GERMINATION REQUIREMENTS AND COLD TOLERANCE OF WILD OATS (*AVENA FATUA* L.) FROM SOUTHWEST OKLAHOMA

By

DALLAS LYNN GEIS

Bachelor of Science in Agriculture

Oklahoma State University

Stillwater, Oklahoma

1992

Submitted to the Faculty of the
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GERMINATION REQUIREMENTS AND COLD

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FATUA) FROM SOUTHWEST

OKLAHOMA

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ACKNOWLEDGEMENTS

I express my sincere appreciation to my major adviser, Dr. Don S. Murray for his leadership, time, patience, and dedication to the completion of this research. I thank my committee members Dr. Thomas F. Peeper and Dr. Ronald J. Tyrl for their time and input during the course of this research.

I express my deepest thanks to my wife Stacey for her love, patience, encouragement, understanding, and devotion throughout the last two years. I thank my parents Lynn and Ruth for the love, guidance, support, and prayers over the past 24 years. I also thank my brother, Chad, and sister-in-law, Karissa, for their friendship, help, and support. To the rest of my family thank you for your love and support.

Additionally, I thank Andrew Bennett, Joy Rogers-Owens, Jerry Baysinger, Dr. John Altom, and Dr. R. Brent Westerman, James Barnes, David Altom, and David Tague for their friendship and assistance with my research. I express a special thanks to Dianna Banks, without whose help this research would have been impossible. I also thank Mark, Curtis, Greg, Bob, Tracey, Jacki, Lori, Jeff K., Randy, Corky, and Jeff B. for their friendships over the last two years.

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GERMINATION REQUIREMENTS AND COLD TOLERANCE OF WILD OATS (AVENA FATUA L.) FROM SOUTHWEST OKLAHOMA

Abstract. Investigations on the germination of wild oats (Avena fatua L.) from southwest Oklahoma revealed that (1) light does not exhert a significant influence on germination; (2) germination rates were 68% or greater when seed were incubated at constant temperatures from 10 to 25 C; (3) germination rates ranged from 74% at day/night temperatures of 5 to 15 C to 89% when seed were incubated under day/night temperatures of 20 to 30 C; (4) greater than 70% germination was obtained in solutions with pH levels ranging from 5 to 8 with severe reductions in percent germination at pH levels of 3, 4, and 9; (5) over 88% germination was obtained when seed were germinated in aqueous solutions with osmotic potentials ranging from 0.0 to -0.2 MPa; and (6) germination was greatly inhibited as osmotic potentials were reduced to -0.4, -0.6, and -0.8 MPa. These wild oats were grown with 'Scout 66', a hard red winter wheat (Triticum aestivum L.) variety with a known high degree of cold tolerance, and subjected to a constant air temperature of -18 C for various durations ranging from 1 to 54 hours to determine the relative cold tolerance of wild oats from southwest Oklahoma. Regrowth of wild oats after freezing was not significantly affected until after 4.8 h of exposure, while wheat was not affected until after 9 h of exposure. These results suggest wild oats from southwest Oklahoma are distinct from wild oats found in the northern portions of North America. The results also suggest the most limiting factor influencing the germination of wild oats in southwest Oklahoma during the fall, winter, and spring months is the availability of water. The cold tolerance test results suggest wild oats from southwest Oklahoma will be more severely affected by sudden periods of cold stress than wheat varieties with a high degree of cold tolerance. **Nomenclature:** wild oats, *Avena fatua* L. #[1] AVEFA; hard red winter wheat, *Triticum aestivum* L.

Additional index words: Biology, alternating temperature, constant temperature, water stress, osmotic potential, pH, cold stress, AVEFA.

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[1]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 W. University, Champaign, IL 61821-3133.

INTRODUCTION

Wheat producers in southwest Oklahoma have many environmental factors influencing the productivity of their hard red winter wheat (*Triticum aestivum* L.). The environment of this area is subject to drastic changes not only from year to year, but from day to day, with the two major environmental changes in this area of Oklahoma being temperature and moisture. Not only do these two factors greatly influence the production of wheat in this area, they also affect the weeds infesting fields in this hard red winter wheat producing area of North America.

One weed which has plagued wheat producers in this area since 1970, when it was first reported in the area, is wild oats (*Avena fatua* L.). It has been observed that population densities of wild oats in this area can vary substantially from year to year[2]. The environment of this area may play a substantial role in the variation seen in wild oat populations. However, there is no information currently available on how environmental factors affect the germination and productivity of wild oats in southwest Oklahoma.

