The effects of soil moisture stress on water utilization, seed yield components, and grain and baking quality of selected spring wheat accessions
by James Reed Bunker

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Crop and Soil Science
Montana State University

Abstract:
Available soil moisture can have major effects on wheat yield and quality. Screening for drought resistance is important in dryland wheat production. However, soil moisture determinations over time can produce massive quantities of data. Consequently, the ETPROBE software package was developed to calculate seasonal evapotranspiration (ET) from neutron probe moisture determinations. A line-source irrigation system was used to superimpose a moisture gradient across four spring wheat accessions ('Newana', 'Fortuna', MT 7819, and MT 8182) at Manhattan and Huntley, Montana, in 1986 and 1987, respectively. Seed yield, water use efficiency (WUE), kernel weight, plumpness, number, and protein content were determined at both sites. Harvest index was calculated for plots at Manhattan. Wheat samples from each plot were milled, baked, and evaluated for bread loaf volume and texture. Gliadin proteins were analyzed by reversed-phase high performance liquid chromatography (RP-HPLC). Seasonal ET values ranged from 331 to 580 mm at Manhattan and 277 to 485 mm at Huntley. MT 8182 had the highest yield and seed WUE over all moisture regimes at Manhattan. Additionally, MT 8182 had the greatest kernel weight increase at Huntley and the greatest protein percentage decrease with increased ET at both sites. Fortuna had the lowest yield at all moisture regimes and the lowest WUE at the two highest regimes, and was the least responsive accession to increased ET for yield, WUE, kernel number, and protein content at the drier Huntley site. The relative area of a group of late-eluting gliadin peaks (quality gliadin fraction - QGF), expressed as percentage of total gliadin chromatogram area, was positively correlated with increased ET and negatively correlated with loaf volume for Newana and MT 8182 at both sites. Fortuna showed no correlation between increased ET and relative QGF area or between relative QGF area and loaf volume at either site. These results indicate that increased seasonal ET significantly affected protein quality in conjunction with changes in bread baking quality for some spring wheat accessions.

THE EFFECTS OF SOIL MOISTURE STRESS ON WATER UTILIZATION, SEED YIELD COMPONENTS, AND GRAIN AND BAKING QUALITY OF SELECTED SPRING WHEAT ACCESSIONS

by

James Reed Bunker

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Doctor of Philosophy

in

Crop and Soil Science

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 1988

APPROVAL

of a thesis submitted by

James Reed Bunker

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.

12/16/88 Ronald H. Lerken
Date Chairperson, Graduate Committee

Approved for the Major Department

12/16/88 Charles F. McGuire
Date Head, Major Department

Approved for the College of Graduate Studies

1/17/89 Henry L. Parsons
Date Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a doctoral degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. I further agree that copying of this thesis is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for extensive copying or reproduction of this thesis should be referred to University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106, to whom I have granted "the exclusive right to reproduce and distribute copies of the dissertation in and from microfilm and the right to reproduce and distribute by abstract in any format."

Signature James R. Bunker

Date 12/19/88

ACKNOWLEDGEMENTS

I would like to express my thanks to the members of my graduate committee, Drs. Ronald H. Lockerman, Charles F. McGuire, Gerald L. Westesen, Thomas K. Blake, and John R. Robbins, for their support of my research. I also wish to thank the many other faculty members, too numerous to name, who have contributed to my education.

I wish to thank the many other graduate students who have assisted with my research. These include Larry S. Hicks, Kwang-Wook An, Katim S. Tourey, and Deborah J. Solum, all of whom have assisted me in the field work at some time.

I am grateful to the Montana Wheat and Barley Committee for support and funding of my research. I also wish to thank the personnel of the Montana Agricultural Experiment Stations throughout the state for assistance in gathering data and supplying research samples.

Perhaps most of all, I am indebted to my dear wife, Carolyn, and my children, Tiffany, Jennifer, and Kyle, for their support and their sharing of me with the project. They have been very patient and understanding.

