THE SENSITIVITY OF SIMULATED MAIZE YIELDS ON VARIOUS SOIL CHARACTERISTICS IN THAI NGUYEN PROVINCE, VIETNAM

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ABSTRACT

Maize (*Zea mays* L.) is a C4 plant. In Thai Nguyen province, the planted maize areas occupy approximately 20% of the total arable land area with clear variations of grain yields between years and regions. Meanwhile, most of the soil types in Thai Nguyen province are poor in nutrition, which greatly impacts maize yields. Therefore, this study utilized the DSSAT model to simulate maize yield under different soil types to investigate the sensitivity analysis of maize yield under different soil types in Thai Nguyen province. The results showed that under the local soil conditions, simulated annual maize yields show that maize grown at the dominating Fluvisols received much higher grain yield than other soils. Maize grown at Fluvisols during the winter season reaches a higher yield than those grown in the spring and the average annual maize yield. This shows the potential of maize grown at Fluvisols, including the winter season considered as the dry season.

Keywords: *Maize, crop simulation, DSSAT, maize yield sensitivity.*

Received: 15 March 2024; revised: 25 July 2024; accepted: 14 August 2024.

1. INTRODUCTION

Maize (*Zea mays* L.) is a C4 plant [1, 2], with high water use efficiency and optimum temperature than many C3 crops such as rice. In Thai Nguyen province, the planted maize areas occupy approximately 20% of the total arable land area with clear variations of grain yields between years and regions. In recent years, the average maize yields have been rising, reaching yield levels of 4,000 - 5,000 kg/ha due to the new maize varieties with higher yield potential and increasing chemical fertilizing. Meanwhile, cases of lower maize yields were reported caused by extreme temperatures and less precipitation [3] during the growing season, for example in some highland regions and Dak Nong province [4].

Many studies utilize crop grow models such as the Decision Support System for Agrotechnology Transfer (DSSAT) suite of models [3 - 9] to simulate crop growth and yield [3], predicting crop production under climate scenarios [5, 6]. Its principles are based on the correlation between the system of water use for crops. Moreover, DSSAT can be used to assess the irrigation water demand for crop growth and therefore save water supply for a crop in combination with other agricultural water management technologies and strategies such as soil water monitoring, drip irrigation, and residue management [7 - 9]. In particular, DSSAT models were used to predict N release [10], assess the response of nitrogen (N) fertilizer [11], or the effects of other crop management options such as planting date [12].

However, crop-soil water balance may impact maize yield in a certain way that in previous studies hasn't been mentioned. Meanwhile, most soil types in Thai Nguyen province have poor nutrition, which greatly impacts maize yields. Therefore, this study utilized the DSSAT model to simulate maize yield under different soil types to investigate the sensitivity analysis on 1) air temperature and precipitation and 2) soil characteristics for seasonal maize production in

Vietnam, to assess potential adaptation options for maize production under conditions in Vietnam.

2. RESEARCH METHODS

2.1. Study region

Thai Nguyen province is famous for tea production and other agricultural production such as rice and maize. Located in the North of Vietnam, it has typical soil characteristics and climatic conditions that bring a unique and high value for agricultural products that nowhere else has. Ferralsols, Fluvisols and Acrisols are the three main soil types in Thai Nguyen province, whereas Gleyic conditions of these soils are frequently present (near rivers or high levels of groundwater) leading to some limitations for cultivation such as tillage and rooting development, particularly in rainy season from April to August.

The highest temperature and precipitation are presented in summer (June and July) and the lowest numbers are shown in winter (December and January). Generally, summer is the rainy season which is affected by the summer monsoon. In the period of 30 years (1990 - 2019), the annual average temperature in summer was around 30˚C while the average precipitation in summer was approximately 300 mm [13] (Figure 1).

