V. ECOLOGICAL AND SUSTAINABLE AGRICULTURE

SIMULATION OF CROPS YIELD GROWN ON LEACHED SMOLNITSA AND ALLUVIAL-MEADOW SOIL

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Abstract. The study presents results of field experiments with maize conducted during the year 2020 on two fields with different soils in Bulgaria, namely Leached smolnitsa and Alluvial-meadow soil. This article aims to perform a simulation experiment of crop yields to evaluate the limits of maize grain yield grown on soils with different properties and with different levels of nutrients. The multifactorial experiments include the application of mineral fertilizers - ammonium nitrate, superphosphate, potassium sulfate and diatomic earth, containing respectively – nitrogen (N), phosphorus (P), potassium (K), and diatomic earth, which represents 89-95% silica in amorphous form) in a design that allows assessment of the actions and interactions of the four factors, varying on three levels. The simulation is preceded by an analysis of variance and regression analysis of the experimental data. Simulation is performed at medium levels of all nutrients and on concurrent levels of nutrients including the high level of two fertilizers excluding two others. The summary results show that the experimental and simulated maize yields on Leached smolnitsa in Bozhurishte are significantly lower than those on Alluvial-meadow soil in Tsalapitsa.

Keywords: field experiment, maize, simulation, soils, yield

INTRODUCTION

The fundamental difference between the simulation experiment from an experiment in the "real world" is that in the process a simulation experiment is carried out with a model of a real system, and not with the system itself [14]. Simulation models describe the functioning of objects and the flow of processes using computer programs. They can be used in machine experiments to predict the behavior of the system. As a rule, they are used when the analytical model is difficult to explore and interpret, or when experimentation with the real object would be complex, costly, or practically impossible [18]. Crop simulations models are used to determine crop yield, crop water use, and the relationships between the yield and water use under different crop management at the farm and regional levels [10].

In the paper [5] a survey of the history of simulation up to 1981 was presented, with special emphasis on some of the critical advances in the field and some of the individuals who played leading roles in those advances. Models of agricultural production systems were first conceived in the 1960s. One of the pioneers of agricultural system modeling was a physicist, C. T. de Wit of Wageningen University, who, in the mid-1960s, believed that agricultural systems could be modeled by combining physical and biological principles [19].

The book of Dent, Blackie, and Harrison [4] is concerned with the methodology of systems research; the conception, construction, implementation, validation, and exploitation of computer-based simulation models of agricultural systems. The use of simulation in the study of systems has become standard procedure in many disciplinary areas within agriculture, ranging from natural-resource system planning, through grazing-livestock systems, ruminant metabolic systems, plant physiological systems, to biochemical and cellular systems. In our study, the real system was growing maize in field experimental conditions.

The early agricultural engineers and soil physicists were developing soil-plant-water balance models that predicted daily crop evapotranspiration, crop water uptake, and water flow processes in soils [2]. The role of climate change in crop modeling and applications of crop growth models in agricultural meteorology are discussed in an article by Murthy V.R.K., 2002 [13]. The development of agrometeorological and agroclimatological models includes climate crop and soil. The availability of water (which is an observed parameter through rainfall) and water requirement (expressed by PET which is an estimated parameter) are basic inputs in the majority of these studies. Model Simulation of Soil Loss, Nutrient Loss, and Change in Soil Organic Carbon Associated with Crop Production are described in studies by Potter et al., 2006 [16].

Jones et al., 2017 [9] provide a critical overview of past agricultural systems modeling and comprehensive survey of such systems and a long list of references. In 1986 the CERES-Maize model

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linked soil water, soil nitrogen, and crop growth [8]. Later on, Hoogenboom et al. [6] create the DSSAT suite of crop models that combined the CERES family of models with the SOYGRO and PNUTGRO models. Collaborative software development led to an interest in providing open-source versions of widely-used crop simulation models; now being done by some agro-system modelers (e.g., APSIM, DSSAT).

The IBSNAT (International Benchmark Sites Network for Agro-technology Transfer) began in 1982 [17]. The major product of IBSNAT was a Decision Support System for Agro-technology Transfer (DSSAT) [3].

The iCROPM 2020 Symposium entitled "Crop Modeling for the Future", held in February 2020 [7], provided a great opportunity to exchange information on crop model development, evaluation with experimental data, and implementation. The book [15] is designed to further such interaction by presenting the recent work of many of the top agricultural systems modeling researchers in the world.

