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Determination of the water balance components and drought sensitivity indices for a sorghum crop

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DETERMINATION OF THE WATER BALANCE COMPONENTS AND DROUGHT SENSITIVITY INDICES FOR A SORGHUM CROP

by

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Determination of the Water Balance Components and Drought

Sensitivity Indices for a Sorghum Crop

BY

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GRADUATE COLLEGE
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DETERMINATION OF THE WATER BALANCE COMPONENTS AND DROUGHT SENSITIVITY INDICES FOR A SORGHUM CROP

Marcelo B. Paes de Camargo, Ph.D.
University of Nebraska, 1993

Advisor: Kenneth G. Hubbard

An agrometeorological study was conducted to determine soil water balance and to test for specific drought effects in a sorghum crop at Mead, NE.

Field experiments were conducted with eight different water treatments in a randomized factorial block irrigation design during 1990 and 1991 growing seasons. Pertinent meteorological, plant, and soil variables were monitored through the season. The components of the water balance equation for the sorghum crop, especially evapotranspiration and soil water content, were calculated using a model that describes the processes of crop transpiration, soil evaporation, and the hydrological balance of the root zone. The simulated (model) and observed (neutron probe readings) soil water content in the root zone compared well for all water treatments with average d-index of agreement 0.90.

A crop specific drought index (CSDI) for sorghum was also developed. This index is based upon the daily soil water balance. The major cause of grain yield data variability was

associated with timing of water use during the season and frequency, timing, and amount of irrigation and rainfall. The relative impact of water stress during each of the three periods of growth is reflected by sensitivity coefficients (λ) where $[ET_a/ET_p]^{\lambda}$ was determined for the three stages of growth. These ratios were used to form a multiplicative model for estimating sorghum grain yield using field data in 1990 and 1991. The CSDI using λs derived from ET_a/ET_p ratios gave better results than when T_a/ET_p ratios were used. The resulting model estimates of yield were in close agreement with observed values when tested using an independent data set, and presented better performance when compared with two other models.

Examination of ET from a study involving all combinations of irrigation and nonirrigation over three growth stages appears to realistically differentiate coefficients describing sensitivity of sorghum yield to time and amount of water use. We conclude that the inclusion of CSDI-sorghum to extract the yield signal from evapotranspiration as estimated within the soil water balance model will improve monitoring of the impact of drought in relation to sorghum production.

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Finally, I dedicate this work to my family. I am eternally grateful to my wife Telma Helena and to my sons Guilherme and Daniel for their love and support of me over the years. Thank you.

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CHAPTER 1

INTRODUCTION

Agricultural productivity is greatly influenced by the uncontrollable forces of weather. For example, drought regularly diminishes crop production in the Great Plains and Midwest regions of the United States where it is a characteristic feature of the climate. In fact, these areas have been affected by six major and numerous minor drought episodes, as well as many dry spells during the past century alone (Wilhite, 1990). As a result of this recurring phenomenon, substantial crop production losses occur annually over at least a portion of the region. A crisis in food supply could occur as a result of drought in the Great Plains because of a heavy world dependence on the export of food from the United States (Robinson and Hubbard, 1990).

Sorghum yields are substantially limited by drought in most sorghum production areas of the world (Eastin et al., 1986). Recently the need to understand the plant's environmental responses to drought has been emphasized with the hope that a better understanding will improve both sorghum grain modeling and production (Krieg and Lascano, 1990).

A potential use for improved sorghum models is estimation of grain yields to determine the feasibility of expanding sorghum production into areas where observed weather and soil data are available. There are many possible applications for such a model in studies of drought impact assessment. The Palmer Drought Severity Index (PDSI, see Palmer, 1965a, 1965b) has been used to determine eligibility for emergency drought relief programs. But lack of correlation between PDSI or CMI values and actual severity of drought impacts on agricultural production make these indices inappropriate for drought impact assessment (Meyer et al., 1993). These index values cannot be directly linked to drought impact because each crop responds differently to moisture and heat stress. According to Wilhite (1987), new techniques based on specific crop responses need to be developed to enhance "drought impact assessment".

