AN ABSTRACT OF THE THESIS OF

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Title: WATER INJECTION INTO THE SEED ZONE AS AN AID TO EMERGENCE OF DRYLAND CEREALS

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Floyd E. Bolton

An adequate stand at the optimum time is an important factor affecting potential yield and soil erosion control. However, obtaining adequate stands of fall planted winter wheat in the dryland areas of the Pacific Northwest is often complicated by marginal seed zone soil moisture. The purpose of this laboratory study was to assess the value of adding water to the seed zone at planting (water injection) and to determine what rates of water were required to insure quick and uniform emergence under sub-optimal soil moisture conditions. Adding water to the seed zone increased the percent stand and/or the emergence rate over those treatments not receiving water at each of the five levels of moisture tension (-5, -8, -11, -15, -20 bars) at 13°C and 18°C mean seed zone soil temperatures. Among those treatments not receiving water the percent stand and the emergence rate decreased with each unit increase in moisture tension, until at -20 bars there was no emergence. The effective range of water injection was between -5 and -20 bars. However, the practical range appears to be between -5 and -14 bars. A graph was constructed to illustrate the minimum amount

of water required to obtain 80% stand, 3 days after initial emergence for those parameters of soil temperature and soil moisture tension studied. From these data it appears that water injection has the potential to enhance stand establishment under sub-optimal soil moisture conditions. Field trials are needed to substantiate laboratory findings.

Water Injection into the Seed Zone as an Aid to Emergence of Dryland Cereals

by

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Typed by Mary Jo Stratton for James P. Estes Jr.

DEDICATION

To my wife, Kathy Jo,

my son, Jimmy,

and my daughter, Audra

ACKNOWLEDGMENTS

I wish to express my sincere gratitude to Dr. Floyd E. Bolton for his encouragement and guidance during the course of my study at Oregon State University and for his help in the preparation of this thesis.

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WATER INJECTION INTO THE SEED ZONE AS AN AID TO EMERGENCE OF DRYLAND CEREALS

INTRODUCTION

In many areas of the Columbia Basin of the Pacific Northwest a fallow-wheat rotation is used rather than annual cropping. Annual precipitation in these zones is usually less than 375 mm and is quite variable. The purpose of the fallow period is to store moisture in the soil profile from one season so it can be used by the crop during the following season. This means that for a given field only one crop is harvested every 2 years. Over the years farmers in these drier zones have found that utilizing a fallow-wheat rotation stabilizes and often increases grain yields.

In the lower rainfall areas there are many factors affecting grain yields and hindering grain yield increases. One of the most limiting factors to grain yields is stand establishment. Obtaining adequate stands of fall planted winter wheat is often complicated by marginal seed zone soil moisture. Time of planting is primarily influenced by moisture in the seed zone. It has been observed (Russelle 1979) that there is a reduction of seed zone soil moisture near the end of the fallow period. Planting in the early fall before the residual moisture of the fallow period is reduced below optimal levels insures emergence. However, this practice may allow excessive plant growth before the winter cold period begins, depleting soil moisture that could be used by the crop in the spring during the critical time of plant development. Early fall planting has also shown an increased incidence of disease. Planting can be delayed until after a fall rain to insure emergence. Because sufficient rainfall is often not received before late in the fall season, seed germination is hindered by the reduced soil temperature.

A poor stand in the winter season increases the potential for soil erosion by wind and water. A poor stand can also have negative effects on grain yields. Bolton (personal communication) found that the amount of precipitation received during the months of September and October of the crop year accounted for the largest amount of variability in grain yields at the Sherman Experiment Station, Moro, Oregon. This is probably due to the effects of soil moisture on stand establishment. Stand establishment determines the potential for the crop whose final yield is then determined by other factors.

To lessen stand establishment problems often encountered with "dry" seeding conditions some growers in the Great Plains of the U.S. are using water injection. Water injected into the seed zone at planting is designed to insure quick and uniform emergence under marginal planting conditions. Some growers also apply other chemicals such as chelated zinc, aldrin and fertilizers with the water.

The purpose of this study was to assess the value of water injection and determine what rates of water would be required to improve stand establishment under simulated fall seeding conditions.

The thesis is presented in three sections: a literature review of topics involved, a manuscript concerning the effects of water injection as an aid to emergence of dryland cereals, and an appendix of information and data not reported in the manuscript.

