PHYSIOLOGICAL MEASUREMENTS OF WINTER WHEAT UNDER STRESS: I. WATER RELATIONS, GROWTH, ELEMENTAL COMPOSITION, AND YIELD OF WHEAT GROWN WITH FERTILIZER PLACED IN STRIPS OR BROADCASTED II. WATER RELATIONS OF WHEAT GROWN IN NORTH-SOUTH VERSUS EAST-WEST DIRECTIONS III. WATER RELATIONS OF WHEAT CULTIVARS GROWN WITH CADMIUM

By

CALVIN H. PEARSON

Bachelor of Science

Brigham Young University

1978

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
December, 1979

PHYSIOLOGICAL MEASUREMENTS OF WINTER WHEAT UNDER STRESS: I. WATER RELATIONS, GROWTH, ELEMENTAL COMPOSITION, AND YIELD OF WHEAT GROWN WITH FERTILIZER PLACED IN STRIPS OR BROADCASTED II. WATER RELATIONS OF WHEAT GROWN IN NORTH-SOUTH VERSUS EAST-WEST DIRECTIONS III. WATER RELATIONS OF WHEAT CULTIVARS GROWN WITH CADMIUM

Thesis Approved:

M. B. Kirkham
Thesis Advisor

James D Ownby

Lavoy I. Croy

Norman N Durham
Dean of the Graduate College

PREFACE

The traditional organization of this thesis has been altered to assist the reader in understanding the material. The thesis contains three independent areas which have been prepared for publication. The results have been written to suit the format for publication. Information shown in this pattern will allow the reader to understand the material more easily than if the traditional form had been used. In each chapter, the information is given under the usual headings of a publication: abstract, introduction and literature review, materials and methods, and results and discussion. All the references are given collectively at the end of the thesis. A general summary of the results from the entire thesis is reported for all three studies.

The three areas are:

I - Water relations, growth, elemental compositions, and yield of wheat grown with fertilizer placed in strips or broadcasted.

II - Water relations of wheat grown in north-south versus east-west direction.

III - Water relations of wheat cultivars grown with cadmium.

I would like to thank sincerely, Dr. Mary Beth Kirkham, my major advisor. Her kind and sincere help has made the work of producing this thesis a gratifying task. I would also like to thank Dr. Lavoy I. Croy, committee member, for his genuine interest, helpful knowledge, and friendly association. I would also like to acknowledge Dr. James D. Ownby, committee member, for his part in giving me much of the basic

information for understanding the physiology of plants. My appreciation also is extended to Harold Gray, fellow graduate students, and professors who have offered their knowledge, services, and equipment to assist my research. My thanks go to the Agronomy Department and OSU for the tools of learning they offered me, and also to Dr. Ronald McNew for help with the statistics.

Special appreciation and love go to my wonderful wife, Heidi for her support and concern, and for her time spent typing this thesis.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER I

WATER RELATIONS, GROWTH, ELEMENTAL COMPOSITION, AND YIELD OF WHEAT GROWN WITH FERTILIZER PLACED IN STRIPS OR BROADCASTED

ABSTRACT

A physical theory of fertilizer placement, proposed by van Wijk and de Wit in the Netherlands in the 1950's, predicts that fertilizer use is more efficient if the fertilizer is put in strips rather than broadcasted. Results of many experiments show that yields are greater if fertilizer is localized rather than spread throughout the soil. The physiological reasons for the differences in yield of plants grown with the two types of fertilizer placement have not been studied extensively. No information exists concerning the osmotic potential of plants grown with fertilizer in strips or broadcasted, even though osmotic damage with contact placement is of prime concern. Therefore, to determine how severe osmotic injury is with stripped compared to broadcasted fertilizer, wheat (Triticum aestivum L. em. Thell, 'Osage'), was grown both in the greenhouse and in the field, with fertilizer (urea ammonium phosphate, 28:28:0, 200 kg/ha) placed in strips with the seed at planting or broadcasted before planting worked into the surface to approximately a 5 cm depth. Control plants grew with no fertilizer. The soil was a Kirkland silty loam (Udertic Paleustoll). In addition to osmotic potential; total water potential, stomatal resistance, leaf area,

germination rates, and height were measured during the experiment. At harvest, grain yield of field-grown plants and vegetative yield of greenhouse-grown plants were determined. Elemental composition of the shoots and roots of wheat from the greenhouse, were analyzed. Protein in the grain was evaluated.

During the first 20 days after planting, the osmotic potential, as well as the total water potential, of greenhouse-grown plants with fertilizer placed in strips was 2 to 3 bars lower, and the stomatal resistance was 2 to 3 sec/cm higher, than those of plants grown with the broadcasted fertilizer. These differences were not observed in the field where plants under the two fertilizer treatments had similar total water potentials, osmotic potentials, and stomatal resistances 20 days after planting, when the first measurements began, until the end of the experiment. During the winter months in the field, control plants had lower total water and osmotic potentials, and higher stomatal resistances, than fertilized plants. Leaves of greenhouse-grown plants with the stripped fertilizer had 16% more nitrogen (N) and 44% more phosphorus (P) than leaves of plants grown with the broadcasted fertilizer. There was no significant difference in concentration of any element in the roots. Field plants grown with the broadcasted fertilizer were tallest and had the largest leaf area. However, grain yields of plants grown with the stripped and broadcasted fertilizer were the same. Therefore, more vegetative growth in the field did not result in a higher grain yield. Protein was highest in the plot with the stripped fertilizer. The results showed that, 20 days after planting, the osmotic potentials of plants grown with fertilizer placed in strips or broadcasted were the same. Much of the extra N and P in the leaves of plants with the stripped fertilizer must have been taken up during the first 20 days of growth when the osmotic potential was lowered.

INTRODUCTION

The physical theory of fertilizer placement (de Wit, 1953; van Wijk, 1966) predicts that, at low rates of fertilizer application, more fertilizer will be taken up if it is placed in a strip (row, band) than if it is broadcasted. The literature reports many successful experiments with stripped placement. Higher yields often have been obtained using the same amount of fertilizer per unit area in strips than with broadcasting. Olson and Dreier (1956) reviewed papers published between 1900 and 1953. Franklin (J. D. Franklin. 1978. Drill application of ammonium phosphate fertilizers with the seed of irrigated barley on calcareous soils. M. S. Thesis, Montana State Univ., Bozeman, Mont. 128 p.) cites work printed since 1956. In January, 1979, I did a survey of abstracts of articles, concerned only with wheat grown with fertilizer placed in strips or broadcasted, and published in the last five years. Sixty-two experiments had been done. Thirty-four of the experiments showed higher yield with stripped than with broadcasted treatments; 11 showed lower yields; and 17 showed no difference.

There is a monetary incentive to put fertilizer in strips rather than to broadcast. During World War II when fertilizer was scarce, English farmers realized more economical use of fertilizer for grain crops by means of localized fertilizer placement (van Wijk, 1966 p. 4). More recently, research in Indiana (Barber 1974, 1976, 1977a, 1977b) indicates it is profitable to apply fertilizers to only part of the soil rather than to broadcast. Regarding phosphorus placement, Tisdale and Nelson (1975) explained that band placement reduces the surface contact between the soil and fertilizer which causes a reduction in fixation. Therefore, this results in a more economical use of the fertilizer. However, for a dissenting view see Fox and Kang (1978), who worked with corn (Zea mays, L.) in the tropics. They found that major economies in fertilizer use were not achieved as a result of localized placement. Farmers find stripped placement of fertilizer bothersome and often avoid it (Regis D. Voss, Iowa State Univ., and Billy B. Tucker, Okla. State Univ., personal communications). But many farmers are restricting use of fertilizer because of its high price. They might be willing to place fertilizer in strips if they could save money. Also, they would conserve fuel because they could place the seed and fertilizer together and make only one trip across a field at planting time.

The physical theory assumes that at low salt concentrations, roots in stripped treatments will take up more fertilizer because they are in closer contact with the fertilizer than roots in broadcasted treatments (de Wit, 1953; Mortvedt, 1976; van Wijk, 1966). At high concentrations, the fertilizer becomes toxic, presumably because of unfavorable osmotic suctions (de Wit, 1953: Passioura and Wetselaar, 1972). However, few articles in the literature report physiological reasons for yield differences of plants grown with fertilizer placed in strips or broadcasted. None of the articles shows the plant-water relations and the osmotic potential of plants. Osmotic potential is of primary importance when considering localized versus broadcasted fertilizer treatments. This experiment was conducted to see if we could measure physiological differences among wheat plants grown in the greenhouse or the field with fertilizer placed in strips or broadcasted.

The fertilizer was urea ammonium phosphate, a new fertilizer developed by the Tennessee Valley Authority, with several advantages (Allen, 1970; Hundal et al., 1977; National Fertilizer Development Center, 1976). It provides a 1:1:0 ratio granular fertilizer for use in bulk blends or fluid suspension. It is potentially useful in the production of high-analysis grades having ratios such as 1:1:1, 1:1:2, 3:1:0 because only one material (either urea or potash) needs to be added to the 28:28:0. The P_2O_5 in the fertilizer is 100% available and essentially all water soluble. The fertilizer is lighter in weight than other forms of P fertilizer. In the granulation process, no dryer is required. Also, when ammonium sources of N fertilizer are placed in a strip containing phosphate, the presence of the ammonium fertilizer increases the uptake of P. Mixing the two fertilizer materials together has no effect on the uptake of N from the ammonium source (Fried et al., 1975).

In semi-arid regions, like the Southern Great Plains, the potential market for urea ammonium phosphate is large because soils are N- and P- deficient (Oklahoma Agricultural Extension Service and Oklahoma Plant Food Educational Society, Inc., 1977). Placement of P, particularly, is important with small grains because the effective growing season is shorter and soil temperatures are cooler than with larger-grained crops like corn (Zea mays L.) (Olsen and Flowerday, 1971). Stripped placement of P at planting appears more desirable since P does not move in the soil to a great extent (Phillips and Webb, 1971; Tucker, 1968), especially under dry conditions (Schlenhuber and Tucker, 1967; Watanabe et al., 1960). Experiments in which urea ammonium phosphate has been banded or broadcasted in the Southern Great Plains have been carried out (Leikam et al., 1977). Yields were higher with the banding, But, again, no work concerning its effect on osmotic potentials of plants has been published. The main objective of this research, therefore, was to measure the osmotic potentials of wheat grown with urea ammonium phosphate placed in strips or broadcasted. Total water potential, stomatal resistance, germination rates, height, leaf area, elemental uptake, and yield were also measured.

MATERIALS AND METHODS

The field study was conducted between October, 1978, and June, 1979, at the Oklahoma State University Agronomy Research Station, Stillwater, Oklahoma. There were six adjacent plots, as follows:

Plot 1 - Fertilizer in strips; plants in east-west rows
Plot 2 - Fertilizer broadcasted; plants in north-south rows
Plot 3 - Fertilizer in strips; plants in north-south rows
Plot 4 - Fertilizer broadcasted; plants in east-west rows
Plot 5 - No fertilizer; plants in east-west rows
Plot 6 - No fertilizer; plants in north-south rows

The wheat was planted in different row directions to minimize the effect of row orientation. In Oklahoma, row direction has an influence on yield (Erickson et al., 1979). The row direction study is found in chapter 2. The plots with the fertilizer each measured 23.5 x 28.0 m and the plots with no fertilizer (controls) each measured 16.5 x 16.5 m. Winter wheat had been cropped on the land for the past two years and had been plowed after harvest each year. Each year it was tilled prior to planting, and during the summer it was fallowed.

The soil was a Kirkland silty loam, which is classified as an Udertic Paleustoll; fine, mixed, thermic (Gray and Roozitalab, 1976). Soil samples were taken from each plot and analyzed for pH, NO_3^-N, P, and K using standard soil-test procedures (details of procedures may be obtained from the Soil and Plant Testing Laboratory, Department of Agronomy, Oklahoma State University, Stillwater). The plots did not vary significantly in fertility. The average pH was 4.8 and the average NO_3^-N, available P, and available K were 40, 71, and 368 kg/ha, respectively. These soil test results showed that the soil was low in N, but high in P and K (Tucker, 1968; Oklahoma Agricultural Extension Service and Oklahoma Plant Food Educational Society, Inc, 1977).

On October 12, 1978, the urea ammonium phosphate (28:28:0) was placed on plots 2 and 4, at a rate of 200 kg/ha, using a Gandy Turf Spreader, which was 120 cm wide. On October 13, the entire land was tilled including the broadcasted area. The broadcasted fertilizer was incorporated into the ground to about the 5 cm depth. On October 14 (day 1), the wheat (Triticum aestivum L. em. Thell. 'Osage') was planted at the 2 cm depth in all plots using a John Deere grain drill, 20 cm between rows. In plots 1 and 3, fertilizer was placed with the seed. The width of the fertilizer band was 2 cm. In the other plots, only seed was planted. The seed was planted at a rate of 67 kg/ha.

Germination counts in each plot were made on days 18, 19 and 27 after planting. On days 14, 20, 27, 39, 48, 146, 164, 174, 181, 188, 195, 207, and 228, height of four plants, chosen at random in each plot, was measured from the ground to the tip of the longest leaf. After heading, height was measured from the ground to the tip of the head, excluding the awns. Leaf area was measured on the same days, except for day 228 (leaf area was measured on day 224) using a leaf-area meter (Portable Area Meter Model LI-3000 and Transparent Belt Conveyer Accessory Model LI-3050A, LI-COR, Inc., Lincoln, Nebraska). Total leaf area of the four plants, chosen at random from each plot, was measured between days 14 and 164. Between days 174 and 224, only flag-leaf area were measured. On the same days as listed above, but starting on day 20 and continuing through day 224, with a measurement on day 56, total water potential was measured on two plants in each plot using thermocouple psychrometers (Model C-52 Sample Chamber, Wescor, Inc., Logan, Utah). A leaf disc (6 mm in diameter) was cut in the field from a mature, young leaf and immediately placed in the stainless-steel holder of the thermocouple chamber. After an equilibration time of two hours (Nelson et al., 1978) the potential was measured using a microvoltmeter (Model HR-33T Dew Point Microvoltmeter, Wescor, Inc., Logan, Utah). The tissue was then frozen by removing the stainless-steel holder, covering it with transparent tape, and putting it in a freezer at -25°C for 24 hours, after which time repeatable osmotic potentials were obtained. The osmotic potential was determined using the same procedure as was used to determine total water potential. On the days that leaf area was measured (day 14-224), diffusive resistance of stomata on the upper leaf surface was measured on four plants, randomly chosen in each plot, with a calibrated stomatal diffusion porometer (Kanemasu, et al., 1969) (Model LI-65 Autoporometer and Diffusive Resistance Sensor LI-20S, LI-COR, Inc., Lincoln, Nebraska). On day 39, it took longer than two minutes for the meter to respond, so the stomata were considered closed and values are not reported. All measurements, as described above, were taken between 0900 and 1000 hours.

Neutron probes (Nuclear-Chicago P-19 probe) were installed in the center of each plot on October 18 and measurements were taken on days 18, 53, 145, 182, and 232.

Meteorological data were provided by the Oklahoma State University Agronomy Research Station Class AB Weather Station, Stillwater, Oklahoma (National Oceanic and Atmospheric Administration, 1978-1979a, 1978-1979b), located 500 m northwest of the plots. Data are only presented for the months during which the wheat was in the ground. Environmental conditions also were determined directly at the plots each day that plant measurements were taken. The weather conditions are given in Table I.

On day 256, a one-meter-square area in the center of each plot was hand harvested by pulling up every plant. Roots were cut off, plants were weighed, and the number of tillers were counted. On day 259 (June 25, 1979), the plots were harvested by a small-plot combine (Chain Machine Co., Haven, Kansas), which cut a 150 cm swath. Three swaths were taken from each of the six plots, which resulted in 18 samples. Combining was done in a direction perpendicular to row plantings. Test weight of the grain was determined (Model 26 Hand Type Weight Per Bushel Tester, Seedburo Equipment Co., Chicago, Illinois). Grain moisture content was determined (Model 7000 Grain Moisture Sensor, Nova Sensor Corp., Anoka, Minnesota). To obtain 1000-kernel weight, 100 seeds from each of the 18 samples were weighed. The grain and straw were analyzed by the Oklahoma State University Soil and Plant Testing Laboratory for N, P, K, Ca, Mg, Mn, Fe, and Zn. Protein was obtained by using the Udy dye method (Protein Analyzer Model S, Udy Analyzer Co., Boulder, Colorado).

TABLE I

ENVIRONMENTAL CONDITIONS DURING EXPERIMENT. MONTHLY DATA CAME FROM THE CLASS AB WEATHER STATION LOCATED ABOUT 500 m NORTHWEST OF THE EXPERIMENTAL PLOTS. DAILY DATA WERE OBTAINED AT THE PLOTS.

