

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

U·M·I

University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

PREVIEW

Order Number 9322789

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

Camargo, Marcelo Bento Paes de, Ph.D.

The University of Nebraska - Lincoln, 1993

PREVIEW

U·M·I

300 N. Zeeb Rd.
Ann Arbor, MI 48106

PREVIEW

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

by

Marcelo Bento Paes de Camargo

A DISSERTATION

Presented to the Faculty of
The Graduate College in the University of Nebraska
In Partial Fulfillment of Requirements
For the Degree of Doctor of Philosophy

Major: Agronomy

Under the Supervision of Professor Kenneth G. Hubbard

Lincoln, Nebraska

March, 1993

DISSERTATION TITLE

Determination of the Water Balance Components and Drought

Sensitivity Indices for a Sorghum Crop

BY

Marcelo Paes de Camargo

SUPERVISORY COMMITTEE:

APPROVED

DATE

Kenneth G. Hubbard
Signature

3-11-1993

Kenneth G. Hubbard, Chair
Typed Name

Dean E. Eisenhower
Signature

3-11-1993

Dean E. Eisenhower
Typed Name

S. B. Verma
Signature

3-11-1993

Shashi B. Verma
Typed Name

Donald A. Wilhite
Signature

3-11-1993

Donald A. Wilhite
Typed Name

Signature

Typed Name

Signature

Typed Name



**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 λ s 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.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to those who helped me along this journey.

Dr. Kenneth Hubbard, my advisor, for his guidance, patience and mainly the encouragement throughout my graduate education.

Drs. Shashi Verma, Dean Eisenhower, and Donald Wilhite for serving on the supervisory committee with critical reviews.

Drs. Steve Meyer and Joon Kim for their helpful suggestions on reviewing the manuscript.

Jerry Schmidt, Karl Blauvelt, Allen Dutcher, and James Hines for their technical assistance in instrument maintenance and data processing.

My thanks also go to the other staff members in the Department of Agricultural Meteorology for their valuable assistance.

I would like to express a special gratitude to Mr. Francisco Flores-Mendoza for his encouragement and willingness to help with data collection and processing even during times of fatigue.

Profound appreciation is also extended to my particular friends Drs. Cezar Mesquita, Jose Carlos Chitollina, Marcos Lenza, and Carlos Medeiros for their unmeasurable help during the toughest moments.

I am indebted to CNPq-Brazil (Conselho Nacional de Desenvolvimento Científico e Tecnológico) for funding the study and to IAC-Brazil (Instituto Agrônomo de Campinas) for having made possible the opportunity for advanced study in the United States.

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.

PREVIEW

TABLE OF CONTENTS

	Page
ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iv
CHAPTER 1. INTRODUCTION.....	1
CHAPTER 2. COMPONENTS OF A DAILY WATER BALANCE FOR A SORGHUM CROP UNDER DIFFERENT IRRIGATION TREATMENTS.....	5
2.1 Introduction.....	5
2.2 Material and Methods.....	6
2.3 Results and Discussion.....	30
2.4 Summary.....	61
CHAPTER 3. DETERMINATION OF THE DROUGHT SENSITIVITY INDICES.....	64
3.1 Introduction.....	64
3.2 Material and Methods.....	74
3.3 Results and Discussion.....	80
3.4 Summary.....	113
CHAPTER 4. SUMMARY AND CONCLUSIONS.....	117
REFERENCES.....	122
APPENDIX.....	

List of Figures

	<u>Page</u>
Figure 2.1 Schematic diagram of the study site at the Agricultural Meteorology Laboratory at Mead, NE	8
Figure 2.2 Schematic diagram of each plot showing the location of the equipment used in 1990 and 1991	10
Figure 2.3 Field neutron probe calibration (Campbell Pacific, Model 503) in 1990 and 1991 at Mead, NE	15
Figure 2.4 Crop coefficients (Kc) by growth stage for this study and for Hinkle et al. (1984) ..	24
Figure 2.5 Soil reduction factor as a function of available water	26
Figure 2.6 Simulated and observed total soil water in the root zone (150 cm) for a sorghum crop (treatments A, B, C, and D) at Mead, NE, for the 1990 growing season	36
Figure 2.7 Simulated and observed total soil water in the root zone (150 cm) for a sorghum crop (treatments E, F, G, and H) at Mead, NE, for the 1990 growing season	37
Figure 2.8 Simulated and observed total soil water in the root zone (150 cm) for a sorghum crop (treatments A, B, C, and D) at Mead, NE, for the 1991 growing season	38
Figure 2.9 Simulated and observed total soil water in the root zone (150 cm) for a sorghum crop (treatments E, F, G, and H) at Mead, NE, for the 1991 growing season	39
Figure 2.10 Simulated and observed total soil water content in root zone (150 cm) for all treatments in 1990	42

