Sensitivity analysis of AquaCrop model for maize crop in a humid subtropical climate in Brazil

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Abstract: Crop growth models are abstract tools that represent a real system, being a simple and important technology to develop studies aiming to improve the yields of the most agricultural crops, like the maize in Brazil. The objective of this study was to analyze the sensitivity of the main AquaCrop model input parameters, as well as their responses in maize yield estimation, in State of Paraná, Southern Brazil. The analyses were performed with the genotype 30R50YH, 2014/15 planted on April 11, 2014. The parameters analyzed refer to crop, soil and soil management. The parameters were modified individually, maintaining the others fixed. With the results, the sensitivity index (*SI*) was calculated, which allowed the identification of the most sensitive AquaCrop parameters. The parameters related to the crop showed a higher sensitivity, as they were associated with the main equations of the model. The parameters related to the harvest index (HI_o), saturated hydraulic conductivity (K_{SAT}), soil water stress (*Ks*) and air temperature stress (*ATS*) did not present sensitivity in the model for the conditions evaluated. According to the *SI*, the crop coefficient with complete canopy expansion ($Kc_{TR,x}$) was the most sensitive parameter in the model (*SI* = 1.0777), as it directly affected the maize biomass production and yield formation.

Keywords: modeling, mathematical models, sensitivity analysis, maize, *Zea mays*

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1 Introduction

Brazil has become an important maize producer, competing strongly with the United States in world cereals markets (USDA, 2019). The growth in agricultural production is the result of research and the technologies adoption that aim to improve crop yields in the country. With this in mind, the use of crop growth patterns has increased in order to understand the interaction between the soil-plant-atmosphere continuums. They are important tools to simulate the growth and development of crops, as well as assessments of climate impact (Zhao et al., 2019), allowing time and computational savings and financial resources.

Crop growth models are results of mathematical equations that represent the biological processes which influence plant growth and development, depending on time, environment and genotype (Picheny et al., 2017; Yin et al., 2018; Lecerf et al., 2019). Crop growth patterns play an important role in the development of sustainable management under several agroecological and socio-economic conditions. They are alternatives to field experiments, which require large amounts of resources and may not provide sufficient information in space and time necessary to identify appropriate and effective

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management practices (Jones et al., 2016).

Different crop growth models are used in several studies, and the uncertainties associated with these models are rarely evaluated (Li et al., 2015). Many applications of large-scale agricultural models imply imprecise parameters. In the use of models, mainly for places and crops different from those used in their development, obtaining and establishing reliable parameters is important, since most models are generally not calibrated for the environmental conditions in which they were developed (Palosuo et al., 2011).

Sensitivity analysis allows identifying and quantifying the uncertainties that are often associated with the model parameters, investigating how the variation in the output data can be attributed to the input factors (Senaviratne et al., 2014; Pianosi et al., 2016). There is often no need to calibrate all the models parameters, but rather the most sensitive ones, which are generally responsible for most of the variability in results, reflecting with greater intensity in the output data (Wang et al., 2013; Senaviratne et al., 2014).

Seeking to meet the demand for simpler models, the Food and Agriculture Organization (FAO) developed the AquaCrop, a crop growth simulation model that uses relatively few explicit and intuitive parameters, containing input variables that require simple methods of determination. The main functions present in AquaCrop are described in Steduto et al. (2012) and Raes et al. (2018b).

Research aimed at calibration, validation and understanding of management practices in productivity simulations with AquaCrop has already been carried out for different crops and locations around the world. However, the understanding of the influence of input parameters on AquaCrop performance, on agricultural crop productivity estimation in the Brazilian scenario, remains limited. In this context, the aim of the present study was to analyze the sensitivity of the main AquaCrop input parameters, as well as the model responses in maize productivity estimation.