	Monthly Data				
Month	Rain	Average Temperature	Average Evapotranspiration	Solar Radiation (Monthly Average of Noon Values)	Wind
	cm	°C	cm/day	w/m^2	km
Oct.1978	3.8	16.1	0.57	580	4448
Nov.	9.4	10.3	...†	331	4385
Dec.	0.9	2.8	...	388	5155
Jan.1979	4.5	- 5.3	...	391	4648
Feb.	0.8	- 1.8	...	432	4368
Mar.	9.0	9.9	...	643	5911
Apr.	8.0	14.6	...	659	4824
May	14.2	18.8	0.61	605	4764
June	11.0	24.7	0.64	667	4576

TABLE I (Continued)

Daily Data

Date (Days After Planting)	Air Temperature Canopy Height	Relative Humidity	Average Wind Direction	Solar Radiation	Cloud Cover
	°C	%	m/sec	w/m^2	(0-10 with 0=no clouds)
27 Oct. 1978 (14)	15.0	69	2.57(S)	490	0
2 Nov. (20)	17.2	70	2.83(S-SE)	438	0.5
9 Nov. (27)	11.7	73	4.12(SE)	390	1
21 Nov. (39)	1.1	...	2.83(N)	44	10
30 Nov. (48)	5.0	...	2.06(E-NE)	123	8.5
19 Dec. (67)	17.8	86	2.57(S)	...	7
8 Mar. 1979 (146)	10.6	57	2.57(SE)	900	4
26 Mar. (164)	15.6	71	2.06(E-NE)	750	3
5 Apr. (174)	22.8	52	2.95(S)	810	0
12 Apr. (181)	14.4	68	5.14(W)	830	3
19 Apr. (188)	22.8	70	6.43(S)	370	10
26 Apr. (195)	17.2	51	3.60(N)	865	0
8 May (207)	23.3	75	6.95(S)	130	7
25 May (224)	20.0	56	2.06(S)	675	2

† Data not available.

The greenhouse experiment, conducted at the Controlled Environmental Research Laboratory, Oklahoma State University, Stillwater, lasted between January 15 and March 18, 1979 (64 days). During this time, the day and night temperatures varied from 18 to 36°C and 12 to 23°C, respectively. Relative humidity varied between 40 and 96%. The cultivar of wheat used in the field experiment was also used in the greenhouse experiment. The wheat was grown in 13 wooden containers (62 cm long, 30 cm wide, 21.5 cm deep), varnished and painted for waterproofing. Twelve 16 mm holes were drilled equidistant apart in the bottom for drainage. The same treatments, as done in the field, were repeated in the greenhouse study. Five containers had fertilizer placed in strips; five containers had the fertilizer broadcasted; three containers had no fertilizer. Before planting, salinity sensors (Soil Salinity Sensor Model 5000-A read with Salinity Bridge Model 5500, Soilmoisture Equipment Corp., Santa Barbara, California) and soil thermocouple psychrometers (PT-51 Soil Hygrometer/Psychrometer, Wescor, Inc., Logan, Utah) were placed in the containers. Soil psychrometers were attached to the same microvoltmeter which was used to determine plant potentials. Each container with the stripped treatment had two salinity sensors: one in the middle of the container (2 cm depth) and one in the row where the seed was planted (2 cm depth). Each container with the stripped treatment also had two soil psychrometers, adjacent to the salinity sensors, but 10 cm distant. The containers with the broadcasted fertilizer and with no fertilizer each had one salinity sensor and one soil psychrometer placed at the center of the container.

The soil in the containers was the same as used in the field, except in the greenhouse the soil was autoclaved for four hours at 35°C at .54 atmospheres. It was saturated with water three days before planting and was kept moist during the study. The soil psychrometers in all containers always read more than -0.1 bar, so soil potentials are not reported. In the stripped treatments, there were two rows per box, 15 cm long (running the width of the container) and 20 cm apart, equidistant from each edge of the container. The same rate of seeding was used in the greenhouse as in the field. This resulted in about 22 seeds per row. The same measurements as done in the field were done in the greenhouse, except leaf area and water content of the soil were not determined. The greenhouse experiment provided data on electrical conductivity of the soil solution which the field experiment did not. The wheat was not vernalized in the greenhouse, so no grain formed. At the end of the greenhouse study, the shoots were cut at the soil surface and dried to constant weight at 70°C and weighed. The plants were analyzed by the Oklahoma State University Soil and Plant Testing Laboratory for N, P, K, Ca, Mg, Fe, Mn, and Zn.

Statistical procedures described by Steel and Torrie (1960) were followed. Standard errors of the means were determined for the height, leaf area, total water potential, osmotic potential, stomatal resistance, and electrical conductivity. An analysis of variance was calculated for the grain-yield data. Duncan's new multiple-range test (5% level) was used in analyzing the nutrient-uptake data and data obtained at harvest (number and weight of tillers/m^2, test weight, grain moisture, 1000-kernel weight).

RESULTS AND DISCUSSION

Germination

In both the field and greenhouse, plants started to emerge about the same time in all treatments (about 10 days after planting in the field), but rate of emergence was different (Table II). Plants grown with the fertilizer placed in strips germinated more slowly than plants grown with the broadcasted fertilizer. This suggested that the high osmotic concentration in the soil solution inhibited germination. This has been observed frequently (de Wit, 1953; Lawton and Davis, 1960; United States Salinity Laboratory Staff, 1954). In the greenhouse, all seeds finally emerged. But in the field, more seeds germinated in the broadcasted area than in the stripped area.

Stomatal Resistance

The control plants in the field in the winter tended to have high stomatal resistances (Figure 1), which correlated with the low potenials of these plants (Figures 2, 3). Greenhouse-grown plants with the fertilizer placed in strips had high resistances just after planting which correlated with the low potentials of these plants at this time (Figures 2, 3). At other times, stomatal resistances were similar among the three treatments, both for plants in the field and greenhouse. Stomatal resistance was lower under field conditions than under greenhouse conditions. But plants in the greenhouse were generally operating at higher total water and osmotic potentials than the plants in the field. These results showed that, even though relative differences in stomatal resistance and leaf potentials might be similar under field

TABLE II

GERMINATION RATE OF WHEAT GROWN WITH FERTILIZER PLACED IN STRIPS OR BRAODCASTED. CONTROLS GREW WITH NO FERTILIZER.

	Days After Planting					
Greenhouse	6	8	9	12	15	22
Average no. of plants/row (about 22 seeds/row planted)†						
Strip	2	6	10	17	21	22
Broadcast	16	21	21	22	22	22
Control	19	20	20	21	21	21

	Days After Planting		
Field	18	19	27
Average no. of plants/m^2 †			
Strip	96	121	123
Broadcast	145	171	180
Control	74	123	128

† Average coefficient of variation was 16%.

† Average coefficient of variation was 14%.

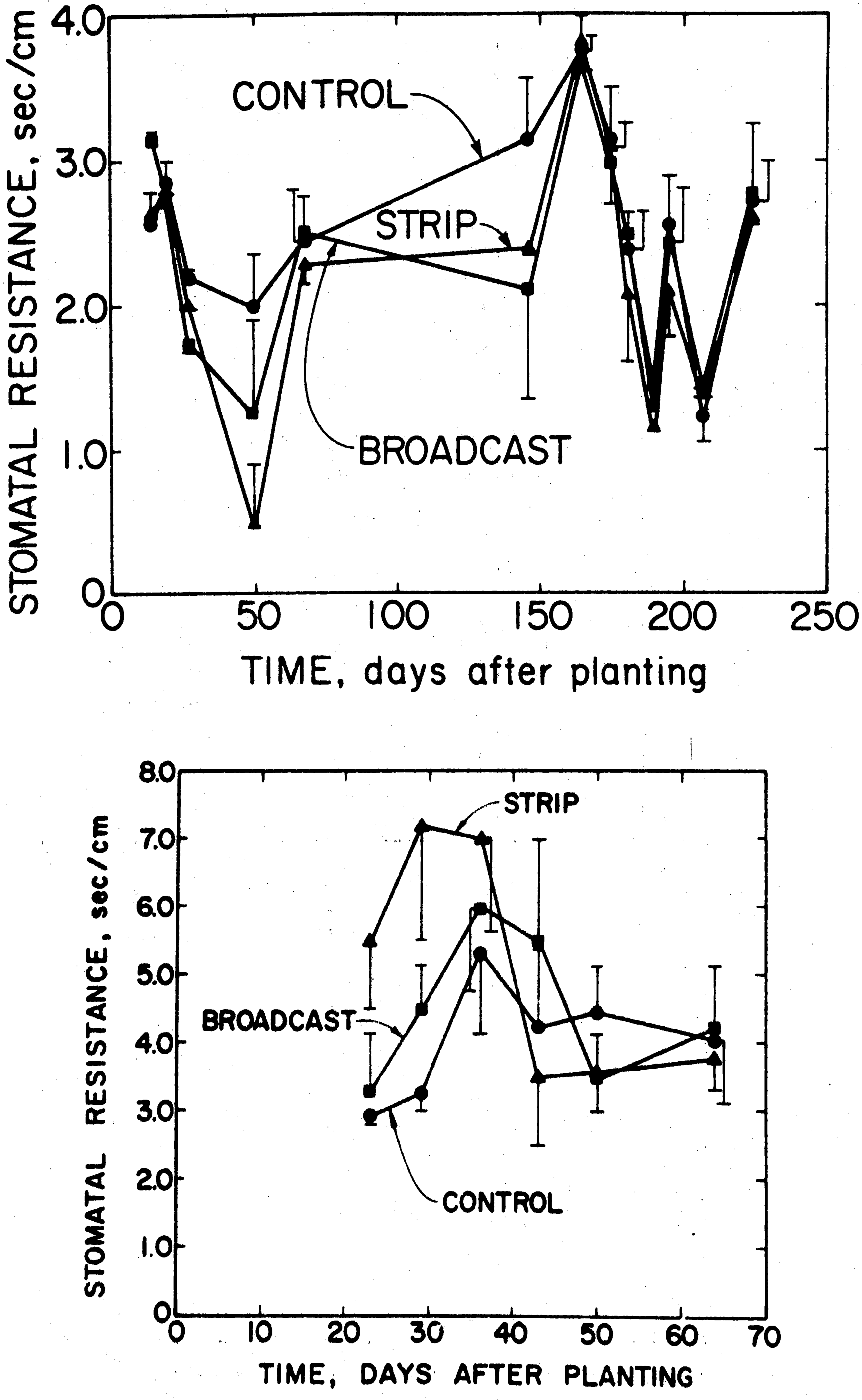


Figure 1. Stomatal Resistance of Wheat Grown With Fertilizer Placed in Strips or Broadcasted. Controls Had no Fertilizer. Above: Field Results. Below: Greenhouse Results. Vertical Lines Indicated the Standard Error. Only Half the Standard-Error Line Has Been Drawn to Avoid Cluttering the Figure.

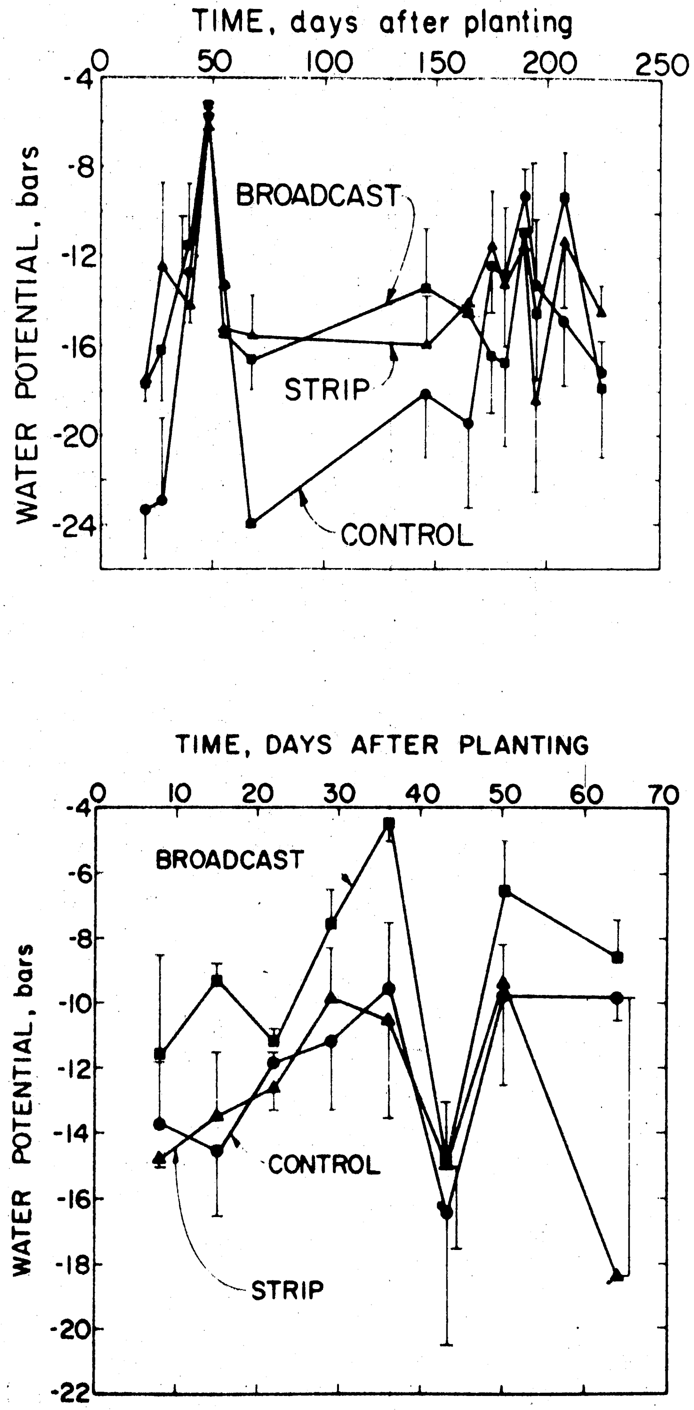
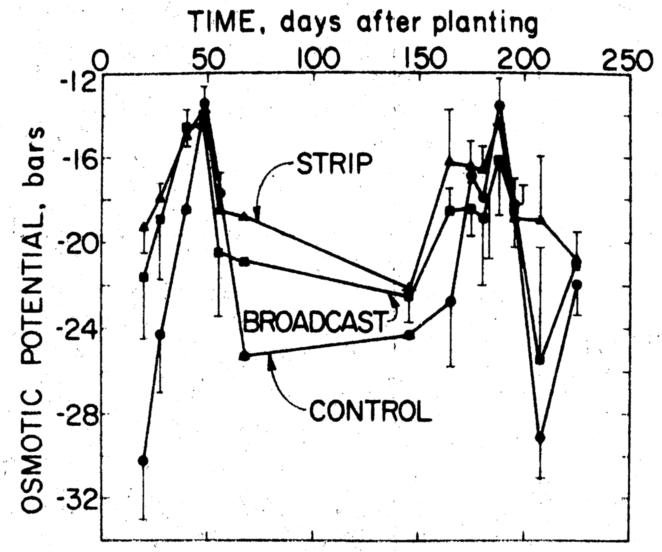


Figure 2. Water Potential of Wheat Grown With Fertilizer Placed in Strips or Broadcasted. Controls Had no Fertilizer. Above: Field Results. Below: Greenhouse Results. For Vertical Lines, See Legend of Figure 1.



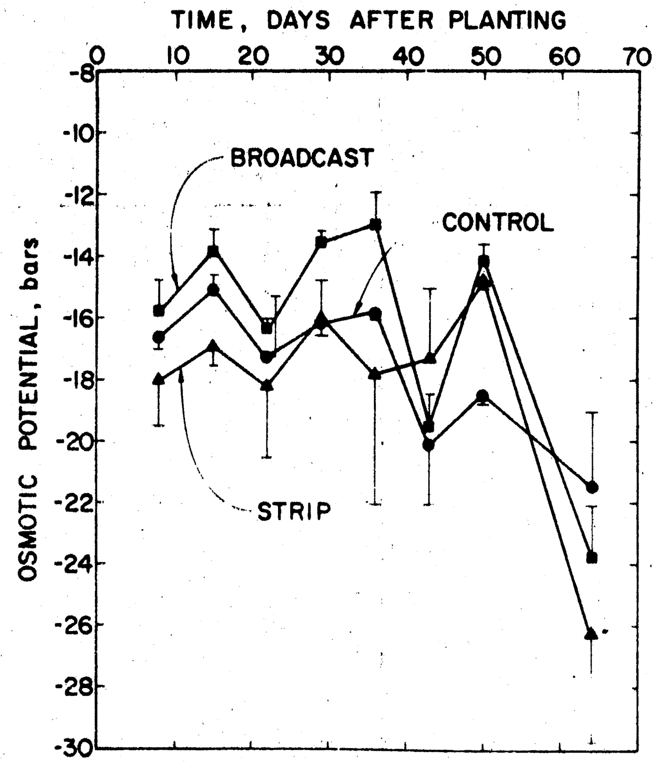


Figure 3. Osmotic Potential of Wheat Grown With Fertilizer Placed in Strips or Broadcasted. Controls Had no Fertilizer. Above: Field Results. Below: Greenhouse Results. For Vertical Lines, See Legend of Figure 1.

and greenhouse studies, absolute values will be different in the two environments.