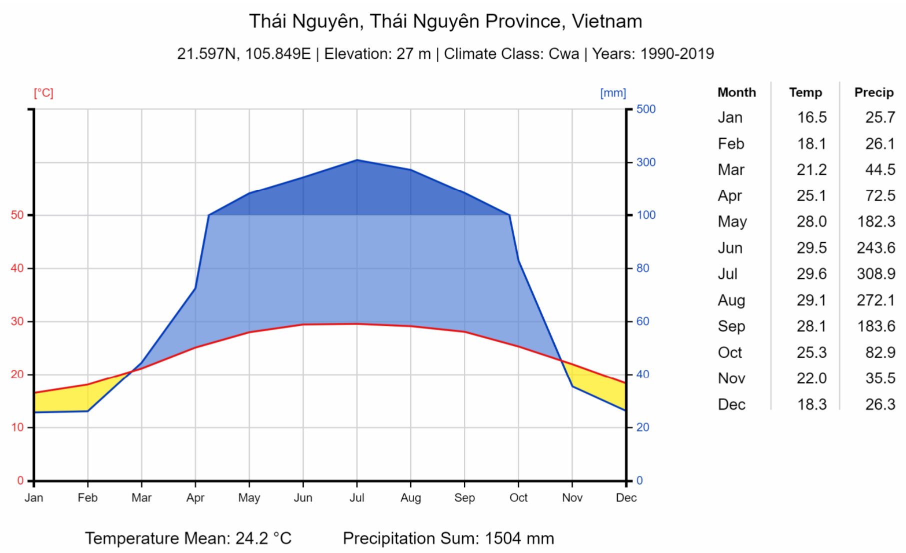


Figure 1. Precipitation and temperature conditions in Thai Nguyen province, Viet Nam from 1990-2019 (21.59N, 105.849E; Elevation 27 m [13])

2.2. Crop simulation database

To simulate maize yields and figure out the interaction between maize growth and soil-climatic conditions using the DSSAT CERES-Maize model, Crop characteristics, weather data, soil properties and crop management are 4 needed types [14].

Crop data and field experiments with maize varieties were conducted in 2008 in Thai Nguyen province, Vietnam for winter and spring maize. The results of the field experiment were published in Thai Nguyen scientific journal in 2008 [15]. The observed annual statistical maize yields (containing all growing seasons in the case study region) over the 15-year historical period (2000-2014) show an advance in the average of 3,000 kg/ha in 2000 to 4,100 kg/ha in 2014.

Climatic data were collected from all local weather stations in Thai Nguyen province by the Department of Environment and Resources, Thai Nguyen Center for Hydro-Meteorological Forecasting, and Thai Nguyen University of Agriculture and Forestry. The historical weather data were obtained for 55 years from 1961 to 2015 including daily hourly sunshine duration, temperature, rain, and relative humidity factors (Table 1).

Table 1. Weather stations in Thai Nguyen province

Stations	Latitude	Longitude	Height (m a.s.l)	Period (daily data)	Weather variables				
					Sun (hours)	Temperature (°C)		Rain (mm)	Humidity (%)
						Max	Min		
Thai Nguyen	$21^0$36" N	$105^0$50"	35.3	1990 - 2015	+	+	+	+	+
Dinh Hoa	$21^0$53" N	$105^0$38"	98.0	1961 - 1990	-	+	+	+	+

Note: (+) Available data (-) Unavailable data

However, to run the crop model and fit the required input format for radiation as the energy equivalent of the model, solar radiation (Rs) and extraterrestrial radiation (Ra) equations [16] were applied to receive the energy equivalent as follows:

The extraterrestrial radiation, Ra, for each day of the year, is shown by equation 1:

$$Ra = \frac{12(60)}{\pi} G_{SC} d_r [\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)] \quad (1)$$

Ra is expressed in the above equation in MJ m^{-2} day^{-1}. The latitude, j, expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degrees to radians is given by:

Solar radiation (Rs) afterward can be calculated with the Angstrom formula which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \quad (2)$$

Rs is expressed in the above equation in MJ m^{-2} day^{-1}. Depending on atmospheric conditions (humidity, dust) and solar declination (latitude and month), the Angstrom values a_s and b_s will vary. As no actual solar radiation data are available and no calibration has been carried out for improved a_s and b_s parameters for our study region, the values $a_s = 0.25$ and $b_s = 0.50$ were used as recommended [16].

Table 2. Soil profile sites of three dominating soil types of the study region Thai Nguyen province

Site	Name	Location	
1	Calcic-Acric Ferralsol	$21^0$46'N, $105^0$28'E, 350m a.s.l	Vo Nhai district
2	Gleyic (clay mineral) Acrisol	$21^0$43N", $105^0$42" E, 152m a.s.l	Dong Hy district
3	Gleyic Fluvisols	$21^0$30', $105^0$36', 22m a.s.l	Phu Binh district

Soil characteristics were collected mainly from the soil quality analysis processed on an annual basis in the Thai Nguyen province. The data was provided by the Thai Nguyen Resources and Environment Department. They include soil general information (soil location with the soil profile name, soil color, drainage, runoff, percentage of slope, fertilizer factor (0 - 1), runoff potential, soil physical and chemical parameters such as master horizon, clay, silt and stone content, organic carbon, pH in water, cation exchange capacity and total nitrogen. The locations of our reference soil types were chosen based on the local soil map from 3 different districts of the Thai Nguyen province from the North to the South (Table 2). The set of soil input data for the three soil types for the crop model sensitivity analysis is listed in table 3.