This article aims to perform simulation experiments of crop yields to evaluate the limits of maize grain yield grown on soils with different properties with different levels of nutrients.

MATERIALS AND METHODS

On the experimental fields of ISSAPP "N.Poushkarov" in Bozhurishte, Sofia district (Leached smolnitsa soil) and Tsalapitsa, Plovdiv district (Alluvial-meadow soil) during the year 2020 field experiments were conducted with the application of mineral fertilizers – ammonium nitrate, superphosphate, potassium sulfate and diatomic earth, containing respectively – nitrogen (N), phosphorus (P), potassium (K), and diatomic earth, which represents 89-95% silica in amorphous form). The test crop was Maize (*Zea mays* L), medium-early hybrid – Pioneer 8834 from FAO group 310. The experiment includes 9 variants of fertilization in three blocks with the size of the experimental parcels – 25 m^2. The design of treatments is presented in Table 1. Experimental design, which is 1/2 replication of a 2^4 factor scheme with added control variant was used in the planning of multifactorial experiments that allow the assessment of actions and interactions of the four factors, varying on three levels.

Table 1. Design for field experiments with four factors

Variant	Factors			
No	A	B	C	D
1	1	1	1	1
2	2	1	1	2
3	1	2	1	2
4	2	2	1	1
5	1	1	2	1
6	2	1	2	2
7	1	2	2	2
8	2	2	2	1
9	0	0	0	0

The corresponding quantities of fertilizers are as follow:

A0 = N 0, A1 = N 10, A2 = N 20 kg/da;

B0 = P 0, B1 = P 8, B2 = P 16 kg/da; (1da=1000m^2)

C0 = K 0, C1 = K 6, C2 = K 12 kg/da;

D0 = Si 0, D1 = Si 1.4, D2 = Si 2.8 kg/da.

In our study, we used the following mathematical model, which we consider subject to simulation modeling

$$Y = \sum_{i=0}^{7} b_i X_i + e,$$

where Y is the crops yield, X_i are the nutrients (N, P, K, Si) and their interactions, b_i are the corresponding regression coefficients, e is the random error.

Examples of yield simulation are presented in [12], using data from different locations. Statistical measures and indices were applied to evaluate the model that included mean bias error (MBE) and root mean square error (RMSE) [11].

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(S_i - O_i),$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2}.$$

The results of a stochastic simulation can be summarized using histograms. A histogram is a representation of the distribution of numerical data. Simulation experiments were running in Microsoft Office Excel [1].

RESULTS AND DISCUSSION

The first step of the study is a statistical analysis of variance, which includes the four nutrients (N, P, K, Si) and estimates of their main effects and three interactions as shown in Table 2 and Table 4 from data of the experimental fields – Bozhurishte and Tsalapitsa.

Table 2. Analysis of variance for maize yield (Bozhurishte 2020)

Source	SSQ	DF	MS	F	p
N	53461	1	53461	5.826	0.0261
P	11176	1	11176	1.218	0.2835
K	67995	1	67995	7.410	0.0135
Si	18579	1	18579	2.025	0.1710
N.P	30714	1	30714	3.347	0.0831
P.K	76326	1	76326	8.318	0.0095
K.Si	58285	1	58285	6.352	0.0208
Treatment	1153882	7	164840	17.960	<0.0001
Residual	174355	19	9177		
Total	1328237	26			

The analysis shows that factors nitrogen (N), potassium (K), and interactions PxK, and KxSi are significant at 5% level. Other sources also have F-values > 1. This justifies their inclusion in the second step of statistical analysis. Results of regression analysis from maize yield data are given in Table 3.

Table 3. Regression analysis of maize yield - Bozhurishte

Coeff.	Variable	Estimate	Std. err.	|t|	p
b0	Const.	577.00	55.310	10.430	<0.0001
b1	N	66.580	27.580	2.414	0.0261
b2	P	30.400	27.550	1.104	0.2835
b3	K	-77.340	28.410	2.722	0.0135
b4	Si	-201.70	141.80	1.423	0.1710
b5	N.P	-4.289	2.344	1.829	0.0831
b6	P.K	4.699	1.629	2.884	0.0095
b7	K.Si	23.470	9.311	2.520	0.0208

The regression equation is

Y=577.00+66.580*N+30.400*P-77.340*K-201.700*Si-4.289*NP+4.699*PK+23.470*KSi,

with R2 = 0.8687.

