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E82-10213

AgRISTARS

EW-U-1-04208
JSC-17797

NASA-TM-84740

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

Early Warning and Crop Condition Assessment

November 1981

A METEOROLOGICALLY DRIVEN GRAIN SORGHUM STRESS INDICATOR MODEL

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(E82-10218) A METEOROLOGICALLY DRIVEN GRAIN SORGHUM STRESS INDICATOR MODEL (NASA) 18 p HC A02/MF A01 CSCL 02C N82-23591
Unclas
G3/43 00218

Early Warning and Crop Condition Assessment
1050 Bay Area Blvd.
Houston, Texas 77058

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TECHNICAL MEMORANDUM

A METEOROLOGICALLY DRIVEN GRAIN SORGHUM STRESS INDICATOR MODEL

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Houston, Texas
November 1981

1. Report No. EW-U1-04208 JSC-17797	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A Meteorologically Driven Grain Sorghum Stress Indicator Model		5. Report Date November 1981
		6. Performing Organization Code
7. Author(s) T.W. Taylor - USDA/ARS F.W. Ravet - NASA		8. Performing Organization Report No.
9. Performing Organization Name and Address Agricultural Research Service Early Warning and Crop Condition Assessment Research Unit 1050 Bay Area Blvd. Houston, TX 77058		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address AgRISTARS Program at Johnson Space Center Houston, TX 77058		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A grain sorghum soil moisture and temperature stress model described herein was developed to serve as a meteorological data filter to alert commodity analysts to potential stress conditions and crop phenology in selected grain sorghum production areas. The model also identifies optimum conditions on a daily basis and planting/harvest problems associated with poor tractability.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Sorghum Stress Phenology Soil Water Budget Model	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
unclassified	unclassified		

*For sale by the National Technical Information Service, Springfield, Virginia 22161

JSC Form 1424 (Rev Nov 75) NASA — JSC

UNITED STATES DEPARTMENT OF AGRICULTURE

AGRISTARS-EARLY WARNING/CROP CONDITION ASSESSMENT

A METEOROLOGICALLY DRIVEN GRAIN SORGHUM STRESS INDICATOR MODEL

FIRST ISSUE

1. REASON FOR ISSUANCE

Document the development of a model capable of giving an early indication of actual or potential plant stress due to moisture and temperature.

2. COVERAGE

The moisture/temperature values which both stress and optimize the vigor of grain sorghum by specific growth stages are reviewed. A description of the model structure and stress parameters are set forth. Model output and preliminary results are discussed.

3. PREPARED BY

Terry W. Taylor — Date: 10/2/81

F.W. Ravet — Date: Oct 2, 1981

METEOROGICALLY DRIVEN GRAIN SORGHUM STRESS INDICATOR MODEL

PART 1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this section is to document a grain sorghum hazard model that detects plant stress due to moisture deficiency and adverse temperatures. A brief synopsis of the climatic stress thresholds for sorghum (Sorghum bicolor (L.) Moench) at different growth stages is also given.

1.2 SITUATION

USDA policy is to provide American farmers and commodity analysts with the most timely information concerning world and national agricultural activities. Early Warning/Crop Condition Assessment, located in Houston, Texas is one of eight projects of the AgRISTARS program. AgRISTARS is the program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing and is a cooperative effort of 5 Federal agencies. These agencies are: Department of Agriculture (USDA); National Aeronautics and Space Administration (NASA); Department of the Interior (USDI); and the Agency of International Development (USAID).

Early warning of changes affecting production and quality of commodities and renewable resources is the number one priority area of the Secretary's Initiatives. The overall objective of the EW/CCA Project is to provide a capability for the USDA to respond in a timely manner to factors which affect the quality and production of economically important crops. The response will involve identifying the occurrence of environmental and agronomic factors which influence crop condition and determine the severity of the area affected. This research activity will be directed toward tecniques which will augment and strengthen the operational Crop Condition Assessment Division (CCAD) of the Foreign Agricultural Serivce (FAS) and provide new analysis tools to domestic users in USDA.

The CCAD operations plan calls for assessment based on a convergence of evidence from all sources. In 1981, this consists of the traditional sources plus increased use of agrometeorological models that can be used to infer crop conditions and initial subjective operational use of remote sensing techniques.

A sorghum stress indicator model was developed to alert a crop analyst of a potential problem area. The model utilizes meteorological data because it is generally available much sooner than Landsat data, and provides daily data versus the eighteen day interval data from Landsat. This model eliminates the necessity of spending time and resources to concentrate on areas which the model indicates have high probability that stress is occurring or is likely to occur. After a potential stress area has been identified, an analyst can assess the condition using meteorological, Landsat, and ancillary data. This model is not intended as a stand-alone system, but rather, an indicator (data filter) to a crop analyst to initiate an investigation of the area.