The regional acreage of Ferralsols, Acrisols, and Fluvisols within the study region is 75.68%, 1%, and 8%, respectively. Ferralsols and Acrisols have some similar characteristics, especially a low pH and total N content (Table 3). In addition to the three main soil types, pure Gleysols are present in the study region, however they occupy extremely tiny proportions. Fluvisols and Gleyic soil conditions are commonly found in areas of high groundwater level, near river banks, and are affected by flooding in the rainy season in case of poor water-drainage systems.

Table 3. Soil properties of examined soil profiles within the study region

Profile	Depth (bottom)	Texture (%)		pH	OM	Total N	CEC	Drained		Bulk density
	(cm)	< 0.002 mm	0.02 - 0.002 mm	KCl	%	%	cmol/kg	Lower limit	Upper limit	g/cm^3
Calcic-Acric Ferralsol	0 - 20	15.2	33.3	4.5	0.8	0.03	10.1	0.074	0.150	1.40
	20 - 80	16.5	30.1	4.2	0.3	0.01	7.0	0.076	0.271	1.48
	80 - 120	16.9	30.9	4.4	0.1	0.01	7.6	0.07	0.136	1.51
Gleyic (clay mineral) Acrisol	0 - 20	15.1	49.8	5.2	1.49	0.05	11.5	0.064	0.143	1.2
	20 - 90	23.7	9.8	4.2	0.44	0.04	5.7	0.052	0.078	1.56
	90 - 120	23.7	9.1	4.3	0.37	0.03	4.3	0.051	0.075	1.58
Gleyic Fluvisols	0 - 20	18.2	33.5	6.0	1.7	0.06	18.1	0.147	0.283	1.29
	20 - 60	20.1	32.9	5.5	0.3	0.03	11.1	0.121	0.226	1.47
	60 - 120	17.8	35.1	5.0	0.1	0.01	9.4	0.106	0.209	1.48

Note: OM: Total organic matter; CEC: Cation exchange capacity

2.3. Sensitivity analysis

In this study, the sensitivity analysis was carried out for fixed irrigation (keeping approximately 50% available soil water reflecting applied local irrigation practices) conditions for spring and winter maize. In this way was to demonstrate the maize production sensitivity to temperature and precipitation changes of 8 different combinations (Table 4) related to the baseline climate and close applied crop management practices. Further, the sensitivity analysis was carried out for the 3 different soil types as presented in table 3.

Table 4. Sensitivity scenarios for analyzing the effect of climate parameters on local maize yield

Scenario	Change of daily temperatures (°C)	Change of daily precipitation[1] (%)
1	+ 2	0
2	+2	-25
3	+2	+25
4	+4	0
5	+4	-25
6	+4	+25
7	0	-25
8	0	+25

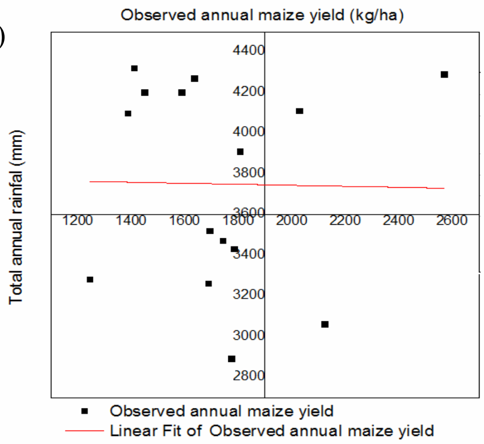
[1] Only if precipitation >0

3. RESULTS AND DISCUSSION

3.1. Relation between past climate conditions and maize yields

To indicate the correlation between the grain yields and daily weather data, the Pearson correlation and R-square (R2) value were used for each weather element including temperature, rainfall, air relative humidity, and solar radiation. The results showed that all of the weather parameters in a single did not have a significant influence on maize yields with the highest Pearson's correlation coefficient being -0.40 for solar radiation (Figure 2b), followed by relative air humidity and temperature with Pearson's correlation coefficients of -0.36 and 0.19, respectively (Figure 2c, d). Finally, annual rainfall seemed to have no effect on maize yield with a Pearson's of approximately 0.00 (Figure 2a). However, solar radiation and temperature were reported as two main factors that affected yield potential based on the maize yield database in Nebraska USA and Southeast Asia [17]. Moreover, under optimum conditions of water and nutrients, solar radiation was found as a limiting factor under late planting (July) through heavy cloud cover during the peak rainfall months of August and September in northern Ghana [18]. In our case, even though there is no significance, less solar radiation hints also to a negative yield effect, where precipitation changes did not have an effect probably through the still positive water balance in the past decades.