Wild oats were introduced into north-central Texas in the early 19th century when cultivated oat (*Avena sativa* L.)

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[2]Murray, D. S. 1994 Personnal Communication. Row Crops Weed Control Research, Oklahoma State University, Stillwater, OK 74078.

production began (18). Since then, the wild oats found in north-central Texas have become naturalized to the environmental conditions present and are considered to be distinctly different from wild oats found in the northern areas of North America (18), where they have become a weed problem primarily in wheat.

It is believed wild oats entered southwest Oklahoma from north-central Texas[3]. During a period from 1970 to 1975, wild oats invaded approximately 64,000 ha of wheat in the counties of Cotton and Tillman and have continued to spread to other areas of the state.

Wild oat densities of up to 385 plants/m^2 have been reported in some wheat fields in southwest Oklahoma. With each plant capable of producing up to 250 seeds/plant, the possibility exists for a large amount of seed being added to the soil seed bank and dispersed to other areas in any one year. A wild oat 'seed' is actually a caryopsis, consisting of a seed, lemma, and palea. However, for the remainder of this manuscript the caryopsis of wild oats will be referred to as a seed. Seeds are spread by machine, wind, water, and animals, and upon reaching the soil, are able to remain viable for up to 7 yr, which facilitate the spread and

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[3]Peeper, T. F. 1994 Personnal Communication. Small Grain Weed Control Research, Oklahoma State University, Stillwater, OK 74078.

increase of the population.

Since the appearance of wild oats in southwest Oklahoma, control has been attempted (14, 15). However, the practice of grazing cattle on wheat pasture during the fall, winter, and early spring months hinders control through both cultural and/or chemical means. Winter wheat is planted as early as late August to obtain early grazing; thus, preventing the destruction of early fall emerging wild oats during soil preparation and planting.

Another problem related to the grazing of wheat pasture is restrictions placed on the use of herbicides for wild oat control. The only herbicide currently recommended for wild oat control in Oklahoma is diclofop-methyl [methyl 2-[4-(2,4-dichlorophenoxy) phenoxy] propanoate], which has a season-long grazing restriction (17). In recent years, the wheat pasture obtained was more valuable to the producer than the wheat grain crop. Therefore, few producers are willing to give up grazing to manage wild oat infestations through the use of chemical and/or cultural methods.

In evaluating and classifying several species of _Avena_, Peier (18) reported _A_. _fatua_ L. from north-central Texas to be distinct from _A_. _fatua_ found in other areas of North America due to the absence of dormancy and growth habit. Many researchers have investigated factors affecting the germination (5, 7, 8, 11, 12) and dormancy (1, 3, 6, 13, 19, 20, 21) of wild oats found in the northern areas of North America. Wild oats from these areas are a problem in cereal grain production during the spring and summer months. However, the wild oats found in the hard red winter wheat producing areas of southwest Oklahoma appear to exhibit little or no dormancy, just as those found in north-central Texas. The wild oats in southwest Oklahoma, unlike those found in northern areas of North America, are a problem in wheat during the fall and winter months as well as the early-spring months. Unfortunately, no research has been done concerning the influence of environmental factors on germination of wild oats found in southwest Oklahoma or their cold tolerance.

Many environmental factors such as light (2, 4, 5, 11, 12), temperature (7, 8, 22, 23), soil pH (4, 10, 23), and water stress (7, 23) influence the germination of weed seed. Cumming and Hay (5) reported light does not influence the germination of non-dormant wild oats or wild oats with broken dormancy. Wild oats from the northern areas of North America have been reported to germinate over a relatively broad range of temperatures with temperatures around 20 C providing maximum germination (7, 8). The effect of alternating temperatures on wild oat germination has not been reported.

Soil solution characteristics can greatly influence the germination weed seed. Germination of seed collected near Pullman, WA was reported to decrease linearly with increasing water potentials ranging from -0.025 to -1.4 MPa (7). Several scientists have reported the influence of solution pH on germination of broadleaf weed seeds. However, no reports were found on the influence of pH on wild oat germination.

Winter wheat production in southwest Oklahoma is subject to drastic changes in the air temperature over short periods of time. Extreme temperature fluctuations can severely affect wheat populations in the field in this hard red winter wheat producing area of North America. In this region, it is not uncommon for air temperatures during the late fall or early winter months to drop from 15 to 20 C down to -5 or -10 C in a matter of hours. After a period of 1 or 2 days, the temperature may then recover to 15 or 20 C. Many times the wheat has not been exposed to acclimating temperatures; thus, the result of such extreme temperature changes is often a reduction of a producers wheat stand.