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES - Continued

ABSTRACT

Available soil moisture can have major effects on wheat yield and quality. Screening for drought resistance is important in dryland wheat production. However, soil moisture determinations over time can produce massive quantities of data. Consequently, the ETPROBE software package was developed to calculate seasonal evapotranspiration (ET) from neutron probe moisture determinations. A line-source irrigation system was used to superimpose a moisture gradient across four spring wheat accessions ('Newana', 'Fortuna', MT 7819, and MT 8182) at Manhattan and Huntley, Montana, in 1986 and 1987, respectively. Seed yield, water use efficiency (WUE), kernel weight, plumpness, number, and protein content were determined at both sites. Harvest index was calculated for plots at Manhattan. Wheat samples from each plot were milled, baked, and evaluated for bread loaf volume and texture. Gliadin proteins were analyzed by reversed-phase high performance liquid chromatography (RP-HPLC). Seasonal ET values ranged from 331 to 580 mm at Manhattan and 277 to 485 mm at Huntley. MT 8182 had the highest yield and seed WUE over all moisture regimes at Manhattan. Additionally, MT 8182 had the greatest kernel weight increase at Huntley and the greatest protein percentage decrease with increased ET at both sites. Fortuna had the lowest yield at all moisture regimes and the lowest WUE at the two highest regimes, and was the least responsive accession to increased ET for yield, WUE, kernel number, and protein content at the drier Huntley site. The relative area of a group of late-eluting gliadin peaks (quality gliadin fraction - QGF), expressed as percentage of total gliadin chromatogram area, was positively correlated with increased ET and negatively correlated with loaf volume for Newana and MT 8182 at both sites. Fortuna showed no correlation between increased ET and relative QGF area or between relative QGF area and loaf volume at either site. These results indicate that increased seasonal ET significantly affected protein quality in conjunction with changes in bread baking quality for some spring wheat accessions.

CHAPTER 1

INTRODUCTION

Moisture stress is an important factor limiting worldwide crop production. Moisture availability influences both choice of crop and management techniques. Selection of species and genotypes better adapted to soil moisture stress is a feasible alternative in areas with limited precipitation. Therefore, evaluation of crop responses to available moisture and screening for drought resistance are important.

The line-source sprinkler irrigation system is capable of generating a soil water gradient across genotypes planted in strips perpendicular to the irrigation line. This system, in conjunction with neutron probe soil moisture determinations, provides an excellent means of relating changes in individual crop parameters to soil moisture. However, soil moisture determinations made at frequent time intervals at several depth increments over several treatment combinations result in massive quantities of data. Manipulation and analyses of these data can be cumbersome without a microcomputer software program. Consequently, a microcomputer software package was developed to expedite evaluation of soil moisture data from the field. The ETPROBE program converts raw neutron count data into soil water content for integration with precipitation and irrigation data to calculate soil water depletion, plant available water (PAW), and/or evapotranspiration (ET).

Yield is an important parameter to be examined in field experiments, especially those dealing with crop production improvement such as drought resistance screening. Seasonal ET is used as an indicator of soil water availability. Seed water use efficiency (WUE), which indicates the amount of seed yield per unit of water used (ET), and harvest index (HI), which indicates the proportion of above-ground biomass channeled into seed yield, can be utilized to select plants with optimum yield potentials. These parameters are good indicators of the degree to which yield potential was realized under diverse growing conditions.

Quality is also an important factor in wheat production and utilization. Wheat quality is influenced by kernel weight, size, and protein content. Additionally, kernel number per unit area may affect wheat quality and yield by indirectly affecting kernel weight and size, which ultimately affect relative protein content.

Hard wheat quality is determined by the end-use product which primarily involves bread-making. Bread loaves made from wheat grown over different environments show differences in loaf volume and other baking quality characteristics. However, the effects of growing season soil moisture on specific protein components that influence bread baking quality are not well defined.

