PROJECT COMPLETION REPORT

WATER-CONSERVING WHEAT IRRIGATION SCHEDULES BASED ON CLIMATIC DATA

by

M. B. Kirkham

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ABSTRACT

Wheat farmers in the Southern Great Plains often over-irrigate and lose water. An analysis of the relationship between Oklahoma wheat yields and rainfall history showed that wheat yields are best when rain falls within an interval of about five days in late March. Yet wheat farmers do not start applying irrigation water until after 1 April. The purpose of this research was to test the hypothesis that irrigation scheduling could be based on correlations between rainfall and yield determined from historical data. Water would be conserved and yields would be increased since wheat would receive water at critical stages necessary for maximum growth. Water-use efficiency should be increased because a farmer could apply his allocated amount of water at times to insure high yields.

Irrigation schedules based on correlations between yield and rainfall determined from historical records were developed. Dates were isolated when correlations were high. Field plots were established and irrigation water was applied at a critical time determined from the historical analysis. Yield from plots with a revised irrigation schedule was compared to that from plots irrigated according to normal methods that farmers now use. The results showed that water-use efficiency and yields were higher with a revised irrigation schedule than with a normal irrigation schedule. Four publications resulting from the funds granted by Office of Water Research and Technology are attached.

Keywords: water conservation, irrigation efficiency, wheat, rainfall history, semiarid climates, irrigation, scheduling, groundwater, grains, plant growth, climatic data

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INTRODUCTION

Wheat farmers in the semiarid Southern Great Plains often overirrigate and lose precious groundwater which is being mined from the Central Ogallala Formation. Farmers are abandoning the land because they no longer can afford to pump water from the deepening groundwater source. An analysis of the relationship between Oklahoma wheat yields and rainfall history showed that wheat yields are best when rain falls the last week in March. But wheat farmers do not start applying irrigation water until after 1 April. The purpose of this research was to develop irrigation schedules based on correlations between yield and rainfall determined from historical records. Field plots were established and irrigation water was applied on a critical date determined from the historical analysis. Yield from the plots with a revised irrigation schedule was compared to that from plots irrigated according to normal methods that farmers now use. Water-use efficiency was greater with the revised irrigation schedule than with the normal irrigation schedule. Similar, revised schedules could be initiated in other areas of the country based on their climatic records.

OBJECTIVE

The specific research objective was to test the hypothesis that irrigation scheduling can be based on correlations between rainfall and yield determined from historical data. In other words, the research attempted to answer the following question: Should irrigation water be applied at those times during a year when the historical data show that yields and rainfall are most strongly correlated?

PROCEDURE

Correlations between spring rainfall and grain yield were determined for winter wheat cultivars grown between 1960 and 1977 at Stillwater, in the East Central region of Oklahoma, and at Goodwell, located in the drier, western part of the state.

Irrigation water was applied to field-grown wheat at Goodwell to determine if yields would be greater if water were added at the time when the correlation between yield and rainfall were highest. Two irrigation schedules were used. Plants grown with the revised irrigation schedule received 15.2 cm of irrigation water in the spring added in 7.6 cm increments on 20 March and 24 April, and plants grown with the normal irrigation schedule received 22.8 cm of irrigation water added in 7.6 cm increments on 20 March, 3 April, and 24 April. Control plants were grown dryland. Plant water potential, osmotic potential, stomatal resistance, and leaf temperature were monitored monthly in the spring on plants under the three watering regimes to quantify plant-water stress.

ACHIEVEMENT OF OBJECTIVE

At Stillwater, cultivars exhibited maximum positive correlations between rainfall and yield in the fourth week of March, when stem-extension occurs. Smaller positive correlations were observed in mid-April when flowering. Results at Goodwell were similar except that the correlations between rainfall and yield were lower and occurred earlier than at Stillwater and showed a less marked secondary peak at flowering. Both stem-extension and flowering were critical stages of water requirement.

The field experiment showed that yields were highest for the revised treatment (average yield: 4470 kg/ha) and were 23% more than yields for the plants under the normal irrigation schedule (average yield: 3640 kg/ha). Average yield of dryland plants was 1660 kg/ha. After March, plants grown under the revised treatment showed more plant-water stress than plants grown under the normal irrigation treatment. Dryland plants showed more stress than irrigated plants throughout the experiment.

LISTING OF RESULTS

Peak correlations between rainfall and yield of winter wheat occurred at stem-extension and flowering, critical stages for water requirement. It is suggested that long-term climatic data could be used to determine optimum timing for irrigation of wheat. Such an approach would save water and energy by limiting irrigation to those times when analysis of local records demonstrates the maximum positive correlation between rainfall and yield.

In a field experiment, yield and water use efficiency were maximum when irrigation water was applied under a revised regime, which received 7.6 cm less water, than under a regime normally used by farmers.

Two additional studies were done. The studies and results are as follows:

1. Two areal scales were used to determine the effect of land size on wheat-yield estimates from climatic data. The larger scale was the state of Oklahoma and the smaller scale included five crop reporting districts within the state. Two multilinear regression models were developed. One used unadjusted, and the other square-root adjusted, climatic data. Any comparative advantage of district modeling over a state model was judged upon the correlation coefficients of the model and its estimation capability over a five-year trial period. When state and district models were compared in estimation capability, the state model achieved more accurate yield estimates of district wheat yields than did the individual district models.

2. Winter wheat was grown in rows on ridges tilled in the east-west direction, under irrigated and dryland conditions in the Panhandle of Oklahoma, to determine if yield of plants in south-facing rows was greater than yield of plants in north-facing rows. In addition to yield, measurements of height, leaf temperature, stomatal resistance, leaf water potential, and leaf osmotic potential were taken on plants in north- and south-facing rows. Differences in stomatal resistance, water potential, and osmotic potential of north-and south-facing plants could not be detected. South-facing plants had a cooler leaf temperature than did north-facing plants. South-facing plants grew more than 10 cm taller, and yielded as much as two times more, than did north-facing plants. The results showed that wheat in the Panhandle of Oklahoma should be planted on south sides of ridges for maximum yields.

LIST OF PUBLICATIONS (attached)

Greene, D. M., and M. B. Kirkham. 1980. Water-conserving wheat irrigation schedules based on climatic records. Irrigation Science 2: (in press).

Peck, R. A., and M. B. Kirkham. 1979. Water relations and yield of winter wheat grown under three water regimes in the High Plains. Proc. Oklahoma Academy Science 59: 53-59.

Greene, D. M., S. M. Sutherland, and M. B. Kirkham. 1979. Influence of area on winter wheat climatic models. Climatic Change 2: 21-32.

Kirkham, M. B. 1979. Plant-water relations and yield of wheat on ridges tilled in the east-west direction, p. 271-276. _In_ Proc. of the 8th Conference of the International Soil Tillage Research Organization, ISTRO. University of Hohenheim, Hohenheim, West Germany.

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Irrigation Science 2, ■■ – ■■ (1980)

Irrigation
Science

Water-conserving wheat Irrigation Schedules based on Climatic Records

D. M. Greene and M. B. Kirkham

Department of [illegible]ology, Baylor University, Waco, Texas 76703, and Department of Agronomy, Oklahoma State University, Stillwater, Oklahoma 74074, USA

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Summary. Correlations between spring rainfall and grain yield were determined for four winter wheat cultivars (*Triticum aestivum* L. em. Thell. 'Triumph', 'Wichita', 'Concho', and 'Triumph 64'), grown between 1950 and 1977 under dryland conditions at Stillwater, in the East Central region of Oklahoma, and at Goodwell, located in the drier, western part of the state.

At Stillwater, all but one of the cultivars exhibited maximum positive correlations between rainfall and yield in the fourth week of March, when stem-extension occurs. Smaller positive correlations were observed in mid-April when flowering. Results at Goodwell were similar except that the correlations between rainfall and yield were lower and occurred earlier than at Stillwater and showed a less marked secondary peak at flowering. These results agree with those of experiments in which irrigation has been applied at different growth stages of wheat, and have shown that both stem-extension and flowering are critical stages of water requirement. As the results of this climatic study show that the peak correlations between rainfall and yield occur at these same two stages, it is suggested that longterm climatic data could be used to determine optimum timing for irrigation of wheat.

Such an approach should save water and energy by limiting irrigation to those times when analysis of local records demonstrates the maximum positive correlation between rainfall and yield.

Wheat farmers in the semi-arid Southern Great Plains of the USA often over-irrigate leading to a rapidly declining level of the ground water mined from the Central Ogallala Formation, the aquifer underlying a large portion of the Great Plains (Mapp et al., 1975). Land is being abandoned because farmers cannot afford to pump from the deepening ground water source. To avoid this situation, the remaining ground water must be more wisely used (Mapp and Dobbins, 1976).

Most wheat farmers in the Southern Great Plains irrigate wheat in the following manner (Garton, 1963; New, 1977; Pope and Hay, 1976). One irrigation is given in the fall before September or October planting. After planting, another irrigation is

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applied. In the spring, two or three irrigations are applied, starting in the first part of April and ending before harvest in late June or early July. The total amount of irrigation water applied is approximately 30 cm. Most farmers irrigate at random times and do not use plant, soil or meteorological factors to decide when to irrigate. A simple, cheap, and sound basis for scheduling irrigations would be welcomed.

Long-term yield and climatic data would appear to be a good source of information on crop response to climatic factors (van Bavel, 1960; Pumphrey, Ramig and Allmaras, 1979). By calculating yield-response-to-rainfall on the basis of long term data, the crop itself shows any critical periods of response to water application. Yields will be high if rain falls or irrigation is applied at the critical times and low yields will be obtained if rain does not fall or irrigation is not applied at these times.

The extensive literature dealing with rainfall and yield relationships has been reviewed (Stanhill, 1973). Correlations between rainfall at different phenological periods and yield have been obtained for wheat, rye, and maize, although the response of different cultivars apparently has not been published.

In this study, four cultivars of wheat were examined, to determine if high correlations existed between wheat yields and rainfall at specific times during the life cycle of the plants that could then be used to determine the optimum time for irrigation. In addition to rainfall, temperature and yield relationships were determined.

Materials and Methods

Two sites were studied, both located in the large wheat-producing area of Oklahoma: Stillwater, in the central part of the state and Goodwell, 480 km west of Stillwater and in Oklahoma's Panhandle. Grain yields of winter wheat (*Triticum aestivum* L. em. Thell.) grown between 1950 and 1977 on experimental field plots under dryland conditions at the Stillwater Agronomy Research Station and the Goodwell Agronomy Research Station were obtained from the files of the Agricultural Experiment Station, Stillwater. Yields of the cultivars which had the longest records were chosen. These were 'Triumph', 'Wichita', 'Concho', and 'Triumph 64' for which 26, 22, 22, and 14 years of data were recorded, respectively, for Stillwater, and 16, 15, 16, and 10 years of data, respectively, for Goodwell. Fewer years were available for Goodwell as the dryland crops at this site often yielded less than 800 kg/ha and, if this happened, they were not harvested. Weather data between 1950 and 1977 for Stillwater and Goodwell were available from Climatological Data (United States Department of Commerce, 1950 – 1977) and were obtained from the two official weather stations located on the Stillwater and Goodwell Agronomy Research Stations. The average yearly rainfall for Stillwater and Goodwell is 90 and 43 cm, respectively. The soil at the Stillwater Agronomy Research Station is a silt loam and that at the Goodwell Agronomy Research Station is a clay loam.