LITERATURE REVIEW

Moisture

There is an optimal level of substrate water status for germination, with a lower germination percentage occurring on either side of this optimum level. The optimum level for rate of germination, however, is higher than for germination percentage. At supra-optimal levels of moisture supply seeds can be stressed because they are not able to cope with the high rate of water uptake and/or the reduced oxygen supply. This stress usually causes a reduction in the rate and sometimes the total germination percentage (Gulliver and Heydecker 1972). In dryland agriculture, supra-optimal levels are seldom reached. Typically, dryland soils are moderate to low in moisture content at seeding time. Hunter and Erickson (1952) concluded that at soil moisture tensions higher than that required for germination, seeds were unable to obtain sufficient moisture for germination. This was apparently due to the soil water being absorbed to the surface of the soil particles with a force greater than the absorbing capacity of the seed. They also concluded that at low moisture contents the rate of soil moisture movement was too slow to supply the seed with the water necessary for germination. However, Owens (1952) working with wheat, found that germination occurred at moisture tensions as high as -31 bars, given enough time.

In order for seeds to obtain moisture from the soil, two primary forces must be overcome: moisture tension and osmotic forces. Ayers (1952) working with onion seed found that as soil moisture stress increased, the rate of emergence decreased. If soil moisture continued to decrease, total germination decreased.

Collis-George and Sands (1959) examined the influence of the physical energy of soil water on the germination pattern of medic seeds. Seeds were sown on an artificial media (cellophane membrane) and soil. They reported a decreased rate of emergence as the soil moisture tension increased. As soil moisture tension continued to increase, the total percentage of germination was reduced. They also found that as the pores in the soil emptied of water the rate and total germination was lower for the soil than for the artificial media at the same moisture tension. Seeds placed directly on the cellophane membrane behaved as if in a system of water filled pores. From this they concluded that the decline in germination was controlled by the soil moisture tension and the soil permeability; i.e., it is not the water stress that is the decisive factor, but instead it is the water transport that is critical to seed germination. They recommended that the soil water characteristics should be defined as well as the moisture content.

Hadas (1969) made calculations of the time required for two different seed sizes, 2 mm and 10 mm in diameter, to imbibe water. The seeds were placed in a silty loam soil with a poor water conductivity and a bulk density of 1.45 g/cm^3. He found that at wilting point with a seed-soil water contact of 1%, the time required to take up 90% of the seed's water was 0.33 and 0.86 days for a 2 mm and 10 mm diameter seed, respectively. Hadas also calculated the time required for a seed to imbibe water with a diffusivity value 1,000 times smaller than the soil diffusivity value with a seed coat one-tenth the diameter of the seed. At wilting point with a 1% contact area the time required was 0.42 days for a 2 mm diameter seed and 1 day for a 10 mm diameter seed. Hadas reported very good correlation between his calculated values and experimentally observed values. He concluded that the imbibition process is little affected by the total contact area and total water stress. However, these two factors plus water uptake rate and part of the seed in contact with the soil water may be decisive in the triggering stage that initiates seed germination.

Hadas (1970) used clover and chickpea seeds to examine the relative importance of seed and soil factors affecting or controlling germination. He found that water uptake by the seed was restricted as the soil moisture content decreased. Also, the lower the moisture content, the smaller was the initial seed-soil water contact area.

Dasberg (1971) used a gamma ray attenuator to investigate to what extent the rate of water movement in the soil limited seed water uptake and germination. Working with Oryzopsis halciformis he found that as the soil water content increased, seed water uptake and germination increased. He observed that the initial growth rate of the seedling roots seemed to be less influenced by soil water content than did the growth rate of the shoots. Experimental evidence (Itai and Vaadia 1965, as reported by Dasberg 1971) suggests that the roots react to soil water stress by synthesizing certain substances which regulate shoot growth. The distance from which seeds absorbed water was not affected by the initial soil water content. For O. halciformis the distance from which the seeds absorbed water was 10 mm.

Ward and Shaykewich (1971) conducted experiments to determine if the hydraulic conductivity of the soil influenced germination of wheat. They presented the relationship of seed water content, diffusivity and hydraulic conductivity with the seed water potential of wheat. They determined that the water potential of wheat seed at 9.18, 10.56 and 13.66% (gross water content) was -2300, -1550 and -812 bars respectively. They concluded that the hydraulic conductivity of the seed hindered germination until the water content increased to near that required for germination. They found this minimum value for germination to be 40% (wt/wt). At this point the seed's hydraulic conductivity reached approximately the same order of magnitude as the hydraulic conductivity of the soil.

