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Simulation and performance yield of soybean and maize crops by AquaCrop, in Campos Gerais, Paraná State

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Abstract: The computational models that simulate yield of agricultural crops are important to planning activities. The objective of this study was to verify the performance of AquaCrop model to simulate soybean and maize yield in Campos Gerais region, in different soil types. The AquaCrop was used to estimate yield, requiring climate, soil, crop and soil management input data. In the analysis were used data from 21 and 32 experiments with maize and soybeans, respectively, carried out in the ABC Foundation, from years harvest between 2006 and 2014. For soybean crop, the highest absolute and relative errors of productivity simulations occurred in less productive crops, due to the lack of rain during sowing, water deficit in the harvest or high temperatures in the first weeks after the plants emergence. The highest absolute and relative errors verified in the simulations with maize crop experiments did not allow defined pattern identification. The AquaCrop achieved "very good" and "excellent" performances in the simulations of soybean and maize yield it the analyzed locations. The soil type affected the results from the analyzes of the two crops, and the Latossolos provided better performance and higher correlation compared to other soil types.

Keywords: software, mathematical model, estimative, agricultural crops.

Simulação e desempenho da produtividade das culturas soja e milho no AquaCrop, nos Campos Gerais, Estado do Paraná

Resumo: Modelos computacionais que simulam a produtividade de culturas agrícolas são cada vez mais necessários às atividades de planejamento. Teve-se por objetivo no presente trabalho verificar o desempenho do modelo AquaCrop para simular a produtividade das culturas soja e milho na região dos Campos Gerais, em diferentes tipos de solo. O AquaCrop foi utilizado para estimar as produtividades, sendo necessários dados de clima, solo, cultura e manejo do solo como entrada. Nas análises foram utilizados dados de 21 e 32 experimentos com soja e milho, respectivamente, realizados na Fundação ABC, dos anos safra entre 2006 e 2014. Para cultura da soja, os maiores erros absoluto e relativo das simulações de produtividade ocorreram nas safras menos produtivas, tendo como motivo a falta de chuvas na semeadura, déficit hídrico na safra ou altas temperaturas nas primeiras semanas após a emergência das plantas. Os maiores erros absoluto e relativo verificados nas simulações com os experimentos da cultura do milho não possibilitaram a identificação de um padrão definido. O AquaCrop obteve desempenhos entre "muito bom" e "ótimo" nas simulações das produtividades das culturas soja e milho, nos locais analisados. O tipo de solo interferiu nos resultados das análises das duas culturas, sendo que os Latossolos proporcionaram melhor desempenho e maiores correlações comparado aos demais solos estudados.

Palavras-chave: software, modelo matemático, estimativa, cultivos agrícolas.

Introduction

Computational models that simulate growth, development, and yield of agricultural crops are more important and are increasingly being used in countries that have technified agriculture. They are important systems in sustainable management development, contributing for the accomplishment of studies and yield increase of diverse crops.

Simulation models of agricultural production generally use water relations in the estimates, since there is a direct relationship between crop yield (Y) and the ratio between crop transpiration (Tr_c) and potential evaporation (E_o) (Steduto et al., 2012; Raes et al., 2018a). Equations relating grain yield to meteorological variables are being developed and tested, trying to settle functional relations of yield prediction for models or simulation systems (Scheraiber, 2012; Souza et al., 2013; Islam et al., 2016).

In search for higher precision and robustness, the models became more complex, being one of the largest difficulties to the use of agricultural simulation models, due to the complexity, knowledge degree and understanding of functionality. There is also an incompatibility between models, since they are very heterogeneous and elaborated without any interaction. Another serious problem is to find data that accurately describes the variability in agricultural crop systems (Janssen et al., 2017). In order to minimize some of the problems mentioned, researchers associated to the Food and Agriculture Organization (FAO) developed AquaCrop.

Steduto et al. (2012) and Raes et al. (2018a) consider AquaCrop an evolution, differing from main agricultural yield simulation models for its simplicity. The AquaCrop was developed from the Doorenbos & Kassam equation in two main aspects: separation of evapotranspiration (ET) in soil evaporation (E) and the crop transpiration (Tr); and yield (Y) estimation from biomass production (B) and harvest index (HI).

The main advantage of models computer simulation is related to the quickness productivity results obtained, when compared to field experiments. The use of crop simulation models results in reductions in the planting crops costs, obtaining a greater amount of information regarding plants responses to the environmental conditions evaluated and the creation of unknown scenarios (Corrêa et al., 2011).