Data for only two months, March and April, were used in this study. These months were selected on the basis of the results of a previous investigation (Greene, Sutherland and Kirkham, 1979) which showed that March rainfall and temperature were the most important climatic variables in determining wheat yields in Oklahoma. It also showed that rainfall in all months, except for December, up to and including March increased wheat yields. Rainfall in late spring, particularly May and June, decreased wheat yields. April data were included in the present analysis to examine if the favorable influence of rainfall in March continued into April. Thus, the selection of the two months is based on the facts that: one, the single most important month for wheat yields in Oklahoma has been determined to be March (see Tables I and II of Greene et al., 1979); and two, April is a month of transition, in which rainfall gradually becomes negatively correlated with yield. It is interesting to note that in Czechoslavakia, weather conditions in both March and April are also the most important in determining winter wheat yield (Úlehla, 1978).

Daily values of rainfall and minimum temperature were used. Minimum temperature was chosen because preliminary work showed that minimum temperature explained more of the yield variation than average temperature which in turn accounted for more yield variation than maximum temperature. The daily analysis of March and April weather data was carried out on running totals of seven consecutive daily rainfall data, the total of which was assigned to the median, i.e., fourth of the seven days. This procedure was continued from March 1 to 7 through the week of April 24 to 30. The same 7-day running mean, as outlined for rainfall, was used with data of minimum daily temperature. Statistical levels of significance of the correlations were determined using Clopper-Pearson charts (Steel and Torrie, 1960, p. 354).

Results and Discussion

Maximum positive correlations between rainfall and yield occurred for three of the cultivars in the fourth week in March at Stillwater (Fig. 1), suggesting that this is the critical stage when water is required for maximum yield. At this site, stem (culm) extension takes place, and the reproductive head differentiates and starts to develop

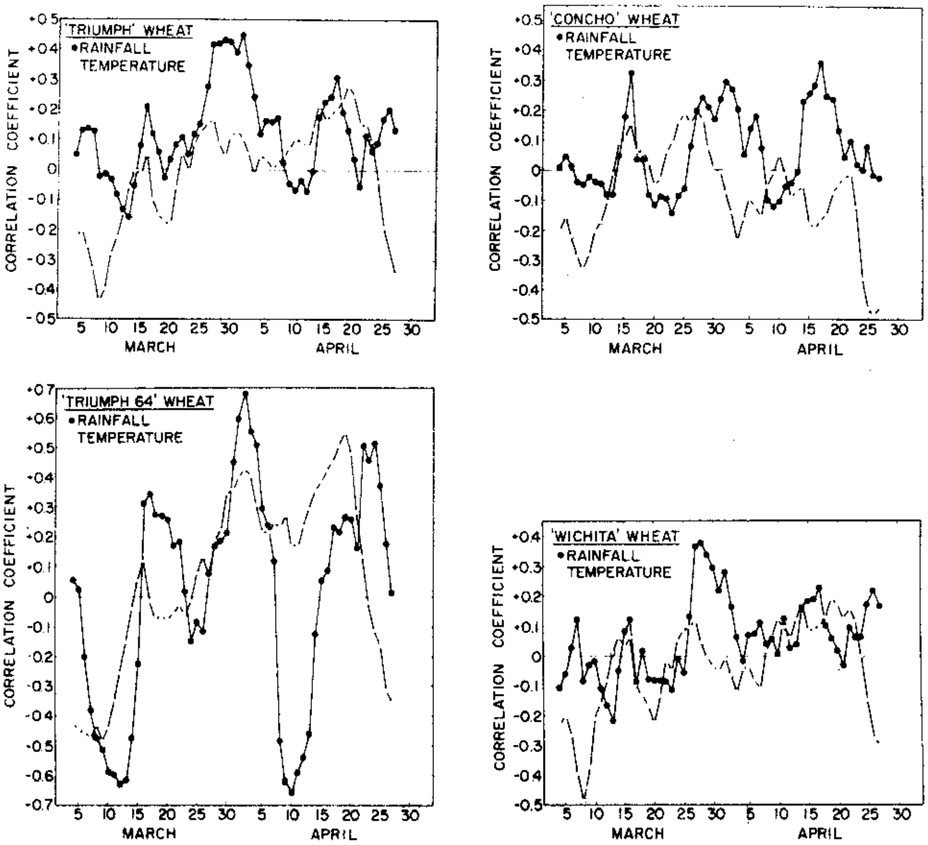

Fig. 1. Correlations between March and April rainfall and yield (•), and temperature and yield (□), for four winter wheat cultivars grown at Stillwater, Oklahoma, between 1950 and 1977. The average of the confidence limits for the correlation coefficients, as determined using Table A.15A in Steel and Torrie (1960, p. 458, confidence coefficient of 0.95), was ±0.15

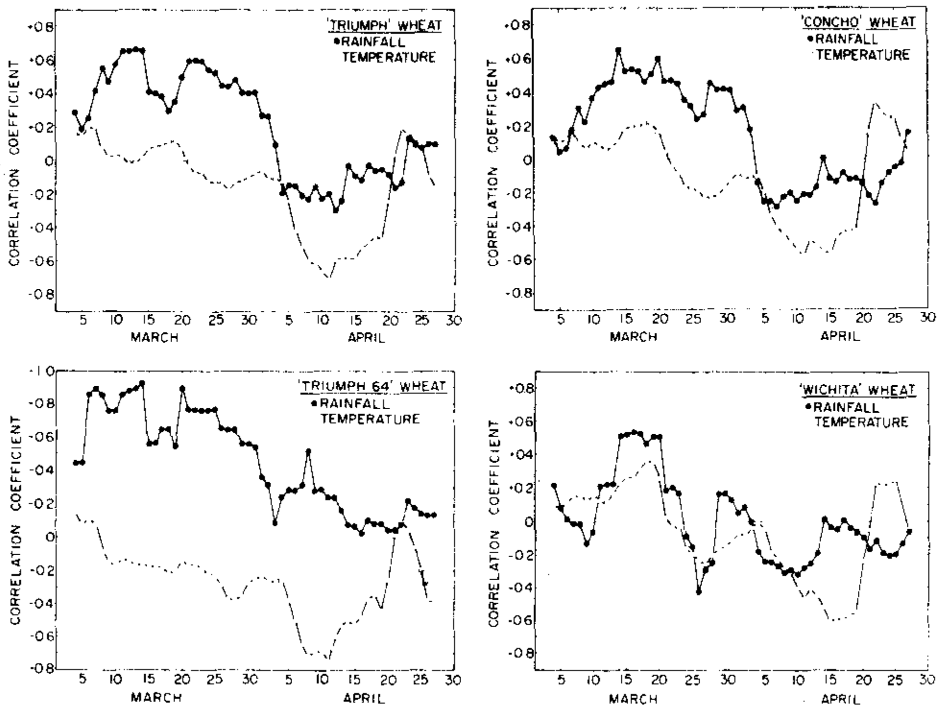

Fig. 2. Correlations between March and April rainfall and yield (•), and temperature and yield (□), for four winter wheat cultivars grown at Goodwell, Oklahoma, between 1950 and 1977. For confidence limits see legend of Figure 1

inside the stem in the fourth week in March. In the second week of April, the heads of grain appear and flowering begins. A secondary peak of positive correlations between rainfall and yield also occurred in mid-April, but except for the cultivar Concho, which had equally high peaks in March and April, April peaks were not as high as those that occurred in March. The April peaks coincided with flowering time.

These results agree with those derived from earlier irrigation experiments reported in the literature (Salter and Goode, 1967). For example, in Washington State, Robins and Domingo (1962) irrigated spring wheat at different times during the growing season. They concluded that anthesis was the most crucial stage. Yields were lowest if wheat did not receive water at this stage. Abdel-Samie and Talha (1967) studied winter wheat in Egypt and contended that if enough water were applied at planting to establish the wheat, stem elongation was the most critical time for watering. Flowering was the second most critical period.

The present analysis agrees with the Egyptian workers' data in that during stem elongation in the fourth week in March, the highest positive correlation between rainfall and yield occurred for all cultivars except Concho. However, this cultivar also showed a high secondary peak at that stage, too. Except for Concho, smaller peaks were evident at flowering time in April. Concho may have responded differently than the other cultivars because of its drought resistance (E. L. Smith, personal communication).

The Goodwell results (Fig. 2) were similar to the Stillwater results except that maximum correlations in March were lower and less pronounced. This may have been due to the fewer years used in the Goodwell analysis. Another explanation may be the greater water holding capacity of the heavier soil at Goodwell compared to Stillwater or different rainfall distribution. The Goodwell data also showed April peaks coincide with flowering time.

Positive correlations between rainfall and yield were higher than those between temperature and yield (Figs. 1 and 2). Negative correlations between temperature and yield were usually higher than the negative correlations between rainfall and yield. The fact that winter wheat is a cool-season crop may explain the lack of strong positive correlations between temperature and yield. The response to interactive effects of temperature and rain on yield is unknown, but likely to be minimal, as there is a positive correlation within years between the two climatic factors. The thirty-year climatic means show that both temperature and rainfall increase during the two-month interval from 1 March to 30 April.

The suggested method of scheduling irrigation water based on the correlations between rainfall and yield would allow irrigations to be timed to coincide with dates showing maximum positive correlations between rainfall and yield. Similarly, cloud-seeding operations, which are in wide-spread use in Oklahoma, could take place at these times. Conversely, irrigation applications should be omitted during periods when correlations are negative. Specifically, the omission of the second spring irrigation is recommended. Irrigation schedules established using climatic and yield data from the locality under consideration should increase water use efficiency and save energy needed to pump water from deep sources.

However, the suggested use of long-term climatic data in irrigation scheduling requires caution. The analysis only indicates that, *on an average*, yields are increased by water supply in late March and mid-April and are unaffected or less affected by water supply at other times. Thus, the use of long-term climatic records are only useful as a guide to irrigation scheduling if current weather events are also taken into account. For example, obviously there would be no point in irrigation during the last week of March if 5 cm of rain fell on the day prior to irrigation being scheduled.