Pawloski and Shaykewich (1972) studied the effects of hydraulic conductivity on wheat seeds at several different water potentials (-0.8, -5.3, -7.8, -15.3 bars). Seeds were placed on the surface of two soils and a semi-permeable membrane. They found that at a given water potential, germination rates were the same for both soils but seeds on the membrane system consistently germinated faster. Because the hydraulic conductivity was different on the two media, they concluded that the hydraulic conductivity of the soil is an important factor affecting germination under water stress.

Hadas and Russo (1974a) investigated water uptake by seeds as affected by water stress, capillary conductivity and seed-soil water contact. They used experimental procedures that allowed them to test the effects of matric potential at a perfect seed-water contact while eliminating the effects of capillary conductivity. They found that for water potentials of 0 to -3.8 bars there was no direct effect on imbibition or germination. However, Hadas and Russo were careful to point out that with a lowering of the water potential in real soil there is a decrease in the seed-water contact and hydraulic conductivity which would affect water uptake.

In another experiment Hadas and Russo (1974b) were able to measure the separate effects of contact area and hydraulic conductivity on water uptake and germination. They found that lower hydraulic conductivities or smaller seed-soil water contact reduced the rate of water uptake. They concluded that the reduced rate of water uptake could cause delayed germination as long as the external water potential was less than the critical threshold value necessary for germination.

Askraf and Alu-Shakra (1978) studied the effect of wheat seed germination under moisture stress. They reported that the speed of germination was inversely related to the intensity of moisture stress. They found that total germination was not reduced except at 15 to 18 bars tension. They also observed that wheat seeds would not germinate until they reached 50% moisture content on a fresh weight basis.

Species differ in their ability to germinate at low moisture contents or high moisture tensions. Hunter and Erickson (1952) found that corn, soybeans, rice and sugar beets germinated consistently better at soil moisture tensions not higher than -12.5, -6.6, -7.9, -3.5 bars respectively. They also observed that there was a minimum seed moisture content that had to be reached before germination took place. This minimum level was species specific. They found this level for corn was 30.5%, for sugar beets 31%, rice 26.5% and soybeans 50%.

Varieties also differ in their ability to germinate at high moisture tensions. Helmerick and Pfeifer (1954) made field observations of 12 different fall seeded winter wheat varieties under limited moisture conditions. They interpreted the difference in performance between the 12 varieties under the same environmental conditions to mean that varieties differ in their ability to germinate and establish a stand. Further laboratory studies support this hypothesis. Testing the two varieties Yogo and Cheyenne at 12 levels of osmotic pressure (0-11.5 atm) showed Yogo to be superior (at the 1% level) to Cheyenne in germination and growth.

Gul and Allen (1976) tested several lines of wheat to determine if these lines differed in their ability to germinate and emerge under various soil moisture tensions. They found a doubling of emergence time for each 4 bars decrease in water potential. None of the lines tested reached 80% stand in 5 days after initial emergence at -14.4 bars and few lines reached 80% stands in 5 days at -10.2 bars.

Temperature

Temperature influences biological systems by affecting various metabolic processes and ultimately growth. Species differ in the range of temperature within which germination will occur. The range of temperatures within which germination occurs for a given species will be influenced by such factors as the genetic difference within a species, the source of the seed, and the age of the seed (Mayer and Poljakoff-Mayber 1963).

For each species there is an optimum, minimum and maximum temperature. The minimal and maximal temperatures are those temperatures that just permit germination. The optimum temperature is that temperature that allows the highest percentage of germination in the shortest period of time (Noggle and Fritz 1976). Peterson (1965) reported the minimum, optimum and maximum temperatures for wheat as 3.5-5.5, 20-25 and 35 $^{\circ}$C respectively. Mayer and Poljakoff-Mayber (1963) suggested that the optimum temperature for germination shifts with the amount of time allowed for germination. As the time allowed for germination increases, the optimum temperature for germination decreases.

Gulliver and Heydecker (1972) reported that there is an optimum temperature for both total germination and germination rate. The optimum temperature for rate of germination is higher than for total germination. At supra-optimal temperatures the proportion of seeds that germinate is reduced. However, those seeds that can physiologically keep up with the increasing temperature germinate at an increasing rate up to an optimal temperature.