When fully acclimated, wheat can withstand temperatures down to -21 C, but fully acclimated oats can only tolerate temperatures down to -10 C (9). If acclimated wheat is able to withstand lower temperatures than acclimated cultivated oats, the possibility exists that wheat without the benefit of acclimation could withstand sub-freezing temperatures for longer periods of time than unacclimated wild oats.

If wild oats have a lesser degree of cold tolerance than wheat to sudden temperature drops, wild oat populations in the field might be substantially reduced in comparison to that of wheat during a sudden cold spell. Thus, information concerning the cold tolerance of non-acclimated wild oats to that of non-acclimated wheat could be useful in determining population dynamics or overall competitiveness of wild oats with wheat as affected by various periods of sub-freezing temperatures.

Cold tolerance of wild oats has been investigated (18). Evaluations were made of wild oats collected from central and north-central Texas for characteristics of potential agronomic value. Peier (18) in evaluating the cold tolerances of wild oats in Texas, reported that some of the wild oats collected tended to exhibit equal or superior hardiness to the cold tolerant variety of cultivated oats, Bronco. However, the cold tolerance field tests did not yield consistent results at different locations over time; therefore, Peier (18) was unable to make inferences into the cold tolerance of the wild oats found in central and north-central Texas.

At present, no information is currently available concerning how light, temperature, soil pH, water stress, or cold stress influence the severity of wild oat infestations in this hard red winter wheat producing area of North America. The environment and period in which wild oats found in southwest Oklahoma grow differs significantly from the environments of previously studied wild oats.

Therefore, the objectives of this research were: 1) Determine the effects of light, temperature, pH, and water stress on the germination of wild oats from southwest Oklahoma, and compare the results to information available from the northern areas of North America. 2) Compare the cold tolerance of non-acclimated wild oats from southwest Oklahoma to that of a non-acclimated wheat variety with a known high degree of cold tolerance. This information will be used to determine the effect of exposure to sub-freezing temperatures for various durations on the survival and productivity of wild oats compared to that of winter wheat. The information obtained from these two sets of experiments may help reveal why the severity of wild oat infestations in southwest Oklahoma varies from year to year.

MATERIALS AND METHODS

Seed source. The seed used in the following experiments were obtained from wheat harvested in June, 1993 from a wild oat infested wheat field southwest of Lawton, OK. The wheat was processed through a seed cleaner several times with the wild oat seed being hand sorted from the screenings, which contained various weed seeds, chaff, and A. sterilis. The seed was then stored at approximately 25 C (room temperature) with a voucher specimen being deposited in the Oklahoma State University Herbarium (OKLA).

Germination requirements (general). Preliminary experiments indicated the collected wild oat seed exhibited little or no dormancy, and that germination was not influenced by the presence or absence of light. Also indicated was that 5 d of incubation resulted in maximum germination over a wide range of constant temperatures. Therefore, all germination experiments, unless otherwise stated, were conducted under constant light and cumulative germination rates were recorded after 5 d of incubation. A seed was considered to have germinated when a radicle visibly protruded through the lemma. In the experiments evaluating the influence of pH and water stress, germination chamber temperatures were maintained at 20 C.

Twenty seed were placed between two pieces of 9 cm filter paper in unsealed petri dishes (100 by 15 mm). The paper was moistened with 5 ml of distilled water, pH approximately 5.9, or test solution.

Germination experiments involving temperatures equal to or greater than 15 C were conducted in two growth chambers under fluorescent lights producing a photon flux density of 10 $\mu mol/m^2/s$ with a relative humidity of 100%. Experiments involving temperatures of 5 or 10 C were conducted in a growth chamber equipped with fluorescent lights producing a photon flux density of 160 $\mu mol/m^2/s$ and a relative humidity of 50%. Measurements were taken to determine if gradients existed with respect to light intensity, relative humidity, or temperature; none were present.

Experiments were conducted three times using a randomized complete block design with five replications, each petri dish representing a replication. Twenty seed were placed between the two sheets of filter paper in each petri dish; thus, each replication involved 100 wild oat seed.

Temperature. Constant temperature. Temperatures were held constant at 5, 10, 15, 20, 25, and 30 C during the 5 d incubation period to evaluate the effect of various constant temperatures on the germination of wild oat seed.