a)



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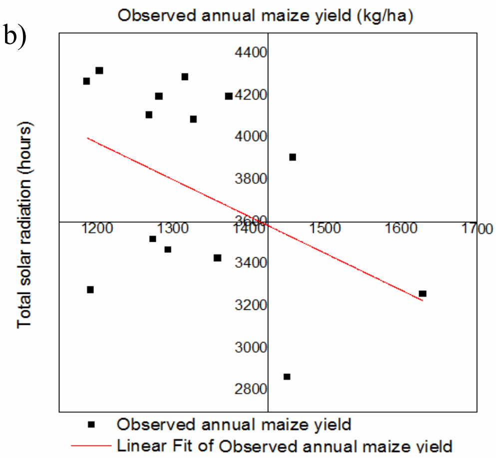


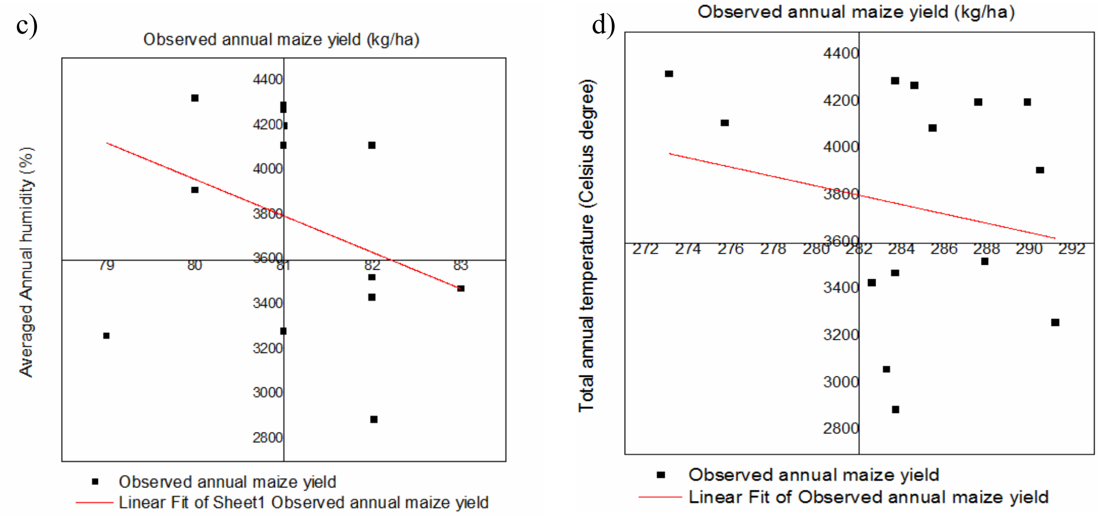
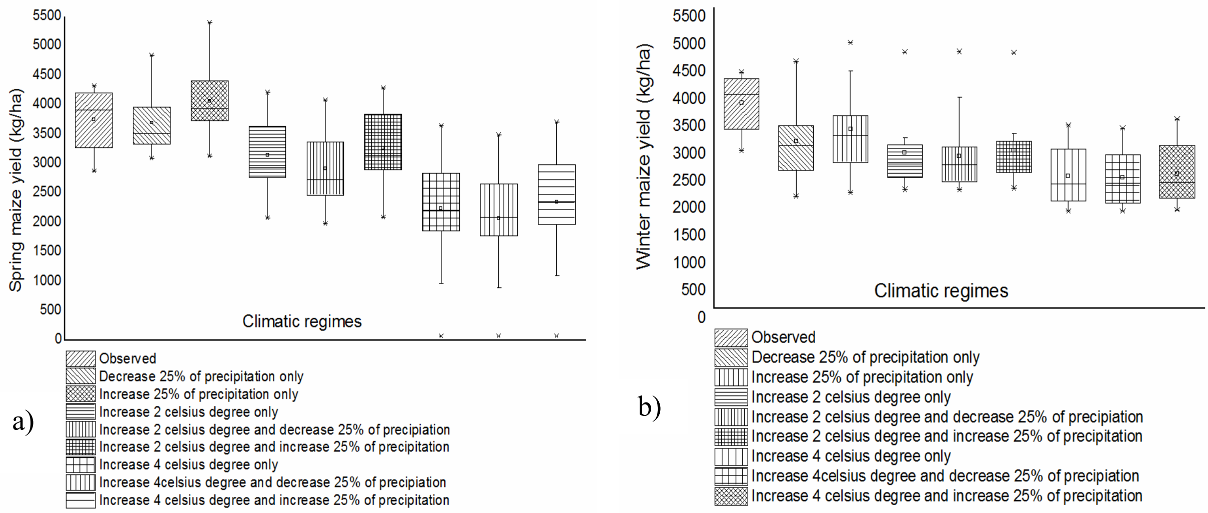