Soil temperature can affect the rate and total percentage emergence of seedlings by influencing coleoptile elongation. It has been shown that there is a close association between coleoptile length and other seedling traits. Allen et al. (1962) found that a positive correlation exists between coleoptile length and field emergence rate. Burleigh et al. (1964-1965) found a close positive association between the degree of coleoptile elongation and the emergence ability of the seedlings. Burleigh et al. (1964-1965) studied the effects of temperature on eight winter wheat varieties and selections. They found 15.5°C to be the optimum temperature for coleoptile elongation in the varieties and selections tested. At temperatures above and below 15.5°C coleoptile lengths were reduced. They concluded that the optimum range for coleoptile growth was narrow.

From the foregoing review it appears that the optimum temperature for coleoptile elongation of wheat (15.5°C as reported by Burleigh 1964-1965) is lower than the optimum temperature for germination (23°C as reported by Peterson 1965). Singh and Gill (1972) found that the optimum temperature for emergence and stand was 20°C. They reported that there were considerable changes in growth and metabolic behavior as the soil temperature increased from 15° to 35°C. At soil temperatures above and below 20°C the elongation of the coleoptile, growth of the shoots and synthesis of chlorophyll were inhibited.

Seedling growth is adversely affected by extremes in temperature. Temperature stress can occur in two forms, heat stress and cold stress. Russian scientists Valovich and Grif (1974) used 60 different plant species to determine the effects of low temperatures on germination and growth. They found that the root growth rate at 10°C was 14 times slower than that of the control at 20-23°C. They also reported a 2-3 fold reduction in growth with a temperature reduction from 10-5°C and a 4-6 fold reduction due to a change in temperature from 5-0.5°C. Valovich and Grif concluded that the rate of growth is temperature dependent. As the temperature is decreased there is an accelerated decrease in the rate of growth.

Connveme and Laude (1972) studied the effects of heat stress on growth of barley and wheat coleoptiles. They subjected 4-day-old wheat seedlings to a temperature of 46°C for varying lengths of time.

They found that coleoptile elongation and coleoptile lengths 24 hours after stress were significantly smaller for stressed seedlings than for unstressed seedlings. The stunting effect of stress increased as the duration of heat stress increased.

Temperature x Moisture Interactions

McGinnies (1960) studied the effects of moisture stress and temperature on germination of six range grasses. He found that at favorable soil temperatures the six range grasses germinated and emerged fairly well despite relatively high osmotic potentials. However, the adverse affects of moisture stress on germination and emergence increased as the soil temperature deviated from the optimum.

Tadmor *et al*. (1969) investigated the interactive effects of osmotic potential and temperature on the onset, rate and final germination of wheat and barley. Onset of germination was similar for all soil temperatures (4, 10, 15, 20, 25°C) except at 4°C where germination was greatly retarded. At osmotic tensions greater than 4 atm, onset of germination was delayed. The effects of osmotic potential on rate of germination were greater at near optimal temperatures. At 4°C the rate of germination was so slow that osmotic potentials, except at the greatest tensions, hardly affected the rate. The effects of osmotic potential on final germination were greatest at unfavorable temperatures. Final germination became more dependent on osmotic potential as the temperature deviated from the optimum. There were no temperature x osmotic potential effects except at the highest osmotic potential (15 atm) at low temperatures.

Lindstrom et al. (1976) studied the interactive effects of soil water potential, soil temperature and seeding depth on emergence of two winter wheat varieties (McCall and Nugaines). They found that lowering the seed zone temperature decreased the amount of moisture necessary for the seeds to germinate and emerge. This was due to the increase in the threshold or critical water potential for emergence as the temperature increased. In their laboratory study the rate of wheat germination was progressively decreased as the water potential decreased but ultimately germination occurred at -20 bars. However, 80% emergence was never obtained in the laboratory below -10 bars. They concluded that germination is rarely the limiting process in emergence but what is most important or critical is the rate of sub-surface elongation.

Conway (1978) studied the effects of temperature and moisture stress to determine at what levels of stress stand establishment problems are encountered. He found that minimum stands were attained under high soil temperatures (22^{o}C) and high moisture stress (-6 bars). Stand establishment problems diminished at lower levels of moisture stress and at lower soil temperatures. He concluded that soil temperature and moisture significantly affect percent stand, days to 25% emergence, shoot length, coleoptile length, seedling dry weight, and ATP levels. He suggested that even though soil moisture content has been shown to affect coleoptile length, the magnitude of the effect is small in relation to the effect of temperature on coleoptile length.