Water Potentials

In the field, the total water potential (Figure 2) and osmotic potential (Figure 3) of the plants grown with fertilizer were similar. Measurements of potential started 20 days after planting, when leaves were large enough for stomatal resistance measurements. Changes in leaf potential which might have occurred in the 10 days between emergence and the first measurement, therefore, were not observed. However, in the greenhouse, the plants grown with the fertilizer placed in strips had a lower total water potential and a lower osmotic potential in the first 20 days after planting than did the plants grown with the broadcasted fertilizer (Figures 2, 3). When the high salt concentration was present near the plant in the stripped treatment, the plant took up the salts, the osmotic potential was lowered, and, consequently, the total water potential was lowered. Electrical-conductivity (Figure 4) measurements confirmed that concentrations were high in the stripped areas. But the conductivity fell a short distance from the strip. Between strips the conductivity was the same as that in treatments with the broadcasted fertilizer. The roots did not have to grow far to get out of the zone of high salt concentration. The strips were 22 cm apart. If the roots grew only 10 cm, they were not in the zone of high salt concentration. The osmotic potential of greenhouse-grown plants with stripped fertilizer was more negative than the broadcasted fertilizer, except between 40 and 50 days after planting. Yet, the osmotic potential of plants grown in the field with broadcasted fertilizer was

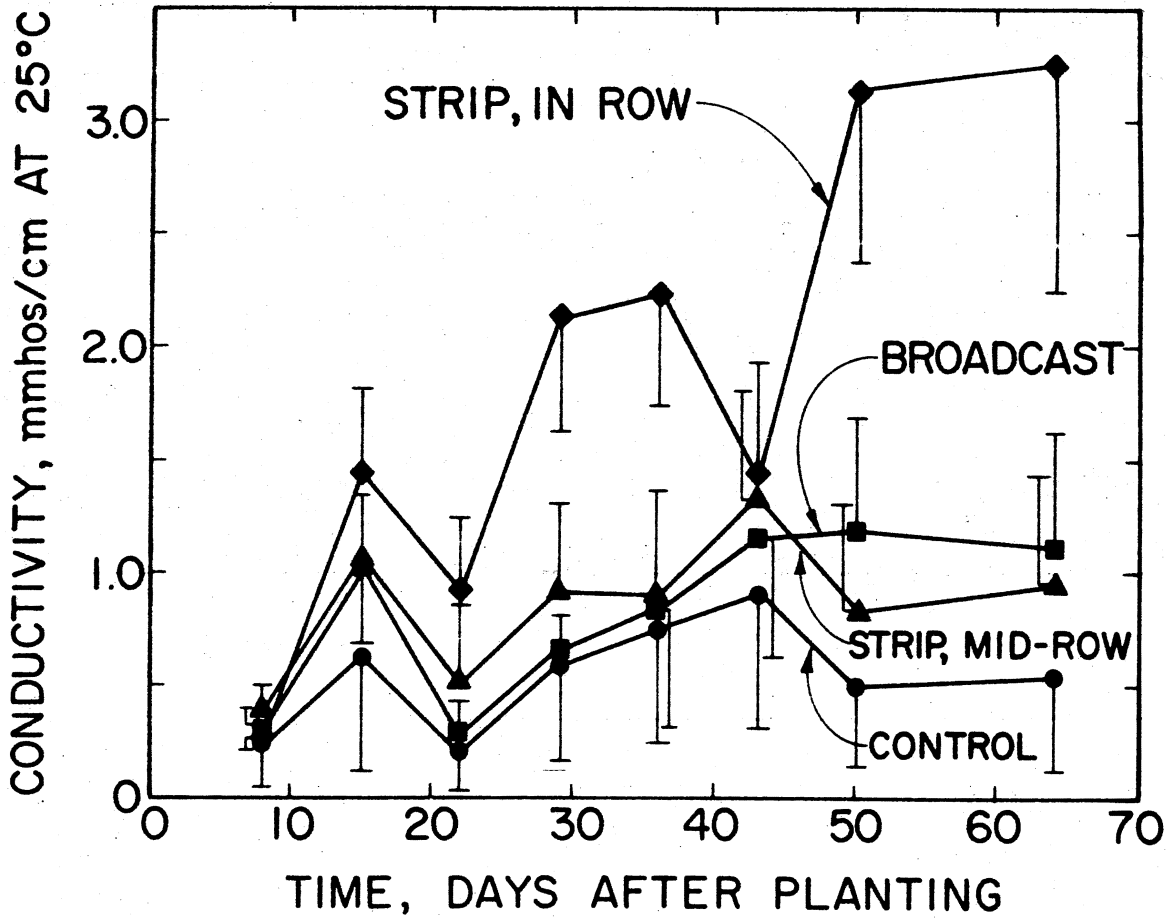


Figure 4. Electrical Conductivity of a Silty Loam Soil With Fertilizer Placed in Strips or Broadcasted. Controls had no Fertilizer. Experiment Was Done Under Greenhouse Conditions. For Vertical Lines, See Legend of Figure 1.

slightly lower than plants with stripped fertilizer placement.

The low water and osmotic potentials of the control plants, especially in the field during the winter months, were unexpected. Apparently, inadequate amounts of fertilizer can cause low potentials as well as excessive amounts of fertilizer. Frost resistance depends on an increase in cell sap concentration of soluble organic substances and inorganic ions to lower the freezing point. In this connection, the influence of plant nutrition is important. Kemmler (1974) reported results of an experiment in the U.S.S.R. where resistance to winter killing is of particular importance. Losses of winter wheat due to winter killing were lowest in plots that had received a complete NPK treatment in the autumn. He also pointed out that adequate fertilization results in a deep root system which permits a better chance of survival than a weak root system. The 1978-1979 winter in Stillwater was one of the coldest ones on record. Perhaps the plants grown with the fertilizer were better able to adjust to the cold conditions because of their high fertility, which the control plants could not do. The control plants in the greenhouse had water potentials similar to the plants grown with fertilizer (day 49, Figure 3). This suggested that the low water and osmotic potentials of control plants observed in the field were the results of the outdoor environmental conditions, in combination with lack of fertilizer, and not due just to lack of fertilizer.

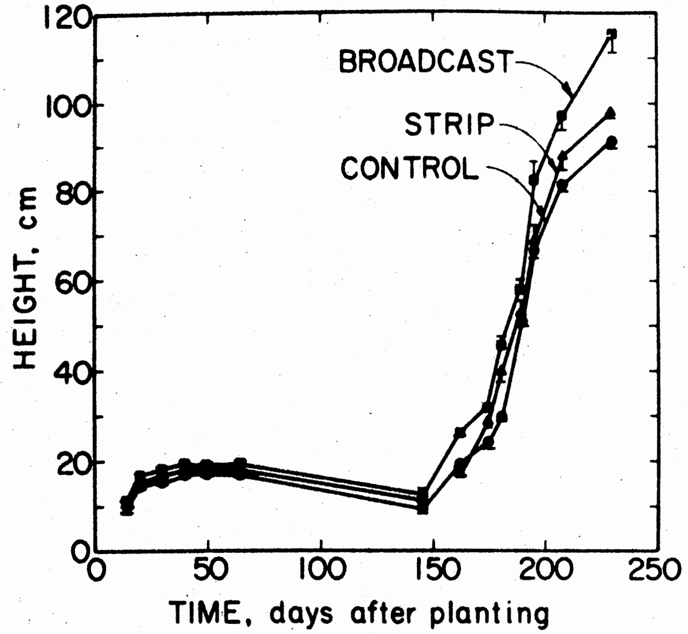
In the field, the plants grown with the broadcasted fertilizer tended to have an osmotic potential intermediate between the plants grown with the stripped fertilizer (highest potential) and those grown with no fertilizer (lowest potentials). Obviously, the high concentration of fertilizer placed in strips next to the seed had no effect on osmotic potentials after 20 days.

Growth

Plants grown with the broadcasted fertilizer were the tallest (Figure 5) and had the largest leaf area until flag leaves began to senesce about 200 days after planting (Figure 6). Armyworms infested the plots 220 days after planting. Damage done by armyworms to the flag leaf resulted in a greater reduction in leaf area than would normally be expected. The distribution of armyworms was fairly uniform throughout all the plots. Consequently, each treatment experienced the same condition. On day 228, plants grown with the broadcasted fertilizer were 17 cm taller than plants grown with the fertilizer placed in strips (115 vs. 98 cm, Figure 5). In the greenhouse, the plants grown with the stripped fertilizer were the shortest until the end of the experiment when heights of all plants were similar (Figure 5). Differences in leaf area between the two fertilizer treatments were most apparent 164 days after planting when plants grown with the broadcasted and stripped fertilizer had total leaf areas of 168 and 72 m^2, respectively (Figure 6).

Soil-Water Content

Control plants in the field were not utilizing the available water (Figure 7). The vegetative growth of the control plants was smaller than that of plants grown with fertilizer (Figures 5, 6) and there was less leafy area for transpiration. Consequently, less water was removed from plots with control plants than plots with fertilized



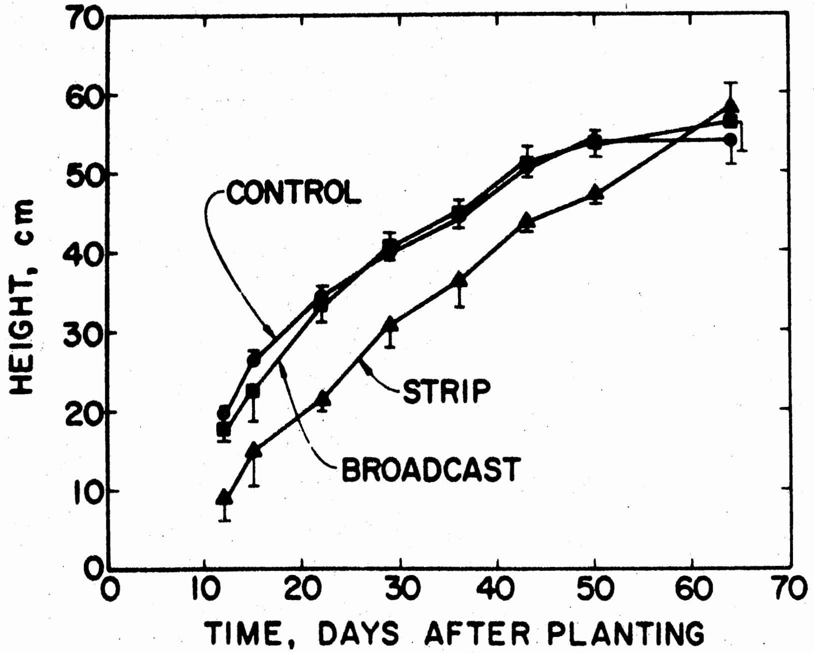


Figure 5. Height of Wheat Grown With Fertilizer Placed in Strips or Broadcasted. Controls Had no Fertilizer. Above: Field Results. Below: Greenhouse Results. For Vertical Lines, See Legend of Figure 1.

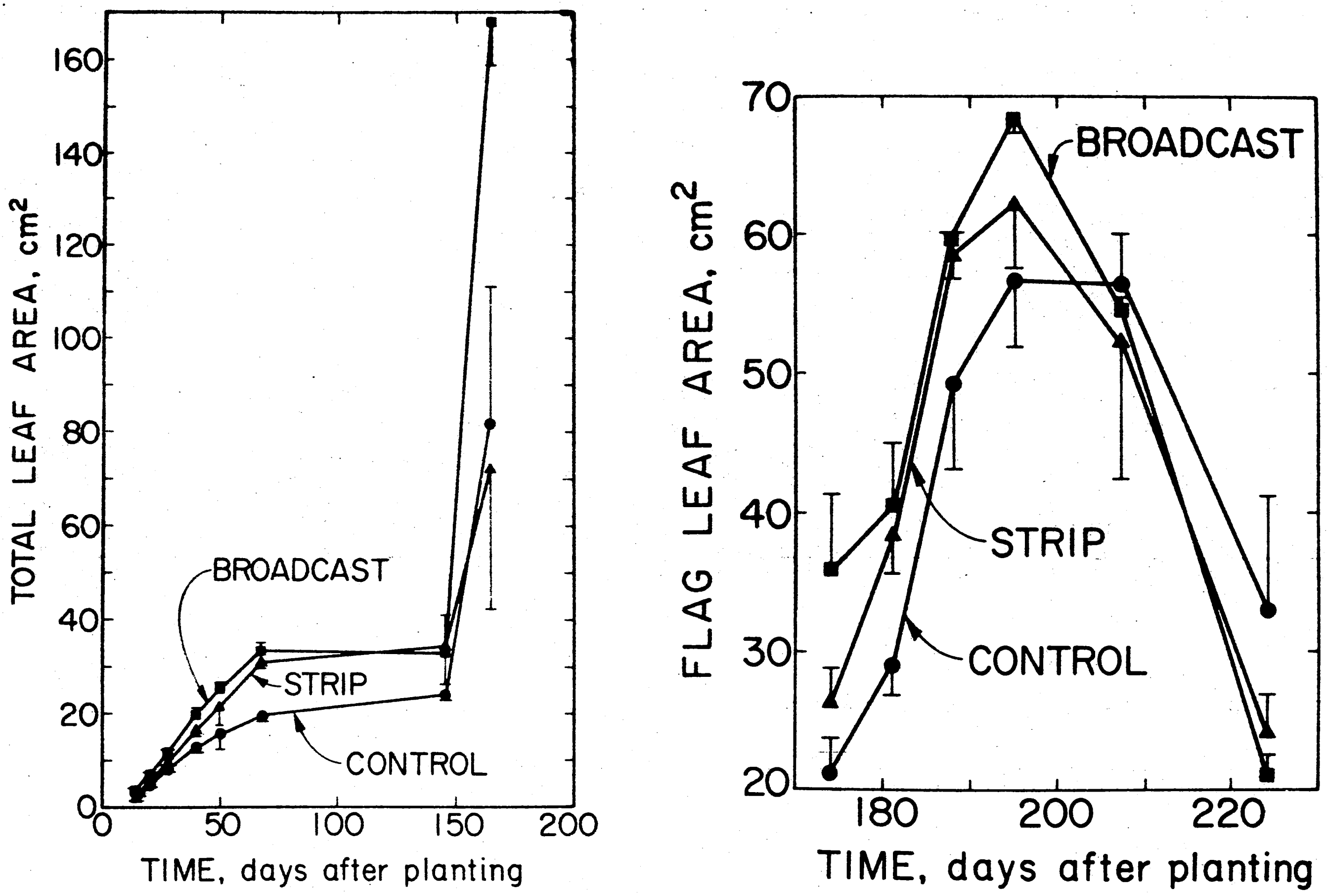


Figure 6. Leaf Area of Wheat Grown With Fertilizer Placed in Strips or Broadcasted. Controls Had No Fertilizer. Experiment Was Done Under Field Conditions. Left: Total Leaf Area of a Plant. Right: Leaf Area of Flag Leaf. For Vertical Lines, See Legend of Figure 1.

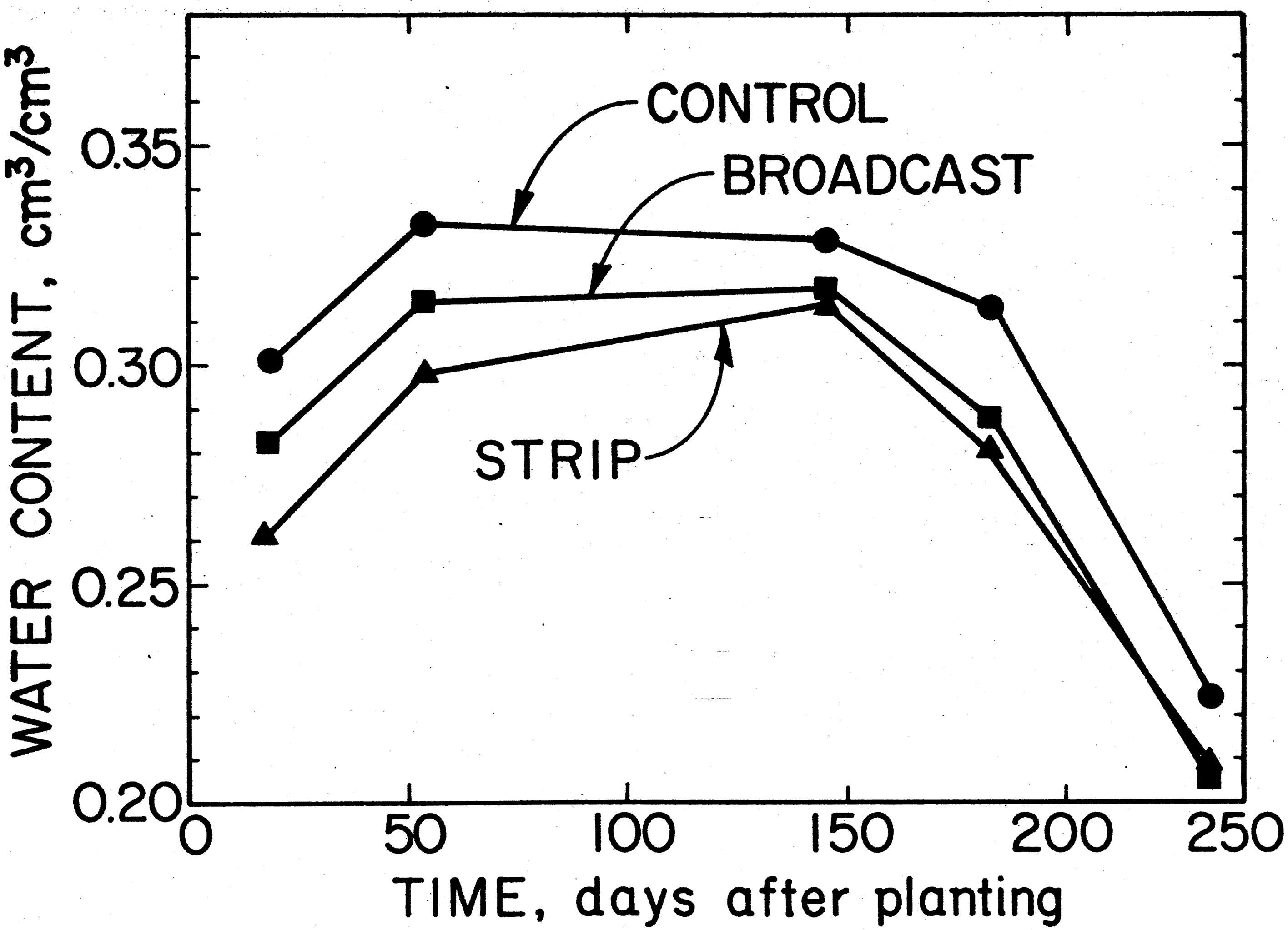


Figure 7. Water Content of a Silty Loam Soil With Fertilizer Placed in Strips or Broadcasted. Controls Had no Fertilizer. Experiment Was Done Under Field Conditions. No Standard-Error Lines Are Shown Because the Lines Fell Within Symbols.

plants. The broadcasted and stripped fertilizer placement had nearly the same soil-water content. At the beginning of the experiment the stripped plot had less water in the profile, but at the end of the experiment the water content was the same as the plots with broadcasted fertilizer. This was expected since the plants in the stripped fertilizer treatment had smaller height and leaf area (Figures 5,6), and required less water from the profile.