Figure 2.11	Simulated and observed total soil water content in root zone (150 cm) for all treatments in 1991	42
Figure 2.12	Simulated and observed soil water content for five 30 cm soil layers during the 1990 growing season for treatment A	46
Figure 2.13	Simulated and observed soil water content for five 30 cm soil layers during the 1990 growing season for treatment H	47
Figure 2.14	Simulated and observed soil water content for five 30 cm soil layers during the 1991 growing season for treatment A	48
Figure 2.15	Simulated and observed soil water content for five 30 cm soil layers during the 1991 growing season for treatment H	49
Figure 2.16	Daily ET values estimated by the model and estimated by BR system for nine days in 1990	51
Figure 2.17	Energy balance components for the sorghum crop on a clear day in 1990 (DOY 230)	53
Figure 2.18	Diurnal patterns of Bowen ratio on DOY 230 (1990)	54
Figure 2.19	Components of seasonal water use for treatments A and H in 1990	58
Figure 2.20	Components of seasonal water use for treatments A and H in 1991	59
Figure 3.1	Accumulated rainfall during growing season of 1990 and 1991 compared with normal rainfall at Mead, NE	81
Figure 3.2	Average sorghum grain yield for the different treatments in 1990 and 1991	84
Figure 3.3	Sorghum crop height as a function of days after emergence for treatments A and H in 1990 and 1991	87
Figure 3.4	Sorghum crop LAI as a function of days after emergence for treatments A and H in 1990 and 1991. Logistic curves were fitted to the measured data	88

Figure 3.5	Sorghum grain yield as related to seasonal transpiration and ET at Mead, NE, in 1990 and 1991	91
Figure 3.6	Actual vs. predicted Y/Yp using Tanner and Sinclair (1983) model for 1990 and 1991 data	95
Figure 3.7	Relationship between yield and ET/ETp ratios by growth stages for a grain sorghum crop in 1990 and 1991	97
Figure 3.8	Predicted vs. actual CSDI for the derivation year (1990) and the validation year (1991) using ETa/ETp relations	103
Figure 3.9	Predicted vs. actual CSDI for the derivation year (1991) and the validation year (1990) using ETa/ETp relations	104
Figure 3.10	Predicted vs. actual CSDI both 1990 and 1991. In this case both years were used to form the predicted equation	105
Figure 3.11	Predicted vs. actual CSDI for Sandhills area, Central NE. Actual CSDI taken from Garrity, 1980	107
Figure 3.12	Actual and predicted Y/Yp ratios for sorghum CSDI, Doorenbos and Kassan (1979), and Tanner and Sinclair (1983) models for eight treatments in 1990 and 1991	111

List of Tables

	<u>Page</u>
Table 2.1 Technical specifications for irrigation in 1990 and 1991	12
Table 2.2 Growing degree days (GDDs) adapted from Vanderlip (1979) used to determine sorghum growth stages, and crop coefficients (Kc) adapted from Hinkle et al. (1984) and Robinson (1988)	19
Table 2.3 Input soil characteristics for a sorghum crop model at Mead, NE in 1990 and 1991	28
Table 2.4 Irrigation applied per treatment (mm) and statistics for each day of application during 1990	31
Table 2.5 Irrigation applied per treatment (mm) and statistics for each day of application during 1991	32
Table 2.6 Irrigation duration and statistics for each irrigation application during 1990 and 1991	34
Table 2.7 Statistics on soil water balance model performance, by treatments, during 1990	41
Table 2.8 Statistics on soil water balance model performance, by treatments, during 1991	41
Table 2.9 Statistics on soil water balance model performance, by layer. Data is for five 30 cm soil layers for the treatment A during 1990	44
Table 2.10 Statistics on soil water balance model performance, by layer. Data is for five 30 cm soil layers for the treatment H during 1990	44
Table 2.11 Statistics on soil water balance model performance, by layer. Data is for five 30 cm soil layers for the treatment A during 1991	45
Table 2.12 Statistics on soil water balance model performance, by layer. Data is for five 30 cm soil layers for the treatment H during 1991	45