The quality and quantity of flour derived from wheat depends on kernel properties and proper grain processing. The protein component of flour, which is directly related to that of the whole grain, is highly important in determining bread quality. One particular characteristic indicative of bread quality is loaf volume, which depends on protein quantity and quality. The gluten protein fractions, gliadins and glutenins, are closely associated with loaf volume and dough strength, respectively. Each of these fractions contains numerous individual proteins with relatively similar amino acid compositions and functionalities. It is possible that differential relationships among individual proteins comprising the gliadin fraction determine the specific characteristics. Electrophoretic and chromatographic techniques allow separation and comparative analyses of proteins. High-performance liquid chromatography (HPLC) is an analytical tool capable of separating and quantifying individual gliadin protein fractions. This method is extremely sensitive and has a high recovery rate.

The objectives of this study were to 1) develop a software program (ETPROBE) for managing and processing neutron probe soil moisture determination data, 2) evaluate the utility of the line-source irrigation system for multiple screening processes, 3) determine yield, harvest index, and water use relationships of four morphologically diverse hard spring wheat accessions under increasing soil moisture regimes, 4) evaluate the effects of differential seasonal ET on kernel quality characteristics, 5) determine relationships among gliadin protein components influenced by differential field soil moisture, and 6) examine associations between gliadin protein components and bread baking quality.

CHAPTER 2

LITERATURE REVIEW

Crop

Wheat (*Triticum* spp.) is an extremely important food crop throughout the world. Reitz (1967) reported wheat to be the national food staple in 43 countries. Evans et al. (1975) indicated that wheat was cultivated approximately 10,000 years ago in the area of the Fertile Crescent. According to Martin et al. (1976), emmer (an ancestor of common wheat) was cultivated before 7000 B.C. Poehlman (1979) reported that wheat was cultivated in Greece, Persia, Egypt, Europe, and Southeast Asia in prehistoric times, and was brought to the United States by the early colonists.

Wheat is comprised of the genus *Triticum* of the tribe Triticeae in the Poaceae family. The genus was named by Linneaus in 1753. *Triticum* species have been divided into three groups based on chromosome number: diploids (n=7), tetraploids (n=14), and hexaploids (n=21) (Briggle, 1980). Most of the commercially grown wheat is the hexaploid *Triticum aestivum* L. em Thell. (bread or common wheat). Other major species include *T. durum* Desf. (durum wheat, a tetraploid) and *T. compactum* Host (club wheat, a hexaploid; considered by some to be a type of *T. aestivum*).

Line-source Irrigation System

Lack of sufficient soil moisture to ensure optimum crop growth and yield is a worldwide problem. The effects of plant available water (PAW) on specific growth and yield functions have been reported for several crops (Bauder et al., 1978; Black, 1966; Hanks, 1974; Heady and Pesek, 1954; O'Neill et al., 1983; Shimshi et al., 1982; Singh, 1981; Westesen et al., 1987).

The line-source irrigation system described by Hanks et al. (1976) is a field technique capable of providing a uniform water gradient across plots planted perpendicular to the water source. It allows imposition of a water gradient within a relatively small plot area at a single field site, reducing environmental and soil parameter variations inherent with multiple-site studies. Use of collection devices permits monitoring of system uniformity and quantification of water applied in the different regimes within the gradient. O'Neill et al. (1983) stated that the line-source system could be used to screen large numbers of germplasm for drought resistance.

An inherent limitation involves the validity of certain statistical tests with the line-source design. A valid F-test cannot be made for the main effects of irrigation level using analysis of variance (ANOVA), since the irrigation levels are fixed. However, F-tests from ANOVA are valid for randomized treatments and interactions. Hanks et al. (1980) stated that irrigation main effects are generally large enough to be obvious and that statistical analysis of these is not critical. Johnson et al. (1983) described a procedure using multivariate methods that allows statistical analysis of irrigation main effects when this parameter is critical.