In the literature there are several examples of crop simulations with AquaCrop in the world, where satisfactory results have been obtained: wheat production submitted to water deficit in Northern China (Iqbal et al., 2014); potato cultivation under different irrigation conditions in Spain (Montoya et al., 2016); amaranth, chard, and spider-plant production in different water regimes in Gauteng Province, South Africa (Nyathi et al., 2018). The applicability of the AquaCrop model in several crops and countries has shown its robustness and comprehensiveness, but few studies are aimed at its validation and use in Brazil. The Campos

Gerais region is a reference point in grain research and production in Paraná State. Data collected at Experimental Stations in the region have already supported numerous studies aiming to identify the performance of water-culture functions or testing models to estimate crop yields (Araujo et al., 2011, Rosa et al., 2018)

As a model that simulates agricultural production, AquaCrop allows the assumption of ideal scenarios for plant growth and development, being used in decision support and crop management, being able to identify better sowing times, cultivars choices, evaluation of risks and investment, aiming at achieving highest productivity and solving problems mainly regarding drought periods (Oliveira, 2018).

Considering the AquaCrop contributions to crop planning and research, as well as the limited evidence of its use in Brazil, it is believed that the verification of its performance in simulation of agricultural yield may be interesting for the national scenario. In this sense, the aim of this study was to verify the performance of AquaCrop to simulate soybean and maize crops yields in Campos Gerais region, in different soil types.

Material and methods

The present study was carried out in Campos Gerais-PR, a reference region of grains production in Brazil, using maize and soybean historical crop data (2006/07 to 2013/14 harvests) of "ABC Foundation - Agricultural Research and Development". The experimental plots and weather stations used are from the Agrometeorology Sector in Arapoti, Castro, Socavão and Ponta Grossa cities in Paraná State and Itaberá, São Paulo State (Table 1), which show flat to gently undulating relief, typical of the cities around. The soil tillage system is no-tillage with homogeneous vegetable mulching. The crop rotation system used is alternated between soybean and maize in the summer, and wheat and black oats in winter. Pest and disease control is performed according to usual methods pattern in the region, and fertilization is performed by supplying all the nutrients necessary for the full crop development.

To verify the performance of AquaCrop under agricultural production conditions, 21 and 32 yield simulations of maize and soybean crops (kg ha^{-1}), respectively, were carried out for comparison with real productivities observed in the field (kg ha^{-1}), harvests from 2006/07 to 2013/14. To perform the analyzes, it was necessary to insert the following input data into the model (Raes et al., 2018b):

a) Climate: The climate data used came from the agrometeorological stations in each Experimental Field. The minimum and maximum air temperature (°C) and rainfall (mm day^{-1}) data were obtained from the climatic databases provided by ABC Foundation Agrometeorology Sector. The reference evapotranspiration (mm day^{-1}) was estimated using the Penman-Monteith method (ASCE-EWRI, 2005). The mean yearly atmospheric CO_2 concentrations (ppm) are provided by AquaCrop program, measured at the Mauna Loa observatory in Hawaii (Raes et al., 2018b);

b) Crop: the data required was the planting date, duration of each phenological cycle (day), plant population (plants ha^{-1}) and effective rooting depth (m). The data came from historical experiments series carried out at the experimental stations of ABC Foundation, harvests from 2006/07 to 2013/14;

c) Soil: For each experimental plot (50 x 100 m) five representative experimental points were identified.

According the effective rooting depth of studied crops, the soil layers considered at each point were 0.0–0.10 m; 0.10–0.25 m and 0.25–0.40 m. At each point and soil layer, disturbed and undisturbed samples were collected, totaling 75 soil samples (5 experimental stations, 5 experimental points and 3 depths). The volumetric water content at saturation ($m^3 m^{-3}$) and field capacity ($m^3 m^{-3}$) were determined according to Teixeira et al. (2017), using undisturbed soil samples collected with volumetric rings with 5 cm diameter and 3 cm height. The soil moisture at field capacity ($m^3 m^{-3}$) was determined when water balance kept stable in the tension table, at a tension of 0.01 MPa. The water content at permanent wilting point ($m^3 m^{-3}$) was estimated in the soil water retention curve, created with SPLINTEX pedotransfer software (Prevedello, 1999). Volumetric water content at 1.5 MPa tension was considered a permanent wilting point. The saturated hydraulic conductivity (mm day^{-1}) was determined with constant head permeameter, according to Teixeira et al. (2017). Soil volumetric water content at planting time ($m^3 m^{-3}$) was estimated according to Souza et al. (2013). Thus, at the moment prior to planting, in which there was a large rainfall volume, it was considered that the soil reached the water content at field capacity. From this date onwards, the daily inflow and outflow water in soil began to be accounted until planting time.

d) Management: The fertilization level was considered near optimal. As the areas were under no-tillage system, the soil cover by mulches was considered fixed at 50% in all Experimental Stations.

