SENSITIVITY OF BRAZILIAN MAIZE CULTIVARS TO WATER DEFICIT BASED ON AN AGROMETEOROLOGICAL CROP YIELD MODEL

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ABSTRACT: Shortage of water is the most important limiting factor for crop production around the world. Maize is moderately drought-sensitive; however the degree of damage will depend on the developmental phase in which water deficit is experienced. Therefore, the knowledge of the sensitivity to water deficit of the Brazilian maize cultivars can help growers to find the best options for their climatic conditions, during a given growing season. Based on that, the objectives of this study was to determine the sensitivity of 26 maize cultivars to water deficit, taking into account a simple agrometeorological crop yield model. Maize actual yield (Ya) and agronomic data for 26 cultivars as well as soil information were obtained from the Maize National Assays, conducted by EMBRAPA (Brazilian Agricultural Research Corporation), in ten locations distributed in the states of Paraná, São Paulo, Minas Gerais, and Goiás, during the years from 1998 to 2006. The water deficit sensitivity index (Ky) was determined for the four developmental phases of each cultivar through the crop yield depletion model, presented by Doorenbos and Kassam (1994). The results showed that the cultivars can be divided in two groups of resistance to water deficit: normal and higher. The normal resistance cultivars presented Ky ranging from 0.4 to 0.5 for vegetative phase, from 1.4 to 1.5 for flowering phase, from 0.3 to 0.6 for fruiting phase, and from 0.1 to 0.3 for maturing phase; whereas the higher resistance cultivars presented lower values, respectively: 0.2-0.4; 0.7-1.2; 0.2-0.4; and 0.1-0.2.
KEYWORDS: crop yield model, drought resistance, *Zea mayz*, water balance.

SENSIBILIDADE DE CULTIVARES BRASILEIROS DE MILHO AO DÉFICIT HÍDRICO UTILIZANDO MODELO AGROMETEOROLÓGICO DE ESTIMATIVA DA PRODUTIVIDADE

RESUMO: A falta de água é o principal fator limitante da produção agrícola no mundo. A cultura do milho é considerada como moderadamente resistente à seca, entretanto o grau de dano causado pelo déficit hídrico irá depender da fase de desenvolvimento em que tal déficit ocorre. Portanto, o conhecimento da sensibilidade ao deficit hídrico das cultivares brasileiras de milho pode ajudar os agricultures a escolher a melhor opção para suas condições climáticas e para a época de cultivo. Baseando-se nisso, o objetivo do presente estudo foi determinar a sensibilidade de 26 cultivares de milho ao deficit hídrico, levando-se em consideração uma abordagem agrometeorológica. Dados de produtividade real (Ya) e agronômicos de 26 cultivares de milho foram obtidos dos Ensaios Nacionais de Milho, conduzidos pela EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), em dez localidades distribuídas pelos estados do Paraná, São Paulo, Minas Gerais e Goiás, entre os anos de 1998 e 2006. O índice de sensibilidade ao deficit hídrico de cada cultivar foi determinado para cada uma das quatro fases da cultura de cada cultivar por meio do modelo de penalização da produtividade, apresentado por Doorenbos e Kassam (1994).

Os resultados mostraram que as cultivares de milho podem ser classificadas em dois grupos de resistência ao déficit hídrico: normal e elevada. As cultivares de resistência normal apresentaram valores de Ky variando de 0,4 a 0,5 para a fase vegetativa, de 1,4 a 1,5 para a fase de florescimento, de 0,3 a 0,6 para a fase de frutificação, e de 0,1 a 0,3 para a fase de maturação; enquanto que as cultivares classificadas como de elevada resistência apresentaram respectivamente os seguintes valores de Ky: 0,2-0,4; 0,7-1,2; 0,2-0,4; e 0,1-0,2.
PALAVRAS-CHAVE: modelo de produtividade, resistência à seca, *Zea mayz*, balanço hídrico.