Figure 2. Relationship between weather parameters and historical maize yield in Thai Nguyen

The observed annual statistical maize yields (containing all growing seasons in the case study region) over the 15-year historical period (2000 - 2014) show an advance in the average of 3,000 kg/ha in 2000 to 4,100 kg/ha in 2014.

3.2. Sensitivity of simulated maize yield to temperature and precipitation change

A model sensitivity analysis can reveal if a crop model responds in the correct direction or an acceptable range against changes in critical inputs such as weather, crop, and soil parameters. It is, for example, often used to intercompare different crop models, to identify weaknesses of crop models in certain environments, or better to understand the results of simulated scenarios [19]. In this study, the sensitivity analysis was carried out for rainfed spring and winter maize at soils with suitable water storage capacity in comparison to irrigated cases (Figure 3a-c). The results show that the DSSAT CERES Maize model is sensitive to simulating the maize yield under different temperature and rainfall conditions. Simulated maize yields showed a strong response to increasing temperatures, where it decreased when temperature increased in comparison with the measured conditions (Observed) (period 2000 - 2015).



c)

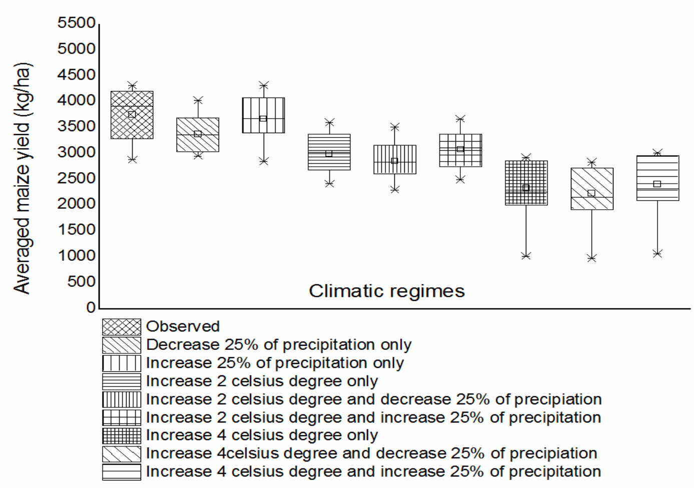


Figure 3. a - c. Change of simulated maize yields under different temperature/precipitation sensitivity scenarios for spring, winter maize season, and annual averaged yields (irrigated case)

The annual maize yields decreased by 19% and 37% when the temperature increased by 2 and 4˚C, respectively. Furthermore, the sensitivity of the DSSAT model to changes in rainfall was noticeable and showed a clear trend in combination with an increase in temperature. The highest decrease of simulated annual maize yields of approx. 40% were obtained at a 4˚C increase in temperature and a 25% decrease in rainfall. However, the most notable change in maize yield was generally recorded by increases in temperature. Similarly, in China, an increase of 2˚C in temperature could affect maize yield by more than a 20% change in precipitation. A greater change in precipitation led to more maize yield variability during El Niño years, especially in dry seasons [20].

Generally, in this case study region grain yield change is proportional to the amount of precipitation and is negatively affected by high temperature simultaneously, especially in the spring maize growing season. A strong effect of increasing temperatures on simulated irrigated maize yields (under current production technology) was shown by approximately 10% yield loss per 1˚C of warming (Figure 4).