Nutrient Uptake

In the greenhouse, shoots of plants with the fertilizer placed in strips took up more N and P than shoots of plants with the fertilizer spread by broadcasting (Table III). Shoots of plants with the stripped fertilizer had 16 and 44% more N and P, respectively, than shoots of plants with the broadcasted fertilizer. Concentrations of other elements (K, Ca, Mg, Fe, Mn, Zn) in the plants were similar for the three treatments. This could be expected since the fertilizer contained only N and P. There was no significant difference in the concentration of any element in the roots (Table III).

Nutrient analysis of the straw from the field in the broadcasted plots showed that K and Mg was significantly greater than straw in the stripped or control plots (Table III). Yet, N, Fe, and Mn content of the grain in the control plots was lower than the N, Fe, and Mn content of the grain analyzed from the stripped or broadcasted plots. Concentration of other elements in plants grown under the three treatments was similar (Table III). The reason for the increased content of the elements (N, Fe, Mn) is not understood.

The percent protein in the grain of plants grown in the control

TABLE III

ELEMENTAL COMPOSITION AND DRY WEIGHT OF SHOOTS AND ROOTS OF GREENHOUSE-GROWN WHEAT WITH FERTILIZER PLACED IN STRIPS OR BROADCASTED. CONTROL PLANTS GREW WITH NO FERTILIZER. ELEMENTAL COMPOSITION OF STRAW AND GRAIN, AND GRAIN-PROTEIN CONCENTRATION, FROM THE FIELD-GROWN PLANTS ALSO ARE SHOWN.

	Strip	Broadcast	Control	Strip	Broadcast	Control
	Shoots			Roots		
			%			
N	3.22b	2.85a	2.84a†	0.86a	0.78a	0.86a
P	0.37c	0.26b	0.21a	0.19a	0.14a	0.12a
K	5.05a	5.16a	5.41a	0.52a	0.52a	0.58a
Ca	0.42a	0.37a	0.39a	0.27a	0.22a	0.28a
Mg	0.12a	0.11a	0.11a	0.11a	0.11a	0.11a
			µg/g			
Fe	2540a	1420a	1520a	...‡	...	...
Mn	388a	363a	445a	58a	54a	61a
Zn	85a	103a	137a	20a	18a	19a
			g/container			
Dry weight	15.5ab	20.3b	15.2a	1.9a	4.8a	3.5a

TABLE III (Continued)

	Strip	Broadcast	Control	Strip	Broadcast	Control
	Straw			Grain		
%						
N	0.43a	0.54a	0.44a	2.29a	2.27a	2.09b
P	0.023a	0.036a	0.026a	0.268a	0.295a	0.283a
K	0.900a	0.746b	1.004a	0.372a	0.403a	0.381a
Ca	0.263a	0.232a	0.283a	0.102a	0.109a	0.106a
Mg	0.071a	0.067b	0.074a	0.088a	0.095a	0.088a
µg/g						
Fe	85.5a	48.4a	48.0a	41.2a	46.9a	33.1b
Mn	64.1a	63.5a	55.4a	42.3a	29.25a	26.03b
Zn	trace	trace	11.0	28.01a	45.1a	28.4a
percent protein	...	...	...	13.3a	13.1a	12.3b

† Means in each row followed by the same letter are not significantly different at the 0.05 level according to Duncan's new multiple-range test.

† Data not available.

plots was significantly lower than the percent protein in the grain from the other two treatments. (Table III). Low fertility in the control plots evidently reduced protein formation.

Harvest

There was no significant difference among grain moisture contents (Table IV). However, the test weight of plants grown without fertilizer was higher than those grown with fertilizer. Also, the 1000-kernel weight of control plants was higher than that of fertilized plants. High test weights can result from small seeds, more of which will fit into a specified volume than larger seeds. However, the 1000-kernel weight results suggested that the higher test weight of control plants was due to heavier seeds and not to smaller seeds. It is not known why the low-fertility treatment favored heavier seeds. Larger seeds often have more starch and less protein (D. A. Guthrie. 1978. Combining ability analysis of grain protein and other traits in a series of winter wheat hybrids. M. S. Thesis. Oklahoma State University, Stillwater, 43p.). Perhaps low-N treatment inhibited protein formation more than carbohydrate production.

Weight and number of tillers/m^2 agreed with the growth data. Plants with the stripped fertilizer did not produce as much vegetative material as did plants grown with the broadcasted fertilizer.

Both fertilizer treatments and row direction affected grain yield (Table IV). Therefore, the results from each plot are presented. The best yield was obtained from the plot with fertilizer placed in strips with rows oriented in the east-west direction. The high-yield results of east-west plants agreed with those obtained during the previous two

TABLE IV

HARVEST DATA, PERCENT MOISTURE, TEST WEIGHT, 1000-KERNEL WEIGHT, NUMBER OF TILLERS/m^2, WEIGHT OF TILLERS/m^2, AND YIELD OF WHEAT GRAIN GROWN IN THE FIELD WITH FERTILIZER PLACED IN STRIPS OR BRAODCASTED. CONTROLS GREW WITH NO FERTILIZER.

	Grain Moisture %	Test Weight kg/hl	1000-Kernel Weight g	Number of Tillers/m^2	Weight of Tillers/m^2 g
Strip	11.8a†	77.7a	32.6b	640ab	1395ab
Broadcast	11.7a	78.1a	31.1a	732b	1505b
Control	11.5a	79.3b	34.5c	517a	1166a

	Yield kg/ha‡
Strip	
EW rows	3060
NS rows	2760
Mean	2910ab
Broadcast	
EW rows	2980
NS rows	3000
Mean	2990b
Control	
EW rows	2870
NS rows	2590
Mean	2730a

† Means in each column followed by the same letter are not significantly different at the 0.05 level according to Duncan'a new multiple-range test.

‡ Standard deviations are given with mean values.

years. The 1976-1977 data have been published (Erickson et al., 1979). The 1977-1978 results (unpublished) were the same as the 1976-1977 results. The control plants with no fertilizer, and in the east-west direction, yielded more than plants fertilized in strips and oriented in the north-south direction. In this case, row direction had a more profound effect than fertilizer.

CHAPTER II

WATER RELATIONS OF WHEAT GROWN IN NORTH-SOUTH VERSUS EAST-WEST DIRECTION

ABSTRACT

Wheat (*Triticum aestivum* L. em. Thell. 'Osage') was planted in an east-west and a north-south row direction to determine the effects of row orientation on stomatal resistance, leaf water potential, osmotic potential, plant height, leaf area, soil water content, elemental composition of wheat straw and grain for N, P, K, Ca, Mg, Fe, Zn, and Mn, percent protein in the grain, weight of tillers/m^2, number of tillers/m^2, 1000-kernel weight, test weight, percent moisture in the grain, and yield.

Major differences for the plants during the growing season were determined. Plants in the north-south direction averaged 0.7 sec/cm lower stomatal resistance during late fall and winter than plants in the east-west direction for the same period. Total water potential of wheat plants in the east-west direction averaged 3.4 bars higher (less negative) during winter and early spring than potentials of plants grown in the north-south direction. However, osmotic potentials of plants in the east-west direction averaged 2.9 bars lower (more negative) during the winter months than osmotic potentials in the north-south direction. Plant height between north-south and east-west orientations showed no significant difference. Yet, plants in the north-south

direction averaged 40 cm^3 greater leaf area than east-west rows 164 days after planting. Soil water content in the north-south direction averaged 0.02 cc/cc lower than east-west row orientation. Nutrient analyses of the wheat grain showed that the north-south rows had consistently higher nutrient content than the east-west rows. However, the straw content for the nutrients elements showed a reverse situation. The east-west direction had a higher nutrient content than the north-south rows, except for Mn. Protein content for the east-west rows was 13.0%, and the north-south was 12.8%. Kernel weight per 1,000 seeds for the east-west and north-south directions was 32.9 and 32.6 grams, respectively. The east-west plants had a 7% higher yield than north-south rows.

INTRODUCTION

Researchers have done a considerable amount of work to manipulate row spacing and planting patterns to increase yields (Chin Choy and Kanemasu, 1974; Luebs et al., 1975). Some research has been conducted with row positions on beds to determine the effect on yield and yield components (Day et al., 1976). However, little research has been done to study the effects of row direction on agronomic crops. Most of the work that has been done with row orientation tends to show that crops planted in north-south direction is more beneficial than in an east-west direction. Pendleton and Dungan (1958) found that field differences for spring oats were greater in north-south rows during a seven year study than yields in east-west rows. Row direction research conducted in Canada showed that north-south rows again yielded more than east-west rows by 9% for barley and by 4% for oats (Austenson and Larter, 1969). North-south planting significantly produced higher yields than east-west rows for wheat (Shekhawat et al., 1966). Work on bajra crop by Sandhu (1964) found that north-south rows increased plant height, forage, and grain yield per acre by 2.5, 5.8, and 8.3%, respectively. However, these increases were not statistically significant.

Other work that has been conducted has produced results that favor east-west planting over north-south rows. Water use efficiency and yield for wheat was found to be higher in east-west rows than north-south rows (Verma et al., 1977). The ratio of net radiation at the ground to that above the crop was 3% less for north-south corn rows at Ames, Iowa, and 10% less from July 15 to August 15 over the ratio for east-west rows (Yao and Shaw, 1964). East-west wheat rows yielded more than north-south rows; yet, the difference was not significant (Sharma and Singh, 1971). Wheat planted in east-west direction in Oklahoma had a 10% higher yield than north-south (Erickson et al., 1979).

Some studies show no effect on row orientation. The protein content in wheat rows was not significantly influenced by row direction (Reddy et al., 1976). Two studies with barley and corn showed that row orientation had no effect on yield (Yao and Shaw, 1964: J. C. Smith, 1976. The effect of row direction and row spacing on several agronomic characters of winter barley. M. S. Thesis University of Georgia, Athens, Georgia. 30p.)

Oklahoma environment creates physiological differences in plants that are grown in different row directions, especially east-west and north-south directions (Erickson et al., 1979). Stomatal resistance, leaf water potential, osmotic potential, plant height, leaf area, soil water content, elemental composition of straw and grain, protein content in the grain, weight of tillers/m^2, number of tillers/m^2, 1000-kernel weight, test weight, percent moisture in the grain, and yield were taken for information needed to understand the effect of row direction on winter wheat.

MATERIALS AND METHODS

The study was conducted between October, 1978, and June, 1979, at the Oklahoma State University Research Station, Stillwater, Oklahoma. Winter wheat (Triticum aestivum L. em. Thell, 'Osage') was planted on six adjacent plots in a north-south or an east-west direction. Four of the six plots each measured 23.5 x 28.0 m, and the remaining two measured 16.5 x 16.5 m. Winter wheat had been planted on the ground for the previous two years. Each year it was tilled prior to planting, and during the summer it was fallowed.

The soil was a Kirkland silty loam which is classified as an Udertic Paleustoll; fine, mixed, thermic (Gray and Roozitalab, 1976). Each plot was sampled and analyzed for pH, NO_3^--N, P, and K using standard soil-test procedures (details of procedures may be obtained from the Soil and Plant Testing Laboratory, Department of Agronomy, Oklahoma State University, Stillwater, Oklahoma). The test results showed that the soil was low in N(40 kg/ha), but high in P(71 kg/ha) and K(368 kg/ha) with a pH of 4.8. The plots had uniform fertility (Tucker, 1968; Oklahoma Agricultural Extension Service and Oklahoma Plant Food Educational Society, Inc. 1977).

All plots were clean-tilled on September 25, 1978, and October 6, 1978. On October 12, 1978, two plots, designated as either east-west or north-south orientation, were broadcasted with urea ammonium phosphate (28-28-0) at a rate of 200 kg/ha, using a Gandy Turf Spreader which made 120 cm swath. On October 13, the plots were again tilled, thus incorporating the broadcasted fertilizer into the ground to a 5 cm depth. Wheat (Triticum aestivum L. em. Thell. 'Osage') was planted on October 14 (day 1) using a John Deere grain drill. Row widths were 20 cm with a planting depth of 2 cm. In two plots, designated as either east-west or north-south direction, the fertilizer was placed with the seed at a rate of 200 kg/ha. The width of the fertilizer band was 2 cm. The two remaining plots, one east-west and one north-south, received no fertilizer. All plots were planted at a rate of 67 kg/ha.

Meterological data were provided by the Oklahoma State University Agronomy Research Station Class AB Weather Station, Stillwater, Oklahoma (National Oceanic and Atmospheric Administration, 1978-1979a; 1978-1979b), located approximately 500 m northwest of the plots. Environmental conditions were also determined directly at the plots at the time plant measurements were taken and the data presented are for only the months of the wheat growing season. Environmental conditions are given in Table Table I (page 10).

All measurements were taken between 0900 and 1000 hours. On days, 14, 20, 27, 39, 48, 67, 146, 164, 174, 181, 188, 195, 207, and 224, diffusive resistance of stomata on the upper leaf surface was measured on four plants, randomly chosen in each plot, with a calibrated stomatal diffusion porometer (Kanemasu et al., 1969) (Model LI-65 Autoporometer and Diffusive Resistance Sensor LI-205, LI-COR, Inc., Lincoln, Nebraska). On day 39, it took longer than two minutes for the meter to respond; hence, the stomata were considered closed and the values are not reported. Total water potential measurements began on day 20 and continued through day 224, with a measurement also on day 56. Two plants were randomly sampled in each plot, and thermocouple psychrometers (Model C-52 Sample Chamber, Wescor, Inc., Logan, Utah) were used to determine total water potential. A leaf disc (6 mm in diameter) was cut in the field from a mature, young leaf and immediately placed in a stainless-steel holder of the thermocouple chamber. After an equilibration time of 2 hours (Nelson et al., 1978), the potential was measured using a microvoltmeter (Model HR-33T Dew Point Microvoltmeter, Wescor, Inc., Logan, Utah). The tissue and stainless-steel holder were removed from the sample chamber, covered with transparent tape, and frozen for 24 hours at -25°C. The sample and holder were again put in the sample chamber and the same procedure used to determine total water potential was used to obtain osmotic potential. Plant height was measured from the ground to the tip of the longest leaf from four randomly chosen plants from each plot. After heading, height was measured from the ground to the tip of the head, excluding awns. Plants were measured on the above mentioned days for stomatal resistance with an additional measurement on day 228. Leaf area was measured on the same days, except for day 228 (leaf area was measured on day 224) using a leaf-area meter (Portable Area Meter Model LI-3000 and Transparent Belt Conveyor Accessory Model LI-3050A, LI-COR, Inc., Lincoln, Nebraska). Between days 14 and 164 total leaf area of four randomly chosen plants from each plot was measured. Only the flag-leaf was measured between days 174 and 224. Neutron probes were installed in the center of each plot on October 18. Measurements for soil water content were taken on days 18, 53, 145, 182, and 232. Straw and grain were analyzed by the Oklahoma State University Soil and Plant Testing Laboratory for N, P, K, Ca, Mg, Fe, Mn, and Zn. Protein content in the grain was determined by using the Udy method (Protein Analyzer Model S, Udy Analyzer Co, Boulder, Colorado).

On day 256, a one-meter-square area near the center of each plot was hand harvested by pulling up every plant. Roots were cut off and the bundles from each plot were weighed and the number of tillers was counted. On day 259 (June 29, 1979), the plots were harvested by a small-plot combine (Chain Machine Co., Haven, Kansas). Each of the six plots was sampled by three 150 cm wide swaths which resulted, therefore, in 18 samples. Combining was done perpendicular to the row plantings. Weight per 1,000 kernels was obtained from 100 seeds from each of the 18 samples, and analyzed according to the row direction of the sample. Test weight of the grain was determined (Model 26 Hand Type Weight Per Bushel Tester, Seedburo Equipment Co., Chicago, Illinois), and grain moisture content was also determined (Model 700 Grain Moisture Sensor, Nova Sensor Corp, Anoka, Minnesota).