Table 1. Characterization of location, soil, climate, geographic coordinates and altitudes of ABC Foundation experimental stations.

Locality	State	Soil (1)	Texture (2)	Climate (3)	Latitude (4)	Longitude (4)	Altitude (4) (m)
					---------- (degree) --------		
Arapoti	Paraná	LATOSSOLO VERMELHO Distrófico típico	Sandy clay loam	Cfa/Cfb(5)	24.18° S	49.85° W	902
Castro	Paraná	CAMBISSOLO HÁPLICO Distrófico típico	Clay	Cfb	24.85° S	49.93° W	1001
Itaberá	São Paulo	PLANOSSOLO HÁPLICO Distrófico típico	Clay	Cfa	24.07° S	49.15° W	735
Ponta Grossa	Paraná	LATOSSOLO VERMELHO Distrófico típico	Sandy clay	Cfb	25.01° S	50.15° W	1000
Socavão	Paraná	ORGANOSSOLO MÉSICO Sáprico típico	Clay	Cfb	24.68° S	49.75° W	1026

(1)Classification obtained from ABC Foundation soil maps (scale 1:10000); (2)Obtained with disturbed samples and densimeter method, according to Teixeira et al. (2017); (3)Adapted from Alvares et al. (2013); (4)Geographical coordinates measured with GPS device; (5)Climate transition site

The input data were inserted into AquaCrop generating a soil and climate database for each experimental field in harvests between 2006 and 2014. The management data were the same for all simulations, so it was required to change the crop data only.

AquaCrop performs the simulations based on conservative and non-conservative parameters. The conservative parameters do not require calibration (Hsiao et al., 2009; Raes et al., 2018b), and the non-conservative parameters depends on simulator options (cultivar and management) and were inserted according to ABC Foundation protocol data.

Statistical analyzes were performed following the recommendations of Souza (2018). The estimated and real crop (kg ha^{-1}) productivities were compared statistically, considering: linear regression analysis, correlation coefficient, absolute mean errors and relative errors, "*d*" (Willmott) and "*c*" (Camargo & Sentelhas) indexes. The results from the analyzes were organized by localities to verify the possibility of relating the result to the soil type of each Experimental Station.

Results and discussion

Associations between "real yield (Yr) vs estimated (Ys)" for soybean crop

Experiments carried out in Arapoti indicated relative errors (*Er*) less than 10% between real and estimated yield (Table 2) for soybean crop in six of eight harvests. The highest errors occurred in 2011/12 harvest, in which there was low real yield. The decrease in yield occurred by the inexistence of precipitation in the sowing periods (17 to 24/10/2011 and 01 to 10/11/2011). As sowing in two experiments occurred on 10/21/2011 and 11/3/2011, it is believed that soil volumetric water content was not ideal, since soybean seed needs to absorb water at least 50% of its weight to ensure good germination percentage (Embrapa, 2013).

Paredes et al. (2015) verified that AquaCrop is sensitive to soil volumetric water at planting. Thus, small variation in water content can cause reduction in the estimated yield with the model when there is water deficiency in the initial phase of crop. AquaCrop considers that water content in planting time directly affects the percentage of germination (Raes et al., 2018b). Therefore, AquaCrop probably intensified the effect of moisture lack in soil at planting time on the percentage of germination of soybean seeds in Arapoti.

The highest errors in Castro also occurred in harvests with low real crop yield (approximately 2500 kg ha^{-1}). In 2012/13 harvest, two experiments that had early planting (21 and 11/26/2012) showed highest errors (Table 2). As there was no evidence of water deficit in this harvest, the yield decrease was probably related to high temperatures in the first weeks after the plants emergence (02 to 12/12/2012). Raes et al. (2009) consider that the upper temperature limit to soybean development is 30 °C and in the observed period, it was verified higher values of temperature. Experiments in the same harvest, where there was no advance on planting and the average temperature did not exceed the limit of 30 °C, the yield was close to 4000 kg ha^{-1}. Ferreira et al. (2007) notice that the variation of average temperature from 1 °C is already significantly sufficient to altering soybean harvest index (*HI*) in any phenological stage. Changes in harvest index directly affect the estimated yield value.