The maximum of the yield is 1427.45 kg/da at N=22.70, P=13.66, K=15.0 and Si=3.0 kg/da.

Simulation 1 with the yield on Leached smolnitsa is performed at medium levels of all nutrients. The input are selected levels N = 10, P = 8, K = 6, Si = 1.4 (kg/da) and Mean = 952.89, Std. Dev. = 226.02. A sample of 1000 random numbers with normal distribution is generated.

The results are presented in Fig. 1.

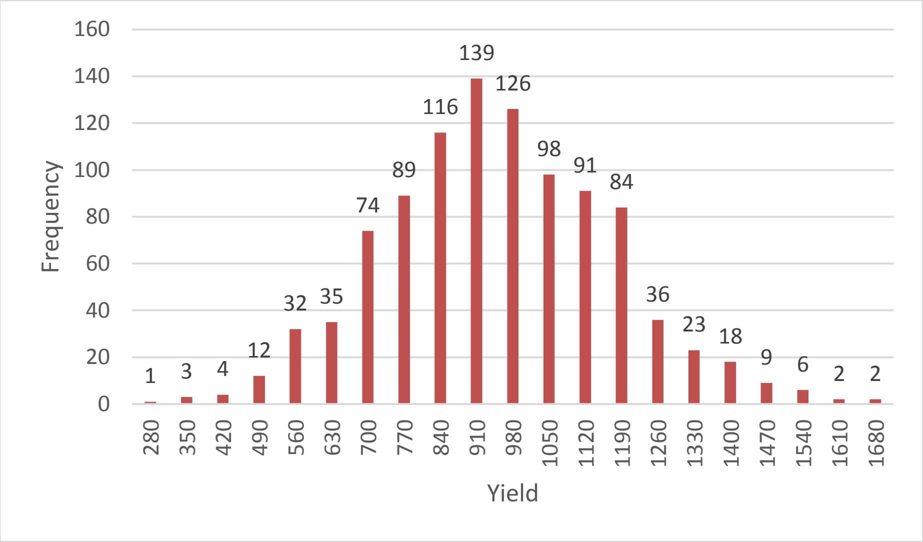

Fig. 1. Histogram of simulation 1 maize yield Bozhurishte

The simulation shows that the probable mean value of the yield is equal to 951.08 kg/da with Std. Dev. = 219.59. All values are in the interval [245, 1714] kg/da.

Simulation 2 with the yield on Leached smolnitsa is performed with high levels of nitrogen and phosphorus without potassium and silicon. Selected levels are: N = 20, P = 16, K = 0, Si = 0 (kg/da). The sample is also with 1000 normally distributed random numbers and Fig. 2 shows the results.

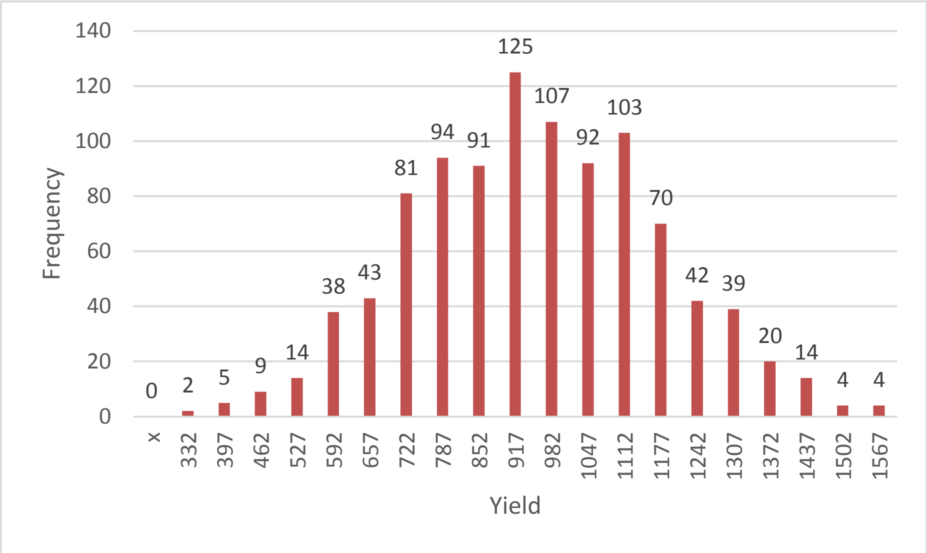

Fig. 2. Histogram of simulation 2 – maize yield Bozhurishte

The simulation shows that the probable value of the mean yield is equal to 955.74 kg/da with Std. Dev. = 223.71. All values are in the interval [300, 1664] kg/da.