RESULTS AND DISCCUSION

Stomatal Resistance

Plants grown in the north-south direction at 50 and 150 days after planting had much lower stomatal resistances than plants grown in the east-west direction (Figure 8). Plants in the north-south direction averaged 0.7 sec/cm lower stomatal resistances during late fall and winter than plants in the east-west direction for the same period. Environmental conditions during this period caused a greater stress for plants in the east-west direction than plants experienced in the north-south direction. Whether this stress was due primarily to temperature change, or some other environmental condition is not known. Despite

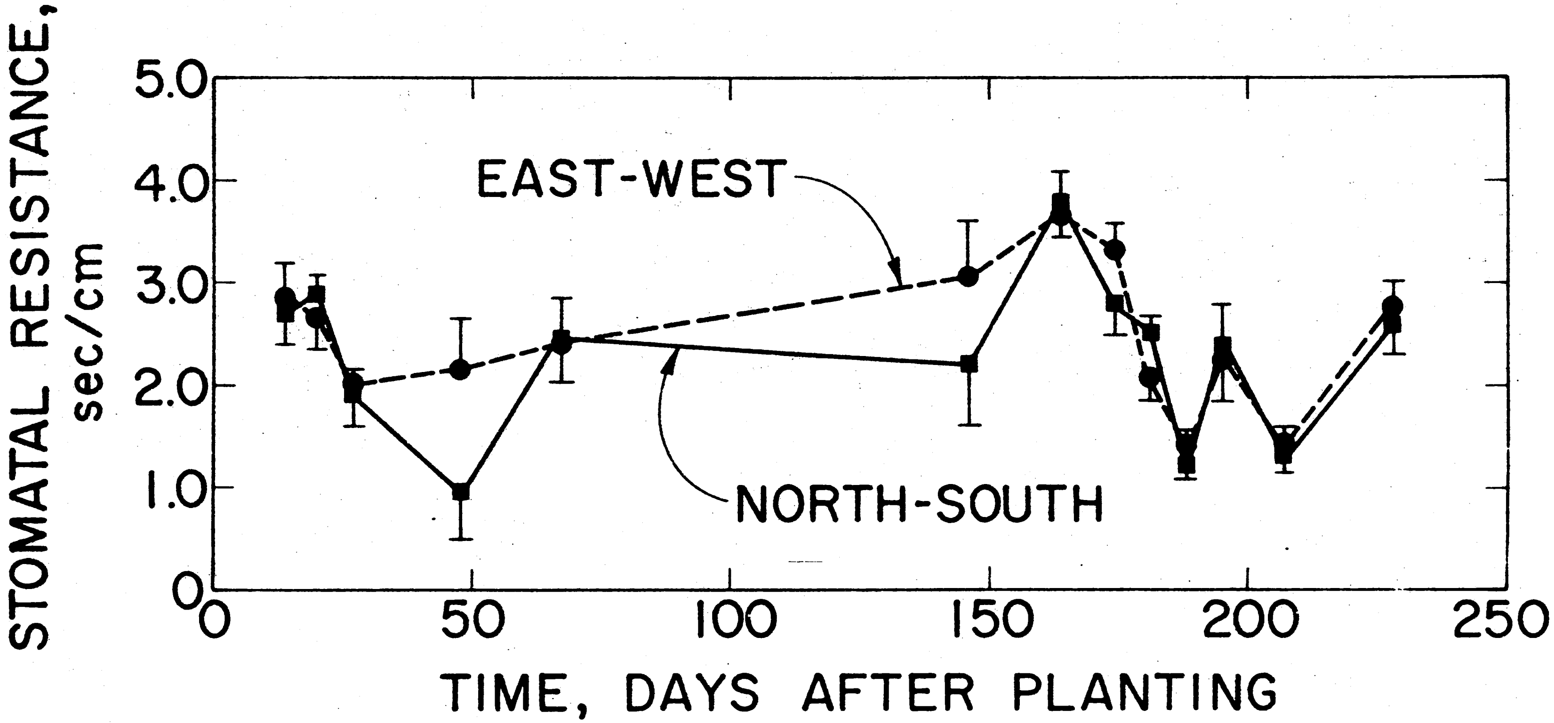


Figure 8. Stomatal Resistance of Wheat Grown in North-South and East-West Directions. For Vertical Lines, See Legend of Figure 1.

these differences, stomatal resistances of plants grown in the east-west direction were not significantly different from those of plants grown in the north-south direction at the 0.05 level (Appendix, Table X).

Water Potentials

During the winter months, plants grown in the north-south direction experienced lower water potentials than plants did in the east-west direction (Figure 9). The water potential of wheat plants in the east-west direction average 3.4 bars higher during winter and early spring than that of plants in the north-south direction. The osmotic potential of plants grown in the north-south direction was higher than the osmotic potential of plants in the east-west direction during the winter months (Figure 10). The osmotic potential of plants in the east-west direction averaged 2.9 bars lower during this period than osmotic potentials in the north-south direction.

The data suggest that plants grown in the north-south direction were under more stress than plants in the east-west direction. This is substantiated by the fact that plants in the north-south direction had a lower total water potential. However, using osmotic potential and stomatal resistance as the critera for stress, plants in the east-west directions were under more stress since stomatal resistances were higher and osmotic potentials were lower. Plants in the east-west direction were quite possibly under more stress than plants in the north-south direction.

From 150 days after planting to harvest, plants in the north-south direction exhibited a greater fluctuation in both osmotic and total

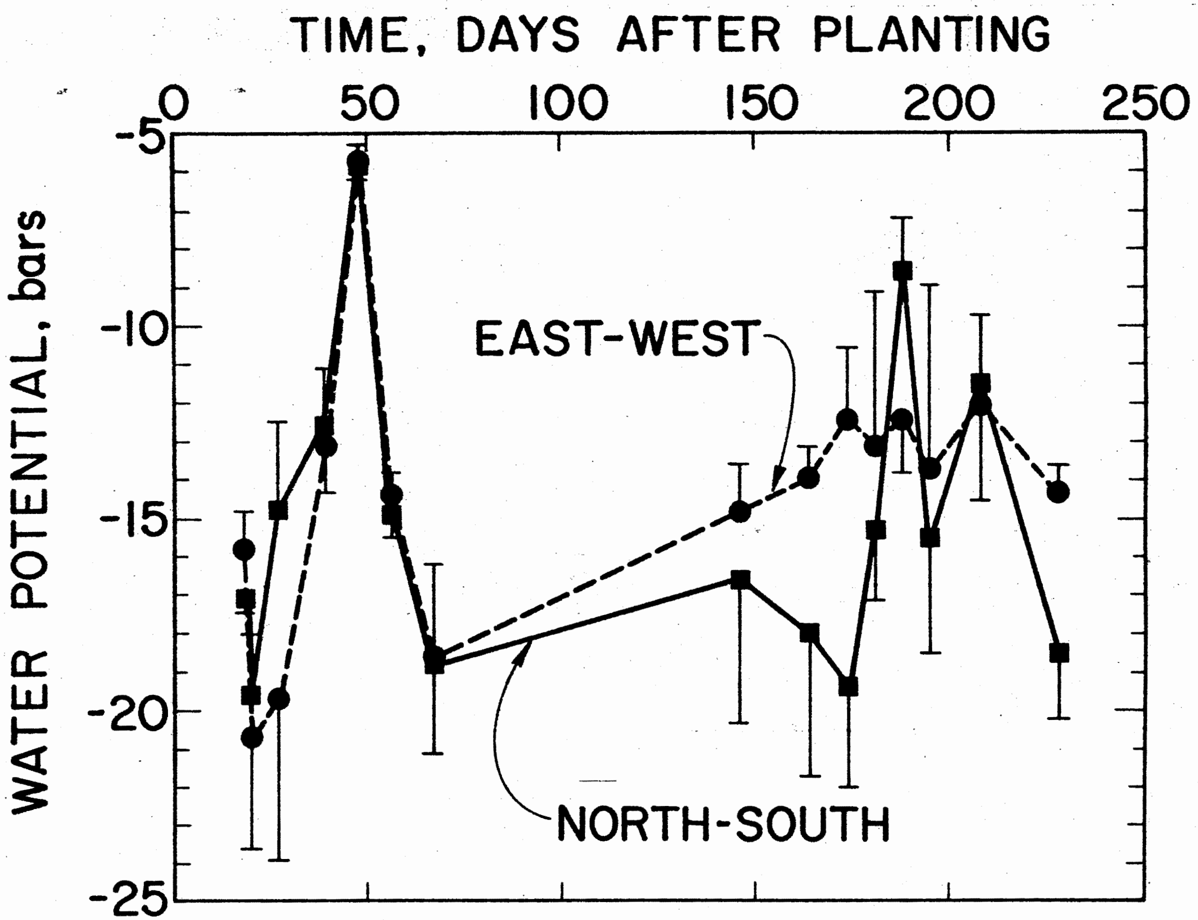


Figure 9. Water Potential of Wheat Grown in North-South and East-West Directions. For Vertical Lines, See Legend of Figure 1.

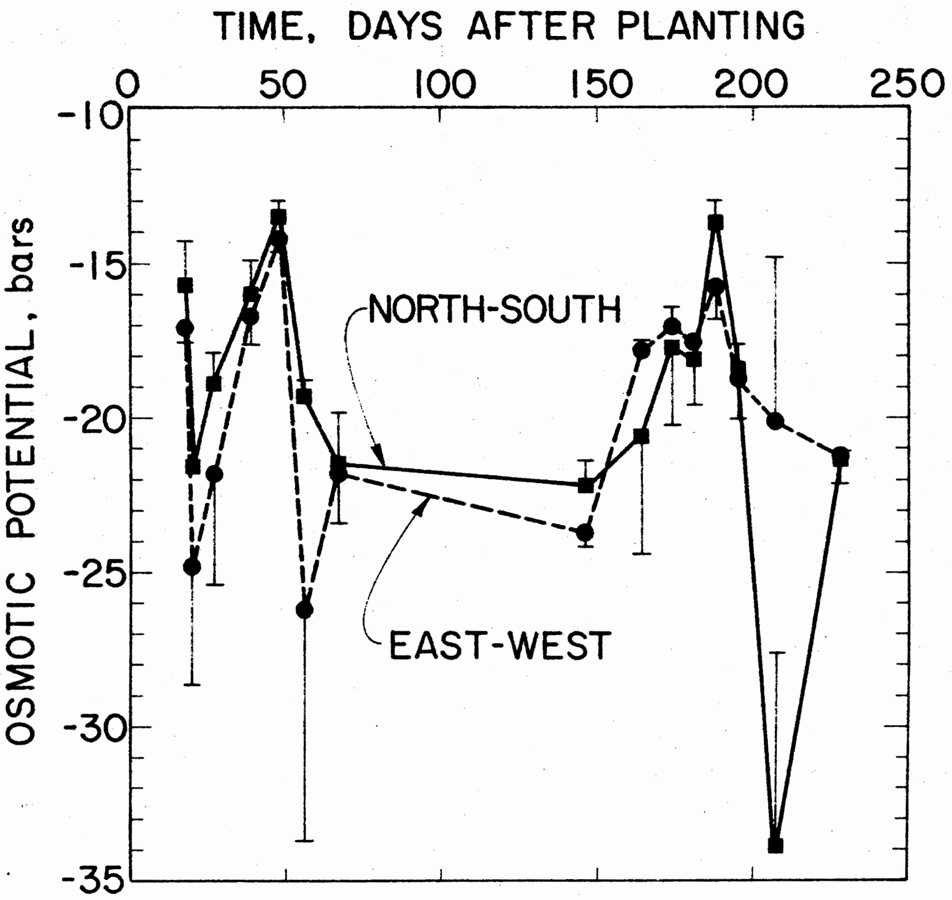


Figure 10. Osmotic Potential of Wheat Grown in North-South and East-West Directions. For Vertical Lines, See Legend of Figure 1.

water potential than plants in the east-west direction. The reason for the greater fluctuation is not known. Analysis of variance was conducted for total water and osmotic potentials and showed the observed significance level was 0.38 for the effect of orientation on total water potential and 0.99 for osmotic potential (Appendix, Table XI).

Growth

Height for plants grown in either north-south or east-west direction was the same (Table V; Appendix, Table XII). Plants grown in the north-south direction had a 40 cm^3 larger leaf area on day 164 than plants in the east-west direction (Table V). At other times leaf areas for both directions were similar. The observed significance level for orientation effect on leaf area was 0.10 for total leaf area and 0.27 for flag leaf area (Appendix, Table XII).

Soil-Water Content

The soil-water of plants grown in north-south and east-west rows had the same soil-water content at planting (0.26) and at harvest (0.15) (Figure 11). Throughout the growth of the plants, east-west rows had a greater soil-water content than north-south rows. Since leaf area and plant height were the same for plants in both directions, it would be reasonable that the water used for plant growth would be similar. According to the soil-water content, plants in the east-west direction had a higher water use efficiency since more water was present in the profile throughout the growing season than plants in the north-south direction. Even though these differences were significant only at the 0.16 level the trend was consistent (Appendix, Table XIII). Verma

TABLE V

PLANT HEIGHT AND LEAF AREA OF WINTER WHEAT GROWN IN AN EAST-WEST VERSUS NORTH-SOUTH DIRECTION

Days After Planting	Plant Height		Leaf Area†	
	E-W	N-S	E-W	N-S
	cm		cm^3	
14	10.8	10.2	3.1	3.1
20	15.4	15.4	6.0	6.0
27	16.2	16.9	9.8	9.9
39	18.2	17.7	16.2	16.6
48	16.4	17.5	22.1	26.2
67	17.7	17.1	26.5	28.8
146	11.4	10.4	31.0	30.7
164	20.9	20.4	87.1	127.5
174	28.3	27.9	24.8	30.8
181	37.9	38.9	33.5	38.7
188	55.2	52.7	56.8	54.3
195	71.9	73.5	62.4	61.0
207	88.7	88.6	50.9	58.1
228	42.9	44.0	28.2	24.1

† Total leaf area of the plant was taken until 164 days after planting after which time only the flag leaf was measured.

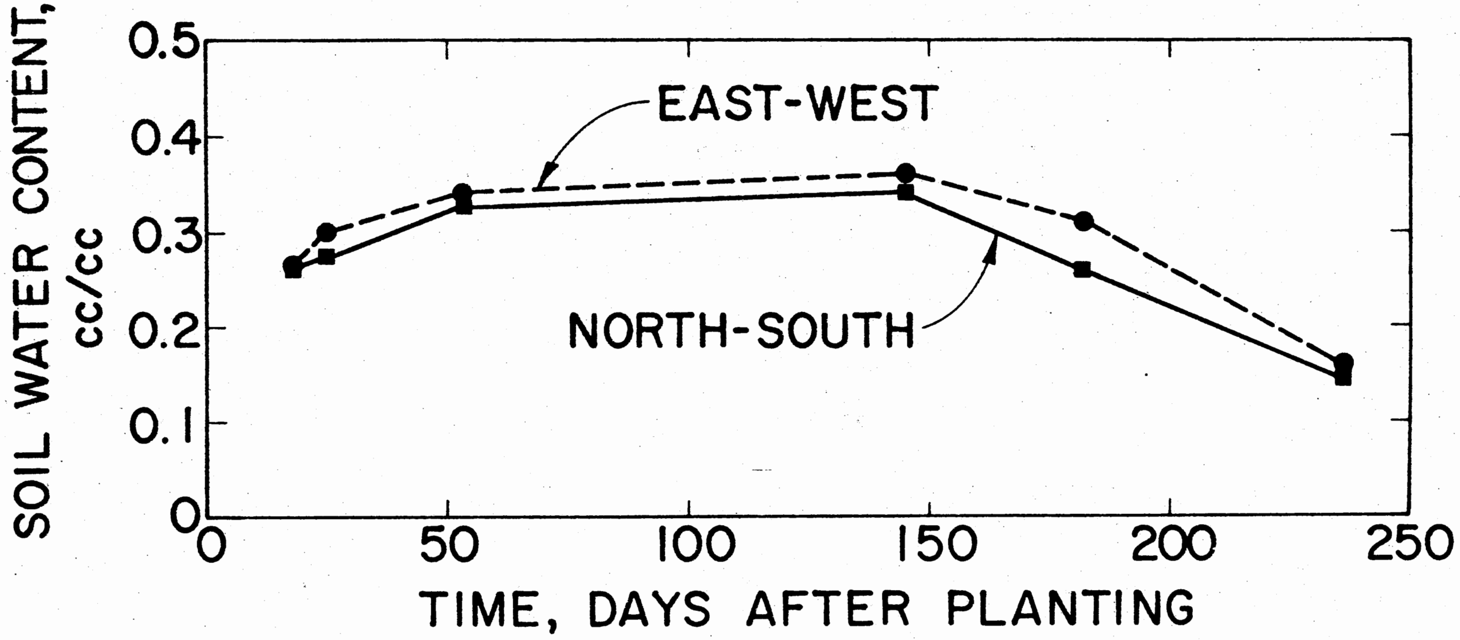


Figure 11. Water Content of a Silty Loam of Wheat Grown in North-South and East-West Directions.

(1977) found that if any growth factor increased yield it would also increase water use efficiency (See subtitle Harvest, bottom of this page).

Nutrient Uptake

Elemental analysis of the straw showed no significant difference (0.05 level) in the east-west or the north-south direction for N, P, K, Ca, Mg, Fe, Zn, and Mn (Table VI; Appendix, Table XIV). However, the amount of nutrients in the straw was greater for plants in the east-west direction, except for Mn content of the straw which was lower. The nitrogen content of the straw for plants in east-west rows was much larger than north-south rows. Pittman (1962) found that wheat roots orient in a north-south direction. Therefore, plants in the east-west direction would orient their roots in a north-south direction which could possibly allow the plant to takeup more nutrients. Plants in the north-south direction would orient roots in the same direction. This would cause roots to overlap and compete for ions in a smaller area than the east-west rows.

Elemental composition of the grain (Table VI) showed that K and Ca was significantly greater in the north-south direction than the east-west direction (0.006 level for K; 0.016 level for Ca) (Appendix, Table XV). The reason for this difference is unknown.

The protein content of the grain was similar between the east-west and north-south rows (Table VII: Appendix, Table XVI).

Harvest

At harvest a one-meter-square area was harvested in each plot and the weight and number of tillers were determined (Table VII). The

TABLE VI

ELEMENTAL COMPOSITION OF WHEAT STRAW AND WHEAT GRAIN GROWN IN AN EAST-WEST VERSUS NORTH-SOUTH ROW DIRECTION.