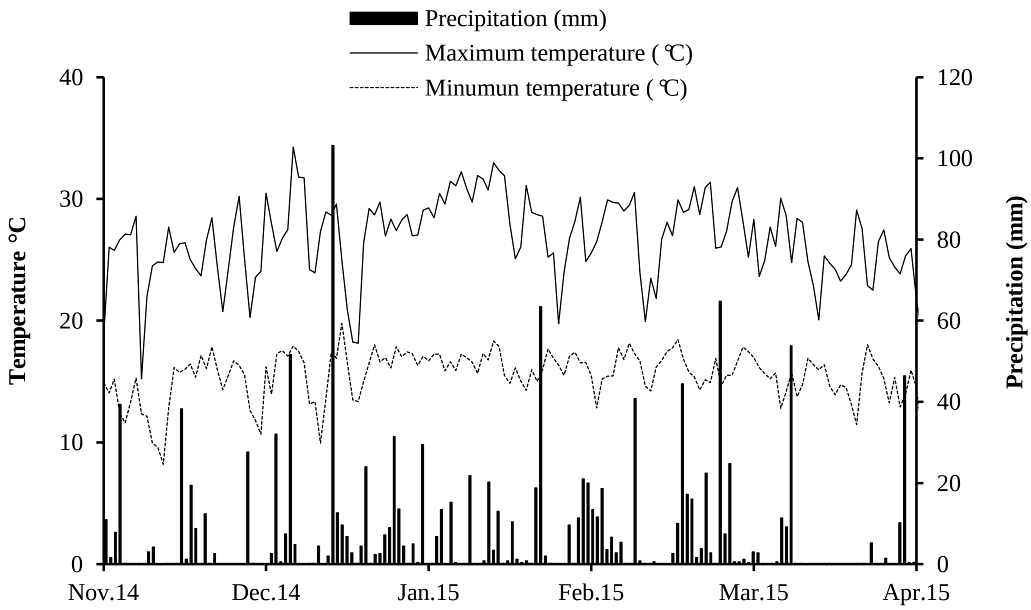


Figure 1 Climate data inserted in the AquaCrop for sensitivity analysis of the main model parameters

2 Materials and methods

This study was conducted for the site of Castro, State of Paraná, latitude 24.85°S, longitude 49.93°W and elevation 1001 meters above sea level, Brazil. The climate in the region, according to Köppen climate classification (Alvares et al., 2013) is *Cfb* (humid subtropical, oceanic climate without dry season, with temperate summer). The soil in the experimental area is classified as Inceptisol. The relief varies from flat to gently undulating. Management practice in the regions is not to plow with residual vegetation, with crop rotation in winter (wheat and black oats) and summer (soybeans and maize).

The model used in the analyses was AquaCrop, Version 5.0, developed by FAO (2016). Data related to the localitie, climate, crop, soil and management practices in the area were inserted in the model. The magnitude values of the climatic variables' series are shown in Figure 1.

In the AquaCrop, the simulation of crop transpiration is obtained by multiplying the evaporating power of the atmosphere (*ETo*) with a crop coefficient (Kc_{Tr}), considering: *i*) the effect of soil water stress (*Ks*), which reduces crop transpiration when insufficient water is available to respond to the evaporative demand of the atmosphere; and *ii*) cold stress coefficient (Ks_{Tr}), which reduces stomatal when there are not enough growing degrees in the day (Equation 1; Raes et al., 2018c). Therefore, *Tr* depends on the fraction of the soil area covered by canopy when there is not enough stress to limit the stomatal opening (Steduto et al., 2012), as well as being part of the two main equations of AquaCrop, being a determinant of the crop biomass accumulation (Equation 2).

$$Tr = Ks \cdot Ks_{Tr} \cdot \left(CC^* \cdot Kc_{Tr,x}\right) \cdot ETo \qquad (1)$$

$$B = WP^* \cdot \sum \frac{Tr}{ETo} \qquad (2)$$

Where: *Tr* – crop transpiration (mm); *Ks* – soil water stress coefficient (dimensionless); Ks_{Tr} – cold stress coefficient (dimensionless); CC^* – fraction of the soil surface covered by green canopy cover, adjusted for micro-advective effects (%); $Kc_{TR,x}$ – maximum crop transpiration coefficient (adimensional); *ETo* – reference evapotranspiration (mm); *B* – biomass accumulation (kg ha^{-1}); WP^* – normalized water productivity (g m^{-2}) (Raes et al., 2018a; Raes et al., 2018c).

Another important equation in AquaCrop is the equation that determines crop yield. The yield (*Y*) is obtained by multiplying the accumulated biomass (*B*) with the adjusted reference harvest index (Equation 3):

$$Y = f_{HI} \cdot B \cdot HI_o \qquad (3)$$

Where: *Y* – crop yield (kg ha^{-1}); f_{HI} – multiplier factor, being positive (f_{HI} > 1) or negative (f_{HI} < 1) (dimensionless), adjusted only under of water or temperature stress conditions; *B* – accumulated biomass (kg ha^{-1}); HI_o – crop reference harvest index (dimensionless) (Raes et al., 2018a; Raes et al., 2018c).

