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CHALLENGES AND DIFFICULTIES ON WATER STRESS EXPERIMENT DESIGNS, DATABASE AND MODELING FOR DROUGHT TOLERANCE PHENOTYPING

A STRATEGY TO MANAGE CROP WATER DEFICIT IN FIELD TRIALS

Camilo de Lelis T. de Andrade[28], *Reinaldo L. Gomide*[28], *Paulo Emílio P. Albuquerque*[28], *Tales A. Amaral*[29], *Cristiano M. R. Silva*[30], *Samira G. A. Araujo*[31]

INTRODUCTION

A plant starts to suffer water deficit when soil-water fluxes toward the roots are not sufficient to supply the plant transpiration plus soil surface evaporation. This is a complex interaction between plant and environment. Characterizing plant and environment (weather, soil) is the first step toward understanding this process. Crop drought tolerance experiments require addressing some questions regarding each specie and the cropping system of a region: 1 – Have the soil physical and chemical attributes been characterized, so that one can verify whether the crop is suffering a single or multiple stresses (aluminum, low pH, low phosphorus, and water deficit)? 2 – Have the weather been characterized at least in terms of rainfall distribution and potential crop water requirements, so that, one can estimate the expected water deficit, onset, duration and intensity? 3 - How tolerant are species and genotypes to water deficit? 4 - Where are the best sites to carry out water deficit studies? 5 – What is the appropriate strategy to impose the water deficit at the right moment, duration and intensity? 6 – What are the available methods to quantify the stress level and what are the difficulties to use them?

The objective of this paper is to address the answer to some of these questions, having Central Brazil's major grain cropping systems as an example.

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[28] Embrapa Maize and Sorghum, Rod. MG 424 km 45, 35701970 Sete Lagoas, MG, email: camilo@cnpms.embrapa.br.

[29] Fapemig Scholarship, Embrapa Maize and Sorghum, 35701970 Sete Lagoas, MG.

[30] CNPq PIBIC Scholarship, Embrapa Maize and Sorghum, 35701970 Sete Lagoas, MG.

[31] Embrapa Scholarship, Embrapa Maize and Sorghum, 35701970 Sete Lagoas, MG.

DEFINING THE STRESS TYPE

In addition to water deficit stress, some crop might experiment one or more type of stresses, such as soil excess water, aluminum toxicity, low pH, and low phosphorus. Characterizing the soils is, though, important to identify the type of stress crops might expect. Crops grown in soils with aluminum and, or pH problems might have limited rooting system which can make them more susceptible to water deficit problems, specially on soils with low water retention capacity, commonly found in Central Brazil.

Only high technology level farmers in Brazil can correct soil fertility to a depth of about 40 cm. Long term no-tillage cropping technology, and more recently, the crop-pasture intercropping systems, can promote deeper soil corrections. Low-income farmers normally do not correct soils properly and in this kind of cropping system, plants might undergo multiple stresses. It is important to identify and define the stress type to clearly define the research strategy.

CHARACTERIZING THE WATER STRESS

Stress characterization should start with a survey of prevailing cropping system in a certain region. Species and cultivars planted, planting periods, yield obtained and expected water deficit crops might experiment along their cycle have to be registered. Weather must be characterized in terms of precipitation, air temperature, radiation, day length and potential crop water requirements distributions. A simple soil water balance can give some insight about possible water deficit problems.

In semi-arid regions of Brazil, crops might suffer some water deficit along the entire cycle and possibly a strong stress at the end. Crops grown during the rainy season (first harvest) in Central Brazil might experiment what is called “dry spells”, which are dry periods within the rainy season (Assad e Castro, 1991). The duration of dry spells varies from days to weeks (Wolf, 1975) and crops are, usually, subjected to a stress at the flowering or pre-flowering stage. For crops planted during the second harvest season (“safrinha”), water deficit normally occurs post-flowering or at the end of the cycle and can last longer.

The level of water-deficit stress a crop might experiment is a result of an interaction with environment, which varies within a season from year to year. Quantifying the stress is a difficult task due to the complexity involved in the processes. Crop growth simulation models can be used to define moment, duration, intensity and average effect of water deficit stresses on crop growth parameters and yield (Heinemann et al., 2007). In general, a preliminary trial is required to quantify the effects of a certain soil-water scarcity to some crop phenotype trait, in addition to yield. Those effects vary among species and may also vary among genotypes.

By combining information from the prevailing cropping system with results from simulations and from preliminary trials, the onset, duration and intensity of expected water-deficit stresses can be estimated for each specie and group of genotypes.