A new index, the Crop Specific Drought Index (CSDI), was developed by Meyer (1990) with the simplicity of the PDSI for estimating the impact of drought on corn production any time during the growing season, using key agrometeorological measurements. The relative sensitivity of yield to available water was determined for several corn growth periods. But according to Meyer, a more accurate determination of the relative sensitivity of corn and other crops is needed.

Grain yields and crop dry matter production are usually linked to one component of the soil water balance, evapotranspiration. However, according to Campbell and Diaz

(1988), all components in the water balance must be considered to determine the amount of water available for evapotranspiration. Direct measurement of the other components of the water balance (e.g., runoff and drainage) is not usually possible. However, modeling of water balance components, together with such measurements as can be made, presents an opportunity to study water use patterns.

In many areas of the United States and other parts of the world, irrigation water is one resource that is limited or becoming limited. As population increases, achieving optimum efficiency of irrigation water used with respect to food production will become increasingly important. According to Hill (1991), irrigation scheduling models can be used to help the producer decide when and how much to irrigate to obtain maximum crop yield or profit. In areas where pumping costs are high or drought is frequent, energy and water conservation are recognized benefits of irrigation scheduling. Drought can strike at any time during the growing season so, the determination of the relative sensitivity to the timing of drought for not only sorghum but also other crops, would be a substantial contribution toward quantifying drought impact assessment and optimizing net profit through irrigation scheduling (Meyer, 1990).

In view of the preceding, an agrometeorological study of sorghum was conducted at the University of Nebraska'sAgricultural Meteorology Laboratory near Mead,

during the summers of 1990 and 1991. The overall objective of this study was to determine the relative sensitivity of sorghum to drought by studying the relationship between sorghum, water use, and grain production. A randomized split block irrigation experiment was designed and conducted to collect data in support of the study. It was assumed that sorghum crop production depends on the natural and managed environmental conditions. The specific objectives were to:

a) estimate and verify all components of daily water balance by growth stage, for all irrigation treatments;

b) find the relative sensitivity of yield to water use in each growth stage.

The objectives are treated sequentially in the following chapters with Chapter 2 dealing with objective a) and Chapter 3 dealing with objective b). Finally, Chapter 4 contains the overall summary and conclusions from this study.

CHAPTER 2

COMPONENTS OF A DAILY WATER BALANCE FOR A SORGHUM CROP UNDER DIFFERENT IRRIGATION TREATMENTS

2.1 Introduction

In the past decade regional climate centers have been established in the United States to enhance national efforts in climate services and applied climate research. By design, these centers are located in regions that differ topographically, climatically, and economically (Hubbard, 1989). The High Plains Climate Center with headquarters at the University of Nebraska-Lincoln entered into monitoring agreements with 6 states (Colorado, Iowa, Kansas, North Dakota, South Dakota, and Wyoming). To date, the High Plains Climate Center has 93 automated weather stations in the Automated Weather Data Network (AWDN). The function of these stations is to obtain relevant data in near real-time.

In the 1980's, a study was initiated at the University of Nebraska-Lincoln to monitor soil water in the High Plains region. This region-wide study linking weather to soil water status was undertaken by the High Plains Climate Center. The soil water balance developed by Hanks (1974) was modified by Hubbard and Hanks (1983), and further modified by Sagar

(1988), and Robinson and Hubbard (1990). Currently, the High Plains Climate Center is concentrating efforts to develop and evaluate models to monitor the soil water status of major agricultural crops in the region using timely weather information.

In this study field experiments were designed to collect soil water data, sorghum crop phenology observations, and weather data to estimate and verify the components of a daily water balance under different irrigation treatments.