Alternating temperature. Seed were incubated under 12 h day/night cycles at temperatures of 5/15, 10/20, 15/25, and 20/30 C.

pH. Buffered solutions were prepared volumetrically using prepackaged buffer powders[4] and distilled water. Solution pH levels were 3, 4, 5, 6, 7, 8, and 9. Solution pH levels were confirmed with a pH meter[5] calibrated using buffer solutions with pH levels of 4.0, 7.0, and 10.0. Distilled water (pH 5.9) was evaluated along with the buffered solutions to serve as a check. Osmotic potentials for each buffered solution and the distilled water were determined using thermocouple psychrometers[6] with electrical conductivities[7] also also being determined (Table 3).

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[4]Hydrion buffer set. Aldrich Chemical Company, Inc., Milwaukee, WI 53233.

[5]Fisher Accumet 825 MP pH Meter. Fisher Scientific, Pittsburgh, PA 15219.

[6]Leaf cutter thermocouple psychrometer. J. R. D. Merrill Specialty Equipment, Logan, UT 84321.

[7]CDM 83 Conductivity Meter. Radiometer/Copenhagen Analytical Instruments Division, Radiometer A/S, Emdrupvej 72, DK 2400 Copenhagen NV, Denmark.

Water stress. Aqueous solutions with osmotic potentials of 0.0 (distilled water), -0.1, -0.2, -0.4, -0.6, and -0.8 MPa were prepared with polyethylene glycol (PEG)[8] using an equation defined by Michel (16). The equation was quadratically solved to give 0.0, 41.87, 62.83, 92.68, 115.66, and 135.05 g PEG per 500 ml of distilled water, respectively. Thermocouple psychrometers[6] was used to measure the water potentials established (Table 4).

Statistical analysis. Data for all experiments were recorded as cumulative percent germination and subjected to analysis of variance procedures in SAS[9]. Analysis of the three experimental runs involving alternating temperatures, pH, and water stress revealed no significant difference between runs. A significant constant temperature by run interaction ($P < 0.05$) was present in the experiments evaluating the effect of constant temperatures on wild oat germination at 10 C with no other interactions being present. The 10 C by run interaction was due to differences in magnitude not response consistency. Therefore, interpretations were related to pooled means of percent germination averaged over runs in all experiments with comparisons being made using a protected Least Significant Difference (LSD) Test at the 5% probability level.

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[8]PEG 8000. Fisher Scientific, Pittsburgh, PA 15219.

[9]SAS, Version 6.0, SAS Institute Inc., Box 8000, Cary, N.C. 27511.

Cold tolerance. A completely randomized split-plot design with five replications was used to evaluate the relative cold tolerance of wild oats from southwest Oklahoma to that of 'Scout 66', a hard red winter wheat variety with a known high degree of cold tolerance. Fifteen wild oat seed and 15 wheat seed were planted in 7.6 L nursery pots. The bottoms of the nursery pots were lined with burlap cloth and evenly covered with approximately 1 kg of air-dried dolomite screenings with the remainder of the pot filled with approximately 5 kg of air-dried sand. Seed were evenly spaced in rows 2.5 cm apart and planted 4 cm deep. Pots were watered to field capacity with tap water and placed in a greenhouse maintained at 20 to 25 C. Pots were subsequently watered throughout the experiment as needed to avoid water stress.

After emergence, visual ratings of growth and development were made during the course of the experiment using the Zadoks growth scale (24). At various times during the experiment, additives were required to control insects, fungal pathogens, and nutrient deficiencies. Dimethoate (O,O-dimethyl S-[N-(methylcarbamoyl) methyl] phosphorodithioate) was applied at 0.4 kg ai/ha to control aphids when the plants had 2 to 3leaves. After the wheat and wild oats reached the 3-leaf stage, plants were thinned to 10 plants per species per pot. After thinning, pots were fertilized at each watering with 100 mg of 15-30-15[10]. Several fungal diseases, developing at the 4- to 5-leaf stage, were treated with triadimefon [1-(4-Chlorophenoxy)-3,3-dimethyl-1(1H-1,2,4-triazol-1-yl)-2-butanone] at 0.1 kg ai/ha.