Physiological Effects of Drought Stress

Drought stress affects wheat growth and development by influencing several physiological processes. The plant compensates for decreased plant available water in the soil by creating a lower (more negative) plant water potential. The resulting internal water deficit modifies turgor pressure in the cells. Modification of turgor affects such processes as cell elongation and cell division, which are directly related to leaf expansion and photosynthetic potential (Clarke et al., 1981; Eastham et al., 1984; Turner and Burch, 1983).

Drought stress increases hydrolysis of proteins and results in increased levels of the free amino acids glutamate and proline. Loss of protein may either result from a decrease in RNA synthesis (Shah and Loomis, 1965) or from an increase in the RNA degradation rate (Barnett and Naylor, 1966; Gates and Bonner, 1959; Kramer, 1969; Slayter, 1969).

Plants subjected to drought stress not only show a general reduction in size, but also exhibit leaf structural modifications. Leaf area decreases due to reductions in cell enlargement. Drought-stressed leaves may have increased pubescence, cutinization, and thickness (Kramer, 1969).

Root development is important in processes associated with drought resistance since it is closely related to soil water absorption. In general, plant water stress decreases as the extent of the root system increases (Townley-Smith and Hurd, 1979). However, this does not mean that yield will be increased with increased root area. Salim et al. (1965) indicated that the extent of cereal crop root growth was highly correlated with soil moisture level. They indicated that root penetration was dependent on the soil depth where water content was above the permanent wilting point (PWP).

Clarke et al. (1981) indicated that plants showed less stress effect on yield when initial soil water was sufficient for plant establishment, since the root system developed prior to anthesis. Passioura (1972) advocated breeding for plants with higher root resistances to limit early season water depletion. However, he also stated that this would not be desirable for wheat grown on low water-holding capacity soils.

Water Stress Measurements

Water stress indicators include leaf water potential, changes in soil water content, and evapotranspiration rate. Plant water potential indicates the ability of a plant to regulate internal water deficits and is dependent on soil water potential. As soil water becomes limiting, the plant has to develop a more negative water potential to maintain water influx. Therefore, it is possible to indirectly evaluate plant water status by measuring soil water status. Gravimetric analysis of soil water content is the standard calibration method. The percentage of water is calculated as the ratio of weight difference between wet and oven-dried soil to the weight of dried soil (Thien, 1983). This ratio is multiplied by soil bulk density to give a gravimetric determination on a volume basis. Each sampling over time differs spatially over the soil being used in the determination since this method is destructive.

Neutron probe determinations of soil water content have the advantage of allowing measurement of the same sample unit of soil over time. Additionally, this technique allows rapid multiple moisture determinations at different soil profile levels. The neutron emitter-counter is lowered to the desired reading depth through an aluminum or polyvinyl chloride (PVC) access tube placed into the soil. Fast neutrons emitted into the soil collide with soil water hydrogen nuclei and are deflected at a slower rate. A portion of these slow neutrons reach the counter and are registered (Thien, 1983). Neutron counts are translated into moisture units with a calibration equation. Neutron probe determinations were used by Jaradat and Konzak (1983) to study soil water depletion patterns as a potential screening method for wheat drought resistance. They showed a 92% correlation between neutron probe and gravimetric determinations.

Evapotranspiration (ET) accounts for changes in soil water content due to both soil evaporation and plant transpiration. The evaporation component is largely dependent on plant cover and decreases with increased plant canopy growth. Transpiration is dependent on physiological processes involving stomatal aperture, water uptake, and atmospheric demand for plant water. Evapotranspiration can be measured using a variety of lysimeters, atmometers, and pan evaporimeters. Blad (1983) gave an excellent discussion of these measuring techniques.