INTRODUCTION: Maize (Zea mays L.) is a essential crop for food security around the world (Campos et al., 2004), and nowadays is becoming also very important for energetic purposes, considering that it is the main raw material for ethanol production in temperate countries of North America, Europe and Asia. The most important limiting factor to maize yield around the world is the occurrence of water deficits during the crop cycle. In Brazil, Bergamaschi et al. (2007) consider the irregular distribution of rainfall, during the crop cycle, as the main factor to explain the maize yield variability, mainly in the state of Rio Grande do Sul, where El Niño Southern Oscillation has a great influence on rainfall patterns. Other studies have revealed an extreme sensitivity of maize plants to water deficit, during a very short critical period, from flowering to the beginning of the grain-filling phase, when the plants present the highest water consumption. The sensitivity of maize to water stress over the whole growing season or at one of the different growth stages of the crop has been widely used in studies aiming to develop deficit irrigation strategies, as well as to determine the yield response factor, also known as water deficit sensitivity index (Ky). The knowledge of Ky of different maize cultivars makes possible to choose the best option for a specific location and season, according to the water deficit conditions, reducing the yield damages. As maize is moderately drought-sensitive and each of its developmental phases has a different sensitivity to water stress, the degree of yield damage will depend on the phase in which water deficit is experienced as well as on the resistance of the cultivar to the water deficit. Based on the discussion presented above, the objectives of this study was to determine the sensitivity of 26 Brazilian maize cultivars to water deficit, taking into account a simple agrometeorological crop yield model, aiming to subsidize growers and other decision makers in relation to maize cultivar choosing.

MATERIAL AND METHODS: Maize actual yield (Ya) and agronomic data for 26 cultivars were obtained from the Maize National Assays, conducted by EMBRAPA (Brazilian Agricultural Research Corporation), from 1998 to 2006, totaling 244 experiments sowed between October and December and harvested between March and June, in a rainfed condition. The number of trials per cultivar ranged from 5 to 17. Weather data for each location and period were obtained from the closest weather station in the region, including data from Instituto Tecnológico SIMEPAR, for locations in the state of Paraná, Escola Superior de Agricultura "Luiz de Queiroz", University of São Paulo, for Piracicaba, State of São Paulo, and AGRITEMPO/EMBRAPA Informática Agropecuária for locations in the states of Minas Gerais and Goiás. The crop yield models presented by Doorenbos and Kassam (1994), to estimate potential (Yp) and actual (Ya) yields, were used as the base to determine the water deficit sensitivity index (Ky) for the 26 maize cultivars, in each one of the four crop developmental phases and also for the entire crop cycle.

The model used for estimating Yp is known as Agro-Ecological Zone model and is based on the assumption that the crop is under optimal growing conditions, without water, nutrients and/or phytosanitary stresses. Under these assumptions, the Yp is only affected by the interaction between the genotype and the weather conditions, which is restricted, in this case, to solar radiation, temperature and photoperiod. The estimated Yp data for each one of the 244 experiments were used together with water balance data to estimate Ya, using the linear crop-water production function presented by Doorenbos and Kassam (1994):

$$Ya = Yp \prod_{i=1}^{m} \left[1 - Ky_i \left(1 - \frac{ETa_i}{ETc_i} \right) \right]$$

The standard Kc and Ky values were used to calculate respectively ETc and Ya. These values were used to generate the first round of estimated Ya data. After that, the calibration of the model was done through Ky manipulation to obtain the best fit between observed and estimated Ya. The process of crop yield model calibration was used to determine the Ky values for the four different growth stages of each cultivar. The calibration aimed to obtain the smallest mean absolute error (MAE) between observed and estimated Ya.