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WATER RELATIONS AND YIELD OF WINTER WHEAT GROWN UNDER THREE WATER REGIMES IN THE HIGH PLAINS*

R. A. Peck and M. B. Kirkham

Department of Agronomy, Panhandle State University, Goodwell, Oklahoma 73939, and
Department of Agronomy, Oklahoma State University, Stillwater, Oklahoma 74074

Five cultivars of winter wheat (*Triticum aestivum* L. em. Thell.) were grown in the field under two ridge-and-furrow irrigation treatments in the Panhandle of Oklahoma to determine if yields could be increased by applying irrigation water at different times in the spring than it is normally applied. The plants grown under the "modified" irrigation schedule received 15.2 cm of irrigation water in the spring added in 7.6-cm increments on 20 March and 24 April, while the plants grown under the "normal" irrigation schedule received 22.8 cm of irrigation water added in 7.6-cm increments on 20 March, 3 April, and 24 April. Control plants were grown dryland. Plant water potential, osmotic potential, stomatal resistance, and leaf temperature were monitored monthly in the spring on plants under the three watering regimes to quantify plant water stress.

Yields were highest for the modified treatment (average yield: 4470 kg/ha) and were 23% more than yields for the plants under the normal irrigation schedule (average yield: 3640 kg/ha). Average yield of dryland plants was 1660 kg/ha. After March, plants grown under the modified treatment showed more plant water stress than plants grown under the normal irrigation treatment. Dryland plants showed more stress than irrigated plants throughout the experiment. Yield and water use efficiency were maximum when irrigation water was applied under the modified regime, which received 7.6 cm less water, than under the normal regime.

INTRODUCTION

Wheat farmers in the High Plains of Oklahoma often over-irrigate and lose precious ground water, which is being depleted from the Central Ogallala Formation (9, 10, 11, 13, 18). Yet other farmers are abandoning the land because they no longer can afford to pump water from the deepening ground water source. Irrigation water must be conserved and applied at times which will maximize yield.

Most wheat farmers in the High Plains irrigate in the following manner (5, 8, 15). They apply one irrigation in the fall before planting wheat in September or October. After planting, they apply another irrigation. In the spring, they apply two to three irrigations, starting about the first part of April and ending before harvest in late June or early July. In the Panhandle, flowering occurs mid- to late May. Total amount of irrigation water used is 30.4 cm or 7.6 cm per irrigation (furrow irrigation). Similar irrigation practices are used on small grains other than wheat (17).

Irrigation scheduling often is based on meteorological factors, such as evapotranspiration rate. However, determination of evapotranspiration rate is not always an accurate method with which to plan irrigations. Research on corn, for example, shows that an irrigation early in the flowering period greatly increases yield, but this timing is not indicated by evapotranspiration measurements (2). For high yield, therefore, irrigation water should be added when the plant needs it, and not at times based on meteorological conditions.

It is generally believed that flowering (anthesis) is the stage at which water should be applied to wheat to insure high yields (8, 15, 16). However, work in Egypt suggests that, if enough water is applied at planting to establish the wheat, yields are maximum if irrigation water is applied at the time of stem extension rather than at flowering (1). Flowering was the second most critical period in the Egyptian study. Stem extension for wheat in the Panhandle starts about mid-March.

Little information has been published concerning irrigations in the Panhandle. Therefore, this experiment was conducted to determine the effect of an alternate irrigation schedule on wheat yield in the Panhandle of Oklahoma. Yield was compared to plants grown under the normal

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*Journal paper no. 3568 of the Oklahoma Agricultural Experiment Station.

irrigation regime for the region. Plants under the normal irrigation regime received 7.6 cm more water than did plants under the modified regime. Wheat also was grown without irrigation water ("dryland" treatment). Plant-water measurements (leaf water potential, osmotic potential, and stomatal resistance) were obtained to quantify plant water stress under the three watering conditions.

MATERIALS AND METHODS

The experiment was carried out at the Panhandle Research Station, Goodwell, Oklahoma during the 1977-1978 growing season. Certified hard red winter wheat (*Triticum aestivum* L. em. Thell.) seed was planted in east-west rows on 13 Oct. 1977, for the three treatments (normal irrigation schedule, modified irrigation schedule, and dryland). The land for each treatment measured 90 meters long and 4.3 meters wide. The treatments were adjacent to each other. The normally irrigated plots were on the north side of the experimental area receiving the modified irrigation schedule. The dryland plots were on the south side of the experimental area receiving the modified irrigation schedule. A John Deere DRB-20-8 grain drill was used to plant the seeds. There were 20 cm between the rows. Six rows of wheat were planted between each two irrigation furrows. There were three beds (three ridges of plants) for each treatment and each bed was 142 cm in width. Nitrogen fertilizer was applied at the rate of 110 kg/ha. An application (0.6 kg/ha) of an ester of 2,4-D was made on 17 March for the control of tansy mustard (*Descurainia pinnata*).

Each of the three plots was divided into five subplots, each containing a cultivar of wheat commonly grown in the Panhandle. The five cultivars were: 'Centurk' (CI 15075), 'Scout 66' (CI 13996), 'Tam W101' (CI 15324), 'Triumph 64' (CI 13679), and 'Vona' (CI 17441). The cultivars were randomly distributed within each treatment. The plots receiving the normal and modified irrigation schedules were planted with 30.5 kg seed/ha and the dryland plots were planted with 15.3 kg seed/ha. The soil type was a Richfield clay loam (12), which is classified as a Aridic Argiustoll.

The plots receiving the normal and modified irrigation schedule were irrigated on 20 September 1977 (pre-planting irrigation), and on 3 November 1977 (post-emergence irrigation), each time with 7.6 cm water. In the spring, these plots received water, as follows:

Treatment	Amount and Date of Water Added
Normal irrigation schedule	7.6 cm water, 20 March
	7.6 cm water, 3 April
	7.6 cm water, 24 April
Modified irrigation schedule	7.6 cm water, 20 March
	7.6 cm water, 24 April
Dryland	See Table 1 for rainfall

Therefore, the plants under the modified schedule received 7.6 cm less irrigation water than did the plants under the normal irrigation schedule.

On four days in the spring (13 March, 12 April, 10 May, 5 June), measurements of height, leaf water potential, leaf osmotic potential, stomatal resistance, and leaf temperature were taken between 08:00 and 10:00 hr on three plants in the center bed of each cultivar within each of the three treatments, as follows. [The center of the bed was measured to avoid border effects (19).] First, height was measured from the ground to the top of the tallest leaf. When heads emerged (mid- to late May), height was measured to the tip of the head, excluding the awns.

Second, leaf temperature of the upper surface was measured using a hand-held, fine-wire thermocouple unit (chromel- constantan, 0.0762 mm diameter, Omega Engineering, Inc., Stamford, Conn.). The hand-held probe was attached to a Keithley Model 155 Null Detector-Microvoltmeter (Keithley Instruments, Cleveland, Ohio). The leaf-temperature measuring device is described by Perrier (14). Air temperature was measured with a thermometer at the top of the canopy.

Resistance of the stomata on the upper leaf surface was measured, immediately after leaf temperature was measured, with a calibrated stomatal diffusion porometer (7) (Model LI-60 and Sensor LI-15S, Lambda Instrument Corp., Lincoln, Neb.).

After stomatal resistances were measured, leaves were sampled for potential measurements. Water and osmotic potentials were determined with thermocouple psychrometers designed by Dalton and Rawlins (3), using the technique described by Ehlig (4). Leaves used for potential, stomatal resistance, and temperature determinations were flag leaves for the May and June measurements.

The wheat was harvested on 26 June 1978, 256 days after planting, with a Hege Model No. 125 combine which cut four rows (90 cm). Three 3-meter samples were taken from each subplot to provide three replications. The center bed of the three beds in each treatment was sampled to avoid errors due to edge effects on rows bordering different treatments. At harvest, height, test weight, and yield were determined.

Meteorological data (Table 1) were provided by the official weather station located 351 m northwest of the plots at the Panhandle Research Station (20). Data in Table 1 also were obtained directly at the field plots on the four days of measurements in the spring. Wind speed was measured with a handheld anemometer (Model A10962 anemometer, Short and Mason, Ltd., Walthamstow, London, England). The anemometer was held 30 cm above crop height to obtain the reported values. Solar radiation was measured using Model No. LI-170 Quantum Sensor attached to Model No. LI-185A Quantum/Radiometer/Photometer of Lambda Instrument Corp., Lincoln, Neb. The quantum sensor was placed at crop height to measure the listed values. Soil water tension at the 50-cm depth was determined with a "Quick Draw" tensiometer (Model 2900, Soilmoisture Equipment Corp., Santa Barbara, Calif.). Soil temperature at the 10-cm and 20-cm depths was obtained with Weston Model 2261 thermometers (Weston Electrical Instrument Corp., Newark, N.J.).

RESULTS

No significant difference in either level or seasonal pattern of leaf water potential,

TABLE 1. *Environmental conditions during experiment. Monthly data and data obtained on the four days of measurements in the spring of 1978 are given. Monthly data came from the official weather station located 351 m northwest of the experimental plots. Daily data were obtained at the plots.*

				Monthly data			
Month	Rain (cm)	Average temperature Max. (C)	Min.	Average evapotranspiration (cm)	Soil temperature, 10 cm Max. (C)	Min.	Wind (km)[a]
Oct. 1977	0.28	24.2	5.3	----[b]	----	----	5775
Nov.	1.63	16.1	—2.1	----	----	----	----
Dec.	0.08	12.0	—6.5	----	----	----	----
Jan. 1978	0.28	3.0	—10.8	----	----	----	----
Feb.	2.16	1.8	—10.7	----	----	----	----
Mar.	0.56	15.1	—1.1	----	----	----	----
Apr.	1.52	23.7	5.3	----	----	----	8893
May	15.34	22.8	9.0	25.1	21.9	14.6	7648
June	6.71	30.3	15.9	35.5	29.6	21.7	6803

				Daily data						
Date	Air temperature at soil surface (C)	Photosynthetically active radiation (μE $m^{-2}sec^{-1}$)	Sky	Wind speed & direction (m sec^{-1})	Soil temperature, 20 cm Nor. (C)	Mod.	Dry[c]	Soil water tension, 50 cm Nor. (centibar)	Mod.	Dry[c]
13 Mar. 1978	18	----	Clear	28.2(W)	9	9	7	1	1	21
12 Apr.	22	1800	Clear	10.9(NW)	14	19	20	15	27	35
10 May	17	600	Partially overcast	10.9(SW)	12	13	14	7	16	21
5 June	16	65	Overcast	2.0(E)	18	18	18	<1	<1	<1

[a] Values totaled for month
[b] Data not available
[c] Normal irrigation, modified irrigation, dryland

osmotic potential, stomatal resistance, or leaf temperature was found among the five cultivars. Therefore, measurements of each parameter taken during the spring have been averaged.

Height

Figure 1 shows the average height of the five cultivars during the spring. After 13 March, when the different irrigation schedules began, plants receiving the modified irrigation were shorter than plants receiving the normal irrigation regime. As expected, the dryland plants were the shortest.