Halitligil (1975) also found that lowering the soil temperature or the water potential increased the number of days to reach 50 and 80% emergence and that lowering the soil temperature delayed germination and emergence more than did a reduction in soil water potential. However, greater delays occurred by the interaction of soil water potential and soil temperature.

Ashraf and Alu-Shakra (1978) investigated wheat seed germination under low temperatures and moisture stress. Using low alternating temperatures of 3 to 10^{o}C and 6 to 15^{o}C they found that germination percentage was not reduced by moisture stress except at 15 and 18 atm. They reported a significant decrease in the rate of germination with the increase of each 3 atm in moisture stress. Seeds at the higher temperature germinated faster than those at the lower temperature. They found that the rate of root growth was lower at the low temperature than at the higher temperature and that each increase in the level of moisture stress resulted in lowering the rate of root growth.

MANUSCRIPT

WATER INJECTION INTO THE SEED ZONE AS AN AID TO EMERGENCE OF DRYLAND CEREALS

Abstract

Obtaining an adequate stand of fall planted winter wheat (*Triticum aestivum* L.) in the dryland areas of the Pacific Northwest is often complicated by marginal seed zone soil moisture. A growth chamber study was conducted to assess the value of adding water to the seed zone at planting (water injection) and to determine what rates of water were required to insure quick and uniform emergence under sub-optimal soil moisture conditions. Adding water to the seed zone increased the percent stand and/or the emergence rate over those treatments not receiving water at each of the five levels of moisture tension (-5, -8, -11, -15, -20 bars) at 13 and 18°C mean seed zone soil temperatures. Among those treatments not receiving water the percent stand and the emergence rate decreased with each unit increase in moisture tension, until at -20 bars there was no emergence. The effective range of water injection was between -5 and -20 bars. From these data it appears that water injection has the potential to enhance stand establishment under sub-optimal seed zone moisture levels.

Additional Index Words: dryland, winter wheat, water injection, stand establishment, seed zone.

Introduction

In the Lower Columbia Basin of eastern Oregon a fallow-wheat rotation is used rather than annual cropping. Annual precipitation in these zones is usually less than 375 mm and is quite variable. Moisture is stored in the soil profile during the fallow period for use by the succeeding crop. A soil mulch is maintained through the spring and summer months of the fallow to minimize moisture losses due to evaporation. The maintenance of the mulch, by periodic tillage, maintains the residual moisture near the soil surface. Seeds can be placed into the residual soil moisture with the use of a deep furrow grain drill. Russelle (1979) reports that even though the level of moisture remains more or less constant throughout the summer, there is a loss both in the amount and level of moisture late in August and September of the fallow. Even though moisture is not at a critical level every year, marginal seeding conditions often exist during the optimum time of planting. Early fall planting before the residual moisture recedes insures emergence. Yet this practice allows excessive autumn growth, which depletes soil moisture that could be used by the crop in the spring during a critical time of plant development. Early fall planting also has shown an increased incidence of disease. However, if planting is delayed until after fall rains to insure emergence, seed germination may be hindered by cold soils.

A poor stand in the winter months increases the potential for soil erosion by wind and water. A poor stand can also have negative effects on grain yields. Bolton (personal communication) found that the amount of precipitation received during the months of September and October of the crop year accounted for the largest amount of variability in grain yields at the Sherman Experiment Station, Moro, Oregon. This is probably due to the effects of soil moisture on stand establishment. Stand establishment determines the potential for the crop whose final yield is then determined by other factors.

To lessen stand establishment problems often encountered with "dry" seeding conditions some growers in the Great Plains of the U.S. are using water injection. Water injected into the seed zone at planting is designed to insure quick and uniform emergence under marginal planting conditions. Some growers also apply other chemicals such as chelated zinc, aldrin and fertilizers with the water.

There is very little published literature on the practice of adding water to the seed zone at planting. A 1-year study (Anonymous 1968) was conducted in Wyoming investigating the effects of water injection on stand establishment of dryland sugar beets. It was concluded from this study that water applied to the seed zone at rates of 45 to 55 gal/acre appeared to be beneficial.