Selecting Species and Screening Genotypes for Water Stress Trials

This is done together with previous topic. Simulation models can be used to evaluate the development of species planted in various potential sites at many dates. Existing field trials results can also provide valuable information and be used to calibrate the simulation models.

In a second phase, a preliminary trial is necessary to screen genotypes by cycle length, plant height and degree of drought tolerance. Potential drought-tolerant species and group of genotype can then be submitted to a more detailed field evaluation. Grouping genotypes by cycle length is very important so that stress can be more easily applied to all them at the desirable moment.

Selecting Sites for Drought Tolerance Field Trials

Once the type, moment and level of water deficit stress were defined for certain specie and genotype group, a site has to be selected where field trials can be carried out. An ideal site would have similar environment conditions (soil physical and fertility and weather characteristics) as the region where the species are to be planted, but with no rainfall during the growing period. Rainfall is, though, the major problem during those trials and irrigation system facility is, of course, required.

At the major grain production region of Brazil there is a well defined dry period, but with low average air temperatures which makes the region unsuited for maize and sorghum drought tolerance field trials. In Northeast of Brazil, one can find sites with a warm and dry season, but with soil physical and chemical properties somehow different from those prevailing at the production region. One must make a decision and accept a trade-off between an ideal and a feasible site.

An alternative to sites located in dry and hot climate, would be to build a rain-out shelter, which allows water stress to be controlled in field trials during the rainy season. This is an expensive and difficult to manage structure, though, and may also affect crop growth due to environmental disturbance.

A Strategy to Control Water Deficit Stress at Field Level

By cutting water supply via irrigation or rainfall, does not necessarily mean that a crop will be submitted to a water deficit. All the interactions between soil-water-plant-atmosphere have to be taken into consideration. This is a dynamic process that depends on: 1- Soil-water retention capacity at the crop rooting zone; 2 - Crop ability to extract water at low potential and to stand a soil-water scarcity; 3 – Crop rooting system depth, and 4 - Prevailing weather conditions, along crop cycle.

Simulation models such as ECOTROP (Sultan et al., 2005) and DSSAT (Hoogenboom et al., 2004) or even a soil-water balance based spreadsheet for irrigation management (Albuquerque and Andrade, 2000), can be used to plan the water deficit application at right moment, duration and intensity, as previously defined.

Since the process is dynamic, updated weather information, along with some forecast of upcoming weather conditions need to be introduced into the models, so that a more realistic prediction of the water deficit can be accessed. By using such strategy the moment of cutting irrigation can be approximately defined. Similar approach can be used to establish the moment of re-initiating irrigation when needed. Some crops like sorghum, in some regions would not need re-starting irrigation due to its drought tolerance characteristic. It is not desirable that the crop undergoes a permanent wilting and dye. To guarantee that, it is necessary basically two things: 1 – To monitor some soil, plant and, or weather parameters; 2 - A correlation between those measured or estimated parameters to the level of crop damage. Without that sort of correlation it is difficult to impose the water deficit at the desirable level.

A common strategy used in field trials is to have two experiments: one with the crop fully irrigated and another with the crop subjected to stress. By observing plant symptoms, such as leaves position, curling and color, in relation to the non-stressed plants and based on previous experience, a skilled field researcher can indicate the approximate moment of cutting and returning the irrigation. This is a very subjective methodology, though, that requires a lot of practice. That type of paired experiments also allows the evaluation *a posteriori* of the level of stress the crop suffered (Figures 1 and 2).

METHODS TO QUANTIFY THE STRESS LEVEL

There are many methods that can be used to directly or indirectly quantify the water deficit stress a plant is submitted at field conditions. Direct methods are based on accessing plant water status. Scholander pump is an apparatus that can be used, although, it is a destructive method. Canopy infrared thermometry is another alternative, but with limited application due to weather conditions. A combination of plant and weather information such as Crop Water Stress Index (CWSI) has been successfully used (Jackson et al., 1982; Albuquerque and Klar, 1997; Albuquerque et al., 1998).

An indirect approach commonly used is to monitor soil-water potential or soil-water content. A gravimetric method can be used to monitor soil-water content and resistance blocks might be employed to estimate soil-water potential. A complete description of available methods to monitor soil-water status is found in Andrade et al. (2008) and Gomide et al. (2001). That kind of information can only be useful if the relationship between stress level and crop damage is known.