The CCAD mission of alert analysis requires a quick response system and will sacrifice exact quantative results to meet their response requirement. A subjective estimate, if timely, which provides information in general terms such as better or worse than last year and an approximate percentage is very useful in assessing an alert situation. As research provides better tools, it is believed that these subjective estimates will iteratively move toward the ground truth.

PART 2.0 STRESS FUNCTIONS

2.1 MAJOR VARIABLES

The degree of stress is dependent on three variables - phenological growth stage, available soil moisture and temperature.

2.2 The growth stages of sorghum have been defined by Vanderlip and Reeves (1972) as:

STAGE NUMBER	PHENOLOGICAL STATE
0.0	Emergence
1.0	Collar of 3rd leaf visible
2.0	Collar of 5th leaf visible
3.0	Growing point differentiation
4.0	Final leaf visible
5.0	Boot
6.0	Half bloom
7.0	Soft dough
8.0	Hard dough
9.0	Physiological Maturity

The hazard model modifies this classification to include the time from planting to emergence and groups the stages into periods having similar thresholds for stress. These periods are:

Period	Phenological State
0.0-1.0	Planting-emergence
1.0-2.0	Emergence-Leaf 7
2.0-3.0	Leaf 8-Boot
3.0-4.0	Boot-Soft Dough. Half-bloom occurs at Period 3.4
4.0-5.0	Soft dough-hard dough
5.0-6.0	Hard dough-Physiological maturity

During each stage optimum and stress conditions exist (Pasternak and Wilson, 1969). Most of these conditions are directly related to meteorological factors. Stress was defined in this model version as those factors considered to significantly affect sorghum development and yield and for which input data are presently available. Problem and optimal conditions that form the model logic are presented by growth stage in Table 1.

TABLE 1

PERIOD	HAZARD CONDITION		OPTIMUM CONDITION	
0.0 - 1.0	$\frac{\text{MAX TEMP + MIN TEMP}}{2}$ Surface Moisture	$< 10^{\circ}C$ $< 18\%$	$\frac{\text{MAX TEMP + MIN TEMP}}{2}$ Surface moisture	$> 18^{\circ}C$ $> 35\%$ $< 80\%$
1.0 - 2.0	Max Temp Min Temp Profile Available Water-holding capacity (AWC)	$> 38^{\circ}$ $< -1^{\circ}$ $> 25^{\circ}$ $< 25\%$ $> 95\%$	Max Temp Profile AWC	$< 36^{\circ}$ 40% - 80%
2.0 - 3.0	Max Temp Min Temp Subsurface AWC	$> 38^{\circ}$ $< 3^{\circ}$ $> 24^{\circ}$ $< 35\%$ $> 95\%$	Max Temp Subsurface AWC	$< 35^{\circ}$ 40% - 80%
3.0 - 4.0	Max Temp Min Temp Subsurface AWC	$> 36^{\circ}$ $< 4^{\circ}$ $> 23^{\circ}$ $< 40\%$ $> 95\%$	Max Temp Subsurface AWC	$< 33^{\circ}$ 50% - 80%
4.0 - 5.0	Max Temp Min Temp Subsurface AWC	$> 40^{\circ}$ $< 2^{\circ}$ $> 24^{\circ}$ $< 35\%$ $> 95\%$	Max Temp Subsurface AWC	$< 37^{\circ}$ 40% - 80%
5.0 - 6.0	Min Temp Subsurface AWC	$< 0^{\circ}$ $< 10\%$ $> 95\%$	Subsurface AWC	25% - 75%

2.3 STRESS CONDITIONS BY GROWTH PERIOD

A. Period 0.0-1.0. Planting requires at least 18% available water in the surface layer with 65% being optimum. Sorghum germination is affected by both moisture and temperature. Mean daily temperatures of less than 10°C will inhibit germination. Optimum conditions occur with daily mean temperatures greater than the 18C and surface layer available water capacities (AWC)[2] in the 30-80% range. Alerts are also issued at this stage for insufficient pre-season stored moisture. The bulk of sorghum is produced by dryland farming and normal precipitation is often insufficient. The amount of necessary stored soil moisture is location dependent. Tractability problems occur at plant and harvest when more than 5mm of precipitation falls on a given day or when soil moisture values exceed 80% AWC.