RESULTS AND DISCUSSION: The yield model calibration process resulted in different values of Ky for the studied cultivars (Table 1). The degree of resistance to the water deficit was measured by the Ky values. Smaller Ky values represent a greater resistance and vice-versa. Based on these results, it was possible to divide the cultivars in two groups in terms of their sensitivity to water deficits. One group, which represents the majority of the cultivars (18), was considered as of normal resistance, since its Ky values does not differ substantially from those presented by Doorenbos and Kassam (1994). The normal resistance cultivars presented Ky ranging from 0.4 to 0.5 for vegetative growth phase, from 1.4 to 1.5 for flowering phase, from 0.3 to 0.6 for yield formation phase, and from 0.1 to 0.3 for ripening phase; whereas the higher resistance cultivars presented lower values, respectively: 0.2-0.4; 0.7-1.2; 0.2-0.4; and 0.1-0.2. The greatest difference between the two groups was observed for the flowering phase, the most sensitive for the water deficit (Bergamaschi et al., 2007). For the group less sensitive to water deficit, Ky during the flowering phase ranged from 0.7 to 1.2, whereas for the most sensitive cultivars Ky in this phase ranged from 1.4 to 1.5.

The cultivars that presented higher resistance to water stress, AG1051, AG6018, AS3466 Top, CD3121, Farroupilha-25, P3081, P30F33, and SHS5050, are those that should be recommended for regions and/or seasons where there is a higher risk of water deficit during the growing season, like during the Fall-Winter season (safrinha) in southern Brazil. On the other hand, the cultivars which presented normal resistance to water stress, like DKB333B, should be recommended for regions with lower risk of water deficits, under rainfed conditions, or for drier regions and/or seasons with irrigation, mainly during the flowering phase, the most sensitive to water stress.

The average potential and actual yield estimates obtained with the crop models for each one of the 26 cultivars are presented in Table 2. The potential yields for the assessed locations and periods ranged from 7951 kg ha^{-1} for SHS4050 to 11156 kg ha^{-1} for AG1051, but with higher values for individual trials, in which potential yield achieved more than 12500 kg ha^{-1}, as observed in Londrina and Senador Canedo for AG1051 in 2001/02, and in Cascavel for DKB747 in 2002/03. The estimated actual yields were very similar to observed data, with underestimation in 16 cultivars and overestimations in 10, with the MBE ranging from -5.7 to +5.8. The MAE between observed and estimated Ya ranged from 298 to 1477 kg ha^{-1}, which represents, in percentage, errors between 3.9 and 15%, considered reasonable in terms of yield modeling. These errors are similar to those found by Soler et al. (2007) when using the DSSAT CERES-MAIZE model to estimate actual yields of rainfed and irrigated maize cultivars in the state of São Paulo. In that study, Soler et al. (2007) found percentage errors ranging from -10.7 to +11.3%.

It is important to emphasize that the models used in this study accounted only for the effect of weather variables, like solar radiation and temperature for Yp and its depletion due to water deficit for estimating Ya. Therefore, other factors as the occurrence of pests and diseases and nutritional deficiency in the 244 field trials are not considered, which could explain part of the errors observed.

Table 1 – Water deficit sensitivity index (Ky) for the different developmental phases of 26 maize Brazilian cultivars.