Paredes et al. (2015), calibrating AquaCrop for soybean in northern China, had to change the reference harvest index (HI_o) value from 0.40 to 0.38. The HI_o is the index for conversion of biomass to yield when water stress does not occur. The change made by the author indicated that even without the occurrence of water deficit, there were sufficient factors to cause significant effect on crop yield, and it was necessary to calibrate the HI_o. The results obtained were interesting and indicate that AquaCrop will need to be tested in future studies to verify its efficiency under atmospheric temperature conditions above the upper limit for soybean.

Table 2. Real average crop (Yr_i) and simulated (Ys_i) yield in AquaCrop for soybean crop, absolute (*Ea*) and relative (*Er*) erros obtained in each experiment installed in Campos Gerais region.

Locality	Soil	Harvest	Yr_i	Ys_i	$Ea = Ys_i - Yr_i$	*Er*
			---------------- (kg ha^{-1}) ----------------			(%)
Arapoti	LVAd	2013/14	4964	4801	–163.33	3.40
Arapoti	LVAd	2013/14	4493	4314	–179.28	4.16
Arapoti	LVAd	2012/13	5066	4751	–314.85	6.63
Arapoti	LVAd	2012/13	4367	4041	–326.13	8.07
Arapoti	LVAd	2011/12	2848	3586	737.75	20.57
Arapoti	LVAd	2011/12	3298	3921	622.68	15.88
Arapoti	LVAd	2010/11	4892	4583	–308.73	6.74
Arapoti	LVAd	2010/11	4454	4337	–117.33	2.71
Castro	CXbd	2013/14	3285	3317	32.08	0.97
Castro	CXbd	2012/13	2679	3304	625.03	18.92
Castro	CXbd	2012/13	3918	3989	70.93	1.78
Castro	CXbd	2012/13	2728	3297	569.40	17.27
Castro	CXbd	2012/13	3408	3476	68.28	1.96
Castro	CXbd	2011/12	3958	3968	9.60	0.24
Castro	CXbd	2011/12	3434	3436	2.50	0.07
Castro	CXbd	2011/12	3923	4048	125.15	3.09
Castro	CXbd	2011/12	3656	3698	41.88	1.13
Castro	CXbd	2010/11	3275	3300	25.50	0.77
Castro	CXbd	2010/11	3655	3716	61.20	1.65
Castro	CXbd	2010/11	3501	3588	87.43	2.44
Castro	CXbd	2010/11	3278	3381	103.16	3.05
Castro	CXbd	2007/08	3370	3422	51.85	1.52
Itaberá	SXd	2013/14	3372	3467	95.27	2.75
Itaberá	SXd	2013/14	2539	3301	761.83	23.08
Itaberá	SXd	2013/14	2833	3691	857.91	23.24
Itaberá	SXd	2013/14	4289	4061	–227.65	5.61
Itaberá	SXd	2012/13	4343	4467	123.68	2.77
Itaberá	SXd	2011/12	4520	4368	–152.35	3.49
Ponta Grossa	LVAd	2012/13	2743	3030	287.23	9.48
Ponta Grossa	LVAd	2011/12	4378	4489	111.23	2.48
Ponta Grossa	LVAd	2010/11	4677	4802	125.40	2.61
Ponta Grossa	LVAd	2006/07	3557	3591	34.32	0.96

In Itaberá, it was also observed that the highest errors of yield estimation occurred in the experiments that had low yield (Table 2), due to water deficit periods. Catuchi et al. (2012) consider that the water requirement to soybean crop increases with the plant development and reaches the maximum during the flowering and grain filling stages. Thus, the AquaCrop routine should consider that the water stress observed, affected the crop with highest severity.

The smaller absolute and relative errors (< 10%) occurred in Ponta Grossa city (Table 2). As in other cities, the highest error was observed in the lower crop yield (2012/13). However, it was verified in 2012/13 harvest that the error was lower compared to other cities. Probably, the smallest yield estimation errors are associated with the local soil conditions, since the climate conditions were similar to the other localities of the region.