2.2 Material and Methods

2.2.1 Experimental Site

Field experiments were conducted during the summers of 1990 and 1991 at the University of Nebraska's Agricultural Meteorology Laboratory (41°09'N, 96°30'W, 354m above m.s.l.) located 50 km northeast of Lincoln, Nebraska. The site is in a rural region, located in relatively flat terrain (0-2% slope). The soil in the study area is a Typic Argiudoll (Sharpsburg silty, clay loam), deep, well drained soil (Garay, 1981). Field preparation included fall plowing, and discing in the spring. A postemergence herbicide was applied for early weed control. When needed, weeds were removed from the field by hand.

Grain sorghum (*Sorghum bicolor* L. Moench cv. DK-57) was planted May 22, 1990 and May 15, 1991 into a 5 ha field

(approximately 250 x 200m) under conditions of natural rainfall with a row spacing of 0.75 m in north-south oriented rows and a population density of 250,000 plants ha^{-1}. The study area and instrumentation had approximately 200 m of fetch to the south across uninterrupted sorghum. Southerly winds (135-225°) prevailed during summer. Two areas inside the main field were subdivided for use in irrigation treatments (Figure 2.1). In 1990, an area (18 x 48 m) in the northeastern part of the field was subdivided in 24 plots of 6 x 6 m. In 1991, an area (36 x 96 m) was subdivided in 24 plots of 12 x 12 m in the north central portion of the field. Agronomic practices and pest management were conducted at near optimum levels to provide a well-developed crop canopy depending only on the soil water content.

2.2.2 Experimental Design

According to Eastin (1972), sorghum growth can be divided into 3 developmental stages:

GS1: *Vegetative*, planting to panicle initiation (PI);

GS2: *Inflorescence Development*, PI to anthesis (Bloom);

GS3: *Grain Fill*, bloom to Physiological Maturity (Kernel dark layer).

The experiment incorporated a randomized split factorial block irrigation design with 8 independent water treatments. The design consisted of 3 blocks and 3 developmental stages (GS1, GS2, and GS3). Experimental units were restricted to

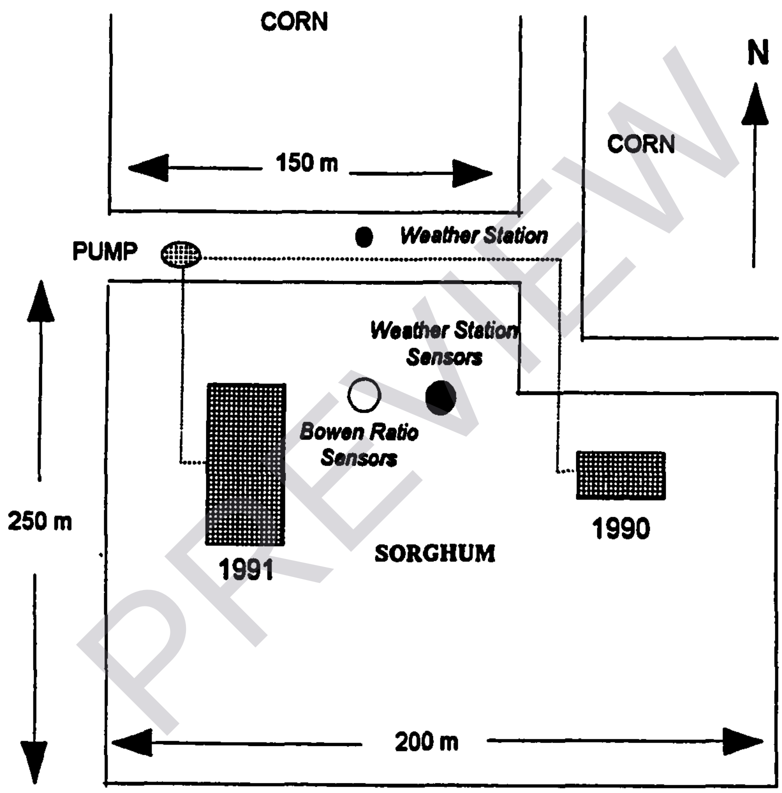

Figure 2.1 Schematic diagram of the study site at the Agricultural Meteorology Laboratory at Mead, NE