An evaluation of plant drought stress parameters in spring wheat
by Katim Seringe Touray

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

Abstract:
Five spring wheat (Triticum aestivum L.) accessions were planted in the Sumner of 1986 near Manhattan, Montana, to assess the relations between various plant drought stress parameters using a line-source sprinkler irrigation system (Hanks et. al., 1976).

Soil moisture content, and soil moisture depletion, were measured and, from these parameters and precipitation measurements, evapotranspiration was computed. In addition, leaf water potential, leaf relative water content, stomatal mass flow resistance, crop canopy temperature, and canopy-air temperature difference were measured.

Results from the analyses of variance did not show significant accession differences in soil moisture content or in their relative water content, canopy temperature, canopy-air temperature difference and stomatal mass flow resistance. However, significant accession differences were found in soil moisture depletion, evapotranspiration, and leaf water potential.

Regression analysis gave good correlations ($R^2 = 0.99$) between canopy-air temperature difference and canopy temperature. Also, canopy temperature was found to be a linear function of stomatal mass flow resistance.

The results obtained suggest that the use of canopy temperature and canopy-air temperature difference as plant drought stress indicators is justifiable in some instances. However, there were indications that caution is warranted in the use of these parameters, especially as a means of screening crops for drought tolerance.

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APPROVAL

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

8/21/87 Date

Hayden Ferguson
Chairperson, Graduate Committee

Approved for the Major Department

8/21/87 Date

Dwane G Miller
Head, Major Department

Approved for the College of Graduate Studies

8-21-87 Date

M Malone
Graduate Dean

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Abbreviation or Symbol	Meaning
B	A composite constant
C_p	Volumetric heat capacity of air
C_s	Stomatal conductance (cm/sec)
CWSI	Crop Water Stress Index (dimensionless)
D	Soil moisture depletion (cm)
E	Transpiration (mm)
E_t	Evapotranspiration (mm)
f(u)	A function of wind speed, u
G	Soil heat flux (W m^{-2} sec^{-1})
I	Irrigation (mm)
IR	Infrared
LAI	Leaf Area Index (dimensionless)
LWP	Leaf Water Potential (MPa)
P	Precipitation (mm)
r_a	Boundary layer resistance (sec/cm)
r_c	Leaf cuticular diffusive resistance (sec/cm)
r_i	Leaf intercellular space diffusive resistance (sec/cm)
r_L	Leaf internal diffusive resistance (sec/cm)
r_{mf} (SMFR)	Stomatal mass flow resistance (sec/cm)
r_s	Stomatal diffusive resistance (sec/cm)

Abbreviation or Symbol	Meaning
r_w	Cell wall diffusive resistance in the leaf (sec/cm)
R	Radiation emitted from the crop canopy (W m^{-2} sec^{-1})
R_e	Rainfall (excluding run-off) (mm)
R_n	Net solar radiation (W m^{-2} sec^{-1})
R_p	Resistance to water flow from the roots to the evaporating surface in the leaves
R_{rs}	Mean resistance to water flow within the roots
RWC	Relative Water Content (%)
SDD	Stress Degree Day (°C)
SMC	Soil Moisture Content (cm)
SPD	Saturation Pressure Deficit (MPa)
T_a	Air temperature (°C)
T_c	Canopy temperature (°C)
T_c-T_a	Canopy-air temperature difference (°C)
u	Wind speed (m sec^{-1})
W_d	Drainage from the root zone (mm)
ψ_L	Mean leaf water potential (MPa)
ψ_m	Matrix potential (MPa)
ψ_p	Pressure potential (MPa)
ψ_{plant}	Whole-plant water potential (MPa)
ψ_s	Solute (osmotic) potential (MPa)
ψ_{soil}	Mean Soil Water potential (MPa)

Abbreviation or Symbol	Meaning
ϵ	Emissivity of crop canopy (dimensionless)
σ	Stefan-Boltzmann constant (5.674×10^{-8} W m^{-2} K^{-4})

ABSTRACT

Five spring wheat (Triticum aestivum L.) accessions were planted in the Summer of 1986 near Manhattan, Montana, to assess the relations between various plant drought stress parameters using a line-source sprinkler irrigation system (Hanks et. al., 1976).

Soil moisture content, and soil moisture depletion, were measured and, from these parameters and precipitation measurements, evapotranspiration was computed. In addition, leaf water potential, leaf relative water content, stomatal mass flow resistance, crop canopy temperature, and canopy-air temperature difference were measured.