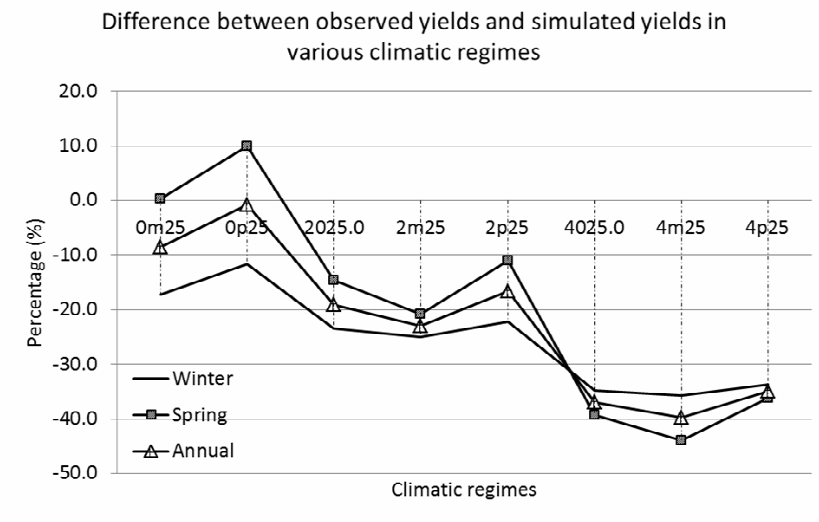


Figure 4. Sensitivity of the DSSAT model

On the other hand, due to the real practical of the locals, it is unrealistic to simulate maize growth under rainfed conditions because the spring maize season is normally quite dry, especially at the beginning of the season.

3.3. Sensitivity of simulated maize yield regarding soil types

The sensitivity of the DSSAT CERES-maize model model about the three main predefined regional soil types was estimated as follows. The three main soil types in Thai Nguyen include Acrisols, Ferralsol and Fluvisols, whose soil characteristics were used as input for the simulation of grain yield over the baseline period of 15 years (2000 - 2014). The simulation was carried out separately for the spring and winter maize growing seasons. In the period (2010 - 2014), the grain yields were higher than the grain yield in the previous decade. The difference between the periods was most markedly in the case of Fluvisol (Figure 5a - d).