The crop analyzed in the present study was maize, genotype 30R50YH, planted on November 04, 2014 in Castro, Paraná State, and harvested on April 24, 2015. The crop parameters used in the simulations were obtained in experiments carried out at ABC Foundation, being: plant population (plants ha^{-1}); sowing, physiological maturation and harvest dates; yield observed in the field (kg ha^{-1}); duration of crop phenological cycle (emergence, maximum canopy cover, flowering, senescence and maturity; Table 1). The other input parameters required in the model for maize crop (Table 1) was based on the values recommended in the AquaCrop Reference Manual (Raes et al., 2018d).

Table 1 Input data used in the AquaCrop model

	Parameter	Value
	------ Crop Phenology ------	
	Threshold air temperatures	
T_{base}	Base temperature (℃) (1)	8.0
T_{upper}	Upper temperature (℃) (1)	30
	Development of green canopy cover	
CC_0	Soil surface covered by an individual seedling at 90% emergence (cm^2 plant^{-1}) (2)	6.5
	Number of plants per hectare (3)	67188
	Time from sowing to emergence (growing degree day) (3)	69
CGC	Canopy growth coefficient (fraction per growing degree day) (1)	1053
CC_x	Maximum canopy cover (%) (3)	95
	Time from sowing to start senescence (growing degree day) (4)	1764
CDC	Canopy decline coefficient (fraction per growing degree day) (1)	0.855
	Time from sowing to maturity (growing degree day) (4)	2065
	Flowering	
	Time from sowing to flowering (growing degree day) (4)	1085
	Length of the flowering stage (growing degree day) (4)	186
	Crop determinacy linked with flowering (1)	Yes
	Development of root zone	
Z_n	Minimum effective rooting depth (m) (3)	0.3
Z_x	Maximum effective rooting depth (m) (3)	2.8
	Shape factor describing root zone expansion (1)	1.3

	Parameter	Value
	---------- Crop transpiration ----------	
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence (1)	1.05
	Decline of crop coefficient as a result of ageing, nitrogen deficiency, etc (% day^{-1}) (1)	0.3
	Effect of canopy cover on reducing soil evaporation in late season stage (3)	50
	---------- Biomass production and yield formation ----------	
	Crop water productivity	
WP^*	Water productivity normalized for *ETo* and CO_2 (g m^{-2}) (1)	33.7
	Water productivity normalized for *ETo* and CO_2 during yield formation (as percent *WP** before yield formation) (1)	100
	Harvest Index	
HI_o	Reference harvest Index (%) (4)	50
	Possible increase of *HI* due to water stress before flowering (%) (1)	None
	Excess of potential fruits (%) (2)	Small
	Coefficient describing positive impact of restricted vegetative growth during yield formation on *HI* (1)	Small
	Coefficient describing negative impact of stomatal closure during yield formation on *HI* (1)	Strong
	Allowable maximum increase of specified *HI* (%) (1)	15
	---------- Stresses ----------	
	Soil water stresses	
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold (1)	0.14
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold (1)	0.72
	Shape factor for Water stress coefficient for canopy expansion (1)	2.9
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold (1)	0.69
	Shape factor for Water stress coefficient for stomatal control (1)	6.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold (1)	0.69
	Shape factor for Water stress coefficient for canopy senescence (1)	2.7
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold (1)	0.8
	Vol at anaerobiotic point (with reference to saturation) (%) (4) (3)	5.0
	Air temperature stress (*ATS*)	
	Minimum air temperature below which pollination starts to fail (cold stress) (℃) (1)	10.0
	Maximum air temperature above which pollination starts to fail (heat stress) (℃) (1)	40.0
	Minimum growing degrees required for full biomass production (℃ day^{-1}) (1)	12.0

Note: (1)Conservative generally applicable; (2)Conservative for a given specie but can or may be cultivar specific; (3)Dependent on environment and/or management; (4)Cultivar specific.

The soil data required in the model were soil texture, volumetric water content at permanent wilting point (θ_{PMP}; m^3 m^{-3}), field capacity (θ_{CC}; m^3 m^{-3}), saturation (θ_{SAT}; m^3 m^{-3}) and saturated hydraulic conductivity (K_{SAT}; mm day^{-1}). The values were obtained by Souza et al. (2017). In the analyses of the present study, three soil layers were considered (Table 2).