Row Direction	N	P	K	Ca	Mg	Fe	Zn	Mn
	%					µg/g		
				Grain Content				
East-West	2.20	0.278	0.381	0.100	0.089	40.0	27.66	37.4
North-South	2.23	0.286	0.398	0.111	0.091	40.8	27.87	39.8
				Straw Content				
East-West	0.52	0.032	0.945	0.273	0.074	60.9	-	57.9
North-South	0.41	0.024	0.921	0.245	0.067	60.4	-	64.0

TABLE VII

WHEAT GRAIN YIELD, TEST WEIGHT, PERCENT GRAIN MOISTURE, PERCENT PROTEIN IN GRAIN, 1000-KERNEL WEIGHT, WEIGHT OF TILLERS/m^2, AND NUMBER OF TILLERS/m^2 IN EAST-WEST VERSUS NORTH-SOUTH ROW DIRECTIONS.

	Grain Yield (kg/ha)+	Test Weight (kg/hl)	% Grain Moisture
East-West	2970± 95	78.3	11.7
North-South	2780±190	78.8	11.7

+ Standard deviation values are given with the mean value.

	% Protein	1000-Kernel Weight g	Weight of Tillers/m^2 g	Number of Tillers/m^2
East-West	13.0	32.9	1428.8	670
North-South	12.8	32.6	1281.3	590

number and weight of the tillers were greater in the east-west direction than the north-south direction. These differences were only significant at the 0.16 level for weight of tillers/m^2, and at the 0.33 level for number of tillers/m^2 (Appendix, Table XVI).

Test weight, 1000-kernel weight, and grain moisture were taken (Table VII). There was no sifnificant difference (0.05 level) for these measurements due to row orientation (Appendix, Table XVII).

Grain yield for the east-west rows was 2970 kg/ha, while the north-south rows yielded 2780 kg/ha (Table VII). Therefore, plants in the east-west direction yielded seven percent more than plants in the north-south direction. The observed significance level due to row direction for yield was 0.21 (Appendix, Table XVII).

CHAPTER III

WATER RELATIONS OF WHEAT CULTIVARS GROWN WITH CADMIUM

ABSTRACT

Stomatal resistance, total and osmotic water potential, and cadmium concentration of two cultivars of winter wheat (Triticum aestivum L. em. Thell. 'Ponca' and 'KanKing') were measured to determine if cadmium concentration could be associated with changes in stomatal resistance and potentials. Plants grew in one of six solutions: (1) distilled water; (2) distilled water with 1μg/ml cadmium (Cd); (3) half the normal strength of Hoagland's nutrient solution; (4) half the normal strength of Hoagland's nutrient solution with 1μg/ml Cd; (5) five times the normal strength of Hoagland's nutrient solution; (6) five times the normal strength of Hoagland's nutrient solution with 1μg/ml Cd. The cadmium was added as $CdSO_4$. Dry weight and cadmium concentration of the roots and shoots were analyzed.

Plants that grew in solutions with cadmium generally had a higher stomatal resistance than plants that grew without cadmium. This indicated that cadmium moved through the plants in the transpiration stream. Cadmium apparently increased the permeability of membranes to ions and water because osmotic potentials were usually lower, and turgor potentials were higher, with cadmium than without. Plants which grew in five strength Hoagland's nutrient solution with cadmium had a higher

turgor potential, and a higher dry weight, than those which grew in five strength Hoagland's nutrient solution without cadmium.

INTRODUCTION

In recent years, the effect of cadmium (Cd) on plants and animals has received much attention. Cadmium has no known essential biological function. Conversely, it is known to have a toxic effect on plants and animals (Page and Bingham, 1973).

Cadmium occurs in nature mainly as a component of minerals in the earth's crust. The average Cd concentration is 0.18 parts per million (ppm). The average concentration in fresh water and sea water is generally 1 part per billion (ppb), and 0.15ppb, respectively (Babich and Stotzky, 1978). However, due to man's manipulation of the environment, Cd has accumulated to levels of toxicity in biological life. Major sources of cadmium release in the environment have been identified. Included are steelmaking processes, electroplating, zinc refining, municipal incineration, paint manufacturing, the plastics industry, the nickel-cadmium battery industry, and the agricultural use of fertilizer (Yost et al., 1975).

Humans can be exposed to cadmium through food, water, and air. Exposure to food is the most significant. The mean daily intake of cadmium is about 170μg. The mean daily excretion is about 140μg. The body burden of cadmium for a "standard man", 50 years of age in the United States, is about 30 mg (Friberg et al., 1971). Estimates of dosages that cause acute or chronic effects are difficult to establish in human beings, and vary according to the dosage level, dosage type, and retention level. Newborn babies contain less than 1μg of cadmium, indicating that the placenta is an effective barrier to cadmium (Friberg et al., 1971).

Inhalation of 0.04g of cadmium oxide fume is generally fatal. Symptoms occur in 4 to 8 hours and include headache, cough, chest pain, weakness, and asphyxial death from pulmonary edema. The ingested lethal dose of Cd is estimated to be in the range of 0.35 to 3.5g. Symptoms include nausea, vomiting, diarrhea, cramps, headache, exhaustion, collapse, convulsions, shock, and death, usually within 24 hours. Chronic poisoning by cadmium can lead to impairment of health or premature death. Small and constant intake symptoms do not appear for 10-20 years (Fulkerson et al., 1973). Cadmium is absorbed through the respiratory system or through the gastrointestional tract and accumulates mainly in the liver, kidneys, and pancreas. Industrial workers who have been exposed to excessive amounts of cadmium develop bronchitis, emphysema, proteinuria, and a continuous decline in health (Page and Bingham, 1973). Cadmium is also suspected of causing hypertension. Evidence that cadmium is carcinogenic is far from conclusive, but the possibility still exists (Friberg et al., 1971).

Plant tissues effectively absorb and translocate cadmium; yet tolerance to Cd is highly crop-specific (Bingham, 1979). Cereals and legumes accumulate less Cd in the shoots than leafy plants such as lettuce, curlycress, and spinach. Cadmium in the plant is the least concentrated in the tuber, seed, and fruit tissue, while the greatest amount is found in leaf tissue (Bingham et al., 1975). When cadmium concentration of plant tops increased in wheat and soybeans, yields decreased with increased levels of Cd (Haghiri, 1973). Cadmium may be absorbed by the roots or by the leaf system. Roots appear to be the most efficient absorption site. Accumulation of Cd in plant tissues usually exceeds the Cd concentration of the soil (Babich and Stotzky, 1978). Concentration of Cd in the plant may be influenced directly or indirectly by the availability of another nutrient. Cadmium uptake in a specific tissue or crop was significantly reduced with additions of Ca, Zn, K or Al (John, 1976). Increasing available soil P increased Cd accumulation (Miller et al., 1976). Cadmium concentration in oat shoots and soybeans was decreased by increasing the cation exchange capacity (CEC) of the soil (Haghiri, 1974; Miller et al., 1976). Organic matter added to the soil retains Cd due to the high CEC which in turn renders Cd less available to plants (Haghiri, 1974; Petruzzelli et al., 1977). Increasing the soil pH causes a decrease in cadmium uptake. Conversely, lower pH increases cadmium uptake (Lagerwerff, 1971; Linnman et al., 1973; Miller et al., 1976).

Cadmium alters the physiology of plants in many aspects. Increased cadmium tissue concentration in corn caused a decrease in the dry weight of roots, stems, and shoots, and leaf chlorophyll concentration (Root et al., 1975; Lamoreaux and Chaney, 1977; Huang et al., 1974). Chlorosis, epinasty, abscission of leaves, and decreased growth rate resulted when soybean seedlings were treated with 1.35 μM Cd (Lee et al., 1976). Photosynthesis and transpiration were reduced when detached corn and sunflower leaves were exposed to various concentrations of Cd (Bazzaz et al., 1974). Increased Cd concentrations caused an increase in respiration (Lamoreaux and Chaney, 1978). Cadmium affects mitochondrial membrane permeability and causes swelling (Hassett et al., 1976; Miller et al., 1973).

Accumulation of cadmium in different wheat cultivars has received little attention. Sempio (1942) found that one cultivar ('Frassineto') absorbed less Cd and was more tolerant to Cd than another ('Virgilio'). Selection of cadmium-resistant cultivars of economically important plants may be useful in areas where concentrations of Cd are unavoidably high.

Previous work by Kirkham (1978b) indicated that cadmium uptake is directly related to transpiration rate. Drought-sensitive wheat plants have a lower stomatal resistance, and a higher transpiration rate, than drought-resistant wheat plants (Kirkham, 1978a; 1979; Kirkham and Ahring, 1978). Therefore, one would hypothesize that wheat cultivars with a higher stomatal resistance would accumulate less Cd than wheat cultivars with a lower stomatal resistance. To test this hypothesis, stomatal resistance and cadmium concentration were measured for two cultivars of winter wheat, one drought-resistant and one drought-sensitive. To characterize the water relations more fully, water potential, osmotic potential, and turgor pressure were determined.

MATERIALS AND METHODS

This study was conducted in a growth room at the Oklahoma State University Controlled Environmental Research Labratory, Stillwater, Oklahoma. The quantum flux density of incident light, provided by cool white fluorescent lamps, was 600 μEinsteins m^{-2} sec^{-1} for 12 hours per day (0600 to 1800 hr.). The day and night temperature varied from 25 to 30°C and 20 to 25°C, respectively. Relative humidity varied between 64 and 94%.

Two cultivars of winter wheat (*Triticum aestivum* L. em. Thell.), one drought-sensitive (cv. Ponca) and one drought-resistnat (cv. Kan-King) (Sandhu and Laude, 1958; Todd and Webster, 1965) were germinated in moist sand thirteen days prior to the time measurements began. The seedlings were in the three leaf stage when they were transferred from the germination dishes to 1.9 liter plastic containers with lids. The containers and lids were painted black to minimize any algae growth. Four 6 mm holes were drilled in the lids of each container, and the plants were threaded through the holes. Cotton was wrapped around the stem of the plant and taped to the lid with filament tape to support the plant. With two culitvars, three replications, and six treatments, 36 containers were required. A complete randomized block design was used. The treatments were:

1 - distilled water
2 - distilled water with 1 μg/ml
3 - half strength Hoagland's nutrient solution
4 - half strength Hoagland's nutrient solution with 1 μg/ml
5 - five times the normal strength Hoagland's nutrient solution
6 - five times the normal strength Hoagland's solution with μg/ml Cd.
Cadmium was added as $CdSO_4$.

The solutions were aerated using two air pumps (Hush III Aquarium Air Pump, Model 83, Metaframe Aquarium Products, Maywood, New Jersey). Each pump aerated 18 containers using rubber tubing and glass t-connectors to link each container together. A small hole was drilled 2 cm from the bottom of each container in which a hypodermic needle was inserted. The hypodermic needle was connected to the rubber tubing and silicone sealer was smeared around the needle and tubing to prevent air or solution leaks. Containers were filled with solution to within 2 cm of the top of the container. On June 26, July 2, and July 6, appropriate solutions were added to each treatment to maintain the desired solution level.

Measurements were taken for 20 days, between 0800 and 0900 hours, and began on June 21, 1979, and ended on July 10, 1979. Diffusive resistance of stomata on the upper leaf surface was measured each day, except on days, 4, 11, 18, 19, and 20 of the 20 day period tested. Stomatal resistances were obtained using a calibrated stomatal diffusion porometer (Kanemasu et al., 1969) (Model LI-65 Autopotometer and LI-205 Diffusion Resistance Sensor, LI-COR, Inc., Lincoln, Nebraska). Stomatal resistance was measured daily on one plant in each container to give 36 measurements per day. Measurements were rotated in a clockwise direction among the four plants in each container so that all the plants were tested every four days. Total water potential was measured on two treatments for each cultivar, i.e., half strength Hoagland's solution with no cadmium and half strength Hoagland's solution with cadmium for both Ponca and KanKing cultivars. Each treatment was sampled twice, making a total of eight measurements taken each day. Thermocouple psychrometers (Model C-52 Sample Chamber, Wescor, Inc., Logan, Utah) were used for obtaining water potential readings. A leaf disc (6 mm in diameter) was cut using a standard paper punch and immediately placed in a stainless-steel holder of the thermocouple chamber. After an equilibration time of 2 hours (Nelson et al., 1978), the potential was measured using a microvoltmeter (Model HR-33T Dew Point Microvoltmeter, Wescor, Inc., Logan, Utah). The tissue and stainless-steel holder were removed from the sample chamber, covered with transparent tape, and frozen for 24 hours at -25°C. The sample and holder were again put in the sample chamber and the same procedure was used to determine osmotic potential that was used to obtain total water potential. Turgor potential was calculated as the difference between osmotic and water potential.

At the end of the experiment (July 10, 1979), the roots and shoots of the four plants in each container were harvested. The four roots were treated as one group and the four shoots were treated as one group. Each group was weighed, dried to a constant weight at 70°C, and re-weighed. Each group was analyzed for cadmium using a perchloric-acid digestion procedure and a Perkin-Elmer Model 403 Atomic Absorption Spectrophotometer (Isaac and Kerber, 1971). Results presented are averages of the three replications (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

Stomatal Resistance

Stomatal resistance measurements showed significant differences among solutions (Table VIII). Plants grown in distilled water with or without cadmium had a high stomatal resistance, while plants grown in half strength Hoagland's solution generally had the lowest stomatal resistance. Drought-resistant plants grown in distilled water and half strength Hoagland's solution with cadmium had stomatal resistances that were two times greater than those of plants grown under the same conditions without cadmium. Yet, stomatal resistances of drought-resistant plants grown in five times Hoagland's solution with cadmium were three times lower than plants in the same solution grown without cadmium. Stomatal resistances of plants grown with cadmium was similar to that of drought-sensitive plants grown without cadmium. There were signifi-

TABLE VIII

EFFECTS OF CADMIUM STRESS ON THE INTERNAL WATER STATUS OF A DROUGHT-SENSITIVE (PONCA) AND A DROUGHT-RESISTANT (KANKING) CULTIVAR OF WINTER WHEAT GROWN IN THREE WATER CULTURES.

	---------- Cadmium ----------			-------- No Cadmium ---------		
Cultivar	Distilled Water	Half-Strength Hoagland	Five Times Hoagland Strength	Distilled Water	Half-Strength Hoagland	Five Times Hoagland Strength
			Stomatal resistance sec/cm			
Ponca	29.83	6.6	13.0	29.3	6.8	9.0
KanKing	53.14	7.4	4.9	24.6	3.8	18.6
			Water potential bars			
Ponca	-14.5	- 9.0	-12.9	- 9.6	-10.5	-12.8
KanKing	-19.2	-11.0	- 9.7	-12.0	- 9.9	-12.4
			Osmotic potential bars			
Ponca	-16.3	-15.4	-21.0	-12.3	-15.6	-17.7
KanKing	-20.8	-16.3	-19.4	-13.1	-15.3	-18.5
			Turgor potential bars			
Ponca	1.8	6.4	8.1	2.7	5.1	4.9
KanKing	1.6	5.3	9.7	1.1	5.4	6.1

cant differences for plants grown in each of the three solutions, and there were also significant differences between the solution and the cadmium treatment. Yet, there was no significant differences (0.05 level) due to the cultivar. [See analysis of variance (Appendix, Table XVIII) using Statistical Analysis System (Barr et al., 1976).]

Water Potentials

Water Potential followed nearly the same pattern that plants experienced for stomatal resistance (Table VIII). Cadmium lowered osmotic potentials, but increased turgor potentials. Plants grown in distilled water without cadmium had high osmotic potentials since there were no salts in the solution for plants to absorb. Osmotic potentials became more negative when cadmium was added to the distilled water. The plants took up the cadmium which caused lower osmotic potentials. Osmotic potentials of plants grown in five times Hoagland's solution with cadmium were low. Plants could absorb the salt that were present in high concentration which lowered the osmotic potential. Plants grown in solutions with cadmium showed that osmotic potentials were lowest for five times Hoagland's strength solution, highest for half-strength Hoagland's solution, and osmotic potential for distilled water was between the other two solutions.

However, turgor potential was lower for plants grown in distilled water with cadmium than plants grown in the same solution without cadmium. Turgor potentials were high in the plants grown in five times Hoagland's nutrient solution. Turgor potentials were the lowest for plants grown in distilled water with or without cadmium, and turgor potentials were usually the highest for plants grown in five times

Hoagland's solution, with cadmium. Plants grown in half strength Hoagland's solution had turgor potentials that usually fell in between the other two solutions.

Cadmium may have a more detrimental effect for nutrient absorption when large quantities of nutrient ions were present or when only minute quantities were in solution. Plants in half-strength Hoagland's solution with cadmium showed higher osmotic potential values than the other two solutions. This shows that under a balanced nutrient condition, the plant absorbs fewer salts than it does in distilled water with cadmium or in a solution containing five times the normal strength of Hoagland's nutrient solution plus cadmium. [See analysis of variance (Appendix, Table XIX) using Statistical Analysis System (Barr et al., 1976).]

Concentration

Plants grown in distilled water with cadmium accumulated a larger quantity of cadmium in the roots than plants grown in either half-strength Hoagland's solution or five times Hoagland's solution with cadmium (Table IX). Plants grown in five times Hoagland's solution with cadmium accumulated less cadmium in the roots than plants grown in half strength Hoagland's solution with cadmium. Plants grown without cadmium showed that some cadmium was present in the roots. Plants grown without cadmium in five times Hoagland's solution had the largest amount of cadmium present in the roots.