Analogous analyses of the data from a field experiment conducted on Alluvial-meadow soil in Tsalapitsa during 2020 follow.

Table 4. Analysis of variance for maize yield (Tsalapitsa 2020)

Source	SSQ	DF	MS	F	p
N	78097	1	78097	5.482	0.0303
P	75348	1	75348	5.289	0.0330
K	112572	1	112572	7.902	0.0112
Si	133042	1	133042	9.339	0.0065
N.P	130014	1	130014	9.126	0.0070
P.K	70119	1	70119	4.922	0.0389
K.Si	62409	1	62409	4.381	0.0500
Treatment	1361970	7	194567	13.660	<0.0001
Residual	270682	19	14246		
Total	1632652	26			

The analysis of variance shows that all factors and interactions are significant at 5% level. This justifies their inclusion in the second step of statistical analysis. Results of regression analysis from maize yield data are given in Table 5.

Table 5. Regression analysis of maize yield - Tsalapitsa

Coeff.	Variable	Estimate	Std. err.	|t|	p
b0	Const.	666.90	68.910	9.677	<0.0001
b1	N	-80.470	34.370	2.341	0.0303
b2	P	-78.930	34.320	2.300	0.0330
b3	K	99.510	35.400	2.811	0.0112
b4	Si	539.700	176.600	3.056	0.0065
b5	N.P	8.825	2.921	3.021	0.0070
b6	P.K	-4.504	2.030	2.219	0.0389
b7	K.Si	-24.280	11.600	2.093	0.0500

The regression equation is

$$Yc = 666.90-80.470*N-78.930*P+99.510*K+539.70*Si+8.825*NP-4.504*PK-24.280*KSi,$$

with R2 = 0.8342.

The maximum the yield is 1794.42 kg/da at N=25.0, P=14.27, K=8.65 and Si=2.46 kg/da.

Simulation 3 with maize yield on Alluvial-meadow soil is performed also with medium levels of all nutrients. Selected levels are: N = 10, P = 8, K = 6, Si = 1.4 (kg/da) and Mean = 1127.15, Std. Dev. = 250.59. The sample of 1000 normally distributed random numbers is generated. The results are presented in Fig. 3.

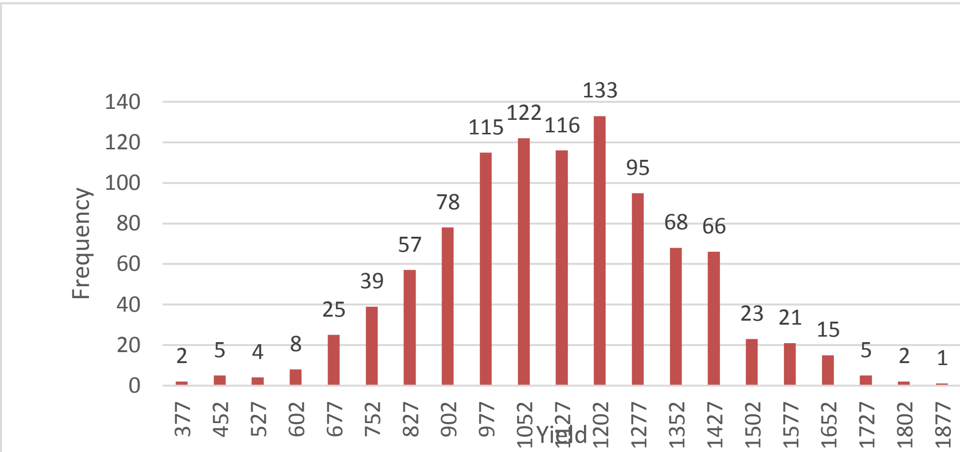

Fig.3. Histogram of simulation 3 – maize yield Tsalapitsa

The simulation shows that the probable value of the mean yield is equal to 1118.98 kg/da with Std. Dev. = 238.84. All values are in the interval [304, 1914] kg/da.