DIFFICULTIES EXPERIENCED DURING FIELD TRIALS

From a technical point of view, the major difficult faced was to apply previously described recommendations to guarantee that the water stress has been imposed to the crops at the right moment, duration and intensity. An attempt was made to use the irrigation management spreadsheet to forecast soil-water balance for maize and sorghum. That tool requires knowledge of genotypes cycle length, root system depth, crop coefficients and soil-water retention data, in addition to daily rainfall and evapotranspiration information. One could not find reliable information about genotypes cycle length and rooting depth, grown at that time of the season, and soil physical parameters were lab-based. By using approximate values, one could estimate the moment to cut irrigation, by considering a forecasted daily evapotranspiration. The irrigation return for maize crop was more difficult to define since there has no information regarding how much of the soil-water has to be withdrawn, so that the plants start to have some growth and yield reduction. With no reliable information about soil-water retention, genotype rooting depth and drought effects on plants, it was difficult to apply the spreadsheet.

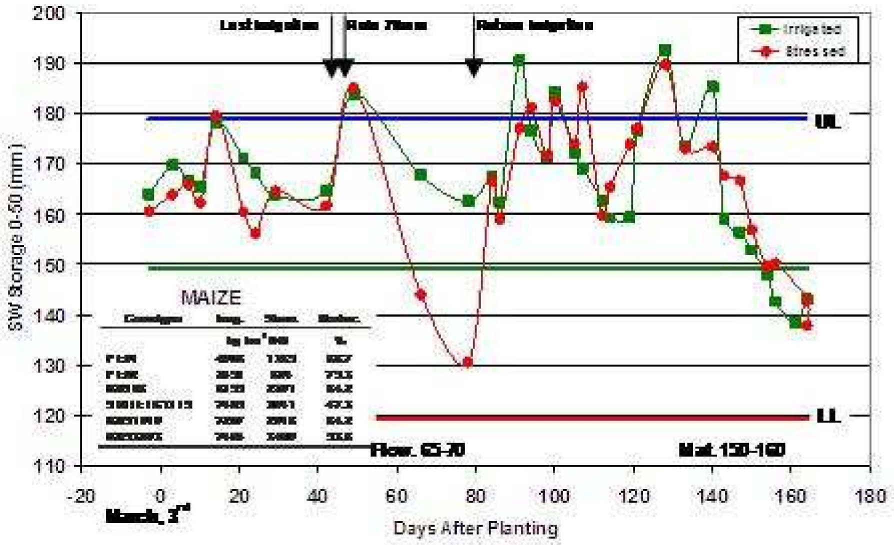

Figure 1. Soil-water storage along maize cycle fully irrigated and submitted to a water stress.

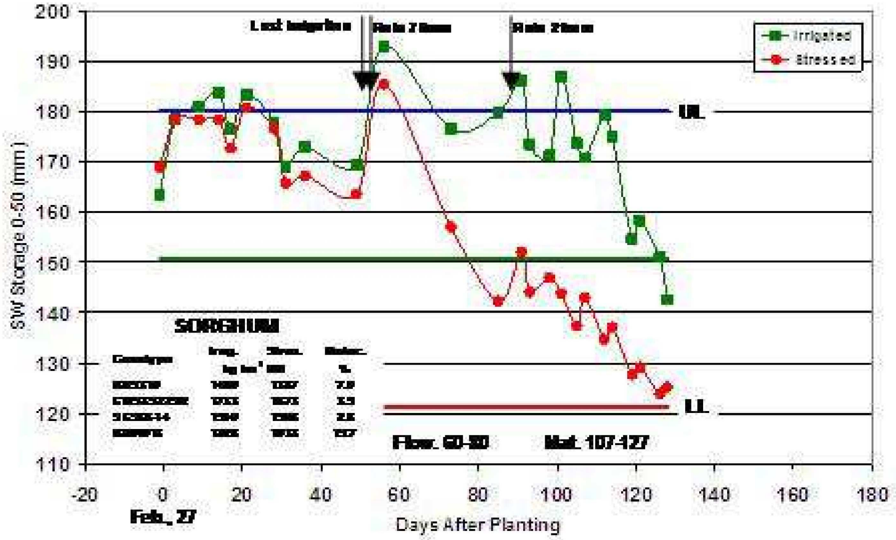

Figure 2. Soil-water storage along sorghum cycle fully irrigated and submitted to a water stress.

For maize trial planted in Sete Lagoas on March 3rd, 2007 (Figure 1), the last irrigation was applied on April 18th (43 days after planting, dap) and a 76 mm rainfall occurred on April 22nd (47 dap). One can notice that the crop started to experiment some stress at about 66 dap, when the soil water dropped to under 50% of available water, and extended to 79 dap, when irrigation re-started. This means that stress occurred later than the planned period of pre-flowering stage. The stress intensity seems to have been appropriated as grain yield reduction for the six genotypes varied from 47.3 to 75.3% when compared to fully irrigated treatment.