The results suggest that there are conditions related to the low yield of soybean that AquaCrop is not able to identify or consider them less intensely. Therefore, it is believed that is necessary to calibrate the coefficients related to water and temperature stress that penalize the crop potential yield with the model. In addition, further studies related to HI_o calibration are required, and the use of AquaCrop in soils with different physical-hydric characteristics.

All simulations in Castro and Ponta Grossa overestimated the yield value. Both cities are located in higher latitudes, have a colder climate and are at lower altitudes in relation to the other locations. The result evidenced the need of adjustments that the model should receive, for condition of increase in potential penalty yield coefficients in mild climate conditions.

Even though there were absolute errors up to 857 kg ha^{-1} in soybean yield simulation with AquaCrop, a high determination coefficient (R^2 > 0.77) was observed between real and simulated yield for the four localities studied (Figure 1). The combined association between "*Yr vs Ys*" from the 32 experiments in the Campos Gerais region (Arapoti, Castro, Itaberá and Ponta Grossa) obtained R^2 = 0.85 on average (Figure 1e).

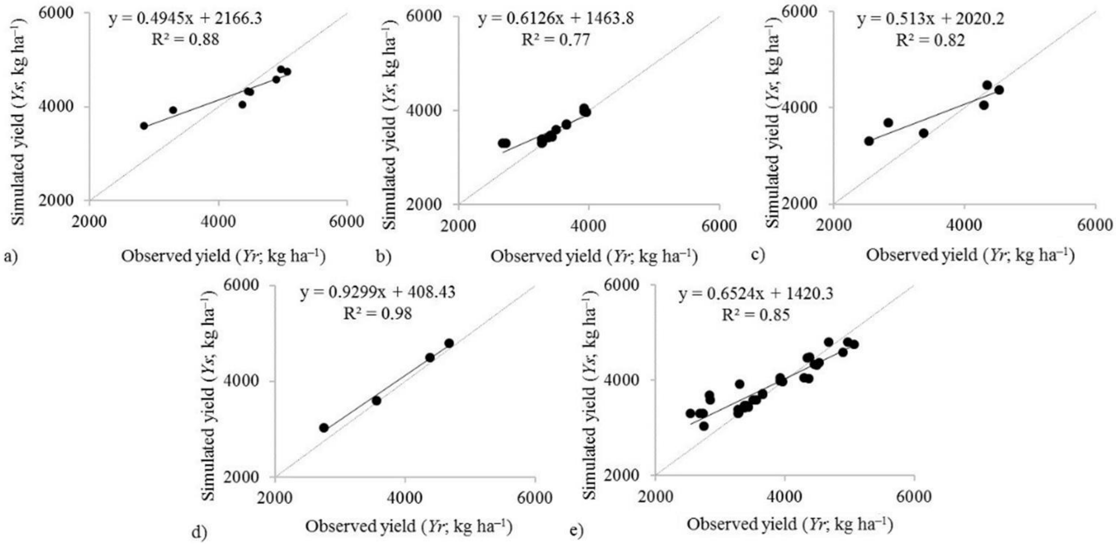

Figure 1. Linear regression and determination coefficients (R^2) between simulated and observed yield with AquaCrop, for soybean crop, in the localities of: a) Arapoti-PR; b) Castro-PR; c) Itaberá-SP; d) Ponta Grossa-PR; and, e) Arapoti, Castro, Itaberá and Ponta Grossa together (32 experiments).

Scenarios disregarding harvests with problems of low yield, due to water deficiency or high temperatures (2011/12 harvest in Arapoti, 2012/13 in Castro and 2013/14 in Itaberá), improved the association between "*Yr vs Ys*" and determination coefficients (R^2) were 0.92; 0.98; 0.89 and 0.99 for Arapoti, Castro, Itaberá and Ponta Grossa, respectively. The association between "*Yr vs Ys*" from the 32 experiments together resulted in R^2 = 0.95.

Therefore, although the AquaCrop still needs adjustments, it can be affirmed that the associations obtained for yields ("*Yr vs Ys*") were high and the model has great potential to be calibrated and validated for soybean in Campos Gerais region.

Associations between "real crop yield (Yr) vs estimated (Ys)" for maize

Different from soybean, which the highest absolute and relative errors occurred for the less productive harvests, the highest errors observed in maize experiments occurred without a defined pattern (Table 3). The largest absolute and relative errors occurred in Socavão district (Table 3), in two experiments of 2012/13 harvest, with 973.70 kg ha^{-1} (7.74%) and 1692.53 kg ha^{-1} (13.7%) errors. Hsiao et al. (2009) comment that absolute errors above 1000 kg ha^{-1} for maize are considered above the limits of model confidence.