Derici (1971) studied the effects of water injection on wheat seeded into air-dry soil. Wheat seeds were placed in dry soil at various levels above a moist soil. At seeding he added water to the seed zone in sufficient quantities to moisten the air-dry soil from the seed to the moist soil below. He concluded that the rates of water necessary at planting to insure emergence under these conditions were out of the range of practicality.

In the study conducted in Wyoming (Anonymous 1968) water was added to the residual moisture already in the seed zone. Therefore, the quantities of water required to insure emergence under these conditions were considerably less than those reported by Derici (1971) who added large quantities of water to air-dry soil.

The purpose of this study was to assess the value of water injection and determine what rates of water would be required to improve stand establishment under simulated fall seeding conditions.

Materials and Methods

Growth chamber studies were conducted using McDermid wheat, a soft white winter type. Seeds of McDermid were screened to a uniform size and tested for germination percentage. The germination percentage at the beginning of the experiment was 96%.

Air-dry Walla Walla silt loam from the Sherman Experiment Station, Moro, Oregon, was passed through a 6-mm sieve to remove clods. Soil for one replication (approximately 32 kg) was adjusted to moisture levels of either -20, -15, -11, -8, or -5 bars tension by spraying air-dry soil with the appropriate amount of water based on the moisture retention curve of the Walla Walla silt loam (Figure 1). The soil was mixed in a cement mixer during the spray treatment to insure uniform distribution of moisture. The soil was then placed in a plastic bag and allowed to equilibrate for 24 to 48 hours. Soil at the appropriate matric potential was placed in a plastic-lined wooden container (50 x 50 x 20 cm) to a depth of 7.5 cm and firmed to a bulk density of 1.0 g/cm^3. Eighteen McDermid wheat seeds were placed 1.5 cm apart in each of eight furrows which were 2 cm deep and 6.8 cm apart. Each of the three replications (or boxes) contained four treatments with two observations per treatment and were arranged in a randomized block design. Distilled water was then applied to the full length of the furrow at the following rates:

	Bars tension				
	-5	-8	-11	-15	-20
Water added*	0	0	0	0	0
	15	20	20	30	40
	30	40	40	50	60
	45	60	60	70	80

*ml/m

The furrows were filled in with 2 cm of soil and compacted to a bulk density of 1.1 g/cm^3. Another 3 cm of soil at the same matrix potential was placed in the box, giving a total planting depth of 5 cm. The box was covered with plastic to reduce evaporation losses.