Table 2 Soil physical-water attributes for sensitivity analyses of maize crop

Texture	Layer	------ Volumetric water content (m^3 m^{-3}) ------			K_{SAT} (4)
	(m)	θ_{PMP} (1)	θ_{CC} (2)	θ_{SAT} (3)	(mm day^{-1})
Clay	0-0.10	0.36	0.50	0.60	418.3
Clay	0.10-0.25	0.33	0.47	0.60	368.3
Clay	0.25-0.40	0.32	0.45	0.60	325.7

Note: Volumetric water content at: (1)Permanent wilting point; (2)Field capacity; (3)Saturation; (4)Saturated hydraulic conductivity.

The AquaCrop has components related to soil management that facilitate the understanding of the soil-plant-atmosphere continuum. The parameters related to the soil management were selected directly in the program. It was considered that the management adopted in the areas did not affect the surface runoff and, since the area had no-tillage practice, the soil coverage by mulches was considered at 100%. The pest control of maize was carried out during crop monitoring by the ABC Foundation. Soil fertility was considered close to ideal.

The climate data inserted in AquaCrop was: maximum and minimum daily air temperature (℃) and rainfall (mm day^{-1}), measured at ABC Foundation (latitude 24.85 °S, longitude 49.93 °W and altitude of 1001 meters above sea level); daily reference evapotranspiration (*ETo*; mm day^{-1}), estimated using the Penman-Monteith method (Allen et al., 1998); and, average atmospheric CO_2 concentrations (ppm), provided internally by the AquaCrop model, based on data obtained from the Mauna Loa observatory, Hawaii (Raes et al., 2018b).

The initial soil water content was considered at 50% of the total available water (value between the field capacity and the permanent wilt point), equivalent to the water retention capacity in the soil root zone. Salinity was not considered.

The sensitivity analysis of AquaCrop was carried out for the parameters related to the crop and soil management. The procedure consisted in varying individually each input parameter required by the model (Raes et al., 2018d), remaining the others fixed, and observing the changes in the estimated productivity values. To assess the sensitivity of the model, the relative sensitivity index (*SI*), proposed by Silva et al. (2009) was adopted (Equation 4):

$$SI = \frac{I_{12} \cdot (R_1 - R_2)}{R_{12} \cdot (I_1 - I_2)} \quad (4)$$

Where: *SI* – model sensitivity index for the input parameters (dimensionless); R_1 – result obtained with the model for the lowest input value; R_2 – result obtained with the model for the highest input value; R_{12} – average of the results obtained with the lowest and highest input value; I_1 – lower input parameter value; I_2 – highest input parameter value; I_{12} – average input parameters value.

The sensitivity of the model to the evaluated parameter is directly related to the value obtained by the relative *SI*. As higher is the index value (in module), more sensitive the model will be to the parameter. Values close to zero indicate that the model had no sensitivity.

3 Results and discussion

In the simulation of maize yield with AquaCrop, the relative *SI* allowed identifying five parameters that showed the highest sensitivity (Table 3). Thus, in decreasing order, the AquaCrop's parameters that most affect the yield of maize crop were: crop coefficient with complete canopy expansion ($Kc_{Tr,x}$; *SI* = 1.0777); reference harvest index (HI_o; *SI* = 1.0002); normalized water productivity for *ETo* and CO_2 (*WP**; *SI* = 0.8828); maximum canopy cover (CC_x; *SI* = 0.8557); and, soil fertility (*SI* = 0.6045).