The 2012/13 harvest (Socavão) recorded periods that characterized water stress between flowering and grain filling, with precipitation of only 3.2 mm between 12/20/2012 and 01/13/2013. Bergamaschi et al. (2004) consider that the period from pre-flowering to the beginning of grain filling for maize is more sensitive to water deficit. Magalhães (2006) and Fagherazzi (2015) consider that during the period of grain filling the highest accumulation of carbohydrate occurs in maize grains. The process is closely related to photosynthesis and presents a high water demand. Therefore, the reported water stresses in these two stages resulted in lower grain weight and yield. The results show that AquaCrop probably underestimated the intensity that water deficit operate on the photosynthetic processes in maize crop. On the other harvests in Socavão (2013/14 and 2011/12), AquaCrop underestimated the yield. The local soil has high content of organic matter (Organosol). According to Ankenbauer and Loheide (2017) and Minasny and McBratney (2018), soil organic matter acts significantly on soil water retention and, consequently, on water balance. In this context, the errors may be related to the lack of model resources to simulate the effect of soil organic matter on water relations.

Castro also presented heterogeneous results (Table 3), with absolute and relative small (98.15 kg ha^{-1}, 0.75%) and large (1225.28 kg ha^{-1}; 9.11%) errors, according to Hsiao et al. (2009) considerations (> 1000 kg ha^{-1}). As the highest error in Castro occurred in the higher yield harvest (14681 kg ha^{-1}), it is believed that AquaCrop has more difficulty to simulate productivities that deviate from the average. However, the results are quite random, making difficult interpretations, as in the experiments carried out in Ponta Grossa, where low and high real productivities did not provide the highest estimated errors using the model (Er < 3.27%; Table 3).

The lowest yield estimation errors for maize crop occurred in Ponta Grossa city, but only three experiments were analyzed in the city. Therefore, it is not possible to confirm the existence of some tendency. The lower variability in the estimates for Ponta Grossa is probably related to the soil attributes, since the other factors are similar among the cities. Therefore, without calibration, the results indicate that AquaCrop was more efficient in the simulations in Latossolos, compared to other studied soils.

Table 3. Real average crop (Yr_i) and simulated (Ys_i) yield in AquaCrop for maize crop, absolute (*Ea*) and relative (*Er*) erros obtained in each experiment installed in Campos Gerais region.

Locality	Soil	Harvest	Yr_i	Ys_i	$Ea = Ys_i - Yr_i$	*Er*
			----------------- (kg ha^{-1})		-----------------	(%)
Castro	CXbd	2013/14	13554	13002	–551.70	4.24
Castro	CXbd	2013/14	13078	13188	109.95	0.83
Castro	CXbd	2013/14	14681	13456	–1225.28	9.11
Castro	CXbd	2013/14	12987	13085	98.15	0.75
Castro	CXbd	2012/13	12453	13021	568.38	4.37
Socavão	OYs	2013/14	13110	12998	–111.59	0.86
Socavão	OYs	2013/14	13661	13406	–254.56	1.90
Socavão	OYs	2013/14	13674	13398	–275.86	2.06
Socavão	OYs	2013/14	13970	13466	–504.01	3.74
Socavão	OYs	2013/14	13002	12855	–147.22	1.15
Socavão	OYs	2012/13	10659	12352	1692.53	13.7
Socavão	OYs	2012/13	13341	13221	–120.35	0.91
Socavão	OYs	2012/13	12945	12745	–200.19	1.57
Socavão	OYs	2012/13	13155	13020	–134.79	1.04
Socavão	OYs	2012/13	11606	12580	973.70	7.74
Socavão	OYs	2011/12	13513	13056	–456.97	3.50
Socavão	OYs	2011/12	11981	12456	474.69	3.81
Socavão	OYs	2011/12	13713	13388	–324.64	2.42
Ponta Grossa	LVAd	2013/14	10233	10112	–120.75	1.19
Ponta Grossa	LVAd	2013/14	10262	10500	238.17	2.27
Ponta Grossa	LVAd	2012/13	12239	11851	–388.06	3.27