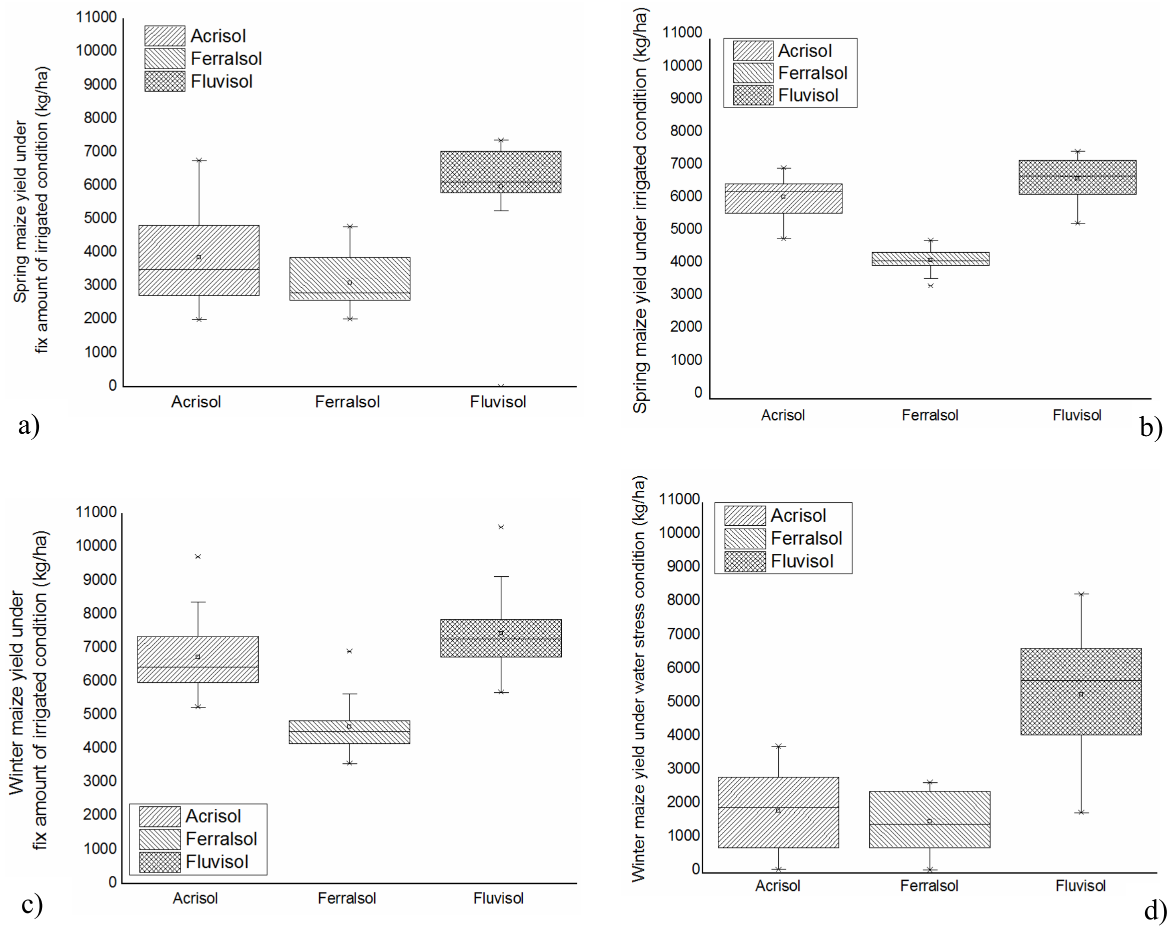


Figure 5a - d. Simulated maize yield under different soil conditions for spring and winter seasons during the period 2000-2014. Boxes are defined with a solid line as the median and a dashed line as the mean

In comparison with simulated grain yield in the winter season, the results showed that maize grown at Fluvisols also received much higher grain yield compared to maize grown on the other soils because of Fluvisols' highest soil water storage capacity. The simulated grain yield of Fluvisols in the winter season was also much higher than those grown in the spring season. Moreover, the simulated grain yield of spring-sown maize indicates that there is a difference between the three soil types but also between the years with lower interannual yield variability than for winter maize. Under the same yearly agronomic management, maize grown at Fluvisols reached high simulated yields at a range from 6,000 to 7,300 kg/ha during the period 2000 - 2009 but declined in the next period of 2010 - 2014, probably caused by adverse weather conditions. Similarly, there was less maize grain yield in Acrisol and Ferralsol soils across the period 2010 - 2014 in comparison with the period 2000 - 2009. Similarly, the simulated grain yields showed a large gap between annual grain yields under drought-stress (rainfed) conditions and irrigated conditions.

4. CONCLUSION AND RECOMMENDATION

Maize yields were limited in these observation periods mainly by other limiting factors than climatic parameters. Maize yield is proportional to the amount of precipitation and is negatively affected by high temperatures simultaneously, especially in the spring maize growing season, particularly, an increase in temperatures strongly impacts on simulated irrigated maize yields (under current production technology). The irrigated maize grain yield is double that of grain yield under rainfed conditions, showing the important role of irrigation for maize production in that region. Hence, farmers need to irrigate their farms in some important periods of crop growth under drought stress; otherwise, crops will lose or obtain very low yields.

In general, the simulated grain yield in the winter season was higher than that in the spring season and much higher than the average annual maize yield, especially in the case of Fluvisols. This shows the potential of maize growing even through the winter season which is considered as the dry season. Under drought stress conditions (rainfed simulation), Acrisols and Ferralsols also show a difference in grain yield. The grain yields of Acrisols were higher than those of Ferralsols. The difference was expressed between different periods, probably caused by the difference in water-holding capacity. Besides, in the winter season, maize grown at Fluvisols received much higher grain yield compared to maize grown on the other soils because of Fluvisols' highest soil water storage capacity. Generally, the differences in simulated yields decreased between the soils under irrigated (no drought stress) conditions, which can be explained by the increasing impact of the soil water holding capacity on crop water availability under drought conditions.

REFERENCES

1. Hardacre, A. & Turnbull, H. L. (1986). *The Growth and Development of Maize (Zea mays L.) at Five Temperatures.* In Annals of Botany (Vol. 58).

2. Wolf, J. &Van Diepen, C. A. (1995). Effects of climate change on grain maize yield potential in the European Community. Climatic Change 29, 299 - 331.

3. Tran, T. M. A., Eitzinger, J., Manschadi, A. M. (2020). Response of maize yield under changing climate and production conditions in Vietnam. *Italian Journal of Agrometeorology,* 25(1): 73 - 84.

4. Uy, T. C., Limnirankul, B. & Chaovanapoonphol, Y. (2015). *Factors Impact on Farmers' Adaptation to Drought in Maize Production in Highland Area of Central Vietnam.* Agriculture and Agricultural Science Procedia, 5, 75 - 82.