Table 3 Parameters used in the sensitivity analysis of AquaCrop

Simbol	Description	*SI*	Ranking
	--- Crop Phenology ---		
	Canopy development		
CC_o	Initial canopy cover with 90% of plant emergence (%)	0.0389	10
----	Plant density (plants ha^{-1})	0.0400	9
CC_x	Maximum canopy cover (%)	0.8578	4
CDC	Canopy decline coefficient (% day^{-1})	0.1385	7
	Root zone development		
Z_{min}	Minimum effective rooting depth (m)	0.0001	16
Z_{max}	Maximum effective rooting depth (m)	0.0005	14
	--- Crop Transpiration ---		
$Kc_{Tr,x}$	Coefficient for maximum crop transpiration	1.0777	1
	---------------------------- Biomass production and yield formation ----------------------------		
	Crop water productivity		
*WP**	Crop water productivity normalized for *ETo* and CO_2 (g m^{-2})	0.8828	3
	Harvest index		
HI_o	Reference harvest index (%)	1.0002	2
----	Possible increase of *HI* due to water stress before flowering (%)	0.0000	17
----	Coefficient describing positive impact of restricted vegetative growth during yield formation on *HI*	0.0000	17
----	Coefficient describing negative impact of stomatal closure during yield formation on *HI*	0.0000	17
	-- Stresses --		
	Soil water stresses		
$p_{exp,lower}$	Lower soil water depletion threshold for canopy expansion	0.0006	13
$p_{exp,upper}$	Upper soil water depletion threshold for canopy expansion	0.0000	17
p_{sto}	Soil water depletion threshold for stomatal control	0.0000	17
p_{sen}	Soil water depletion threshold for canopy senescence	0.0000	17
p_{pol}	Soil water depletion threshold for failure of pollination	0.0000	17

Simbol	Description	*SI*	Ranking
----	Lack of aeration (with reference to soil saturation) (%)	0.0298	11
	Air temperature stress (*ATS*)		
	Minimum air temperature below which pollination starts to fail (cold stress)	0.0000	17
	Maximum air temperature above which pollination starts to fail (heat stress)	0.0000	17
	Soil physical-water attributes		
----	Volumetric water content at permanent wilting point (θ_{PMP})	0.0016	12
----	Volumetric water content at field capacity (θ_{CC})	0.0220	8
----	Volumetric water content at saturation (θ_{SAT})	0.0563	6
----	Saturated hydraulic conductivity (K_{SAT})	0.0000	17
	Soil management		
----	Soil fertility (%)	0.6045	5
----	Soil covered by mulches (%)	0.0003	15

The higher sensitivity of $Kc_{TR,x}$ (Table 3) is due to its contribution to determining plant biomass and, subsequently, grain yield. It is known that the *Tr* to a well water soil is proportional to the effective *CC*. As well as, water stress can induce stomatal closure, and directly affect transpiration. In AquaCrop, the $Kc_{TR,x}$ is a conservative crop parameter and approximately equivalent to the basal crop coefficient at the mid-season, for situations of total *CC* (Raes et al., 2018b). As the $Kc_{TR,x}$ integrates the equation that simulates *Tr* (Equation 1) and is directly related to evapotranspiration, it was expected that this parameter expresses high sensitivity.

The accumulated biomass (*B*; Equation 2) is directly determined by *WP** and *Tr*. Several authors evaluating the productivity of different crops with the AquaCrop model observed that the *B* parameter proved to be sensitive for several environments: Martini (2018) for rainfed maize in Brazil; Razzaghi et al. (2017) for potato crop in Denmark; Lievens (2014) with soybean and sweet maize in Thailand; Xing et al. (2017) with winter wheat in China and Salemi et al. (2011) in Iran. As the *Tr* is influenced by the climate in which the crop is inserted, it can be considered that the intensity of the $Kc_{Tr,x}$ parameter sensitivity depends on the environment under analysis, explaining the wide sensitivity in several places, as well as in the Southern Brazil scenario.

The HI_o (*SI* = 1.0002; Ranking 2; Table 3) is a parameter that depends on the crop cultivar (Raes et al., 2018c; Raes et al., 2018d). The HI_o values in the literature were adjusted considering cultivars with high yield, with no stress condition (Raes et al., 2018b). However, some cultivars in particular may have slightly higher or lower HI_o than common cultivars, which would justify their adjustment (Steduto et al., 2012). When the crop is under water or temperature stress during the cycle, whether in the vegetative period, flowering or grain formation, HI_o is adjusted by a multiplier factor (f_{HI}), performing its correction with the reference value (Raes et al., 2018a). Thus, the reference value is often not the same as verified during the crop development, and it can be higher or lower. The harvest index (*HI*) is an important parameter, which directly influences the determination of the crop grain yield (Equation 3).

Silvestro et al. (2017) observed a moderate sensitivity of HI_o in the analyses for winter wheat in Italy, and low sensitivity with the same crop in China, in relation to other parameters evaluated. Jin et al. (2018) also noted low sensitivity of HI_o for winter wheat in China and spring in Canada. Xing et al. (2017) confirmed that HI_o occupied the third sensitivity position for the grain yield of winter wheat. HI_o was also shown to be sensitive in the simulations performed by Bouazzama et al. (2017), Razzaghi et al. (2017) and Lievens (2014).