Table 2.13	Total water balance values, in mm, for the 3 growth stages, according the components Precipitation (P), Irrigation (I), Transpiration (T), Evaporation (E), Runoff (R), and Drainage (D) in 1990	56
Table 2.14	Total water balance values, in mm, for the 3 growth stages, according the components Precipitation (P), Irrigation (I), Transpiration (T), Evaporation (E), Runoff (R), and Drainage (D) in 1991	57
Table 3.1	Number of heads and statistical data for sorghum grain yield for different irrigation treatments in 1990 and 1991	83
Table 3.2	Maximum crop height and leaf area index (LAI) values in 1990 and 1991 for the grain sorghum crop treatments	86
Table 3.3	Water use (ET), grain yield, and water use efficiency (WUE), and values for K calculated for sorghum crop under eight water treatments in 1990 and 1991	93
Table 3.4	Ratios of ET_a/ET_p , T_a/ET_p , and Actual CSDI for all treatments in 1990 and 1991	99
Table 3.5	Sensitivity coefficients determined using Multiple Regression and Matrix Algebra	100
Table 3.6	Range of ET_a/ET_p ratios during GS1, GS2, and GS3 for Mead (1990 and 1991) and Sandhills (1977 and 1978)	108
Table 3.7	Sensitivity coefficients from previous research compared with CSDI-Sorghum	109
Table 3.8	Actual and predicted Y/Y_p ratios for sorghum-CSDI and for FAO (Doorenbos and Kassan, 1979) and Tanner and Sinclair (1983) models, for 8 treatments in 1990 and 1991 ...	112

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's Agricultural 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

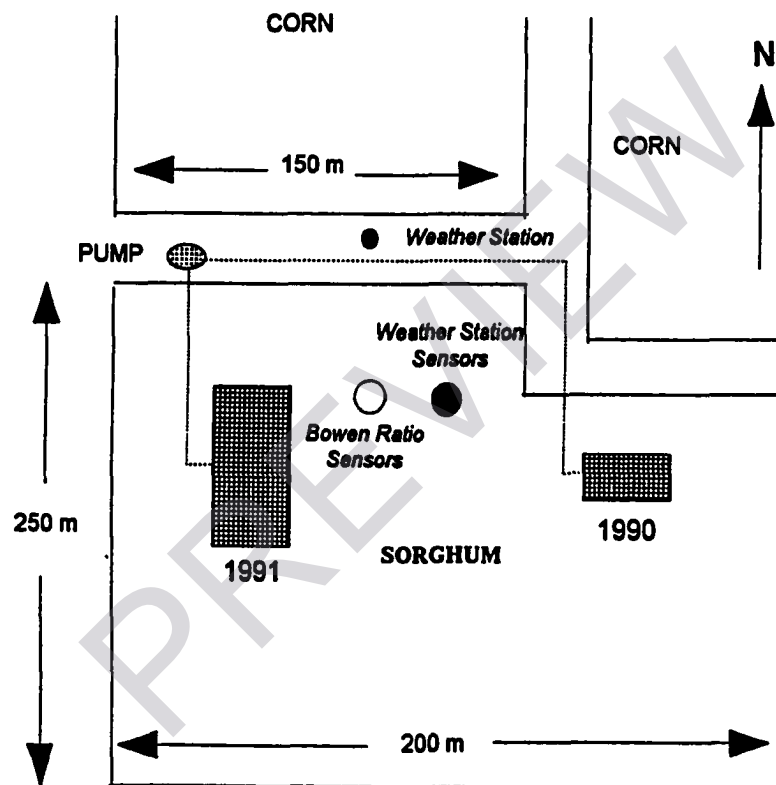


Figure 2.1

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