For sorghum (Figure 2), planted on February 27th, 2007, the last irrigation was applied on April 19th (51dap) and a 76 mm rainfall occurred on 54 dap. Sorghum crop started to suffer some stress by 100 dap. Although sorghum stress had been planned for post-flowering, it occurred too late and had its effects diminished by the 76 mm rain that fell at 54 dap. Yield reduction varied from 2.8 to 15.7% confirming that stress onset, duration and intensity was not enough to cause significant damage to the crop.

Another point that called our attention was the crop water extraction depth. It was assumed that both maize and sorghum majority of the rooting system is 50 cm deep. By analyzing Figures 3 and 4, one can verify that both maize and sorghum crops possibly extracted water deeper than that or some downward flux occurred in such a way that soil-water storage reduced in deep layers. Data from experiments to determine in-field up and low limits for soil-water availability (not shown) indicated that some significant upward water flux also occur and was not accounted for when planning for stress application.

Other difficulties that can be faced when carrying out drought tolerance field trials are the strong labor demand, associated with inappropriate equipments and instruments. Gravimetric method to monitor soil-water content is time-consuming and labor-intensive. Soil spatial variability can be a problem requiring replicated samples to be collected. After cutting the irrigation, it is normally difficult to auger the soil and soil layers can mix up. The volume of plant samples to be processed for leaf area and dry matter, for all genotypes and replications of the two experiments (stressed and irrigated) and for the two crops can be enormous, demanding lots of labor and large lab ovens. If one does not have leaf area meter, area estimation by measuring leaf samples length and width, one by one, is cumbersome and time-consuming.

CLOSING REMARKS

- A careful selection of sites for water deficit stress field trials is a key point; not only the environment has to be adequate but also the required resources (human and physical) to support such a detailed research effort;
- Preliminary experiments are necessary to gather more information needed to properly impose and control water deficit stress in field trials;
- The methodology to impose and control water deficit in field trials need to be refined; more research is needed to access the effects of different deficit stress levels (onset, duration and intensity) into crops growth and yield; plant and soil indicators of water deficit have to be better defined and correlated to crop growth and yield reduction; some sort of automated data collection is required to improve data quality and reduce labor on soil and plant sampling;
- Research on genotypes rooting system development, specially considering water deficit or multiple stresses, is crucial; lab and field methodologies need to be refined;

- Upward soil water movement following a period of drought has to be taken in consideration when imposing the deficit stress and by the simulation models.

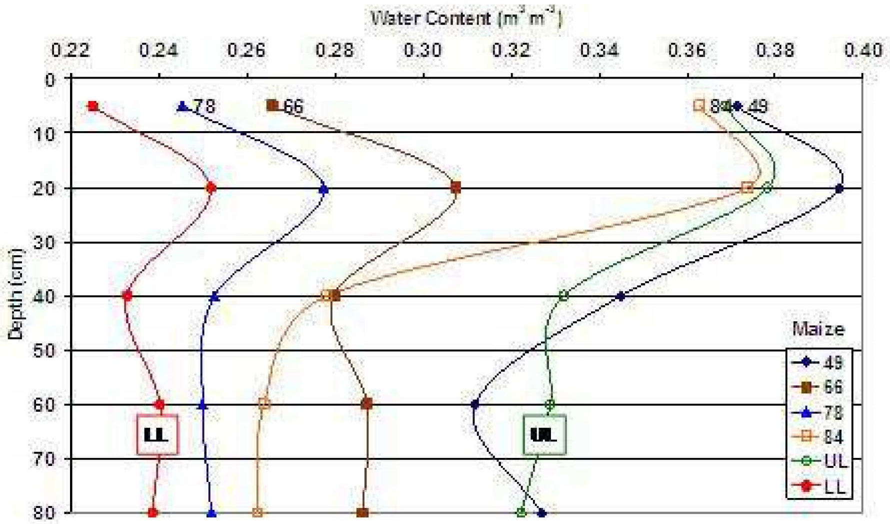

Figure 3. Field-determined upper and lower limits of available water and soil-water profiles during stress application on maize crop.