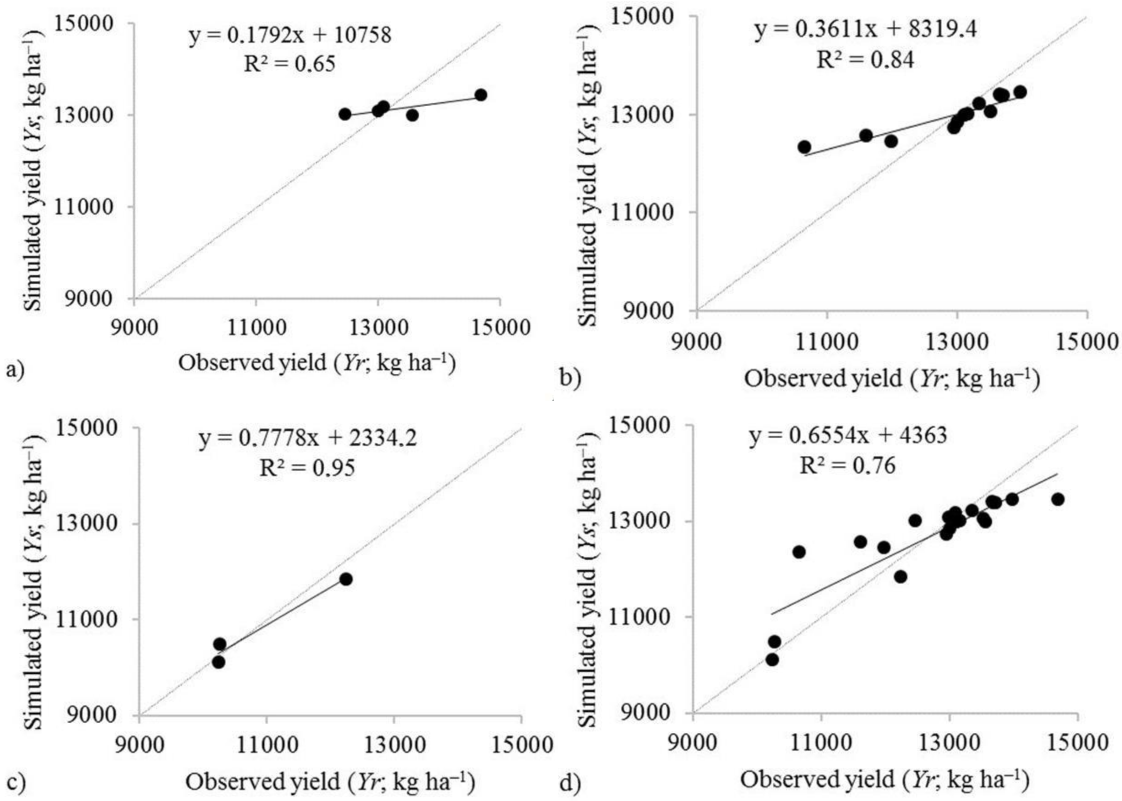

Figure 2. Linear regression and determination coefficients between simulated and observed yield with AquaCrop, for maize crop, in the localities of: a) Castro-PR; b) Socavão-PR; c) Ponta Grossa-PR; and, d) Castro, Socavão and Ponta Grossa together (21

experiments).

Despite the absolute and relative errors in maize yield estimates with AquaCrop and the lower number of experimental harvests available (Table 3), the relation "*Yr vs Ys*" determination coefficients (R^2) were still higher than 0.65 (Figure 2). The combined association between "*Yr vs Ys*" from the 21 experiments in Campos Gerais region (Castro, Socavão and Ponta Grossa) resulted in R^2 = 0.76 (Figure 2D). The results showed that the model, after adjustments, also has the potential to be calibrated and validated for the maize crop in Campos Gerais region.

Analysis set performance

The analysis of relation between "*Yr vs Ys*" performed predominantly between "very good" and "excellent" for maize and soybean, respectively, in Campos Gerais region (Table 4). The correlation coefficients (R) indicated a good association between the values "*Yr vs Ys*" for soybean (R > 0.85) and maize (R > 0.76). Therefore, the performances could be better if the concordance index ("*d*" index) were higher. The "*d*" index is a measure of the distance in which "*Yr vs Ys*" association points are of 45° line (1: 1), in first quadrant, being more connected to the model calibration process. Therefore, it is believed that this aspect can be greatly improved in future studies carried out with AquaCrop in Campos Gerais region.