Roots of plants grown in half-strength Hoagland's solution without cadmium had the smallest amount of cadmium. Roots of plants grown in distilled water without cadmium had a cadmium concentration between the

TABLE IX

EFFECTS OF CADMIUM STRESS ON THE DRY WEIGHT AND CADMIUM CONCENTRATION OF ROOTS AND SHOOTS OF A DROUGHT-SENSITIVE (PONCA) AND A DROUGHT-RESISTANT (KANKING) CULTIVAR OF WINTER WHEAT GROWN IN THREE WATER CULTURES.

	Cadmium			No Cadmium		
Cultivar	Distilled Water	Half-Strength Hoagland	Five Times Hoagland Strength	Distilled Water	Half-Strength Hoagland	Five Times Hoagland Strength
Root cadmium concentration µg/g						
Ponca	1240	982	691	8.1	< 0.1	13.4
KanKing	1254	851	564	1.3	< 0.1	7.5
Shoot cadmium concentration µg/g						
Ponca	9.7	5.1	37.6	2.6	< 0.1	< 0.1
KanKing	12.1	3.5	62.1	< 0.1	0.4	< 0.1
Root dry weight g						
Ponca	0.08	0.11	0.14	0.10	0.05	0.10
KanKing	0.07	0.10	0.15	0.10	0.12	0.11
Shoot dry weight g						
Ponca	0.08	0.22	0.24	0.11	0.14	0.21
KanKing	0.07	0.18	0.20	0.15	0.28	0.17

other two solutions. The reason cadmium was present in the roots of plants grown without cadmium might be due to the presence of cadmium in fertilizers, especially phosphate (Fulkerson et al., 1973). Five times Hoagland's solution would naturally have more cadmium present since the fertilizer rate was high, and consequently, the plants probably took up more cadmium. The half-strength solution had cadmium present, but apparently not as much as was in the five times Hoagland's solution. The cadmium might have been complexed with other ions. The plants grown in distilled water possibly accumulated cadmium in their roots from the air that was bubbled through the solution. Cadmium is in automobile exhaust and cigarette smoke (Page and Bingham, 1973). These pollutants may have entered the growth room when the door was opened. A parking lot was adjacent to the growth room. Since the solution had no other ions in it, cadmium could not complex with it. Therefore, plants took up cadmium.

Cadmium concentration in the shoots was the greatest for plants grown in five times Hoagland's solution with cadmium. Plants grown in half strength Hoagland's solution with cadmium had the smallest amount present in the shoots of plants grown with cadmium while shoot concentration for plants grown in distilled water with cadmium was between the other two solutions. Wheat plants seem to have a mechanism which excludes cadmium from being transported to the leaves unless nutrients ions are numerous or absent (Jarvis et al., 1976). Complex interactions of cadmium occur with other elements (Council for Agricultural Science and Technology, 1976; Kirkham, 1977; Patel et al., 1976; Wallace et al., 1977a; Wallace et al., 1977b). [See analysis of variance (Appendix, Table XX) was done by Statistical Analysis System (Barr et al., 1976).]

Dry Weight

Plants grown in distilled water had the lowest root and shoot dry weight except for roots of drought-sensitive plants grown in half-strength Hoagland's solution without cadmium (Table IX). The dry weight of shoots and roots of plants in five times Hoagland's solution with cadmium was actually higher than plants in five times Hoagland's solution without cadmium. The root and shoot dry weight was greater with cadmium than the root and shoot dry weight of drought-sensitive plants grown in half-strength Hoagland's solution without cadmium. Trace quantities of cadmium have been found to stimulate growth (Kirkham, 1978b; Vallee, and Ulmer, 1972). The drought-sensitive plants grown without cadmium in half-strength Hoagland's solution had a smaller root and shoot dry weight than the drought-resistant cultivar grown in the same solution without cadmium. Drought-sensitive plants may increase growth with small amounts of cadmium in nutrient solutions while drought-resistant plants may not be affected by cadmium, or may even be inhibited in growth by cadmium.

CHAPTER IV

SUMMARY AND CONCLUSIONS

CHAPTER I

The physiological results of strip versus broadcasted fertilizer placement support the theory that fertilizer in strips is more efficient than broadcasted placements. That is, more fertilizer is taken up if placed in strips rather than broadcasted. A high availability of N and P in urea ammonium phosphate resulted in 16 and 44% more N and P uptake in the shoots of plants in plots which received stripped fertilizer than shoots of plants in plots with broadcasted fertilizer.

The proper placement of seed and fertilizer in the same operation would save energy without decreasing yields. In a field experiment, the highest yielding plot was a stripped fertilizer application (Table IV). The stripped fertilizer plots showed osmotic damage at early stages of growth, but overcame it. About 20 days after planting, osmotic potentials of plants grown with fertilizer placed in strips or broadcasted were the same. The broadcasted fertilizer plots had a better overall appearance than the stripped fertilizer plots or the control plots. However, uniformity, greater plant height and leaf area do not necessarily imply greater yield. Slight stress to plants may even increase yields. With energy costs rising, methods to increase the efficiency of fertilizer application, such as stripped-placement of fertilizer, may be worthwhile without compromising yields.

CHAPTER II

The effect of row direction on the growth and yield of wheat in Oklahoma, is evolving into a repeatable study. Oklahoma has strong winds that blow primarily from the south in the summer and from the north during the winter. It has been shown that winds affect the growth of plants (Todd et al., 1972). It is possible that wind plays a major role in the growth of wheat in central Oklahoma.

Three years of data all show a slight increase in yield for rows oriented in the east-west direction. Even farmers with only small wheat acreages may find a significant economic advantage with wheat planted in the east-west direction when wheat is planted for grain yield. Planting in the north-south direction may increase plant growth (Erickson et al., 1979). However, increased yields for forage have not been substantiated fully.

CHAPTER III

A drought-resistant and a drought-sensitive cultivar of wheat were grown in distilled water, half-strength Hoagland's solution, or five times Hoagland's solution. Half the solutions had cadmium and half did not. The effect of cadmium on the water relations of wheat showed considerable variation. Solution differences affected stomatal resistances, but there was no significant difference (0.05 level) for stomatal resistances due to cultivar. Cadmium lowered osmotic potentials, but generally increased turgor potentials. Results from the water potential measurements indicate that the plant can tolerate cadmium most efficiently under a balanced nutrient condition.

Wheat plants seem to have a mechanism to exclude cadmium ions from transportation to the leaves, unless nutrients ions are numerous or absent. Nutrient ion concentrations, and nutrient ion interaction with cadmium seemed to be the most important factors affecting growth.

The amount of research that has been done with water relations of wheat cultivars grown with cadmium is limited. To better understand cadmium, and the effect it has on water relation of wheat cultivars, further research is necessary.

LITERATURE CITED

1. Allen, S. E. 1970. New forms of fertilizer phosphorus. Agronomic evaluation. In Phosphorus in Agriculture. Bull. Doc. No. 55. Int. Superphosphate Manufacturer's Ass. Ltd. Agr. Comm., Paris. 11p.

2. Austenson, H. M., and E. N. Larter. 1969. Effect of direction of seeding on yields of barley and oats. Can. J. Plant Sci. 49:417-420.

3. Babich, H., and G. Stotzky. 1978. Effects of cadmium on the biota: influence of environmental factors. Adv. Appl. Microbiol. 23:55-117.

4. Barber, S. A. 1974. A program for increasing the efficiency of fertilizers. Fert. Solutions 18(2):24-25.

5. Barber, S. A. 1976. Efficient fertilizer use, p.13-29. In F. L. Patterson (ed.) Agronomic Research for Food. Amer. Soc. Agron. Spec. Pub. 26. Amer. Soc. Agron., Madison, Wis.

6. Barber, S. A. 1977a. Placement of phosphate and potassium for increased efficiency. Fert. Solutions 21(2):2p.

7. Barber, S. A. 1977b. Application of phosphate fertilizers: methods, rates and time of application in relation to the phosphorus status of soils, p. 109-115. In The Importance of Phosphorus in Agriculture. Int. Superphospate Manufacturer's Ass., Agriculture No. 70. Int. Superphosphate Manufacturer's Ass., Paris.

8. Barr, A. J., J. H. Goodnight, J. P. Sall, and J. T. Helwig. 1976. A User's Guide to SAS 76. SAS Institute, Inc., Raleigh, North Carolina.

9. Bazzaz, F. A., G. L. Rolfe, and Roger W. Carlson. 1974. Effect of Cd on photosynthesis and transpiration of excised leaves of corn and sunflower. Physiol. Plant. 32:373-376.

10. Bingham, F. T. 1979. Bioavailability of Cd to food in relation to heavy metal content of sludge-amended soil. Environ. Health Perspectives 28:39-43.

11. Bingham, F. T., A. L. Pate, R. J. Mahler, and T. J. Ganji. 1975. Growth and cadmium accumulation of plants grown on a soil treated with a cadmium-enriched sewage sludge. J. Environ. Quality 4:207-211.

12. Chin Choy, E. W., and E. T. Kanemasu. 1974. Energy balance comparison of wide and narrow row spacing in sorghum. Agron. J. 66:98-100.

13. Council for Agricultural Science and Technology. 1976. Application of sewage sludge to cropland: appraisal of potential hazards of the heavy metals to plants and animals. EPA-430/9-76-013. Office of Water Program Operations. U.S. Environmental Agency, Washington, D.C. 63p.

14. Day, A. D., A. Alemu, and E. B. Jackson. 1976. Effect of cultural practices on grain yield and yield components in irrigated wheat. Agron. J. 68:132-134.

15. deWit, C. T. 1953. A physical theory on placement of fertilizers. Versl. handbouwk. Onderz. No. 59.4, lab. of Phys. and Meteorol., Agr. Univ., Wageningen, Holland. 71p.

16. Erickson, P.I., M. B. Kirkham, and J. F. Stone. 1979. Growth, water relations and yield of wheat planted in four row directions. Soil Sci. Soc. Amer. J. 43:570-574.

17. Fox, R. L., and B. T. Kang. 1978. Influence of phosphorus fertilizer placement and fertilizer rate on maize nutrition. Soil. Sci. 125:34-40.

18. Friberg, L., M. Piscator, and G. Nordberg. 1971. Cadmium in the Environment. CRC Press. Cleveland, Ohio, 166p.

19. Fried, M., R. J. Soper, and H. Broedshart. 1975. ^{15}N-labelled single-treatment fertility experiments. Agron. J. 67:393-396.

20. Fulkerson, W., H. E. Goeller, J. S. Gailar, and E. D. Copenhaver (ed.) 1973. Cadmium-The Dissipated Element. Oak Ridge National Laboratory. Oak Ridge, Tennessee. Distributed by National Technical Information Service. U.S. Dept. of Commerce. Springfield, Va. p. 5-28.

21. Gray, F., and M. H. Roozitalab. 1976. Benchmark and Key soils Oklahoma. Okla.Agro. Exp. Sta. Misc. Pub. 97.

22. Haghiri, F. 1973. Cadmium uptake by plants. J. Environ. Quality 2:93-96.

23. Haghiri, F. 1974. Plant uptake of cadmium as influenced by cation exchange capacity, organic matter, zinc, and soil temperature. J. Environ. Quality 3:180-183.

24. Hassett, J. J., J. E. Miller, and D. E. Koeppe. 1976. Interaction of lead and cadmium on maize root growth and uptake of lead and cadmium by roots. Environ. Pollut. 11:297-302.

25. Huang, C.-Y., F. A. Bazzaz, and L. N. Vanderhoef. 1974. The inhibition of soybean metabolism by cadmium and lead. Plant Physiol. 54:122-124.

26. Hundal, H. S., P. S. Deol, and G. S. Sekhon. 1977. Evaluation of some sources of fertilizer phosphorus in two cycles of a paddy-wheat cropping sequence. J. Agric. Sci. 88:625-630.

27. Jarvis, S. C., L. H. P. Jones, and M. J. Hopper. 1976. Cadmium uptake from solution by plants and its transport from roots to shoots. Plant and Soil 44:179-191.

28. Issac, R. A., and J. D. Kerber. 1971. Atomic absorption and flame photometry: techniques and uses in soil, plants,and water analysis, p. 17-37. In L. M. Walsh (ed.) Instrumental methods for analysis of soils and plant tissue. Soil Sci. Sco. Amer., Inc., Madison, Wis.

29. John, M. K. 1976. Interrelationships between plant cadmium and uptake of some other elements from culture solutions by oats and lettuce. Environ. Pollut. 11:85-95.

30. Kanemasu, E. T., G. W. Thurtell, and C. B. Tanner. 1969. Design, calibration and field use of a stomatal diffusion porometer. Plant Physiol. 44:881-885.

31. Kemmler, G. 1974. Modern aspects of wheat manuring. IPI Bull. No. 1, Int. Potash Inst., Berne-Worblaufen, Switzerland. 66p.

32. Kirkham, M.B. 1977. Trace elements in sludge on land: effect on plants, soils, and ground water, p. 209-247. In: R. C. Loehr (ed.) Land as a waste management alternative. Ann Arbor Sci., Ann Arbor, Mich.

33. Kirkham, M. B. 1978. Water potential and turgor pressure as a selection basis for wind-grown winter wheat. Agr. Water Management 1:343-349.

34. Kirkham, M. B., 1978b. Water relations of cadmium-treated plants. J. Environ. Quality 7:334-336.

35. Kirkham, M. B. 1979. Water relations of wheat alternated between two root temperatures. New Phytol. 82:89-96.

36. Kirkham, M. B., and R. M. Ahring. 1978. Leaf temperature and internal water status of wheat grown at different root temperatures. Agron. J. 70:657-662.

37. Lagerwerff, J. V. 1971. Uptake of cadmium, lead and zinc by radish from soil and air. Soil Sci. 111:129-133.

38. Lamoreauz, R. J., and W. R. Chaney. 1978. The effect of cadmium on net photosynthesis, transpiration, and dark respiration of excised silver maple leaves. Physiol. Plant. 43:231-236.

39. Lamoreaux, R. J., and W. R. Chaney. 1977. Growth and water movement in silver maple seedlings affected by Cadmium. J. Environ. Quality 6:201-205.

40. Lawton, K., and J. F. Davis. 1960. Influence of fertilizer analysis and placement on the emergence, growth, and nutrient absorption by wheat seedlings in the greenhouse. Agron. J. 52:326-328.

41. Lee, K. C., B. A. Cunningham, G. M. Paulsen, G. H. Liang, and R. B. Moore. 1976. Effects of cadmium on respiration rate and activities of several enzymes in soybean seedlings. Physiol. Plant. 36:4-6.

42. Leikam, D. F., R. E. Lamond, P. J. Gallagher, B. Hall, K. W. Kelley, D. D. Scott, W. A. Moors, and L. S. Murphy. 1977. Comparisons of methods of N and P application for wheat, p. 20-22 and p. 45-48. In Kansas fertilizer research report of progress-1977. Kansas Agr. Exp. Sta. Rep. of Progress 313.

43. Linnman, L., A. Andersson, K. O. Nilsson, B. Lind, T. Kjellstrom, and L. Friberg. 1973. Cadmium uptake by wheat from sewage sludge used as a plant nutrient source. Arch. Environ. Health 27:45-47.

44. Luebs, R. E., A. E. Loag, and P. A. Nash. 1975. Evapotranspiration of dryland barley with different plant spacing patterns. Agron. J. 67:339-342.

45. Miller, R. J., J. E. Bittell, and D. E. Koeppe. 1973, The effect of cadmium on electron and energy transfer reactions in corn mitochondria. Physiol. Plant. 28:166-171.

46. Miller, J. E., J. J. Hassett, and D. E. Koeppe. 1976. Uptake of cadmium by soybeans as influenced by soil cation exchange capacity, pH, and available phosphorus. J. Environ. Quality 5:157-160.

47. Mortvedt. J. J. 1976. Band fertilizer placement. p.92-96. In Fertilizer Solutions. Nov.-Dec. 1976. Tennessee Valley Authority, Muscle Shoals, Ala.

48. National Fertilizer Development Center. 1976. Preliminary use manual. TVA Urea-Ammonium Phosphate (28-28-0). Nat. Fert. Development Center. Tennessee Valley Authority, Muscle Shoals, Alabama. 5p., 3 figs., 3 tables.

49. National Oceanic and Atmospheric Administration. 1978-1979a. Climatological data. Oklahoma. Vol. 87, 88. Environ. Data Service, Nat. Climatic Center, Asheville, N. C.

50. National Oceanic and Atmospheric Administration. 1978-1979b. Local climatological data, Tulsa, Okla. Monthly summary. Environ. Data Service, Nat. Climatic Center, Asheville, N. C.

51. Nelson, C. E., G. R. Safir, and A. D. Hanson. 1978. Water potential in excised leaf tissue. Plant Physiol. 61:131-133.

52. Oklahoma Agricultural Extension Service and Oklahoma Plant Food Educational Society, Inc. 1977. Oklahoma Soil Fertilizer Handbook. Available from B. B. Tucker, Agron. Dept., Okla. State Univ., Stillwater. 98p.

53. Olsen, S. R., and A. D. Flowerday. 1971. Fertilizer phosphorus interactions in aklaline soils, p. 153-185. In R. A. Olson, T. J. Army, J. J. Hanway, and V. J. Kilmer (ed.) Fertilizer Technology and Use. Soil Sci. Soc. Amer. Madison, Wis.

54. Olson, R. A., and A. F. Dreier. 1956. Fertilizer placement for small grains in relation to crop stand and nutrient efficiency in Nebraska. Soil. Sci. Soc. Amer. Proc. 20:19-24.