Various models have been proposed to estimate ET since direct measurement is not always practical. The original Penman (1948) model was used to estimate evaporation from an open water surface and utilized vapor pressure, air temperature, wind speed, and net radiation. Actual ET over a given time period can also be estimated using the water balance equation cited by Rose (1966):

$$ET = CSM_i + P + I - CSM_t - RO - D$$

where CSM_i is cumulative soil moisture at the beginning of the estimation period, P is precipitation amount, I is the amount of water added by irrigation, CSM_t is cumulative soil moisture at the end of the estimation period, RO is the amount of water lost as runoff, and D is the water lost to drainage. The effects of the last two variables are often considered negligible (Diaz et al., 1983; Garrity et al., 1982).

Yield and Yield Components

Seed yield of wheat and other small grains is a composite of three primary components: spike number per unit area; kernel number per spike; and kernel weight (Singh, 1981). Spike number per unit area is a function of plant number per unit area and spike number per plant (Sebillote, 1980). Spike number per plant is dependent on tiller number, which is inversely related to plant density and buffers seed yield against both overseeding and underseeding (Dewey and Albrechtsen, 1985). Tiller number is determined early in the vegetative phase of growth, and is quite sensitive to drought stress (Kirkham and Kanemasu, 1983).

Kernel number per spike is a function of spikelets per spike and kernels per spikelet. Nicholis and May (1963) suggested that spikelet number per spike is determined by the balance between rate of primordial initiation and rate of spikelet development. Wardlaw (1971) stated that drought stress may reduce kernel number per spike by decreasing the fertilization rate.

Kernel weight is determined during the grain filling stage after kernel number per unit area has been established (Day, 1981; Kirkham and Kanemasu, 1983). Drought stress during the post-anthesis period can reduce kernel weight by limiting photosynthate availability, reducing translocation, and shortening the grain-filling duration (Clarke et al., 1981; Wardlaw, 1967). Lower kernel weight markedly decreases yield since kernel number per unit area can no longer compensate for yield reduction during the post-anthesis period (Aspinall, 1965). Kernel plumpness is strongly associated with kernel weight.

Kirkham and Kanemasu (1983) indicated that kernel weight and kernel number per spike have the greatest effect on grain yield under drought stress. Conversely, spike number per unit area has the greatest effect on yield when water is adequate. Singh (1981) reported kernel number per unit area to be the most important yield-limiting factor. Shanahan et al. (1985) reported a highly significant positive linear correlation between kernel number per unit area and total yield of winter wheat. Keim and Kronstad (1981) found that final number of spikes per unit area determined winter wheat yield under drought stress, with increased spike number under conditions of low plant water.

Water use efficiency (WUE) and harvest index (HI) are important factors directly related to yield potential. WUE describes the efficiency with which a plant produces economic yield per unit of used water (Turner and Burch, 1983). A high WUE value in wheat and other cereals indicates a greater efficiency at producing biomass with a given amount of water. Relations between dry matter production and water use are theoretically based on plant transpiration. However, transpiration is difficult to separate from soil water evaporation in the field, so ET is commonly used to calculate crop WUE (Garrity et al., 1982). Harvest index (HI) refers to the proportion of above-ground biomass that has been channeled into grain production.

Wheat Quality

Protein is one of the most important flour components affecting baking quality. Protein content, expressed as percentage by weight, has been shown to be inversely related to grain yield (Loffler et al., 1985; McNeal et al., 1968; McNeal et al., 1972; Terman et al., 1969). However, Loffler et al. (1985) reported that 'Len' wheat exhibited an exception to this relationship.

The inverse relationship between grain yield and protein content has been attributed to dilution of protein nitrogen with a high ratio of carbohydrates in the kernels. McNeal et al. (1972) reported that eight spring wheat crosses with genetically-controlled high or low grain protein contents absorbed similar amounts of nitrogen from the soil and translocated equal amounts of nitrogen to the grain. They concluded that grain protein percentages were entirely dependent on the amount of carbohydrate translocated to the grain, which was influenced by the number of carbohydrate sinks (kernels).

Terman et al. (1969) suggested that hard wheat protein was affected by soil moisture. Smika and Greb (1973) reported high correlation