On reaching the 6- to 7-leaf stage the wild oats began to joint; therefore, top growth was trimmed to 2.5 cm with fresh and dry weights determined on a per plant basis in order to calculate percent water in the above ground biomass to determine if a correlation existed between above ground biomass water content and the exposure time required for 50% population reduction, LT_{50} (AL). The equation used to determine percent water content was:

$$\text{Percent water} = \frac{\text{fresh weight-dry weight}}{\text{fresh weight}} \times 100$$

Facilities were not present for controlled acclimation; therefore, plants were placed directly into a freezing chamber maintained at -18 C without acclimation in a completely randomized design for various periods of time. Exposure lengths were 0 to 12, 18, 24, 30, 36, 42, 48, and 54 hours. Upon removal from the freezer, soil temperatures were taken at a depth of 2 cm adjacent to the wild oat and wheat crowns (Figure 1). Pots were then returned to the greenhouse. The plants surviving in each pot were scored

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[10]Stern's Miracle-Gro Products, Inc. Port Washington, NY 11050.

according to the amount of regrowth observed. The number of surviving plants was used to determine a LT_{50}. Seven days after the pots had been returned to the greenhouse, aphids were treated with 0.4 kg ai/A of dimethoate. As the regrowth reached the 4- to 5-leaf stage 14 d after removal from the freezer, the wild oats began to joint. Therefore, top growth biomass was collected with average plant fresh and dry weights being determined.

Biomass production was significantly affected when analyzed by analysis of variance. However, in the data obtained, there appeared to be lengths of exposure in which regrowth was not affected by exposure to an air temperature of -18 C and durations of exposure in which the amount of regrowth produced by each species declined linearly. Therefore, the data was analyzed using the PROC NLIN procedure in SAS[8] to develop a plateau-linear model which described the effect of various durations of exposure to an air temperature of -18 C on the vegetative productivity of wild oats and wheat.

RESULTS AND DISCUSSION

Germination requirements (temperature). Constant. The greatest percentage of wild oats germinated at constant temperatures of 15 and 20 C (Table 1). However, percent germination was greater than 80% for temperatures ranging from 10 to 20 C. As the germination temperature was increased to 25 C, percent germination declined, but was still greater than 65%. The two temperature extremes, 5 and 30 C, proved to be detrimental to wild oat germination. Results suggest that a substantial percentage of wild oats from southwest Oklahoma would still germinate at temperatures ranging from 10 to 25 C. These results are similar to previous reports. Fernandez-Quinantilla et al. (7) reported greater than 60% germination for A. fatua L. when germinated under temperatures from 5 to 30 C when using seed collected near Pullman, WA. Sharma et al. (22) reported seed collected from Alberta, Canada had germination greater than 85% at temperatures ranging from 10 to 26.5 C; but that germination dropped to 14% at 32 C. Friesen and Shebeski (8), using seed from Manitoba and Saskatchewan, Canada, reported maximum germination of 77% at 21 C with germination percentages declining to 58 and 46% when germination temperatures were 27 and 16 C, respectively.

Alternating temperatures. Percent germination of wild oats when exposed to various day/night temperatures resulted in germination rates of 74% or greater when exposed to the alternating temperatures for intervals of 12 h each (Table 2). These results suggest that although wild oats from southwest Oklahoma are exposed to temperatures that are less than conducive for germination, they will still be able to germinate when exposed to more favorable temperatures.

The results of both temperature experiments possibly explain why wild oats in southwest Oklahoma emerge over an extended period in the fall and winter. When subjected to constant temperatures ranging from 10 to 25 C more than 65% of the wild oats present in the soil have the potential of germinating. When spread over a period of approximately 6 mo, the number of wild oats that may become established in a field can become quite substantial even if only 65% germinate. The results of the alternating temperature experiment may explain why wild oats continue to germinate and emerge during the winter months due to daytime soil temperatures reaching well into the favorable range of temperatures even during the middle of winter.

pH. Germination of wild oats was greater than 70% at pH levels ranging from 5 to 8 with approximately 43% of the wild oat seed germinating at pH 4 (Table 3). Although the wild oats were able to germinate at pH levels of 4, 8 and 9, the radicles were stunted with a brownish discoloration. In southwest Oklahoma, a large percentage of the soils in wheat production fall well within the pH levels conducive to wild oat germination. Therefore, soil pH does not appear to influence germination.