Potentials

Figures 2 and 3 show average leaf water potential and osmotic potential, respectively, of the five cultivars. Turgor potential can be estimated by subtracting osmotic potential from leaf water potential. On 10 May, water potential of the plants receiving the normal irrigation treatment was higher (less negative) than that of the plants receiving the modified irrigation treatment. On 13 March, 12 April, and 5 June, irrigated plants had similar potentials. On 9-10 April, 1.5 cm of rain fell and the ground was wet for all treatments. Dryland plants had the lowest water potential, except on 5 June, when potentials were similar among all treatments. The ground was wet on this day due to 2.9 cm of rain which fell until an hour before the plants were sampled. Osmotic potential results (Fig. 3) paralleled water potential results, except that the osmotic potentials were more negative. Hence, turgor potentials were positive at all times.

Stomatal Resistance

Figure 4 shows the average stomatal resistance of the five cultivars. Dryland plants had a high resistance on 13 March because of little rainfall (Table 1). The rain that fell on 9-10 April and 5 June resulted in low resistances for dryland plants. On 5 June, all plants had low resistances because moisture was plentiful in the soil in all the plots. On 12 April and 10 May, plants receiving the modified irrigation schedule had a higher stomatal resistance than plants receiving the normal irrigation regime.

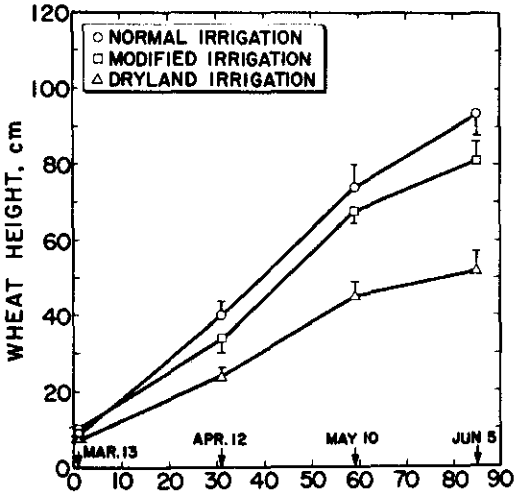

FIGURE 1. Average height of five cultivars of winter wheat grown under three watering regimes. The plants under the normal and modified irrigation schedules received 7.6 cm water per irrigation at different times in the spring (for normal irrigation: 20 March and 3 and 24 April; for modified irrigation: 20 March and 24 April). Vertical lines indicate standard errors. Only half the standard-error line has been drawn to avoid cluttering the figure.

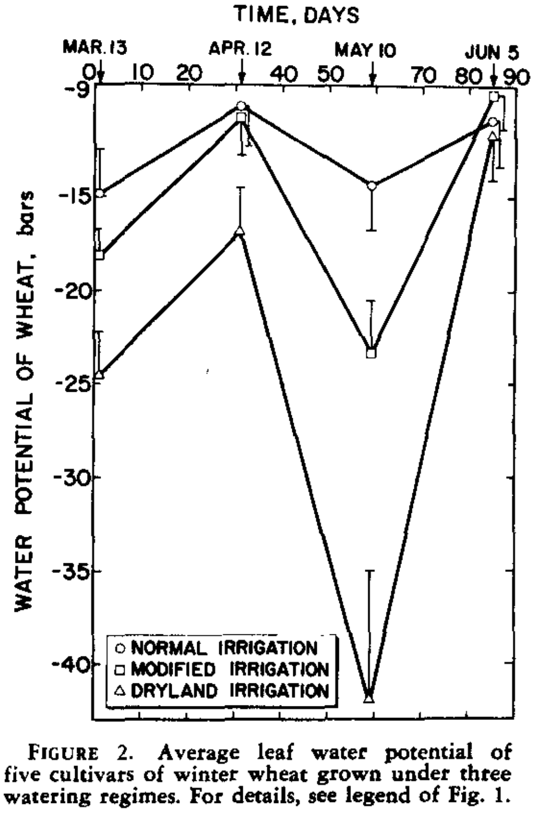

FIGURE 2. Average leaf water potential of five cultivars of winter wheat grown under three watering regimes. For details, see legend of Fig. 1.

Leaf Temperature

Figure 5 shows the average leaf temperature of the five cultivars of winter wheat. On 5 June, just after the rain fell, all leaves were the same temperature. The plants receiving the modified irrigation schedule were warmer than the plants receiving the normal irrigation schedule. This correlates with their higher stomatal resistance (Fig. 4). If stomata are closed or partly closed, less water can be transpired to cool leaves (6).

Grain Harvest

Table 2 shows the height, test weight, and yield of the five cultivars at harvest. Height results were similar to the values taken before harvest (dryland, shortest; normal irrigation treatment, tallest; modified irrigation treatment, intermediate in height).

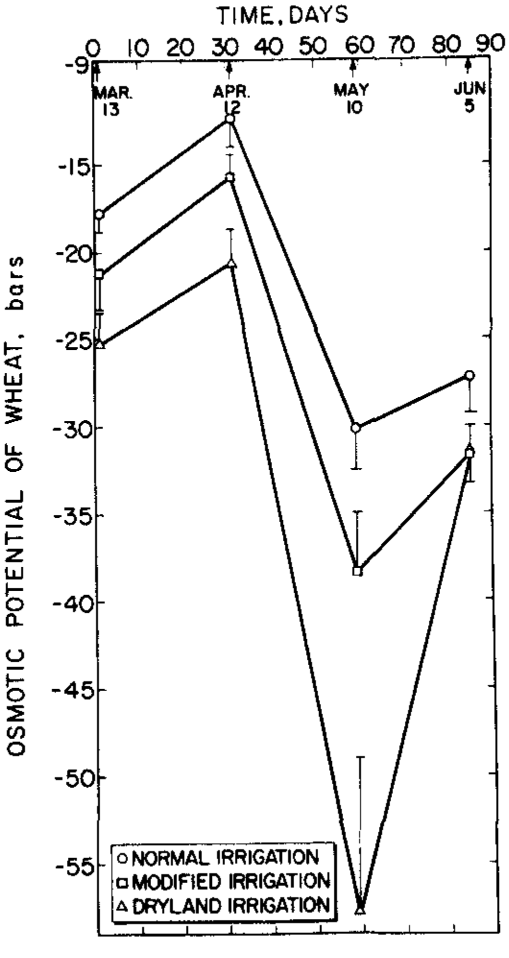

FIGURE 3. Average osmotic potential of five cultivars of winter wheat grown under three watering regimes. For details, see legend of Fig. 1.

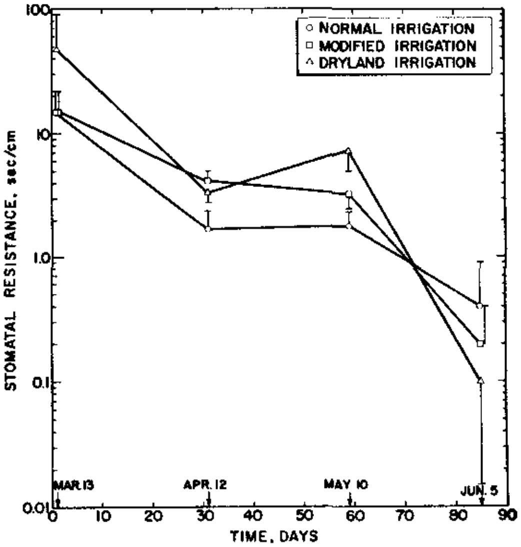

FIGURE 4. Average stomatal resistance of five cultivars of winter wheat grown under three watering regimes. For details, see legend of Fig. 1.

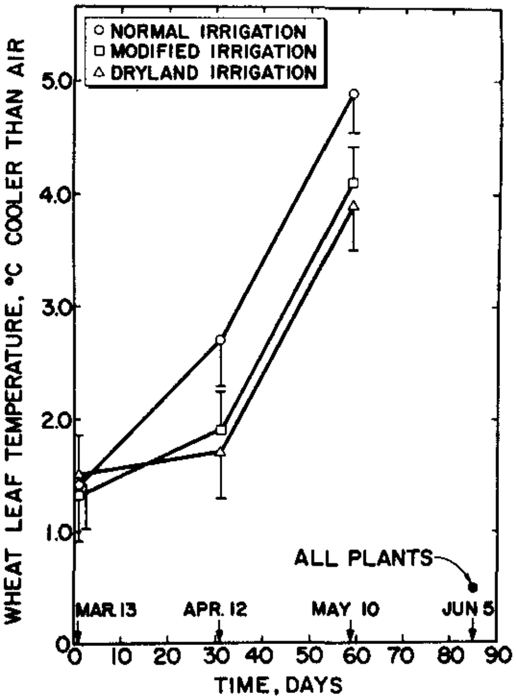

FIGURE 5. Average leaf temperature of five cultivars of winter wheat grown under three watering regimes. For details, see legend of Fig. 1.

The test weight of the dryland plants was lower than that of the irrigated plants. Plants receiving the modified irrigation had a higher test weight than that of the plants receiving the normal irrigation, although the difference was not significant.

Dryland plants yielded the poorest, as expected. However, the plants receiving the modified irrigation treatment yielded 23% more than the plants receiving the normal irrigation treatment (4470 vs. 3640 kg/ha, Table 2).

DISCUSSION

The modified irrigation regime yielded more than the normal regime, even though 7.6 less water was applied to the modified one. The shorter height, lower water potential, lower osmotic potential, higher stomatal resistance, and warmer leaf temperature of the plants receiving the modified irrigation schedule showed that plants were under water stress when measurements were taken in April and May. These plants were showing signs of stress which plants irrigated on 3 April were not. The stress that the plants under the modified irrigation treatment experienced, after water was given at the apparently critical stage in mid-March, was not severe enough to reduce yield.

In Kansas (15) and Texas (8), it is suggested (without supporting data) that irrigation water not be applied to wheat early in the spring because this "causes rank, luxurious vegetative growth and wet conditions which can cause plant lodging and seriously reduce yields" (15). In this experiment, lodging was similar for the two irrigation treatments. Contrary to the Kansas and Texas recommendations, the results of the experiment, although based on limited measurements, showed that wheat yielded well when water was applied early in the spring (mid-March).

Less fuel was needed to pump water for the modified regime because less water was used. Consequently, the modified regime was less costly than the normal regime.

ACKNOWLEDGMENTS

We thank Mr. Leroy L. Penner, Foreman, Panhandle Research Station, for his help throughout this experiment and Prof. Charles E. Denman for help with the statistical analysis of the data.

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Table 2. *Height before harvest, test weight, and yield of five cultivars of winter wheat grown under three watering regimes.*

	Normal irrigation			Modified irrigation			Dryland		
Cultivar	Height (cm)	Test wt. (kg/hl)	Yield (kg/ha)	Height (cm)	Test wt. (kg/hl)	Yield (kg/ha)	Height (cm)	Test wt. (kg/hl)	Yield (kg/ha)
Centurk	102	74	3660	76	78	4280	53	72	2070
Scout 66	92	75	3540	88	77	4700	62	72	1630
Tam W101	67	76	3570	68	79	4650	44	74	1740
Triumph 64	108	78	2740	73	79	3520	58	76	1750
Vona	90	76	4710	80	79	5200	44	73	1090
Average	92	76	3640	77	78	4470	52	73	1660
L.S.D. (5%)	2	2	230	2	1	920	2	2	190
C.V., %	1.2	1.5	3.6	1.2	0.8	11.8	2.8	1.4	6.5

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INFLUENCE OF AREA ON WINTER WHEAT CLIMATIC MODELS

D. M. GREENE, S. M. SUTHERLAND and M. B. KIRKHAM
Department of Geography, University of Oklahoma, Norman, U. S. A.
Department of Agronomy, Oklahoma State University, Stillwater, Okla. 74074, U. S. A.