The *WP** (*SI* = 0.8828; Ranking 3; Table 3) consists of the ratio of biomass produced by transpired water (Raes et al., 2018a), normalized for evaporative demand (*ETo*) and CO_2 concentration in atmosphere. Its value can vary moderately in response to the fertility regime, and remain constant under water deficit conditions, except when severe water stresses are reached. The plant growth mechanism in AquaCrop is mainly driven by water. *WP** is important, as it integrates the equation that determines the crop biomass accumulation (Equation 2).

The sensitivity of *WP** was also observed in the research realized by Xing et al. (2017), being this parameter in the first position among the analyzed parameters. Jin et al. (2018) observed second position in the ranking of calibration priority for *WP** in China, and third position in Canada, as a result of the high sensitivity of this parameter in AquaCrop in wheat simulation. Lievens (2014) also observed high sensitivity in both evaluated crops, with more than 20% of influence on the final productivity. Using the EFAST method (Extended Fourier Amplitude Sensitivity Test), Vanuytrecht et al. (2014) observed that *WP** was the third most sensitive parameter for rice crop in Vietnam, Southeast Asia. Bouazzama et al. (2017) observed that *WP** was highly sensitive in simulating the wheat final yield in Morocco, being one of the most sensitive parameters in AquaCrop for biomass production. However, Silvestro et al. (2017) did not observe significant sensitivity for this parameter.

The CC_x (SI = 0.8578; Ranking 4; Table 3) is determined by the planting density and management practiced (Steduto et al., 2009; Raes et al., 2018c). CC_x is an important parameter, as it integrates Equations 5 and 6 that determine two of four stages of *CC*: growth and decline. *CC** helps in determining the *Tr* (Equation 1), which in turn integrates the biomass equation of the model. The canopy growth curve consists of four phases: In phase 1, *CC* is equivalent to the original canopy coverage with 90% plant emergence. In Phase 2, *CC* grows exponentially, being determined by Equation 5 (Figure 2), which has the CC_o and *CGC* as a variable. Phase 3 is the moment when *CC* reaches the maximum growth, being equal to CC_x. In Phase 4 (last phase), *CC* is determined by Equation 6 (Figure 2), which has the CC_x and *CDC* parameters as a variable (Raes et al., 2018c). Thus, the identification of CC_x values (visualized in the field) is extremely important, since the under or overestimation values can cause substantial changes in the final simulated productivity values.

Lievens (2014) and Razzaghi et al. (2017) also observed high sensitivity of CC_x in AquaCrop. In the research conducted by Vanuytrecht et al. (2014), CC_x was the second parameter with highest influence on rice grain yield.