Water stress. The influence of osmotic potentials of -0.1 and -0.2 MPa did not exert a significant effect on the germination of wild oats as compared to germination obtained when the seed were incubated distilled water (Table 4). However, when the osmotic potential of the test solution was decreased to -0.4 MPa or lower, a significant reduction in percent germination occurred. The results obtained from this experiment differed substantially from results reported by Fernandez-Quinantilla et al. (7) using seed collected near Pullman, WA. They exhibited greater than 50% germination at osmotic potentials down to -1.4 MPa, while only approximately 25% of the wild oats from southwest Oklahoma would germinate at an osmotic potential of -0.8 MPa.

The inability of wild oats from southwest Oklahoma to germinate at low osmotic potentials suggests an adaptation to the erratic rainfall that is indicative to this area of North America. They appear to require adequate moisture to insure that germination, emergence, and vegetative growth will occur before the onset of drought conditions.

Cold tolerance. Average fresh weight biomass production of wild oats before freezing was 2.13 ± 0.25 g/plant, while the average biomass produced by wheat was 0.99 ± 0.13 g/plant. The variability of percent water content of wild oats and wheat before being subjected to sub-freezing temperatures was such that this parameter was of little value for determining cold tolerance. The duration periods investigated did not provide sufficient data to determine a LT_{50}. The duration of exposure in which population reductions would have been experienced was between 18 and 24 h of exposure; therefore, data concerning this parameter will not be discussed. After 24 h of exposure all plants were killed.

The model obtained for wild oat regrowth as a function of time as developed by the plateau-linear procedure in SAS accounted for 81% of the variability in the data. Whereas, the model derived for wheat regrowth explained 72% of the variability in the data.

From the analysis obtained, vegetative regrowth of wild oats was affected only after 4.8 h of exposure to an air temperature of -18 C (Figure 1). In contrast the regrowth of the wheat was not significantly affected until after 9 h of exposure. The model developed for wild oats also indicated that regrowth would decrease in a linear fashion over time according to the equation $Y = 1.32 - 0.06(X)$ after approximately 4.8 hours of exposure. The decrease in regrowth would continue until approximately 21.4 h. A similar trend is observed with 'Scout 66'; however, the linear decrease in regrowth began after approximately 9 h of exposure with the linear decrease descibed by $Y = 0.83 - 0.04(X)$. This decrease would continue until approximately 23.8 h where irreparable damage is predicted to occur.

SUMMARY AND CONCLUSIONS

In summary, results of the various experiments evaluating the germination requirements of wild oats from southwest Oklahoma suggest that the wild oats found in this area are able to germinate over a wide range of temperatures and pH levels. Soil pH levels in this region tend to be well within the range for greater than 70% germination of wild oats. Results also suggest that even though temperatures may not always be at the optimum level, soil temperatures in this region will, more often than not, be sufficient for wild oats to germinate during the fall and winter months.

From the results obtained, it appears the availability of water will be the environmental factor exerting the greatest influence on the germination and emergence of wild oats in southwest Oklahoma. Considering all factors, one can see why wild oats are capable of multiple emergence events during the fall and winter months with the greatest amount of variability being produced by the availability of moisture.

The results obtained from the cold tolerance experiment indicate that wheat with a high degree of cold tolerance will be able to withstand sub-freezing temperatures longer than wild oats. The results also indicate that wheat with a high degree of cold tolerance will be able to compete more effectively with wild oats if exposed for 10 to 15 hours at an air temperatures of -18 C. However, after this period of time both species should experience significant cellular damage which will reduce their ability to recover from severe cold stress.

From the results obtained from all factors evaluated, the variability of wild oat populations from year to year may be attributed to many environmental factors. However, the two factors exerting the most influence on wild oat infestations in southwest Oklahoma, as indicated by this research, were soil moisture and sudden drastic temperature changes.

ACKNOWLEDGMENTS

The authors would like to thank Dr. David L. Weeks and Dr. William R. Raun for their assistance in analyzing the data obtained. Christel Rilling was very helpful in confirming established water potentials. Tracey Johnston-Scott is greatly appreciated for her assistance in determining solution electrical conductivities.

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Table 1. Effect of various constant temperatures on the germination of wild oats from southwest Oklahoma.

Temperature	Germination[a]
C	%
5	0 E
10	81 B
15	88 A
20	89 A
25	68 C
30	7 D

[a]Means followed by the same letter do not differ significantly at the 5% probability level, according to a protected LSD test.

Table 2. Effect of various 12 h diurnal temperature cycles on the germination of wild oats from southwest Oklahoma.