Results from the analyses of variance did not show significant accession differences in soil moisture content or in their relative water content, canopy temperature, canopy-air temperature difference and stomatal mass flow resistance. However, significant accession differences were found in soil moisture depletion, evapotranspiration, and leaf water potential.

Regression analysis gave good correlations ($R^2 = 0.99$) between canopy-air temperature difference and canopy temperature. Also, canopy temperature was found to be a linear function of stomatal mass flow resistance.

The results obtained suggest that the use of canopy temperature and canopy-air temperature difference as plant drought stress indicators is justifiable in some instances. However, there were indications that caution is warranted in the use of these parameters, especially as a means of screening crops for drought tolerance.

INTRODUCTION

Water is a major component of all plants and, is essential for the production of crops. Unfortunately, the importance of water is seldom matched by its availability for agriculture.

As a consequence, modern agriculture has come to rely significantly on the judicious use of limited water resources. In this connection, the quest for efficient means of harnessing, conveying, and applying irrigation water has received considerable time and effort in the last few decades. In areas where irrigation is not common, the maximization of the crop production from available precipitation has been of paramount importance.

Increased efficiency in water use for crop production is beneficial in reducing the amounts of water that would otherwise have been wasted. It is also beneficial in reducing the hazards to the environment posed by the increased use of fertilizers under irrigated agriculture has posed. Contaminated ground water, increased salinity, and toxicity levels in soils are all testimonies to the problems attendant to the inefficient use of irrigation water.

For these reasons, various methods and techniques have been devised to aid in the achievement of better irrigation management practices. The various methods have aimed, with varying degrees of success and acceptance, at finding convenient and economic means of detecting crop water stress, estimating crop water requirements, and achieving efficient irrigation scheduling. Most of the methods developed for estimation of evapotranspiration, and hence the prediction of crop water requirements, are not very suitable for use by an individual farmer. This is because of the scale (in both time and space) and instrumentation factors entailed in the use of these techniques.

Therefore, there has been an increased effort recently to develop methods of crop water stress detection that are fast, economical, and reliable enough to assure that crops would neither be unduly stressed nor would irrigation water requirements be overestimated. For these reasons, crop water parameters that are easily measurable and correlate well with more difficult to measure but reliable water stress indicators, have been used.

Two such parameters, crop canopy temperature and its' difference from air temperature have received enthusiastic support from some researchers. These parameters have been studied in conjunction with other crop water stress parameters such as leaf water potential, leaf relative water content, stomatatal mass flow resistance, and soil moisture depletion.

This study aimed to investigate the relation between these drought parameters in five varieties of spring wheat under four levels of irrigation. Also, the study aimed to assess the efficacy of the use of these parameters in the detection of crop water stress and, explore the potential use of these parameters for irrigation scheduling.

LITERATURE REVIEW

Moisture uptake and use by plants is determined by a wide variety of factors. The factors governing evaporative flux from crops can be grouped into three classes (Reggie, 1971):

a) soil factors;

b) micrometeorological factors;

c) plant factors.

These factors consequently influence various aspects of soil water management, including irrigation scheduling.

Various methods for scheduling irrigation have been proposed, and they can be grouped into three broad classes (Jackson, 1982):

a) soil based;

b) meteorologically based;

c) plant based.

Quite commonly, combinations of the three are used for irrigation scheduling.

Soil based irrigation scheduling techniques rely on the measurement or monitoring of soil moisture content (Gear et al., 1977). The information thus obtained is used with a pre-defined refill point (the point at which irrigation should occur) and a full point to schedule irrigations. The full point is defined as the total soil water holding capacity of a specified depth expressed as depth of water per unit depth of soil after initial drainage has removed some of the water.

Meteorological methods of irrigation scheduling (e.g. Pierce, 1960; Jensen and Haise, 1963) make use of meteorological factors such as air temperature, net radiation, relative humidity and windspeed as inputs in models used for the calculation of evapotranspiration in a given time.