Cultivar	Ky			
	Vegetative Growth	Flowering	Yield formation	Ripening
Normal Resistance				
Al Bandeirante	0.5	1.5	0.6	0.3
AS 1533	0.4	1.4	0.3	0.1
BALU 184	0.3	1.4	0.5	0.2
BALU 178	0.4	1.5	0.5	0.2
BRS-3060	0.4	1.3	0.5	0.2
CO 32	0.4	1.5	0.5	0.2
DKB 333B	0.4	1.5	0.5	0.2
DKB 350	0.4	1.4	0.3	0.2
DKB 747	0.5	1.4	0.4	0.2
P 3041	0.4	1.5	0.5	0.2
PL 6880	0.4	1.5	0.3	0.2
SHS 4050	0.4	1.5	0.5	0.2
SHS 5060	0.4	1.5	0.5	0.2
SHS 5070	0.4	1.5	0.5	0.2
SHS 4040	0.4	1.5	0.5	0.2
XB 7011	0.4	1.5	0.5	0.2
XB 7012	0.4	1.5	0.5	0.2
XB 8010	0.4	1.5	0.5	0.2
High Resistance				
AG 1051	0.3	1.2	0.4	0.2
AG 6018	0.3	1.1	0.3	0.1
AS-3466 Top	0.2	0.9	0.3	0.1
CD 3121	0.3	0.9	0.3	0.1
Farroupilha 25	0.3	1.2	0.3	0.2
P 3081	0.2	0.7	0.2	0.1
P 30F33	0.4	1.0	0.2	0.1
SHS 5050	0.3	0.9	0.3	0.1

CONCLUSIONS: The results obtained in this study allowed concluding that the evaluated maize cultivars can be divided in two groups of sensitivity to water deficit, one with normal resistance to water stress and another of higher resistance. The calibrated crop yield models used resulted in reasonable estimates of Ya, with percentage error ranging from 3.9 to 15%, showing its potential to be used as a yield forecaster, and also for studies related to crop zoning and best sowing dates determination.

Table 2 – Statistics of the comparison between observed and estimated maize yield for the 26 Brazilian cultivars.

Cultivar	Yp Estimated	Ya Estimated	Ya Observed	MBE (%)	MAE (kg ha^{-1})	r	d	c	n
AG 1051	11156	10701	10694	0.1	1235	0.76	0.84	0.63	7
AG 6018	10440	9581	9953	-3.7	1022	0.74	0.86	0.64	9
AL Bandeirante	8483	7957	7850	1.4	1048	0.66	0.75	0.50	7
AS 1533	9294	8378	8673	-3.4	931	0.65	0.77	0.50	9
AS-3466 Top	8717	8003	8204	-2.4	696	0.76	0.66	0.50	5
BALU 178	8622	7991	7962	0.4	921	0.63	0.77	0.49	9
BALU 184	9110	8479	8651	-2.0	855	0.81	0.88	0.71	10
BRS-3060	8990	8234	8272	-0.5	1252	0.43	0.66	0.28	12
CD 3121	9038	8323	8541	-2.5	922	0.64	0.78	0.50	14
CO 32	9465	8729	8573	1.8	829	0.65	0.79	0.51	12
DKB 333B	9682	9069	9617	-5.7	1389	0.65	0.65	0.42	5
DKB 350	9898	9483	9693	-2.2	1447	0.47	0.60	0.28	5
DKB 747	10094	9326	9232	1.0	1242	0.73	0.84	0.61	9
Farroupilha 25	9692	9132	9280	-1.6	1329	0.64	0.77	0.49	8
P 3041	10295	9395	9364	0.3	523	0.70	0.84	0.59	8
P 3081	8797	7815	7969	-1.9	592	0.67	0.79	0.53	6
P 30F33	9396	8731	8904	-1.9	971	0.91	0.88	0.80	9
PL 6880	8286	7544	7871	-4.2	944	0.58	0.61	0.35	11
SHS 4040	8228	7621	7567	0.7	298	0.83	0.89	0.74	6
SHS 4050	7951	7224	7344	-1.6	679	0.37	0.60	0.22	9
SHS 5050	8783	8118	8380	-3.1	689	0.27	0.55	0.15	10
SHS 5060	9689	8781	8296	5.8	1297	0.13	0.41	0.05	10
SHS 5070	8851	8012	8068	-0.7	1086	0.33	0.56	0.18	11
XB 7011	9092	8478	8402	0.9	1105	0.59	0.76	0.45	12
XB 7012	9180	8577	8743	-1.9	974	0.76	0.84	0.63	17
XB 8010	8823	8349	8319	0.4	720	0.70	0.83	0.59	14

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