B. Period 1.0-2.0. During the period from emergence until the collar of the seventh leaf is visible damaging conditions occur when temperatures drop below -1°, fail to drop below 25° or rise above 38C. The minimum moisture requirement is 25% AWC, with values above 95% capacity also deterimental to sustained photosynthesis. Optimal conditions range below 35° with 40-80% AWC in the entire profile.

C. Period 2.0-3.0. During the leaf 8 - boot interval, stress temperature thresholds occur above 38° (day), 24° (night) or below 3° (night). Subsurface AWC's indicate stress below 35% or above 95%, optimal conditions are flagged with temperatures below 35° with soil moisture in the 40-80% range.

D. Period 3.0-4.0 From boot to soft dough, the plant is stressed by AWC values less than 40% or greater than 95%. Cold tolerance continues to decrease with temperatures less than 4°C greater than 23° (night) or greater than 36° (day) being harmful. Optimum conditions are defined as being between 50-80% AWC (subsurface) and less than 33° (day).

[2] Available-water-holding-capacity (AWC) can be defined in laymans terms as the amount of water that a soil will hold that is available to the plant. The technical definition states the AWC as the difference between the upper and lower limits of the moist soil-water state or the difference between the field capacity and the permanent wilting percentage and is usually expressed on a volume basis when the bulk density is known. The concept of AWC can apply to a horizon, layer or pedon. This can be expressed in terms of centimeters of water per specified depth of soil, as the two horizontal dimensions of the water and soil volumes are the same. Thus, the units of AWC applied to characterize polypedons, or soil series are commonly expressed as centimeters (or inches) of available water per unit thickness (cm or inches) of soil, by horizon, or to the depth of rooting.

F. Period 4.0-5.0. Stress values are relaxed somewhat after the pollination period. Adverse temperatures in the dough period are those below 2° greater than 24° (night) and greater than 40°C (day). Moisture requirements range from 40-95% AWC. Temperatures below 37°C with 40-80% AWC are optimal.

G. Period 5.0-6.0. The dry-down from hard dough to physiological maturity is the final period checked in the model. The plant is very hardy and environmental impact on final yield is reduced. Stress conditions occur below 0° with AWC values less than 10% or greater than 95% signaling alerts. Optimal situations are expanded to 25-75% AWC. Freezing temperatures are most damaging to yield. Tractability alerts are generated from growth stage 5.5 to maturity.

PART 3.0 SORGHUM STRESS INDICATOR MODEL

3.1 STRESS MODEL COMPONENTS

The stress model has 3 central components - a hazard model, a crop calendar model and a soil water budget model. These models collectively require daily meteorological data - maximum and minimum temperature and precipitation. The phenology-based hazard routine contains the stress definitions and thresholds. The crop calendar is a fixed-increment degree-day model developed by EW/CCA that requires an actual or estimated planting date. Degree-day summations are location specific. A two-layer soil moisture model as implemented by Ravet and Hickman (1979) is employed to track the amount of plant-available soil water (Appendix 1).

3.2 PHENOLOGY AND DEGREE-DAY CALCULATION

Sorghum phenology is responsive to temperature, photoperiod and stress. The latter 2 components must be included in a "clock" (program subroutine) designed for universal (location-independent) application. However, for the purposes of this model and the location-specific applications, the use of a simple thermal accumulator is apparently sufficient. The most common accumulator is the degree-day (DD). Degree-days (celsius) are calculated as:

$$DD = \left(\frac{\text{Max Temp} + \text{Min Temp}}{2} \right) - 7^{\circ}C$$

The model has been initially programmed to track two areas: the Texas-Oklahoma Panhandle - Kansas region of the United States and the Eastern Cordoba-northwestern Buenas Aires region of Argentina. The DD values of the most common American and Argentine (in parenthesis) hybrids are: 70(70) to emergence, 500 (460) to leaf 7,1050 (935) to Boot, 1510 (1325) to soft dough, 1785 (1565) to hard dough and 1945 (1770) to physiological maturity.

3.3 MODEL PARAMETERS AND OUTPUTS

The model identifies three environmental conditions - optimum, adequate and hazardous. Hazardous conditions include:

(a) Insufficient pre-season stored soil moisture
(b) Planting/harvest delay (tractability problems)
(c) Poor germination
(d) Poor emergence
(e) Adverse growing season soil moisture and temperature (excessive/deficient, phenology-based)
(f) Optimal soil moisture and temperature conditions

The stress indicator model determines the possibility of sorghum stress based on temperature and moisture conditions (see Table 1). The stress and optimal growth conditions are recorded for each growth stage as well as the time the plant remained in these stages. From this information the analyst can judge the degree of damage or stress occurring at a growth stage and then determine the overall effect on crop development. The model does not predict events nor does it attempt to assess the impact of stress; it provides information that indicates conditions occurring within a predescribed geographic area around the data source. The thresholds for temperature and moisture stress are by design "soft", i.e. initial alerts signal mild stress. This is done to give area analysts sufficient time to collect ancillary data. The output from the model is a record of each day that a stress or optimal condition has occured, the reason for the condition and the crop growth stage. At the completion of processing data for a given meteorological station, the data are summarized giving the total days for development, and the number of optimum and hazardous growth days by growth period.