Simulation 4 is performed with high levels of potassium and silicon without nitrogen and phosphorus. Selected levels are: N = 0, P = 0, K = 12, Si = 2.8 (kg/da). A sample of 1000 random numbers with normal distribution is generated. The results are presented in Fig. 4.

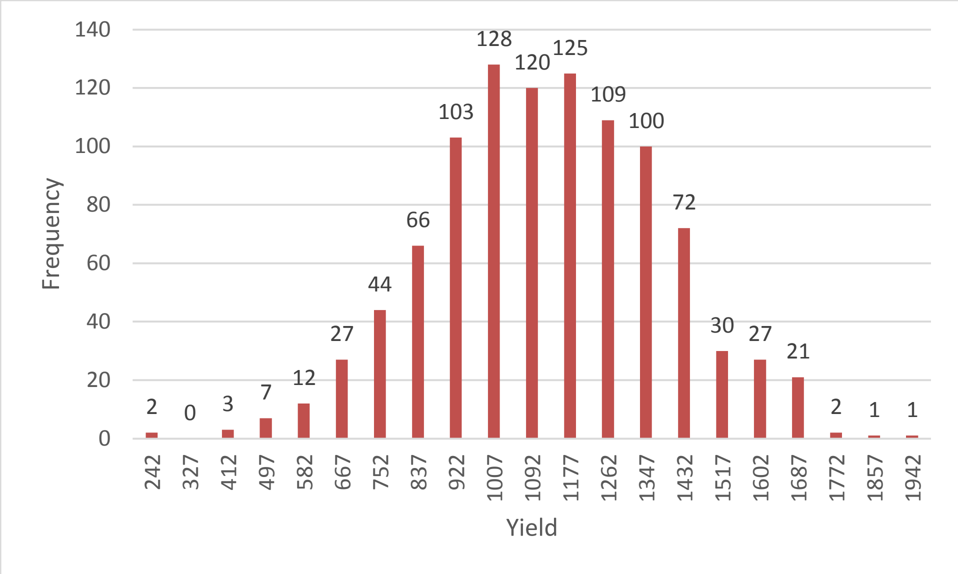

Fig. 4. Histogram of simulation 4 – maize yield Tsalapitsa

The simulation shows that the probable mean value of the yield is equal to 1127.44 kg/da with Std. Dev. = 257.52. All values are in the interval [200, 1984] kg/da.

Table 6. Statistical characteristics of simulations (Yield in kg/da)

Field	Source	Mean	Std.Dev.	95% range	
Bozhurishte	Experiment	952.89	226.02	510	1396
	Simulation 1	951.08	219.59	521	1381
	Simulation 2	955.74	223.71	517	1394
Tsalapitsa	Experiment	1127.15	250.59	636	1618
	Simulation 3	1118.98	238.84	651	1587
	Simulation 4	1127.44	257.52	623	1632

The summary Table 6 shows that the experimental and simulated maize yields on Leached smolnitsa in Bozhurishte are significantly lower than those on Alluvial-meadow soil in Tsalapitsa with a figure of 70 kg/da. Of course, the different meteorological conditions of these fields must also be taken into account.

CONCLUSIONS

The study explains conducted simulation experiments of crop yields to evaluate the limits of maize grain yield grown on the soils with different properties with different levels of nutrients. The analysis of variance shows that factors nitrogen (N), potassium (K), and interactions PxK, and KxSi are significant at 5% level for the field experiment on Leached smolnitsa in Bozhurishte. The simulation performed at medium levels of all nutrients gives the mean value of the yield is equal to 951.08 kg/da. Highest level of nitrogen (N = 20) and phosphorus (P = 16) in absence of potassium and silicon (K = 0, Si = 0) gives the result Mean = 955.74 kg/da. All estimated simulation average values are close to the experimental mean.

The analysis of variance of a field experiment in Tsalapitsa shows that all factors and interactions are significant at 5% level. The simulated data from

Alluvial-meadow soil at medium levels of all nutrients gives a mean value of the yield is equal to 1118.98 kg/da. It is interesting to note that the simulation of yield in the absence of nitrogen and phosphorus (N = 0, P = 0), only with the use of potassium and silicon at the highest levels (K = 12, Si = 2.8) shows a slightly higher result Mean = 1127.44 kg/da, which is almost equal to the experimental mean.