Abstract. Two areal scales were used to determine the effect of land size on wheat yield estimates from climatic data. The larger scale was the state of Oklahoma and the smaller scale included five crop reporting districts within the state. Two multilinear regression models were developed. One used unadjusted, and the other square-root adjusted, climatic data. Any comparative advantage of district modeling over a state model was judged upon the correlation coefficients of the model and its estimation capability over a five year trial period. When state and district models were compared in estimation capability, the state model achieved more accurate yield estimates of district wheat yields than did the individual district models.

1. Introduction

The United States wheat belt extends north from Texas to North Dakota and west to include the northwestern states. The collective influence of climatic factors such as humidity, rainfall, and temperature make this area well suited for wheat production. Annual climatic variability is the predominant cause of yearly fluctuation in per acre wheat yield at a given location. Although extended periods of drought effect wheat yields, climatic variability will be understood in this paper to represent annual climatic changes or departures from the 30 year normal of 1941 to 1970.

Studies which predict wheat yields due to climatic variables primarily have used land areas equal to or larger than a state (Bridge, 1976; Feyerherm, 1977; Lomas, 1972; Thompson, 1962, 1969; Williams, 1972, 1973). Investigations of areas smaller than a state are few (Katz, 1977; Pitter, 1977) and usually have not been done because of loss in reliability of yield data. State-wide yields have an estimated error of 2%, while districts and counties have an error of 6% and 10%, respectively, (H. Peterson, Statistical Reporting Service, U. S. Department of Agriculture, Oklahoma City, Oklahoma, personal communication). Wheat yields are based upon estimates provided by a random sampling of wheat producers. In the sampling process, the greater number of statewide reports minimize the positive and negative departures from the mean. Districts, therefore, have fewer reports than the state and have a greater potential for error.

Since wheat yield is related to climatic variability at both state and district levels (Hewes, 1965; Penman and Long, 1960), modeling of estimated wheat yields due to climate should be able to be applied to areas smaller than a state. Consequently, in this study, two areal scales were included to determine the influence of size on wheat yield estimates in Oklahoma. Oklahoma was chosen because, even though it is a major producer

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of hard red winter wheat, the best grain for bread, little work has been done on modeling wheat in the state. The smaller scale was the Oklahoma crop reporting district which averages 1,920,000 ha. The larger scale encompassed an area of 12,800,000 ha and was composed of the five western crop reporting districts of Oklahoma. Oklahoma has nine districts, but 96% of the state's wheat is grown in the five western crop reporting districts. For this reason, the larger areal scale was considered to represent Oklahoma, although, in area, it was equivalent to the western two-thirds of the state.

2. Methods

2.1. *Study Location*

Figure 1 illustrates the five Oklahoma crop reporting districts, including the Panhandle (five counties), North Central (eight counties), West Central (six counties), Central (13 counties), and Southwest (eight counties) districts.

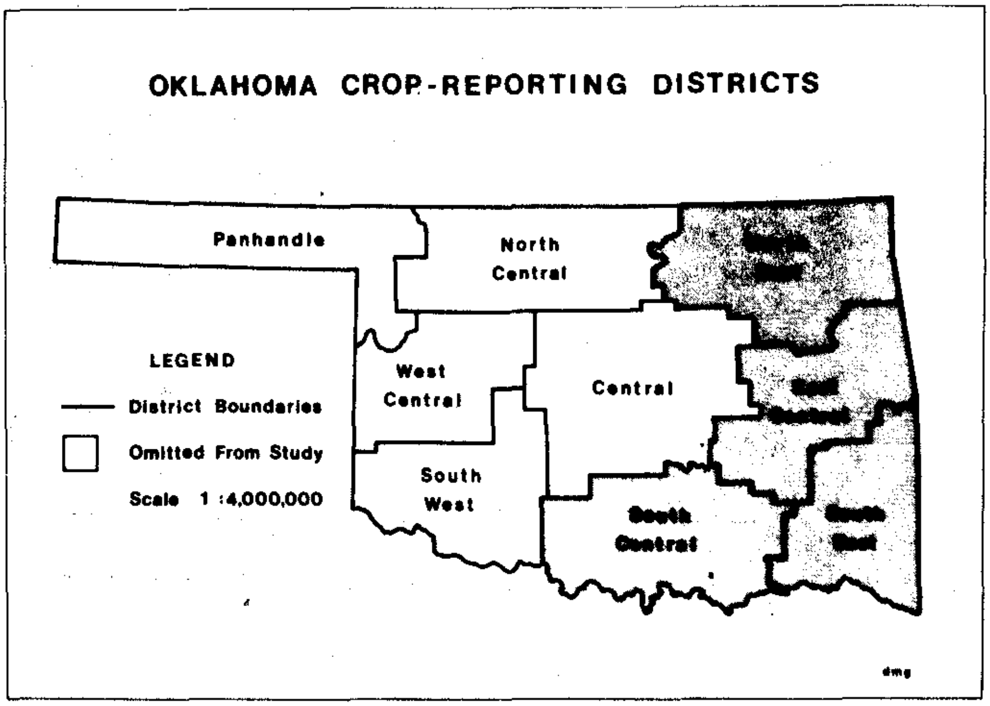


Fig. 1. Oklahoma crop reporting districts utilized in the study.

2.2. *Time*

The time period for the climatic models, described in Section 2.5, included the crop years 1941 to 1970. Model estimates of winter wheat yields for the years 1971 to 1975 were compared to reported yields for those years to test the reliability of the climatic models.

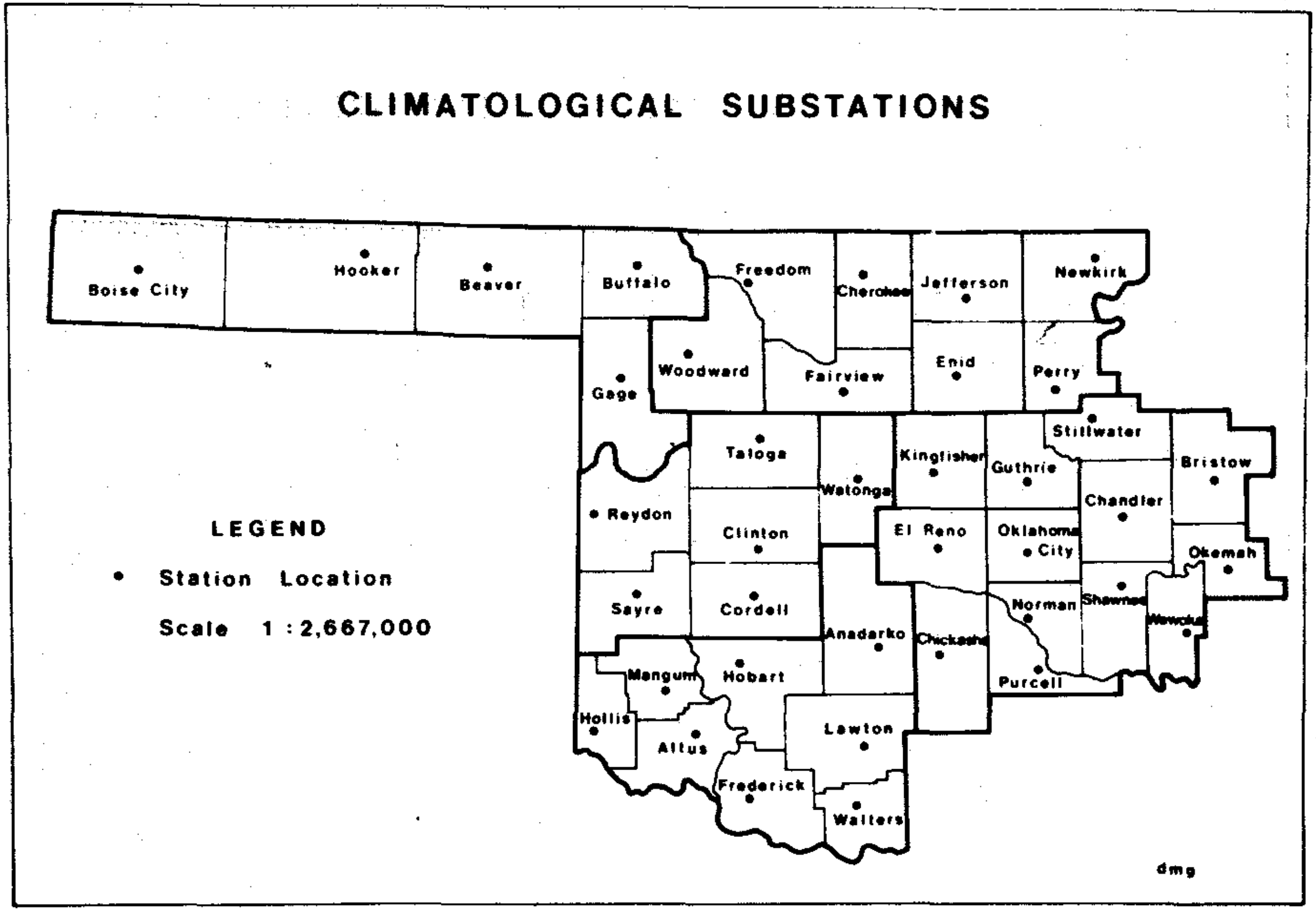


Fig. 2. Location and distribution of forty climatological substations used to obtain weather data.

2.3. *Climatic Data*

Data from 1941 to 1975 from forty climatological substations, one in each of the forty western Oklahoma counties studied, were obtained from *Climatological Data* (United States Department of Commerce, 1941 to 1975). Figure 2 illustrates the location of the forty climatological substations. Each substation was selected for consistency of record and central location within the county. For each year, the monthly rainfall and monthly average temperature were recorded. The temperature and rainfall values for each station were weighted (for weighting factors, see Greene, 1977) to reflect the contribution of wheat production for that county. By this procedure, a localized climate was correlated with wheat yields for each district.

2.4. *Wheat Data*

The wheat yield data, in bushels per harvested acre, for each crop reporting district for the years 1941 to 1975 were obtained from the Statistical Reporting Service (United States Department of Agriculture, 1941 to 1975). The wheat yields were corrected for the effect of technological influences. Many technological innovations occurred during the thirty-five year period studied. Because each innovation could not be accounted for individually (Katz, 1977), the wheat yield data were adjusted to remove the influence of technological factors. Using time as a surrogate for technology (McQuigg, 1975; Thompson, 1962, 1969), the data were corrected with a logistic function by means of a nonlinear least square fitting procedure. The residuals remaining from this practice were then attributed to climatic variation (Greene, 1977).