PART 4.0 CONCLUSIONS

4.1 SUMMARY

A grain sorghum soil moisture and temperature stress model was developed by the Early Warning and Crop Condition Assessment component of AgRISTARS to support the Crop Condition Assessment Division of the Foreign Agriculture Service. The model is essentially a data filter that alerts a commodity analyst to sorghum producing areas that are under a potential stress condition due to adverse meteorological conditions. The model also identifies areas of optimum climatic conditions and planting/harvest problems associated with poor tractability. The model has been developed andtested over 71 station/years in the United States and Argentina under a wide range of climatic conditions with favorable results.

To assess the impact of alerts generated by the model requires the analytical skills of a commodity analyst well versed in agronomy and remote sensing. Future improvements in the model are expected to focus on phenology and spectral inputs.

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APPENDIX I

TWO-LAYER SOIL MOISTURE MODEL

The two-layer soil moisture model in use by CCAD and EW/CCA is similar to the Palmer two-layer model (Palmer, 1965). In the models, the amount of water withdrawn by both direct evaporation from the soil surface and transpiration by plants is determined by atmospheric demand and soil water availability.

Both models assumed that the first inch of available water is held in the layer. The actual thickness of each layer is variable depending on soil type, rooting depth and layers permeability.

The original Palmer model assumed that moisture was removed from the surface layer at a rate equal to potential evapotranspiration calculated by the Thornthwaite method (1948) and that moisture was removed from the lower layer at a fraction of the potential rate. It was assumed tht moisture could not be removed from the lower layer until the surface layer was completely dry. These assumptions do not adequately represent the true layer condition.

The various stress indicator models being developed (Ravet and Hickman, 1979) required more accurate representation of the soil moisture condition, particularly in the surface layer. The two-layer model was modified to allow a more gradual and realistic depletion of the surface layer and also allows moisture to be depleted from the lower layer before the surface is completely dry.

A moisture extraction function was developed to allow depletion from the surface at the potential rate to 75 percent of surface capacity. Below 75 percent, moisture is extracted from the surface at a reduced rate with the lower layer making up the remaining requirement. Moisture is extracted from the lower layer at a fraction of potential. This fraction is calculated as a ratio of actual·water held to that field capacity.

Precipitation enters the model by first completely filling the surface layer and then the lower layer. When the capacity of both layers is reached, excess precipitation is treated as runoff and is lost from the model. The following formulation describes the model:

SOIL MOISTURE EQUATION

Top Layer = Contains 1 inch of plant available water.

Lower Layer = Normally contains between 5 and 10 inches of available water.

L_s = S'_s - (PET-P) D_f

L_u = (PET-P-L_s) $\frac{S'u}{AWC}$: $L_u \leq S'_u$

D_f = Surface moisture extraction function.

D_f = 1 if P PET

D_f = (S'^s ÷ .75) : $.1 \leq D_f \leq 1.$

D_f = .1 if D_f < .1 and D_f = 1. : D_f > 1.

R = Excess P after both layers are filled.

PET = PET'(d) [Thornthwaite, 48]

If T less than 0^o
PET' = 0

If $0^oC < T < 26^oC$
PET' = 1.6 $(\overline{10T/I})^a$

If $T > 26^oC$
PET' = Sin (T - 9.5) -.76

a = $6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + .01792I + .49239$

I = $\sum_{i=1}^{12} (T/5)^{1.514}$

d = -0.767 tan(.410117Cos(.0172264(JDAY-172)))

DEFINITION OF TERMS

L_s	=	Moisture loss form surface
S'_s	=	Available water in surface layer at start
PET	=	Potential evapotranspiration
P	=	Daily precipitation
L_u	=	Loss from lower layer
S'_u	=	Available moisture stored in lower layer
AWC	=	Combined available water capacity; i.e., MAX(S'_s + S'_u)
R	=	Runoff
D_f	=	Surface moisture extraction function
PET`	=	Unadjusted potential evapotranspiration
d	=	Day length adjustment for PET
T	=	Average daily temp degree C
I	=	Annual heat index
JDAY	=	Julian date
a	=	Coefficient

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