5. Ngwira, A., Aune, J. & Thierfelder, C. (2014). *DSSAT modeling of conservation agriculture maize response to climate change in Malawi.* In Soil and Tillage Research (Vol. 143).

6. Iqbal, M. A., Eitzinger, J., Formayer, H., Hassan, A. & Heng, L. K. (2011). A simulation study for assessing yield optimization and potential for water reduction for summer-sown maize under different climate change scenarios. *Journal of Agricultural Science,* Cambridge 149, 129 - 143.

7. Montserrat Salmerón, José Cavero, Ramón Isla, Cheryl H. Porter, James W. Jones, Boote K. J. (2014). *DSSAT Nitrogen* Cycle Simulation of Cover Crop–Maize Rotations under Irrigated Mediterranean Conditions. *Agronomy Journal,* 106(4): 1283 - 1296.

8. Eitzinger, J., Trnka, M., Semeradova, D., Thaler, S., Svobodova, E., Hlavinka, P., Siska, B., Takac, J., Malatinska, L., Novakova, M., Dubrovsky, M., Zalud, Z. (2013a). Regional climate

change impacts on agricultural crop production in Central and Eastern Europe - hotspots, regional differences and common trends. *The Journal Of Agricultural Science,* 151 (6): 787 - 812.

9. Eitzinger, J., Thaler, S., Schmid, E., Strauss, F., Ferrise, R., Moriondo, M., Bindi, M., Palosuo, T., Rotter, R., Kersebaum, K. C., Olesen, J. E., Patil, R. H., Saylan, L., Caldag, B., Caylak, O. (2013b). Sensitivities of crop models to extreme weather conditions during flowering period demonstrated for maize and winter wheat in Austria. *The Journal Of Agricultural Science,* 151(6): 813 - 835.

10. Liu, Hai-long & Yang, Jeng-Yuan & Drury, Craig & Reynolds, Daniel & Tan, Chin & Bai, Youlu & He, Ping & Jin, Jiyun & Hoogenboom, Gerrit (2011). *Using the DSSAT-CERES-Maize model to simulate crop yield and nitrogen cycling in fields under long-term continuous maize production.* Nutrient Cycling in Agroecosystems. 89. 313 - 328. 10.1007/s10705-010-9396-y.

11. Kisekka, I. Kendall C. D., Liwang M., Paz. J. (2017). Crop modelling Applications in Agricultural Water Management. *American American Society of Agricultural and Biological Engineers,* 60(6): 1959 - 1964.

12. Kollas, C. *et. Al.* (2015). Crop rotation modelling-A European model intercomparison. *Europen Journal Of Agronomy,* 70: 98 - 111.

13. Laura Zepner, Pierre Karrasch, Felix Wiemann & Lars Bernard (2020). Climate Charts.net. DOI: 10.1080/17538947.2020. 1829112

14. Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., Wilkens, P. W., Singh, U., Gijsman, A. J., Ritchie J. T. (2003). The DSSAT cropping system model. *Europen Journal of Agronomy,* 18:235 - 265.

15. Nguyen, H. H. (2008). Testing some hybrid corn varieties in spring and winter crops in 2008 in Thai Nguyen. *Thai Nguyen Journal of Science and Technology,* 62(13), 62 - 66.

16. FAO, 1998. *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage.* Rome, 1998

17. J.M. Pasuquin, M.F. Pampolino, C. Witt, A. Dobermann, T. Oberthür, M.J. Fisher, K. Inubushi (2014). *Closing yield gaps in maize production in Southeast Asia through site-specific nutrient management.* Field Crops Research, Volume 156: 219 - 230.

18. Michael Tanu, William Amponsah, Bashiru Yahaya, Enoch Bessah, Samuel Owusu Ansah, Cosmos Senyo Wemegah, Wilson Agyei Agyare (2021). *Evaluation of* global solar radiation, cloudiness index and sky view factor as potential indicators of Ghana’s solar energy resource. Scientific African, Volume 14, e01061.

19. J Eitzinger, M Štastná, Z Žalud, M Dubrovský (2003). A simulation study of the effect of soil water balance and water stress on winter wheat production under different climate change scenarios. Agricultural Water Management, Volume 61, Issue 3: 195 - 217

20. Shuai Chen, Xiaoguang Chen, Jintao Xu (2016). Impacts of climate change on agriculture: Evidence from China. *Journal of Environmental Economics and Management,* Volume 76: 105 - 124