-620.

VAN ROEKEL R.J., COULTER J.A. 2011. Agronomic responses of corn to planting date and plant density. Agronomy Journal 103(5): 1414-1422.

ZIADI N., BRASSARD M., BÉLANGER G., CAMBOURIS A.N., TREMBLAY N., NOLIN M.C., CLAESSENS A., PARENT L.-E. 2008. Critical nitrogen curve and nitrogen nutrition index for corn in Eastern Canada. Agronomy Journal 100(2): 271-276.

ZHAO B., ATA-UL-KARIM S.T., LIU Z., ZHANG J., XIAO J., LIU Z., QIN A., NING D., YANG Q., ZHANG Y., DUAN A. 2018. Simple assessment of nitrogen nutrition index in summer maize by using chlorophyll meter readings. Frontiers in Plant Science 9: 11.