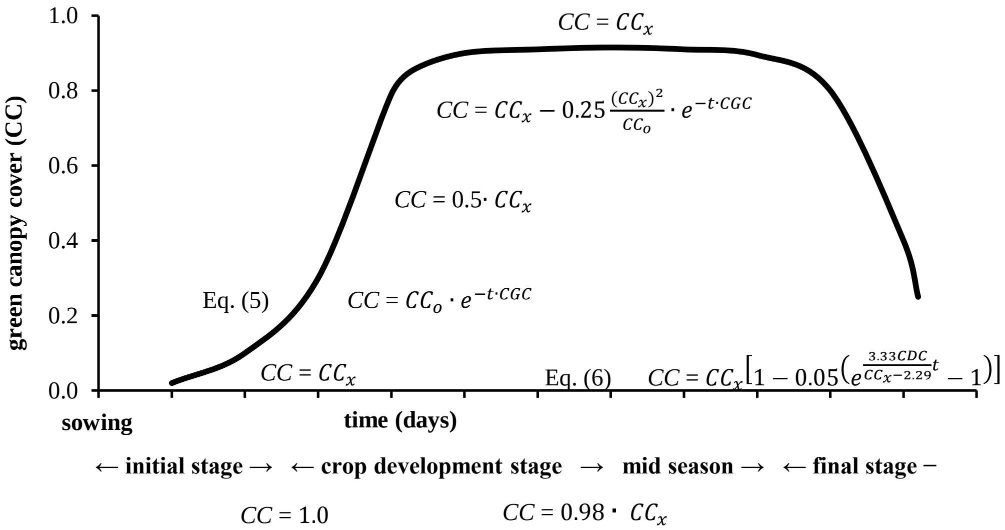
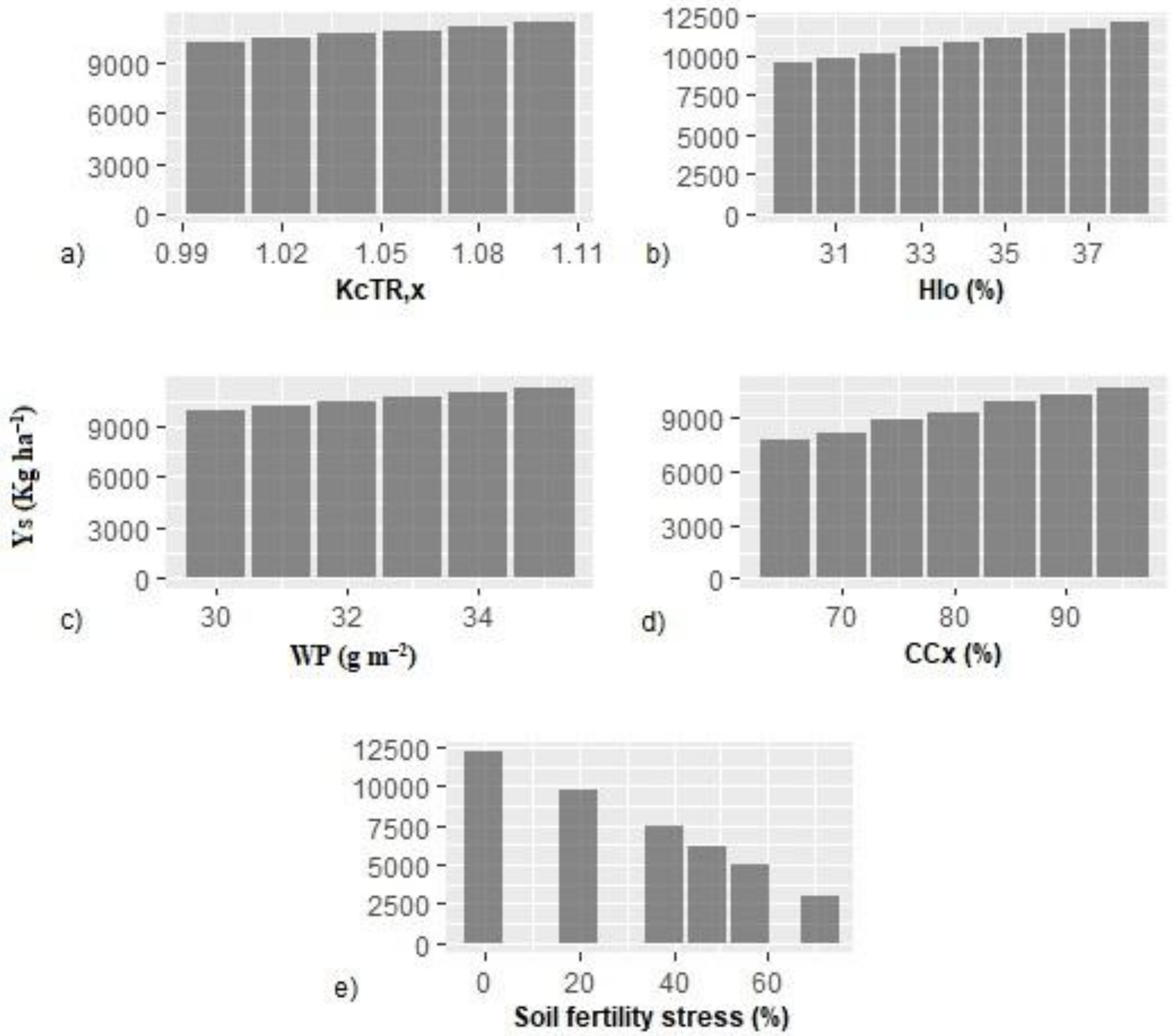


Figure 2 Canopy development during the exponential growth (Equation 5) and exponential decay (Equation 6) (Adapted from Raes et al., 2018c)