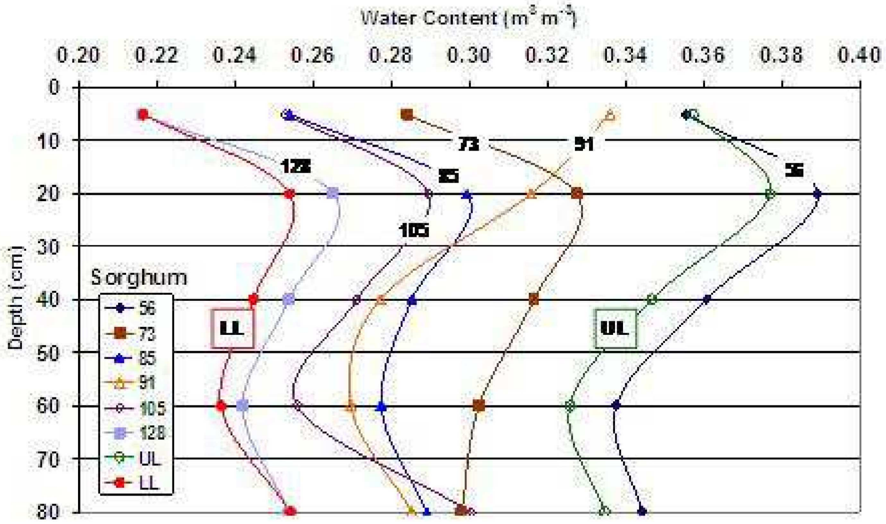

Figure 4. Field-determined upper and lower limits of available water and soil-water profiles during stress application on sorghum crop.

REFERENCES

ALBUQUERQUE, P. E. P., ANDRADE, C. L. T. **Uso de Planilha Eletrônica para a Programacão da Irrigação na Cultura do Milho**. Circular Técnica. Sete Lagoas:Embrapa, 2000.

ALBUQUERQUE, P.E.P.; GOMIDE, R.L.; KLAR, A.E. **Crop water stress index for beans obtained from temperature difference between canopy and air**. In: PEREIRA, L.S.; GOWING, J. Water and the environment: innovative issues in irrigation and drainage. INTER-REGIONAL CONFERENCE "ENVIRONMENT-WATER: INNOVATIVE ISSUES IN IRRIGATION AND DRAINAGE", 1st, 1998, Lisbon. p.189-196. 1998.

ALBUQUERQUE, P.E.P.de; KLAR, A. E. Índice de estresse hídrico da cultura (IEHC) combinado com a temperatura de estresse diário (TED) em feijoeiro (*Phaseolus vulgaris* L.) submetido a diferentes freqüências de irrigação. **Irriga**, Botucatu, v.2, n.2, p.51-67, 1997.

ANDRADE, C.L.T.; BORGES JÚNIOR, J.C.F.; COUTO, L. **Características físico–hídricas e dinâmica de água no solo**. In: ALBUQUERQUE, P.E.P.; DURÃES, F.O.M. (eds). Uso e manejo de irrigação. Brasília: Embrapa Informação Tecnológica, cap. 2, 2008. (in press)

ASSAD, E. D.; CASTRO, L. H. R. Análise freqüêncial da pluviosidade para a estação de sete lagoas, MG. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v. 26, n. 3, p. 397-402, mar. 1991.

GOMIDE, R.L.; ALBUQUERQUE, P.E.P.; KOBAYASHI, M.K.; INAMASU, R.Y. Microprocessor and Automation Techniques for Registration of Water Requirements, Stress Indexes, and Irrigation Timing Criteria of Corn and Beans Crops in the Brazilian South-East Irrigated Fields. *ASAE Annual International Meeting*, ASAE, Sacramento, California, USA, July 30-August 1, 2001. *Paper Number: 01-2049.*

HEINEMANN, A. B.; ANDRADE, C. L. T.; GOMIDE, R. L.; ALBUQUERQUE, P. E. P.; SILVA, S. C. Determinação de padrões de estresse hídrico para a cultura do milho na safra e safrinha no estado de Goiás. Congresso Brasileiro de Agrometeorologia, 15. Aracajú, 2007. **Anais…**

HOOGENBOOM, G., J.W. JONES, P.W.WILKENS, C.H.PORTER, W.D.BATCHELOR, L.A. HUNT, K.J.BOOTE, U.SINGH, O.URYASAV, W.T.BOWEN, A.J GIJSMAN, A.DU TOIT, J.W.WHITE AND G.Y. TSUJI. 2004. **Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.0 [CD-ROM]**. University of Hawaii, Honolulu, Hawaii.

JACKSON, R.D. 1982. Canopy temperature and crop water stress. *Advances in irrigation.* New York, Vol.1, pp.43-85.

WOLF, J. M. **Water constraints to corn production in central Brazil**. 1975. 199 f. Thesis (Ph.D) - Cornell University, Ithaca.