Plant-based methods of scheduling irrigation rely on the evaluation of plant drought stress parameters, e.g. leaf water potential (Scholander et al., 1965), leaf or canopy temperatures (Stone and Horton, 1974), or leaf diffusive resistance (Kanemasu and Tanner, 1969). These techniques are particularly attractive because they provide a diagnostic tool for detecting impending or actual plant water stress from the plant itself. This obviates the need for gathering precise information on available soil moisture content, root distribution and atmospheric evaporative demand (Pinter, Jr., and Reginato, 1982). However, the problem encountered in using plant parameters for scheduling irrigations is that it is a time-consuming method, requiring numerous measurements for the characterization of a field (Jackson, 1982).

The foregoing discussion indicates the complex nature of the interactions between the various factors involved in soil water management for efficient plant production. These factors viz: soil moisture content, evapotranspiration, and plant drought stress parameters have received the attention of researchers during the past couple of decades.

Soil Water Content

Soil water has both direct and indirect influences on plant growth. Soil water directly affects plant growth through its effect on plant water status. For example, soil water potential influences leaf water potential (Campbell and Campbell, 1982) in a manner given by the relationship:

$$\psi_L = \psi_{soil} - E\ (R_{rs} + R_p) \qquad (1)$$

where:

ψ_L = mean leaf water potential;

ψ_{soil} = mean soil water potential;

E = transpiration;

R_{rs} = mean resistance to water flow in the roots;

R_p = resistance to water flow from the roots to the evaporation surface in the leaves.

Ehrler et al. (1978) have also found changes in ψ_{plant} (potential measured on the whole plant) to be determined by changes in volumetric soil moisture content.

Indirectly, soil water acts on other plant growth factors such as soil temperature, soil aeration, and nutrient availability. Consequently, soil moisture conditions that lead to the minimization of plant water stress may result in unfavorable soil temperature or aeration, or may leach nutrients required for plant growth (Campbell and Campbell, 1982).

Often, it is the rate of movement of water within the soil, not water content or potential, which determines the availability of water for plant use, and hence, the need for irrigation (Hillel, 1972). The rate of movement of water within the soil-plant-atmosphere continuum has been explained with the aid of electrical resistance analogs (e.g. Cowan, 1965); which assign resistances to various components of the continum. The significance of each of component toward the determination of the rate of water movement depends on its contribution to the total resistance of the system.

Soil water content is a dynamic parameter, in that it is not constant. One of the factors contributing to changes in soil water content is soil water depletion, which in turn is dependent on a variety of soil, environmental and management factors. For example, Jensen et al. (1971) have expressed soil moisture depletion (D) as:

$$D = \sum_{i=1}^{n} (E_t - R_e - I + W_d) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where:

E_t = evapotranspiration;

R_e = rainfall (excluding run-off);

I = irrigation water applied;

W_d = drainage from the root zone.

In the above relation, D=0, and i=1 after a thorough irrigation, and the terms on the right are daily totals.

Equations (1) and (2) both indicate the importance of evapotranspiration in soil-plant-atmosphere continum, especially as related to its water economy. Evapotranspiration has very intimate, complex and frequently recursive relationships with other plant water stress parameters. For example, Millar et al. (1970) found that transpiration rates of barley decreased with decreasing leaf relative water content (RWC). When RWC reached about 85%, there was a reduction of approximately 50% in actual transpiration recorded. Yang and de Jong (1972) found a similar pattern in the relationship between the two parameters. Thus, transpiration rate dropped rapidly as RWC decreased from 98 to 90%. The decline of transpiration rate became more gradual after RWC reached 90% until a constant transpiration rate of 0.05 g cm^{-2} day^{-1} was reached at about 50% RWC.

Leaf water potential (LWP) has also been found by Yang and de Jong (1972), to decrease with increased evaporative demand (which determines the potential evapotranspiration rate). This is only because leaf water deficits, which determines LWP, are caused by temporary imbalances in the rates of transpiration and water absorption. These imbalances can be caused by either a sudden increase in evaporative demand or by a lowering of water absorption (Ehrler et al., 1966). Furthermore, reduced evapotranspiration rate, by increasing leaf temperature, leads to increased leaf resistance to evaporation (van Bavel et al., 1965).

The transpiration of water from plant leaves leads to a lowering of leaf temperatures by virtue of the latent heat of vaporization of water relative to the heat capacity of plant tissue (Brown and Escombe, 1905). For given conditions, this depression of temperature should be proportional to the transpiration rate (Martin, 1943). Thus, Gates (1964a) found that for bur oak, Quercus macrocorpa, the effective radiation load on the leaf decreased by 0.10 cal cm^{-2} min^{-1} for each