The best performance of AquaCrop occurred in Ponta Grossa city for soybean and maize crops (Table 4). The results were obtained in the experimental stations with Latossolo Vermelho Distrófico típico soil classification, and the performances in the simulations were classified as "excellent".

Table 4. Absolut (*Ea*) and relative (*Er*) errors, correlation coefficient (*R*), "*d*" (Willmott) and "*c*" (Camargo & Sentelhas) indexes and performance between real average crop (Yr_i) and simulated (Ys_i) yield in AquaCrop for soybean and maize, obtained in each experiment installed in Campos Gerais region.

Crop	Locality	*Ea* (kg ha⁻¹)	*Er* (%)	*R*	"*d*"	"*c*"	Performance
				-------	(unitless)	-------	
Soybean	Arapoti	337	0.981	0.939	0.876	0.823	"Very good"
Soybean	Castro	134	0.268	0.880	0.864	0.761	"Very good"
Soybean	Itaberá	370	1.583	0.909	0.843	0.765	"Very good"
Soybean	Ponta Grossa	140	0.877	0.994	0.987	0.981	"Excellent"
Soybean	Campos Gerais (1)	230	0.186	0.925	0.923	0.854	"Excellent"
Maize	Castro	511	0.777	0.811	0.518	0.420	"Bad"
Maize	Socavão	436	0.258	0.921	0.769	0.708	"Good"
Maize	Ponta Grossa	249	0.767	0.980	0.974	0.954	"Excellent"
Maize	Campos Gerais (2)	427	0.187	0.877	0.914	0.802	"Very good"
Soybean and Maize	Campos Gerais (3)	308	0.079	0.995	0.997	0.993	"Excellent"

(1)Considering all the experiments with soybean crop in Arapoti, Castro Itaberá and Ponta Grossa; (2)Considering all the experiments with maize crop in Castro, Socavão and Ponta Grossa; (3)Considering all the experiments with soybean and maize crops in Arapoti, Castro, Itaberá, Socavão e Ponta Grossa.

The performances for soybean were equal or superior to "very good", indicating promising results (Table 4). It is also important to notice that the results were satisfactory in several types of soil, classified as Latossolo Vermelho Distrófico típico (Arapoti), Cambissolo Háplico Distrófico típico (Castro), Planossolo Háplico Distrófico típico (Itaberá) and Latossolo Vermelho

Distrófico típico (Ponta Grossa). Araujo et al. (2011) performing the adjustment of water-culture equations in Ponta Grossa, in Latossolo Vermelho Distrófico típico area with a clay texture soil, also obtained satisfactory results. However, after a series of data deployments, only a predominantly "good" to "very good" results were obtained with Stewart & Jensen's water-culture equation.

The worst performance for maize crop occurred in Castro ("bad"; Table 4). Thus, although Socavão and Ponta Grossa had "good" and "excellent" performance, respectively, it is considered that analyzes with maize crop need to be better assessed, and even consider a larger number of harvests to obtain more conclusions results. Interestingly, the results were obtained in three soil types, classified as Cambissolo Háplico Distrófico típico (Castro), Latossolo Vermelho Distrófico típico (Ponta Grossa) and Organosol Mésico Sáprico típico (Socavão). Therefore, based on the literature, it is considered that the results obtained represent an advance to maize yield estimation in the region. Another interesting aspect to be observed refers to the good performances obtained from "*Yr vs Ys*" analyzes for Campos Gerais region, being: "excellent" for soybean; "very good" for maize; and, "excellent" for maize and soybean analyzes.

AquaCrop has potential to be validated in Campos Gerais region for soybean and maize crops, requiring calibration to obtain more reliable results, allowing the development of scientific studies and achievement of agricultural scenarios. Adjusting the model to specific conditions may significantly increase its efficiency. It is believed that the necessary adjustments to be made have connection with the availability of water for plants, according to the soil physical-water attributes, since the experiments in Latossolos presented small errors, while the other soils presented more expressive errors in high or low yield harvests.

Conclusions

The AquaCrop model responded positively to expectations as to soybean and maize productivities simulation in Campos Gerais region, with "very good" and "excellent" predominantly performances.

The highest errors in soybean estimating occurred in years with low real yield. AquaCrop needs adjustments by calibration in the coefficients that penalize potential yield in Campos Gerais region, when climate factors that affect yield are severe.

The soil type interfered in AquaCrop analysis results, in which the Latossolos presented better performance and higher correlations compared to the other soils studied.

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