2.5. *Model Development*

Multilinear regression (Dixon, 1968) was used to explain the annual wheat yield for Oklahoma based upon the climatic variables (monthly rainfall and temperature). From this regression, each variable was considered for its contribution to the model. The variables which were used in the Oklahoma model were also applied in the crop reporting district models.

The criteria for selection of significant variables utilized a *t*-test with a 10% confidence level. The regression technique proceeded in a stepwise fashion with each iteration increasing the coefficient of determination (R) by adding another variable. The R value gives a measure of the effectiveness of each model (Katz, 1977). The selection of the best model was that step which allowed the greatest number of variables and still maintained the 10% confidence limit. All models determined that the coefficient of determination was significantly different from zero at the 1% confidence level on the basis of the *F*-test. In some instances the *t*-test indicated a confidence level better than 10%. In those cases, the confidence level would have fallen below 10% with the addition of one more variable.

Two treatments were completed for Oklahoma and each of the five crop reporting districts. In each of the two approaches, the dependent variable was the residual or difference between reported wheat yield and the wheat yield trend line. In the first set of regressions, the independent variables were unadjusted monthly temperature and precipitation. Average monthly temperatures from January to June and monthly rainfall from September to June were included for each year 1941 to 1970 inclusive. In the second set of regressions, monthly rainfall normals for the thirty year period (1941 to 1970) were determined. For any given year, monthly rainfall anomalies above or below normal were isolated. The magnitude of the departure of abnormal rainfall was replaced by its square root. By this procedure, extreme rainfall variations were reduced to a range more closely approximating the normal rainfall amount.

3. Analysis

3.1. Least-Square Fitting Analysis

Figure 3 shows the results of the least-square fitting analysis for Oklahoma and the five crop reporting districts. Superimposed on each graph is a solid heavy line which represents the trend of average wheat yields. The rapid increase in wheat yields during the mid-1950's suggests that non-climatological factors were intervening. The characteristic S shape of the solid lines in Figure 3 is most likely explained by the introduction of technological innovations. During this decade, practices such as irrigating, fertilizing, and planting new wheat varieties gained wide acceptance. The departures of reported wheat yields from the solid line are attributed to yearly climatic variation.

Two interesting geographic implications are evident in the graphs of the five crop reporting districts in Figure 3. First, the time of occurrence of the wheat yield increase is virtually simultaneous within the five districts. Second, the amount of increase in yields varies geographically. The largest increase in yield was recorded in the Central district while the Panhandle district recorded the smallest yield increase. Considered together, this evidence suggest that a technological innovation was introduced in all districts simultaneously. The effectiveness of the innovation, however, was greatest in the Central and North Central districts.

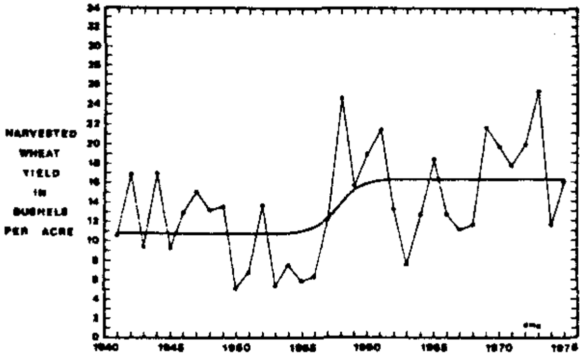
3.2 Stepwise Multilinear Regression

3.2.1 Unadjusted monthly temperature and precipitation

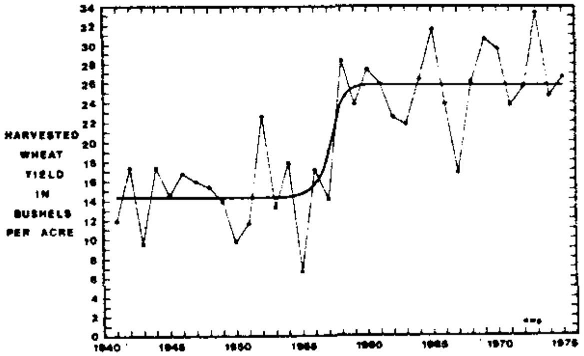
Table 1 shows the regressions for Oklahoma and the five crop reporting districts. Listed in the table are the accepted variables which best estimate wheat yields, their coefficients, R^2, and standard error. The coefficients have been standardized to determine the relative contribution between the variables. Standardizing the coefficients allows a direct comparison of the influence of all of the variables in the multiple regression (Katz, 1977).

A comparison of the coefficients of determination listed in Table I suggests that the district models are as effective as the Oklahoma model in estimating district wheat yield. Three of the five districts report an R^2 higher than the Oklahoma R^2 of 0.733. A possible

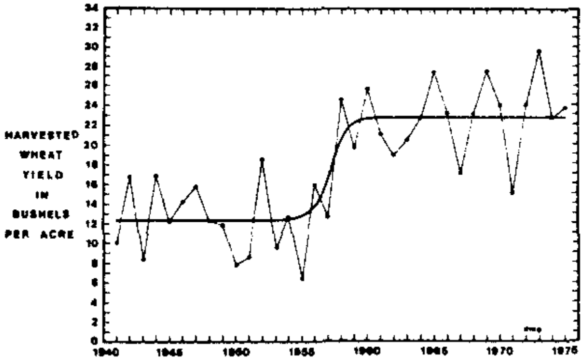
PANHANDLE DISTRICT WHEAT YIELDS 1941 – 1975



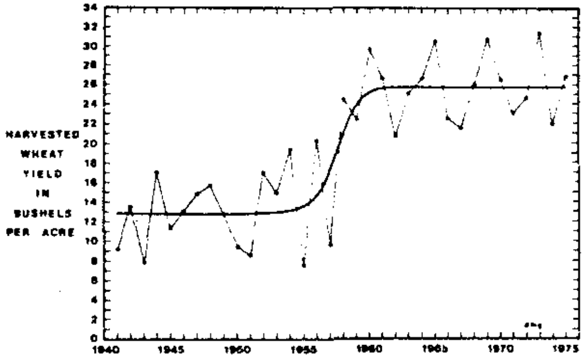
NORTH CENTRAL DISTRICT WHEAT YIELDS 1941 - 1975



WEST CENTRAL DISTRICT WHEAT YIELDS 1941 - 1975



CENTRAL DISTRICT WHEAT YIELDS 1941 - 1975



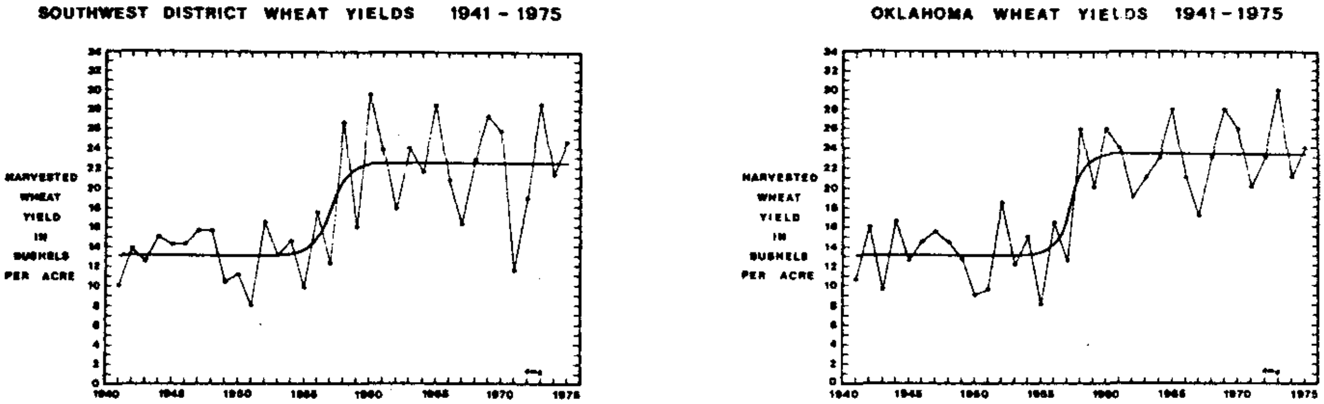


Fig. 3. Oklahoma wheat yields in the state and in five crop reporting districts between 1941 and 1975.

TABLE I: Regression analysis using unadjusted monthly temperature and precipitation data for Oklahoma and five crop reporting districts in the state.

UNADJUSTED COEFFICIENTS 1941–1970 (STANDARDIZED)

	Oklahoma	Panhandle	North Central	West Central	Central	Southwest
Sept.–Oct. Rain		0.328				
Oct.–Nov. Rain	0.340		0.331	0.462	0.433	0.247
Dec.–Jan. Rain			–0.278			
January Rain						0.246
Jan.–Feb. Rain		0.321		0.289	0.206	
February Rain			0.352			
March Rain	0.362	0.344	0.520		0.304	
April Rain		0.164				
May Rain	–0.311			–0.424	–0.489	–0.416
May–June Rain			–0.679			
June Rain	–0.503	–0.208		–0.498	–0.644	–0.464
Jan.–Feb. Temperature			0.266			
March Temp.	–0.384	–0.428	–0.221	–0.303	–0.247	–0.576
R^2	0.733	0.781	0.804	0.630	0.758	0.707
Standard Error	1.904	2.435	2.026	2.315	2.114	2.186

explanation why the West Central and Southwest districts indicated a lower R^2 may be given by the ignored influence of evapotranspiration. The high evapotranspiration rate in the Panhandle may have been less significant a variable as temperature which resulted in a higher R^2 in the Panhandle district.

3.2.2 *Adjusted Monthly Precipitation*

The results of the adjusted precipitation analysis are presented in Table II. A comparison of the accepted variables in this analysis was made with the variables utilized in the unadjusted variable analysis. In the Oklahoma model and the Central district model the accepted variables remained identical in both procedures. Except for the Panhandle district, the remaining crop reporting districts increased the number of acceptable variables as a result of monthly rainfall adjustment.

3.3. *Wheat Yield Estimates*

Figure 4 indicates the estimation capability of the unadjusted and the square root adjusted wheat yield models for 1971 to 1975. All amounts are given as departures from normal rather than actual wheat yield totals. In each case, the reported yield per harvested acre is represented by the solid line. The dotted line shows the unadjusted wheat yield model and the dashed line shows the square root adjusted model. In general, the reported yields and the square root adjusted yields for Oklahoma and the five crop reporting districts agree fairly closely (Figure 4).

TABLE II: Regression analysis using monthly temperature data and square-root adjusted precipitation data for Oklahoma and five crop reporting districts in the state.