55. Page, A. L., and F. T. Bingham. 1973. Cadmium residues in the envrionment Res. Rev. 48:1-44.

56. Passioura, J. B., and R. Wetselaar. 1972. Consequences of banding nitrogen fertilizers in soil. 2. Effects on the growth of wheat roots. Plant Soil 36:461-473.

57. Patel, P. M., A. Wallace, and R. T. Mueller. 1976. Some effects of copper, cobalt, cadmium, zinc, nickel, and chromium on growth and mineral element concentration in chyrsanthemum. J. Amer. Soc. Hort. Sci. 101:553-556.

58. Pendleton, J. W., and G. H. Dungan. 1958. Effect on row direction on spring oat yields. Agron. J. 50:341-343.

59. Petruzzelli, G., G. Giudi, and L. Lubrano. 1977. Cadmium occurance in soil organic matter and its availability to wheat seedlings. Water, Air, and Soil Pollution 8:393-399.

60. Phillips, A. B., and J. R. Webb. 1971. Production, marketing, and use of phosphorus fertilizers, p. 271-301. In R. A. Olson, T. J. Army, J. J. Hanway, and V. J. Kilmer (ed.) Fertilizer Technilogy and Use. Soil Sci. Soc. Amer., Madison, Wis.

61. Pittman, U. J. 1962. Growth reaction and magnetotropism in roots of winter wheat (Kharkov 22 M.C.). Can. J. Plant Sci. 42:430-436.

62. Reddy, M. R., R. Prasad, and A. Austin. 1976. Effect of nitrogen levels and row directions on the protein content and chapati making qualities of wheat genotypes grown in pure and mixed stands. Indian J. Agron. 21:277-281.

63. Root, R. A., R. J. Miller, and D. E. Koeppe. 1975. Uptake of cadmium - its toxicity, and effect on the ion ratio in hydroponically grown corn. J. Environ. Qual. 4:473-476.

64. Sandhu, A. S. 1964. Effect of row direction on the growth and yield of bajra (Pennisetum typhoides). Indian J. Agron. 9:19-22.

65. Sandhu, A. S., and H. H. Laude. 1958. Tests of drought and heat hardiness of winter wheat. Agron. J. 50:78-81.

66. Schlehuber, A. M., and B. B. Tucker. 1967. Culture of wheat, p. 117-179. _In_ K. S. Quisenberry and L. P. Reitz (ed.) Wheat and Wheat Improvement. Amer. Soc. Agron., Madison, Wis.

67. Sempio, C. 1942. Mechanism of the resistance against _Oidium_ produced by cadmium on wheat plants. Ann. Facoltà Agrar. Regia Univ. Perugia 1:119-122. (English abstract: Chem. Abstr. 43: 1463).

68. Sharma, K. C., and M. Singh. 1971. Response of dwarf wheats to row direction and row spacing. Indian J. Agron. 16:396-399.

69. Shekhawat, G. S., D. C. Sharma, and M. B. Gupta. 1966. Wheat growth and production in relation to row spacing and direction of sowing. Indian J. Agron. 11:62-65.

70. Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc. New York. 481 p.

71. Tisdale, S. L., and W. L. Nelson. 1975. Soil Fertility and Fertilizers. Third Edition. Macmillan Publishing Co., New York, 694p.

72. Todd, G. W., D. L. Chadwick, and S.-D. Tsai. 1972. Effect of wind on plant respiration. Physiol. Plant. 27:342-346.

73. Tood, G. W., and D. L. Webster. 1965. Effects of repeated drought periods on photosynthesis and survival of cereal seedling. Agron. J. 57:399-404.

74. Tucker, B. B. 1968. Fertilizer use one wheat. Okla. State Univ. Extension Fact Sheet No. 2217. 4p.

75. United States Salinity Laboratory Staff. 1954. Saline and Alkali Soils. Agriculture Handbook No. 60. U.S. Dept. Agr., Washington, D. C. 160p.

76. Vallee, B. L., and D. D. Ulmer. 1972. Biochemical effects of mercury, cadmium, and lead. Annu. Rev. Biochem. 41:91-128.

77. van Wijk, W. R. 1966. Introduction, the physical method, p. 1-16. In W. R. van Wijk (ed.) Physics of Plant environment. 2nd ed. North-Holland Pub. Co., Amsterdam.

78. Verma, R. S., J. R. Singh, and R. R. Singh. 1977. Water use pattern in wheat as affected by seedrates, row spacings and row orientations under rainfed conditions. J. of Agric. Sci. Res. 16(1):4-7.

79. Wallace, A., E. M. Romney, G. V. Alexander, and S. M. Soufi. 1977a. Some interactions of cadmium with other elements in plants. Commun. Soil Sci. Plant Anal. 8:765-772.

80. Wallace, A., E. M. Romney, G. V. Alexander, S. M. Soufi, and P. M. Patel. 1977b. Some interactions in plants among cadmium, other heavy metals, and chelating agents. Agron. J. 69:18-20.

81. Watanabe, F. S., S. R. Olsen, and R. E. Danielson. 1960. Phosphorus availability as related to soil mositure. Trans. 7th Int. Cong. Soil Sci. III:450-456.

82. Yao, A. Y. M., and R. H. Shaw. 1964. Effect of plant population and planting pattern of corn on water use and yield. Agron. J. 56:147-152.

83. Yost, K. J., J. E. Christian, R. B. Jacko, J. P. Loop, D. R. Masarik, D. W. Neuendorf, and I. E. Smiley. 1975. The Environmental Flow of Cadmium and Other Trace Metals. Progress Rep. July 1, 1974 to July 30, 1975. Source Studies. NSF (RANN) Grand GI-35106. Purdue Univ. West Lafayette, Indiana.

APPENDIX

TABLE X

ANALYSIS OF VARIANCE FOR STOMATAL RESISTANCE OF NS AND EW ROWS

Source	df†	MS†	OSL†	C.V.†
				26.98
Block	2	2.28		
Orient	1	2.40	0.4062	
Block x Orient	2	2.21		
Date	12	13.42	0.0001	
Orient x Date	12	1.19	0.0006	
Error	282	0.40		

† df = degrees of freedom

MS = mean square

OSL = observed significance level

C.V. = coefficient of variation

TABLE XI

ANALYSIS OF VARIANCE FOR WATER POTENTIAL AND OSMOTIC POTENTIAL OF NS AND EW ROWS

Source	df	MS	OSL	C.V.
		Water Potential		
				29.45
Block	2	43.25		
Orient	1	29.50	0.3802	
BLock x Orient	2	23.64		
Date	14	78.22	0.0001	
Orient x Date	13	10.48	0.8765	
Error	53	18.80		
		Osmotic Potential		
				24.36
Block	2	4103.60		
Orient	1	0.0016	0.9944	
Block x Orient	2	25.76		
Date	14	69.34	0.0015	
Orient x Date	13	27.34	0.2810	
Error	49	22.04		

TABLE XII

ANALYSIS OF VARIANCE FOR PLANT HEIGHT, LEAF AREA OF THE FLAG LEAF, AND LEAF AREA OF THE WHOLE PLANT OF NS AND EW ROWS

Source	df	MS	OSL	C.V.
Plant Height				
				16.18
Block	2	1111.42		
Orient	1	0.08	0.9654	
Block x Orient	2	35.11		
Date	13	14117.73	0.0001	
Orient x Date	13	7.45	0.9947	
Error	299	27.60		
Leaf Area of the Flag Leaf				
				26.29
Block	2	391.95		
Orient	1	110.46	0.2736	
Block x Orient	2	49.44		
Date	5	5757.47	0.0001	
Orient x Date	5	363.38	0.3608	
Error	128	131.46		

TABLE XII (Continued)

Source	df	MS	OSL	C.V.
Leaf Area of the Whole Plant				
Block	2	4364.10		84.34
Orient	1	1711.27	0.1005	
Block x Orient	2	205.24		
Date	7	27018.09	0.0001	
Orient x Date	7	1174.23	0.0476	
Error	171	563.87		

TABLE XIII

ANALYSIS OF VARIANCE FOR SOIL-WATER CONTENT OF NS AND EW ROWS

Source	df	MS	OSL	C.V.
				6.64
Block	2	0.0076		
Orient	1	0.0142	0.1574	
Block x Orient	1	0.0009		
Date	5	0.0493		
Orient x Date	5	0.0006	0.5451	
Block x Date (Orient)	15	0.0007		
Depth	1	0.0077	0.0001	
Orient x Depth	1	0.0033	0.0056	
Date x Depth	5	0.0037	0.0001	
Orient x Date x Depth	5	0.0001	0.9122	
Error	18	0.0061		

TABLE XIV

ANALYSIS OF VARIANCE FOR NITROGEN, PHOSPHORUS, POTASSIUM, CALCIUM, MAGNESIUM, IRON, ZINC, AND MANGANESE CONTENT OF STRAW FOR NS AND EW ROWS

Source	df	MS	OSL	C.V.
		Nitrogen		
				9.13
Block	2	0.0070	0.2057	
Orient	1	0.0170	0.0920	
Error	2	0.0018		
		Phosphorus		
				27.78
Block	2	0.0009	0.4088	
Orient	1	0.0001	0.3349	
Error	2	0.00006		
		Potassium		
				13.41
Block	2	0.0336	0.2945	
Orient	1	0.0229	0.3291	
Error	2	0.0140		

TABLE XIV (Continued)

Source	df	MS	OSL	C.V.
		Calcium		
				16.04
Block	2	0.0013	0.5711	
Orient	1	0.0011	0.5005	
Error	2	0.0017		
		Magnesium		
				10.46
Block	2	0.00003	0.6579	
Orient	1	0.00008	0.3467	
Error	2	0.00005		
		Iron		
				79.80
Block	2	925.12	0.7167	
Orient	1	0.38	0.9910	
Error	2	2339.86		

TABLE XIV (Continued)

Source	df	MS	OSL	C.V.
		Zinc		
				206.85
Block	2	66.89	0.5533	
Orient	1	38.51	0.5657	
Error	2	82.83		
		Manganese		
				36.97
Block	2	46.66	0.9155	
Orient	1	55.21	0.7725	
Error	2	505.82		

TABLE XV

ANALYSIS OF VARIANCE FOR NITROGEN, PHOSPHORUS, POTASSIUM, CALCIUM, MAGNESIUM, IRON, ZINC, AND MANGANESE CONTENT OF GRAIN FOR NS AND EW ROWS

Source	df	MS	OSL	C.V.
		Nitrogen		
				3.50
Block	2	0.0744	0.0551	
Orient	1	0.0024	0.5298	
Error	12	0.0060		
		Phosphorus		
				10.84
Block	2	0.0012	0.0799	
Orient	1	0.0003	0.2076	
Error	12	0.0009		
		Potassium		
				12.13
Block	2	0.0015	0.0010	
Orient	1	0.0003	0.0060	
Error	12	0.0022		

TABLE XV (Continued)

Source	df	MS	OSL	C.V.
		Calcium		
				17.12
Block	2	0.00007	0.1059	
Orient	1	0.00048	0.0162	
Error	12	0.00033		
		Magnesium		
				10.35
Block	2	0.00009	0.0637	
Orient	1	0.00001	0.2651	
Error	12	0.00009		
		Iron		
				27.97
Block	2	287.08	0.1806	
Orient	1	2.72	0.8549	
Error	12	127.74		

TABLE XV (Continued)

Source	df	MS	OSL	C.V.
Zinc				
				20.92
Block	2	15.79	0.1863	
Orient	1	0.21	0.8315	
Error	12	33.72		
Manganese				
				24.95
Block	2	479.12	0.2500	
Orient	1	24.04	0.7355	
Error	12	92.77		

TABLE XVI

ANALYSIS OF VARIANCE FOR PROTEIN CONTENT OF GRAIN, WEIGHT OF TILLERS/m^2, AND NUMBER OF TILLERS/m^2 OF NS AND EW ROWS

Source	df	MS	OSL	C.V.
		Protein of Grain		
				2.67
Block	2	1.58	0.0182	
Orient	1	0.05	0.3210	
Error	12	0.12		
		Weight of Tillers/m^2		
				6.11
Block	2	59744.96	0.1029	
Orient	1	32649.13	0.1608	
Error	2	6855.71		
		Number of Tillers/m^2		
				12.12
Block	2	23170.50	0.2008	
Orient	1	9520.17	0.3293	
Error	2	5823.17		

TABLE XVII

ANALYSIS OF VARIANCE FOR YIELD OF WHEAT AND 1000-KERNEL WEIGHT OF NS AND EW ROWS

Source	df	MS	OSL	C.V.
		Yield of Wheat		
				6.13
Block	2	84365.97	0.3078	
Orient	1	125968.54	0.2083	
Error	12	24834.22		
		1000-Kernel Weight		
				3.57
Block	2	16.74	0.0482	
Orient	1	0.44	0.5478	
Error	12	1.36		

TABLE XVIII

ANALYSIS OF VARIANCE FOR STOMATAL RESISTANCE FOR CADMIUM EXPERIMENT

Source	df	MS	OSL	C.V.
				57.87
Soln	2	163449.57	0.0001	
Cd	1	1152.93	0.5673	
Soln x Cd	2	9959.69	0.0741	
PK[†]	1	3.65	0.9742	
Soln x PK	2	1197.51	0.7087	
Cd x PK	1	9.27	0.9590	
Soln x Cd x PK	2	2169.62	0.5396	
Time	13	572.61	0.0100	
Soln x Time	26	903.31	0.0001	
Cd x Time	13	328.45	0.2405	
Soln x Cd x Time	26	469.94	0.0112	
PK x Time	13	347.44	0.1958	
Soln x PK x Time	26	367.10	0.0959	
Cd x PK x Time	13	269.22	0.3327	
Soln x Cd x PK x Time	26	270.72	0.4241	
N[†] (soln x Cd x PK)	24	3427.60	0.0001	
Error	348	262.39		

[†] PK = Ponca and KanKing

N = Number

TABLE XIX

ANALYSIS OF VARIANCE FOR WATER POTENTIAL AND OSMOTIC POTENTIAL FOR CADMIUM EXPERIMENT

Source	df	MS	OSL	C.V.
		Water Potential		
				40.80
Soln	2	154.32	0.0044	
Cd	1	71.88	0.0867	
Soln x Cd	2	136.77	0.0073	
PK	1	8.52	0.5444	
Soln x PK	2	65.67	0.0736	
Cd x PK	1	0.87	0.8458	
Soln x Cd x PK	2	13.67	0.5532	
Error	84	23.87		
		Osmotic Potential		
				34.06
Soln	2	143.69	0.0089	
Cd	1	192.66	0.0102	
Soln x Cd	2	66.91	0.0878	
PK	1	8.54	0.5629	
Soln x PK	2	24.20	0.3914	
Cd x PK	1	6.25	0.6202	
Soln x Cd x PK	2	12.14	0.6191	
Error	76	32.99		

TABLE XX

ANALYSIS OF VARIANCE FOR CADMIUM CONCENTRATION WITH CADMIUM IN ROOTS, CADMIUM CONCENTRATION WITH CADMIUM IN SHOOTS, CADMIUM CONCENTRATION WITHOUT CADMIUM IN ROOTS, AND CADMIUM CONCENTRATION WITHOUT CADMIUM IN SHOOTS

Source	df	MS	OSL	C.V.
With Cadmium in Roots				
				23.91
Soln	2	578568.07	0.0015	
PK	1	29851.83	0.4524	
Soln x PK	2	10171.99	0.8170	
Error	12	49499.11		
With Cadmium in Shoots				
				55.25
Soln	2	3634.66	0.0001	
PK	1	323.17	0.1594	
Soln x PK	2	295.52	0.1704	
Error	12	143.61		

TABLE XX (Continued)

Source	df	MS	OSL	C.V.
		Without Cadmium in Roots		
				80.86
Soln	2	163.67	0.0029	
PK	1	79.67	0.0490	
Soln x PK	2	20.21	0.3303	
Error	12	16.61		
		Without Cadmium in Shoots		
				372.97
Soln	2	2.99	0.4504	
PK	1	2.47	0.4172	
Soln x PK	2	4.02	0.3501	
Error	12	3.50		

VITA

Calvin H. Pearson

Candidate for the Degree

of Master of Science

Thesis: PHYSIOLOGICAL MEASUREMENTS OF WINTER WHEAT UNDER STRESS:
I. WATER RELATIONS, GROWTH, ELEMENTAL COMPOSITION, AND YIELD OF WHEAT GROWN WITH FERTILIZER PLACED IN STRIPS OR BROADCASTED
II. WATER RELATIONS OF WHEAT GROWN IN NORTH-SOUTH VERSUS EAST-WEST DIRECTIONS
III. WATER RELATIONS OF WHEAT CULTIVARS GROWN WITH CADMIUM

Major Field: Agronomy

Biographical:

Personal Data: Born in Ogden, Utah, January, 25, 1954, and raised in Burley, Idaho, the son of Mr. and Mrs. Carmen P. Pearson.

Education: Graduated From Burley High School, Burley, Idaho, May, 1972; received Junior College degree from Ricks College in 1976; received Bachelor of Science degree in Agronomy from Brigham Young University in 1978; completed requirements for the Master of Science degree at Oklahoma State University in December, 1979.

Experience: Research Assistant, Oklahoma State University, Division of Agriculture, September 1978 - December 1979; raised on an irrigated farm growing sugar beets, dry beans, corn, alfalfa, wheat, and barley, and raising beef cattle.

Member: American Society of Agronomy, Alpha Zeta.