Among the parameters related to soil management, soil fertility (SI = 0.6045; Ranking 5; Table 3) was more sensitive (Figure 3e). AquaCrop does not calculate the nutrient cycle and balance, but provides options to adjust the effects of fertility on crop production. The options provided range from “non-limiting” to “very poor”, defining the fertility level which the plants are exposed during the cycle. In simulations, the option is made using the soil fertility stress indicator, which can vary from zero, when fertility is not a limiting factor (*Ks* = 1.0), up to 100%, when the stress is so high that crop production is no longer possible (*Ks* = 0). The option chosen by the user, according to what was observed in the field, can cause increasing reductions in *WP**, canopy growth coefficient (*CGC*) and CC_x, and provide acceleration in canopy senescence but decrease in fertility level (Steduto et al., 2009; Steduto et al., 2012; Hellal et al., 2021; Mansour et al., 2020a, 2020b; Raes et al., 2018b). Changes in *WP**, *CGC*, *CDC* and CC_x parameters directly affect the biomass production and grain yield in the model (Figure 3).



a) crop coefficient with complete canopy expansion ($Kc_{Tr,x}$; dimensionless); b) reference harvest index (HI_o; %); c) normalized water productivity index (*WP**; g m^{-2}); d) maximum canopy cover (CC_x; %); and, e) soil fertility stress (%).

Figure 3 Variation of maize grain productivity (*Ys*) as function of changes in the most sensitive parameters values in AquaCrop model

In the analyses performed by AquaCrop, the following parameters were not sensitive to the conditions evaluated (Table 3): soil saturated hydraulic conductivity (K_{sat}); parameters related to soil water stress ($p_{exp,upper;}$ $p_{sto;}$ $p_{sen;}$ p_{pol}); air temperature stress (*ATS*); and, parameters related to the harvest index.

Plant density (*SI* = 0.04; Ranking 9; Table 3) is a parameter dependent by the management practiced at the cultivation place. The plant population above the considered ideal causes competitiveness and less production. Differently, a smaller population provides greater soil surface exposure and, consequently, highest water loss through evaporation. Two parameters are directly affected by plant density: CC_x and CC_o (*SI* = 0.0389; Ranking 10; Table 3), both of important to determine *CC* during the crop cycle.

The p_{upper} and p_{lower} parameters are related to the type of stress, defining the sensitivity and severity of the soil profile in limit condition. The p_{upper} determines when stress starts, while the p_{lower} is the point at which physiological processes completely cease. In AquaCrop, water stress is divided into reduction of leaf expansion, induction of stomatal closure and triggering of early canopy senescence (Abendipour et al., 2012; Raes et al., 2018b). The p values for canopy expansion (p_{upper} and p_{lower}), stomatal conductance and canopy senescence (p_{upper}) were modified, varying the p values so that water stress changed from "extremely sensitive" to "extremely tolerant". It was observed that only the p_{lower} (SI = 0.0006; Ranking 13; Table 3) of the canopy expansion showed some sensitivity when its values were modified, especially when exposed to "extremely sensitive" and "sensitive" to water stress. The result indicated that during the growing period there was no water stress for the plants, with no significant changes in maize productivity.

The sensitivity of maize crop to soil water logging is specified in AquaCrop and defines the maximum stress limit, values which can vary between 0 ("not stressed when water logged") and 15% saturation ("very sensitive to water logging") (Steduto et al., 2012; Raes et al., 2018b). In the present study, only when the stress level was changed to "very sensitive to water logging" the maize crop showed a decrease in productivity of approximately 5.78% (621 kg ha^{-1}). The resultant result explains the low sensitivity to this stress due to lack of aeration (SI = 0.0298).

The soil covered by mulches (SI = 0.0003; Ranking 15; Table 3) presented low sensitivity, even with variation of 0 to 100% in covered soil. The cover only allows to check if there is or not a decrease in soil evaporation. One distinction of AquaCrop is the separation of the actual evapotranspiration (ET) into non-productive use of water by E and Tr, estimating the biomass production directly from the actual crop transpiration, according to the $WP*$ (Steduto et al., 2012; Raes et al., 2018a). Thus, soil cover has little contribution in calculating biomass production and yield formation in the model, acting more in controlling the water evaporation on the soil surface, maintaining its humidity.

4 Conclusions

The parameters referring to the crop coefficient with $Kc_{Tr,x}$, HI_o, $WP*$ for ETo and CO_2, CC_x and soil fertility resulted in highest sensitivity in AquaCrop for maize crop, in the humid subtropical climate (*Cfb*) in Southern Brazil.

The physical characteristics of soil water had no high levels of sensitivity at AquaCrop.

Soil fertility is the most sensitive management parameter of AquaCrop, affecting $WP*$, which is a direct (biomass) and indirect (productivity) variable of the major AquaCrop equations.

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