SQUARE ROOT ADJUSTED COEFFICIENTS 1941–1970 (STANDARDIZED)

	Oklahoma	Panhandle	North Central	West Central	Central	Southwest
Sept.–Oct. Rain		0.292				
Oct.–Nov. Rain	0.391		0.336	0.603	0.503	0.361
Dec.–Jan. Rain			–0.397			
January Rain						0.338
Jan.–Feb. Rain		0.264		0.380	0.204	
February Rain			0.356			
March Rain	0.351	0.539	0.419	0.323	0.291	
April Rain						–0.199
May Rain	–0.330			–0.394	–0.489	–0.402
May–June Rain			–0.732			
June Rain	–0.479	–0.191		–0.582	–0.715	–0.454
January Temperature				0.283		
March Temperature	–0.342	–0.308	–0.327		–0.203	–0.461
May Temperature			–0.149			
R^2	0.697	0.755	0.868	0.721	0.719	0.715
Standard Error	2.028	2.523	1.660	2.052	2.275	2.203

A question still remaining, of interest to climatic change researchers, is the usefulness of aggregating individual crop-reporting district estimates into a state estimate of wheat yield. Specifically, the five district estimates were averaged (with appropriate weights) to obtain an Oklahoma wheat yield estimate. The Oklahoma wheat yield estimate (derived from district models) is compared to estimates made from the Oklahoma model as shown at the bottom right of Table III. Results indicate that for the five year period 1971 to 1975, the aggregated district estimate of state wheat yield outperformed the state model only one out of five years.

The reverse of the question above is the utility of the state wheat yield model in estimating district yields when given district weather data. Results indicate that the Oklahoma wheat yield model was equally as good in estimating district wheat yields as the district models (Table III). A total of 25 district wheat yield estimates were obtained for five crop reporting districts during a five year period (1971 to 1975). In 13 out of 25 comparisons, the Oklahoma model utilizing regional climatic data obtained closer estimates to the reported wheat yield than did the appropriate district model (Table III). Since the state model achieved closer yield estimates than the district models in 52% of the cases presented, district modeling to obtain district yield estimates serves no practical purpose.

Despite the conclusion that the Oklahoma model is effective in estimating district wheat yields, district estimates remain a practical concern to the wheat producer. A striking example is noted in the Panhandle district for 1973 (Table III). In that year, the Oklahoma model accurately estimated a district yield of 25.4 bushels per acre. This estimate utilized data from five climatic substations within the Panhandle district. The

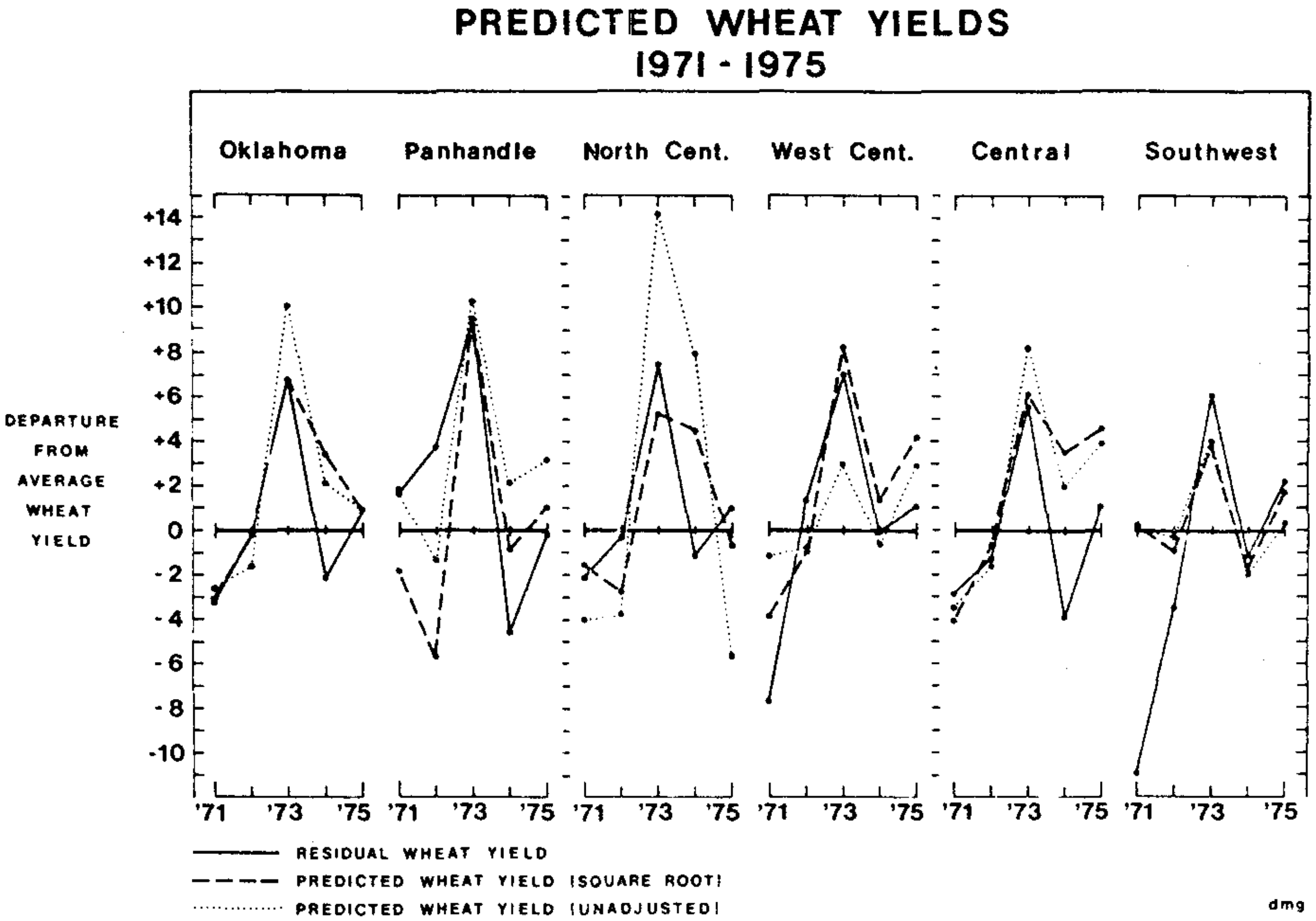


Fig. 4. Predicted and actual Oklahoma wheat yields in the state and in five crop reporting districts using two climatic models.

TABLE III: Comparison of state and crop reporting district models in estimating wheat yields for 1971 to 1975.

Panhandles (5 counties)

	Reported	District	State
1971	17.8	14.4	17.0
1972	19.9	10.6	15.7
1973	25.4	25.7	25.4
1974	11.6	15.3	18.3
1975	16.0	17.2	18.1

North Central (8 counties)

	Reported	District	State
1971	23.7	24.2	22.8
1972	25.5	23.1	26.2
1973	33.3	31.1	33.7
1974	24.7	30.4	31.0
1975	26.8	25.2	26.9

West Central (6 counties)

	Reported	District	State
1971	15.0	18.8	18.1
1972	24.0	21.7	21.4
1973	29.6	30.9	28.7
1974	22.6	24.0	23.8
1975	23.8	26.8	23.9

Central (13 counties)

	Reported	District	State
1971	23.0	21.7	21.6
1972	24.5	25.1	24.4
1973	31.3	31.8	30.5
1974	21.9	29.3	29.4
1975	26.9	30.4	32.5

Southwest (8 counties)

	Reported	District	State
1971	11.5	22.6	19.0
1972	18.9	21.5	20.7
1973	28.5	26.1	25.6
1974	21.2	20.6	21.9
1975	24.6	24.1	19.7

Oklahoma (40 counties)

	Reported	Aggregated Districts	State
1971	20.0	21.2	20.5
1972	23.0	20.9	21.5
1973	30.0	32.1	33.3
1974	21.0	25.9	25.4
1975	24.0	22.5	24.0

same model estimated the 1973 Oklahoma wheat yield at 33.3 bushels per acre, some 3.3 bu/acre in excess of the reported yield for the state. In point of fact, if one compares the state predicted yield (based on all counties and 40 climatic data points) with that of the state model administered to the climatological stations within a specific district, then the latter produces yield estimates more accurately 16 out of 25 times.

The models developed in this study were compared to the one described by the Center for Climatic and Environmental Assessment (C.C.E.A.) (McQuigg, 1975). Over the period 1971 to 1975 in which all models were tested, the square root adjusted model was better than the unadjusted model and both were superior to the C. C. E. A. model.

4. Implications

The Oklahoma and crop-reporting district models presented are useful in determining the capability of district modeling to obtain local wheat yield estimates. The results of this analysis indicate that a state-wide model can be used successfully in obtaining yield estimates at an areal size of the crop-reporting district. The significance of this conclusion suggests that research dealing with the impact of a climatic change on crop yields at the state level will also be valid for crop-reporting districts.

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PLANT-WATER RELATIONS AND YIELD OF WHEAT ON RIDGES TILLED IN THE EAST-WEST DIRECTION

M. B. Kirkham

Department of Agronomy, Oklahoma State University,
Stillwater, Oklahoma 74074 USA

ABSTRACT

Winter wheat (Triticum aestivum L. em. Thell.) was grown in rows on ridges tilled in the east-west direction, under irrigated and dryland conditions in the Panhandle of Oklahoma, USA, to determine if yield of plants in south-facing rows was greater than yield of plants in north-facing rows. In addition to yield, measurements of height, leaf temperature, stomatal resistance, leaf water potential, and leaf osmotic potential were taken on plants in north- and south-facing rows. Differences in stomatal resistance, water potential, and osmotic potential of north- and south-facing plants could not be detected. South-facing plants had a cooler leaf temperature than did north-facing plants. South-facing plants grew more than 10 cm taller, and yielded as much as two times more, than did north-facing plants. The results showed that wheat in the Panhandle of Oklahoma should be planted on south sides of ridges for maximum yields.

INTRODUCTION

In the Panhandle of Oklahoma, where wheat is furrow-irrigated, farmers always have noted that wheat planted on the south side of ridges oriented in the east-west direction grows taller than wheat planted on the north side of ridges. The increase in height has never been quantified. Also, it is not known whether or not wheat on the south side of a ridge yields more than wheat on the north side.

There have been few studies of effects of row orientation on plant growth. Day et al. (5) and Erickson et al. (7) review the literature. Studies show that plants (wheat, barley) oriented in east-west rows yield more grain than plants oriented in north-south rows (4, 5, 7). Day et al. (5) attribute the increased yields to warmer soil temperatures on south-facing rows of crops oriented in the east-west direction, which has been observed by several workers (2,3,8,10). This results in faster germination and early growth of south-facing plants compared to north-facing plants. The warmer temperatures also may have effects during later stages of growth when mature, south-facing plants are directly in sunlight. This might result in wider stomatal openings for increased photosynthesis. If stomata were more widely open in plants on south-facing rows, leaf temperatures would be cooler, too, since transpiration rates would be higher.

The objective of this research was to determine if there were differences in leaf temperature, stomatal resistance, plant water potentials, growth, and yield of winter wheat in north- and south-facing rows sown on ridges in the east-west direction. Measurements were taken during the second half of the wheat's growth cycle (from the beginning of spring growth to harvest, 151 to 235 days after planting.