Alternating temperature	Germination[a]
C	%
5-15	74 B
10-20	78 B
15-25	85 A
20-30	89 A

[a]Means followed by the same letter do not differ significantly at the 5% probability level, according to a protected LSD test.

Table 3. Effect of various buffered solutions pH levels on the germination of wild oats from southwest Oklahoma.

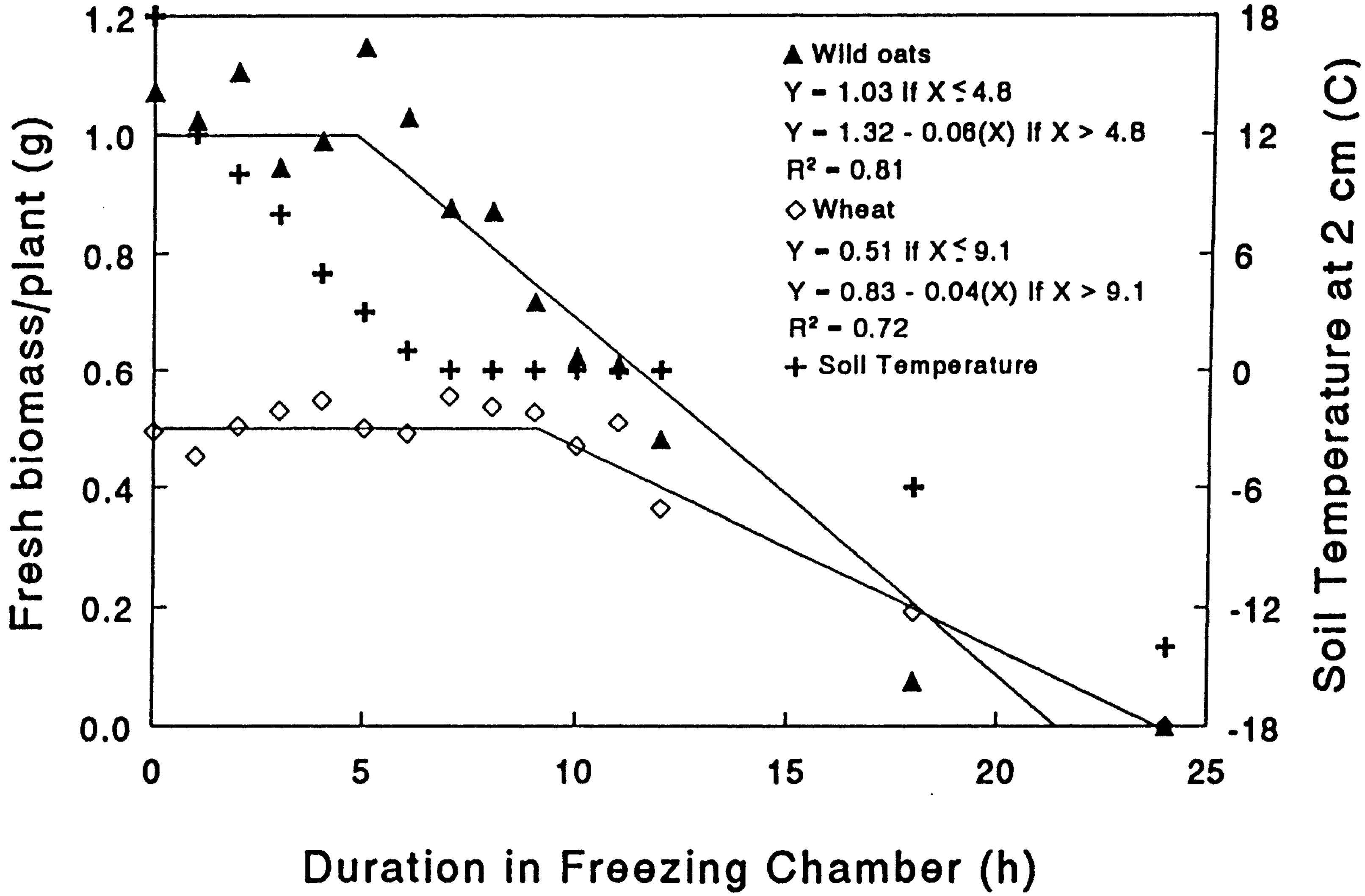
Solution pH	Electrical conductivity	Osmotic potential	Std. Dev.	Germination[a]
	Solution Properties			
	µS	MPa	±	%
3	898	-0.23	0.19	0 E
4	4,550	-0.41	0.05	43 D
5	5,920	-0.35	0.12	79 BC
5.9 (dH_2O)	20	-0.20	0.05	91 A
6	7,010	-0.42	0.07	84 AB
7	8,300	-0.24	0.09	80 BC
8	10,310	-0.48	0.12	73 C
9	6,600	-0.42	0.11	6 E

[a]Means followed by the same letter do not differ significantly at the 5% probability level, according to a protected LSD test.