The presented histograms summarizing the simulated data, as well as Table 6 clearly explain the results of the present study.

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REFERENCES

[1] Adam. How and Why of Running a Simulation in Excel. 2018. Accessed at 03.11.2021. https://www.spreadsheetweb.com/simulation-in-excel/

[2] Boote K.J., J.W. Jones, G. Hoogenboom, J.W. White. The Role of Crop Systems Simulation in Agriculture and Environment. International Journal of Agricultural and Environmental Information Systems (IJAEIS), 2010, 1(1). DOI: 10.4018/ jaeis.2010101303.

[3] Choudhary D. An assignment on Crop Growth Simulation Model for Agriculture. AGMET-703, Crop Weather Models, 2018. DOI: 10.13140/ RG.2.2.35505.28008.

[4] Dent J.B., M.J. Blackie, S.R. Harrison. Systems simulation in Agriculture. Applied Science, 1979. Publ. Ripple Road, Barking, Essex, England. Pp. 188. DOl: 10.1007/978-94-011-6373-6.

[5] Goldsman D., R.E. Nance, J.R. Wilson. A brief history of simulation. In: M.D. Rossetti et al. Eds. Proceedings of the 2009 Winter Simulation Conference. 2009 IEEE, 310-313.

[6] Hoogenboom, G., C.H. Porter, V. Shelia, K.J. Boote, U. Singh, J.W. White, L.A. Hunt, R. Ogoshi, J.I. Lizaso, J. Koo, S. Asseng, A. Singels, L.P. Moreno, and J.W. Jones. Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.7. 2019. (www.DSSAT.net). DSSAT Foundation, Gainesville, Florida, USA.

[7] Hoogenboom G, Justes E, Pradal C, Launay M, Asseng S, Ewert F, Martre P. iCROPM 2020: Crop Modeling for the Future. The Journal of Agricultural Science, 2020, 158, 791–793. https://doi.org/10.1017/ S0021859621000538.

[8] Jones C.A., J.R. Kiniry. CERES-Maize A Simulation Model of Maize growth and development. Texas A&M University Press, 1986. 194 pages.

[9] Jones J.W. et al. Brief history of agricultural systems modeling. Agricultural Systems, Vol. 155, 2017, p. 240-254. https://doi.org/10.1016/ j.agsy.2016.05.014

[10] Khan M.I., D. Walker. Application of Crop Growth Simulation Models in Agriculture with special reference to Water Management Planning. International Journal Of Core Engineering & Management (IJCEM), 2015, Volume 2, Issue 5, p. 113-130.

[11] Kobayashi, K., and Moin Us Salam. Comparing Simulated and Measured Values Using Mean Squared Deviation and its Components. Agron. J., 2000, 92:345–352.

[12] Kumar, S.N., K.V. Kasturi Bai, V. Rajagopal and P.K. Aggarwal. Simulating coconut growth, development and yield with the InfoCrop-coconut model. Tree Physiology, 2008, 28, 1049–1058. Heron Publishing-Victoria, Canada.

[13] Murthy V.R.K. Crop growth modeling and its applications in agricultural meteorology. Satellite Remote Sensing and GIS Applications in Agricultural Meteorology, 2002. pp. 235-261.

[14] Naylor T.H. Computer simulation experiments with models of economic systems. 1971. J. Wiley, New York.

[15] Peart R.M., R.B. Curry. Agricultural systems, Modelling and simulation. Marcel Dekker, New York. 1998. pp. 709. ISBN: 0-8247-0041-4.

[16] Potter et al. Model Simulation of Soil Loss, Nutrient Loss, and Change in Soil Organic Carbon Associated with Crop Production. 2006. USDA, NRCS. Pp. 262.

[17] Rauff K.O. R. Bello. A Review of Crop Growth Simulation Models as Tools for Agricultural Meteorology. Agricultural Sciences, 2015, 6, 1098-1105. http://dx.doi.org/10.4236/as.2015.69105.

[18] Sadovski A. An Introduction to Mathematical Agronomy: Theoretical and Experimental bases. LAP Lambert Academic Publishing, 2020. ISBN 978-620-2-51889-5, 284 pp.

[19] de Wit C.T. Transpiration and crop yields. Volume 64 of Agricultural research report / Netherlands, 1958.

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