MATERIALS AND METHODS

The field-plot layout, instruments used, and details of procedures already have been described (11). To summarize briefly: The experiment was carried out at the Panhandle Research Station, Goodwell, Oklahoma, during the 1977-1978 growing season. Certified hard red winter wheat (Triticum aestivum L. em. Thell.) seed was planted in east-west rows on 13 Oct. 1977. Plants were grown dryland and with furrow irrigation. There were nine beds (nine ridges of plants), six irrigated beds and three dryland beds. Each bed was 142 cm in width and six rows of wheat were planted in each bed. There were 20 cm between rows. In each bed, rows were numbered 1 to 6, with row 1 on the north side and row 6 on the south side. Five cultivars of wheat, commonly grown in the Panhandle, were studied: 'Centurk', 'Scout 66', 'Tam W101', 'Triumph 64', and 'Vona'. The irrigated plots were planted with 30.5 kg seed/ha and the dryland plots were planted with 15.3 kg seed/ha. The soil type was a Richfield clay loam, which is classified as an Aridic Argiustoll. Irrigated plants were given pre-planting and post-emergence irrigations in the fall and not irrigated again until the spring (first spring irrigation was on 20 March).

On four days in the spring (13 March, 12 April, 10 May, 5 June), measurements of height, leaf temperature, stomatal resistance, leaf water potential, and leaf osmotic potential were taken between 08:00 and 10:00 hr on three plants in row 2 (on the north side of a bed) and three plants in row 5 (on the south side of a bed). Rows 1 and 6 were not measured because they were on the sides of the beds. Rows 2 and 5 were on the ridge of a bed.

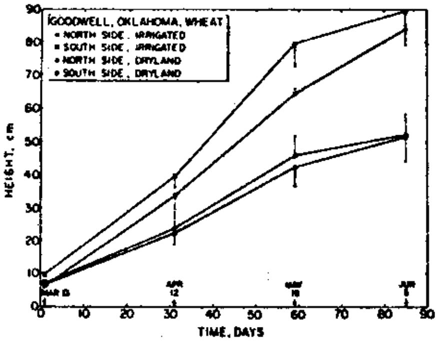
On 5 June 1978, wheat heads were harvested from 30-cm sections in rows 2 and 5. The entire head, including the awns, was weighed and the following four characteristics of the heads were noted: number of spikelets per head (whether filled with grain or not); number of spikelets with at least one grain filled; number of potential grains per head if all grains were filled; number of actual grains filled per head. Ten heads from each 30-cm sample from a row were counted and averaged.

RESULTS

No significant difference in either level or seasonal pattern of leaf temperature, stomatal resistance, leaf water potential, or leaf osmotic potential was found among the five cultivars. Therefore, measurements of each parameter taken during the spring have been averaged.

Height. Under both irrigated and dryland conditions, plants on the south side of a bed were taller than plants on the north side (Fig. 1). Irrigated plants on the south side of rows grew more than 10 cm taller than wheat on the north side. Irrigated wheat on south sides of beds was taller when growth started to resume in the spring (13 March measurements) than other plants. This suggested that the south-facing plants were taller in the fall, too, before winter dormancy set in.

Leaf temperature. Under both irrigated and dryland conditions, leaves of plants on south-facing rows were cooler than leaves of plants on north-facing rows (Fig. 2). Leaf temperatures of south-facing, irrigated plants were as much as 4.5°C cooler than air. Ehrler et al. (6) found leaves of irrigated durum wheat in Phoenix, Arizona, USA, to be as much as 11°C cooler than air just before sunset (see their Fig. 3). Daytime values which they observed were similar to those seen in this experiment. On 5 June, a 2.9 cm rain fell until an hour before measurements were taken. (Reference no.11 gives amounts of rain that fell during the experiment.) Just after the rain, all leaves were the same temperature.



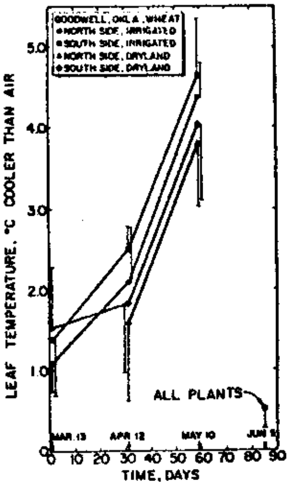


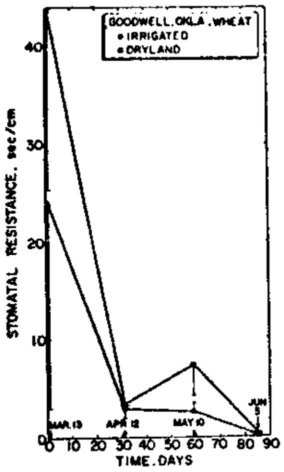
Figure 1. (Left). Height of irrigated and dryland winter wheat in north- and south-facing rows on east-west ridges. Vertical lines indicate standard errors. Only half the standard-error line has been drawn to avoid cluttering the figure. Figure 2. (Right). Leaf temperature of irrigated and dryland winter wheat in north- and south-facing rows on east-west ridges. For vertical lines, see legend of Fig. 1.

Stomatal resistance. Even though leaf temperatures were cooler on south-facing slopes, differences in stomatal resistance of plants in north- and south-facing rows could not be detected. Therefore, leaf temperature appeared to be a more sensitive indicator of water loss from the leaves than stomatal resistance. The stomatal-resistance data from the north- and south-facing rows were averaged together and are presented in Fig. 3. Resistances were high on 13 March because of little rain during the preceding winter. Stomatal resistance of irrigated plants was high, too, because they did not receive the first spring irrigation until 20 March. Rain that fell on 9-10 April and 5 June resulted in low resistances for dryland plants.

Plant potentials. Differences in potentials of plants in rows on north and south sides of beds could not be detected and results have been averaged (Fig. 4). Irrigated plants had a higher water potential, and a higher osmotic potential, than did dryland plants. Dryland plants apparently took up large amounts of salts to adjust to the dry conditions (note the low osmotic potentials in Fig. 4). This resulted in their having a higher turgor potential, after 13 March, than that of the irrigated plants.

Yield. Table 1 shows the yield of the plants on 5 June 1978. Under both irrigated and dryland conditions, plants in south-facing rows yielded more than did plants in north-facing rows. On an average, wheat on south-facing rows under irrigated and dryland conditions, respectively, yielded 1.4 and 1.6 times more than wheat on north-facing rows. In some cases (for example, Centurk, irrigated), the yield was up to two times more when plants were on south-facing rows than when they were on north-facing rows. Day et al. (5) also noted that the south row position on east-west beds of irrigated wheat in Arizona, USA, had a higher grain yield than did the north row position.

The greater yield in this experiment was due to a greater number of spikelets and a greater number of filled grains (Table 2). Except for a few cases (for example, Triumph 64, irrigated; Vona, dryland), plants on south-facing rows had more total spikelets, more spikelets with at least one grain filled, more grains per head, and more potential grains per head.



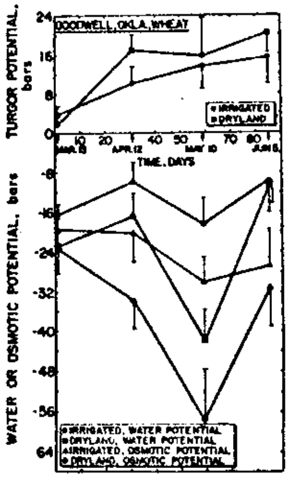


Figure 3. (Left). Stomatal resistance of irrigated and dryland winter wheat grown on east-west ridges. For vertical lines, see legend of Fig. 1. Figure 4. (Right). Water, osmotic, and turgor potential of irrigated and dryland winter wheat grown on east-west ridges. For vertical lines, see legend of Fig. 1.

Table 1. Weight of irrigated and dryland winter wheat heads, harvested 5 June 1978, on north and south sides of east-west ridges. Average coefficient of variation was 23%.

	Irrigated		Dryland	
Cultivar	North side	South side	North side	South side
	g/30-cm of row			
Centurk	43.4	84.5	31.2	83.9
Scout 66	40.5	69.1	12.0	27.1
Tam W101	48.6	63.8	23.5	24.3
Triumph 64	61.6	65.3	29.9	33.3
Vona	74.6	81.6	26.9	29.7
Average	53.7	72.9	24.7	39.7

Table 2. Total number of spikelets per head, number of spikelets per head with at least one grain filled, number of filled grains per head, and number of potential grains per head of irrigated and dryland wheat on north and south sides of east-west ridges. Average coefficients of variation for the above four measurements were, respectively, 8%, 7%, 12%, 12%.

Cultivar & treatment	Total spikelets/ head	Spikelets/ head with at least one grain filled	No. of filled grains/ head	No. of potential grains/ head
Centurk				
Dryland				
North	13	10	25	31
South	14	13	31	32
Irrigated				
North	13	11	25	27
South	12	11	26	28
Scout 66				
Dryland				
North	11	5	11	21
South	11	9	18	24
Irrigated				
North	12	7	16	24
South	14	13	31	33
Tam W101				
Dryland				
North	10	7	15	19
South	12	6	11	21
Irrigated				
North	11	9	20	22
South	12	10	20	24
Triumph 64				
Dryland				
North	12	10	19	22
South	12	11	22	24
Irrigated				
North	13	12	28	29
South	13	10	24	26
Vona				
Dryland				
North	14	6	15	32
South	14	6	13	28
Irrigated				
North	13	12	35	36
South	13	12	35	37

DISCUSSION

The results showed that plants on south-facing rows in ridges tilled in the east-west direction grew taller, had a cooler leaf temperature, and yielded up to two times more than plants on north-facing rows in the same ridges. Plants on south-facing rows probably grew and yielded more because they could absorb more of the sun's energy than could plants on the north-facing rows. South-facing plants produced more photosynthate which resulted in more grains per head than north-facing plants. Light, therefore, might have been partially limiting growth of plants on north-facing slopes. However, the major cause of increased growth of south-facing plants might have been due to temperature rather than light. On 12 April, for irrigated plants, the soil temperature at the 20-cm depth, at the base of the south and north slope, was 19 and 15°C, respectively, and for dryland plants, 21 and 17°C, respectively. On 10 May, plants shaded the soil and differences in soil temperature at the 20-cm depth on north and south slopes could not be detected. As wheat-root temperatures increase from about 15 to 25°C, stomatal conductance increases linearly (9). Therefore, the warmer root temperatures probably resulted in the cooler leaf temperatures of south-facing plants, which transpired more water than north-facing plants. It has been known for a long time that growth increases with increase in temperature, up to an optimum (1,12). The results of this study suggested that it might be worthwhile for farmers in the Panhandle to till the ground into east-west ridges and plant only on the south sides of the slopes. The north-facing slope could be steep so a minimum amount of land would not be planted. Fertilizer could be placed only on the south sides of ridges to ensure maximum growth.

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