Table 4. Effect of various solution osmotic potentials on the germination of wild oats from southwest Oklahoma.

Water potential			
Theortical	Measured	Std. Dev.	Germination[a]
MPa		±	%
0.0 (dH_2O)	-0.20	0.05	89 A
-0.1	-0.27	0.12	90 A
-0.2	-0.18	0.08	89 A
-0.4	-0.45	0.15	74 B
-0.6	-0.51	0.02	54 C
-0.8	-0.82	0.01	26 D

[a]Means followed by the same letter do not differ significantly at the 5% probability level, according to a protected LSD test.



<u>Figure 1</u>. Wild oat and wheat regrowth 14 d after various durations of exposure in a freezing chamber maintained at -18 C with corresponding soil temperatures (C) at 2 cm upon removal from freezing chamber.

APPENDIX

Figure 1 temperature data.

Duration	Temperature						
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Avg.	Std. Dev.
h	C						±
0	18	18	18	18	18	18	0.0
1	11	13	13	12	12	12	0.8
2	8	9	11	10	11	10	1.2
3	4	7	9	9	10	8	1.7
4	3	4	6	7	7	5	1.8
5	2	2	3	4	4	3	1.3
6	1	1	1	1	2	1	0.4
7	1	0	0	1	1	0	0.7
8	0	0	0	0	0	0	0.0
9	0	0	0	0	0	0	0.0
10	0	0	0	0	0	0	0.0
11	0	0	0	0	0	0	0.0
12	0	0	0	0	0	0	0.0
18	-9	-4	-11	-3	-2	-6	5.3
24	-14	-14	-14	-14	-14	-14	0.0

Figure 1 wild oat biomass production data.

	Average biomass/plant						
Duration	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Avg.	Std. Dev.
	g						
h							±
0	1.17	1.07	1.26	0.98	0.88	1.07	0.13
1	1.15	0.85	1.07	0.99	1.05	1.02	0.01
2	1.27	0.99	1.29	0.97	1.02	1.11	0.14
3	1.09	0.75	1.02	0.94	0.92	0.94	0.11
4	1.08	0.92	1.09	0.80	1.06	0.99	0.11
5	1.22	1.37	0.84	1.05	1.12	1.12	0.18
6	1.10	1.10	1.08	0.79	1.08	1.03	0.12
7	0.72	0.99	1.07	0.90	0.70	0.88	0.15
8	0.70	0.75	0.94	1.11	0.86	0.87	0.15
9	0.51	0.78	0.69	0.87	0.74	0.72	0.12
10	0.41	0.87	0.47	0.74	0.62	0.62	0.17
11	0.71	0.58	0.65	0.44	0.66	0.61	0.09
12	0.00	0.61	0.58	0.71	0.51	0.48	0.25
18	0.00	0.03	0.00	0.26	0.09	0.07	0.10
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 1 wheat biomass production data.

Duration	Average biomass/plant						
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Avg.	Std. Dev.
	g						
h							±
0	0.52	0.44	0.51	0.53	0.48	0.49	0.03
1	0.47	0.35	0.57	0.42	0.46	0.45	0.07
2	0.55	0.51	0.44	0.52	0.49	0.50	0.03
3	0.51	0.63	0.63	0.43	0.45	0.53	0.08
4	0.60	0.56	0.58	0.55	0.45	0.55	0.05
5	0.46	0.44	0.57	0.46	0.53	0.49	0.05
6	0.56	0.61	0.39	0.42	0.48	0.49	0.08
7	0.63	0.53	0.60	0.51	0.50	0.55	0.05
8	0.65	0.43	0.58	0.53	0.50	0.54	0.07
9	0.53	0.57	0.55	0.51	0.48	0.53	0.03
10	0.35	0.49	0.54	0.55	0.46	0.48	0.07
11	0.43	0.59	0.42	0.59	0.47	0.50	0.07
12	0.00	0.45	0.37	0.52	0.49	0.63	0.19
18	0.00	0.25	0.00	0.42	0.29	0.19	0.17
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00

VITA

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