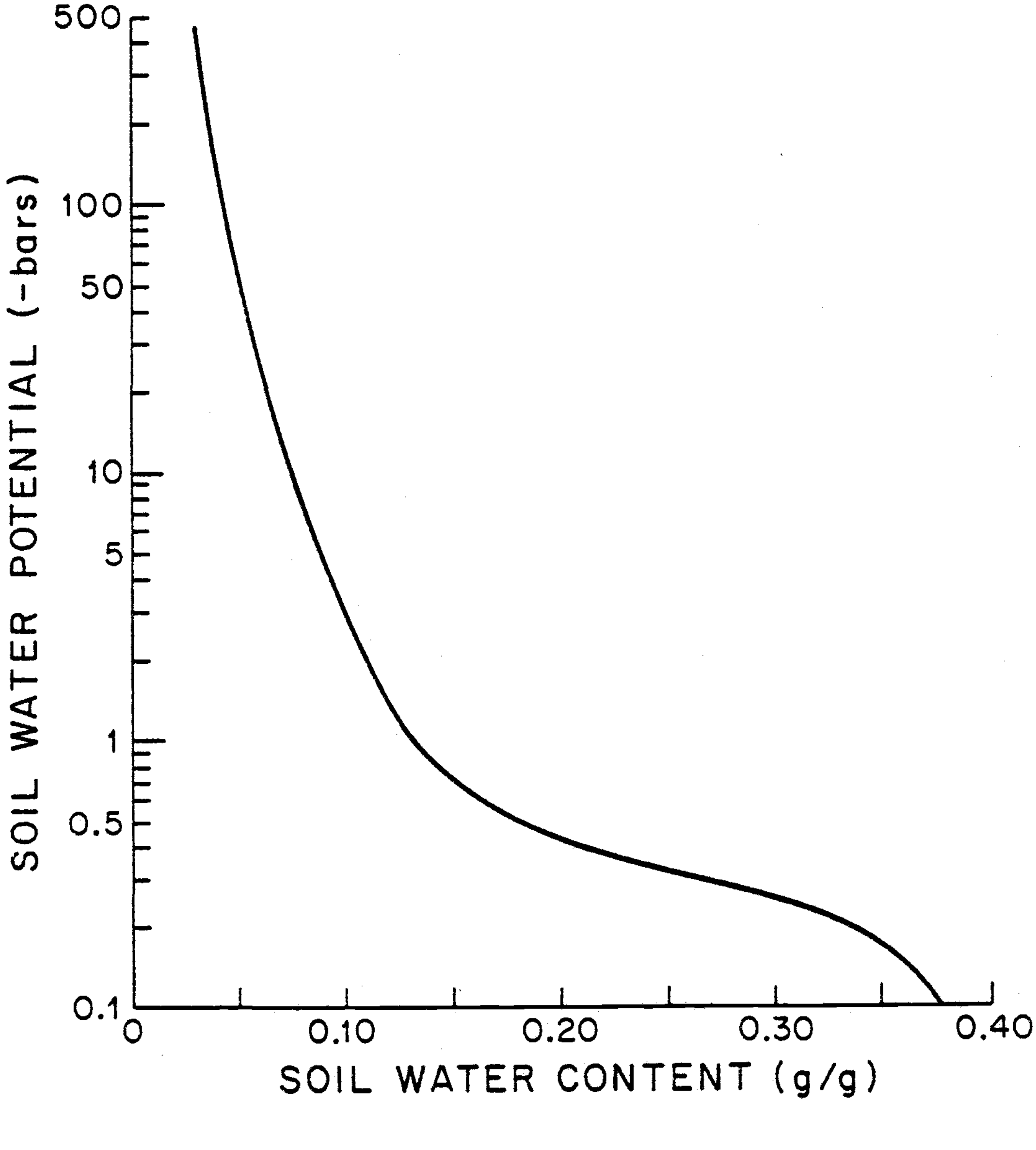

Figure 1. Soil moisture tension curve for a Walla Walla silt loam soil. Moro, Oregon.

Diurnal light and temperature patterns in the growth chamber were adjusted to produce mean seed zone soil temperatures of 13 and 18°C.

To monitor changes in the seed zone moisture content, samplings were made with a small soil probe through access holes in the containers adjacent to the seed zone. Each of the treatments was sampled after planting and again on days 3, 6 and 9 at 18°C and on days 2, 4 and 6 at 13°C. The samplings from two replications were evaluated for gravimetric moisture content and their values pooled.

Seedling counts were made every 24 hours for 14 days following planting. Emergence was considered complete when the coleoptile penetrated the soil surface. Percent emergence and emergence rate were used as indices of stand establishment. Percent emergence was obtained by dividing the number of emerged seedlings by the number of seeds planted per treatment and multiplying the results by 100. The emergence rate index was calculated in a manner similar to that outlined by Allan _et al_. (1962). This index is a weighted relative figure giving more credit to those treatments that emerge faster than those treatments that emerge slower. Initial emergence at 18°C began 6 days following planting and at 13°C on the ninth day. The index was calculated using the number of newly emerged seelings each day for 5 days following initial emergence.

Results and Discussion

Preliminary growth chamber studies were conducted to determine the effective range of water injection. These preliminary studies showed that at moisture tensions less than -5 bars, germination and emergence were adequate without added water. At -20 bars it took relatively high rates of water to obtain minimal stands in the 14-day test period. At moisture tensions greater than -20 bars even high rates of water added to the seed zone were not sufficient to insure emergence. From the preliminary study it was concluded that the practical range of water injection was between -5 and -20 bars.

Field studies at the Sherman Experiment Station, Moro, Oregon, have shown that the average optimum date for planting is between September 15 and October 15. The normal range of seed zone moisture encountered during this period is between -5 and -15 bars. Seldom is the soil moisture below -20 bars.

Water added to the residual moisture of the seed zone at five levels of moisture tension significantly increased percent stand at both seed zone soil temperatures (Figures 2 and 3). The exception was at 13°C, where at -5 bars moisture tension there was no significant stand difference between treatments. However, the treatments that received water emerged at a faster rate. The percent stand of those treatments that did not receive water decreased with each unit increase in moisture tension, until at -20 bars tension there was no emergence.

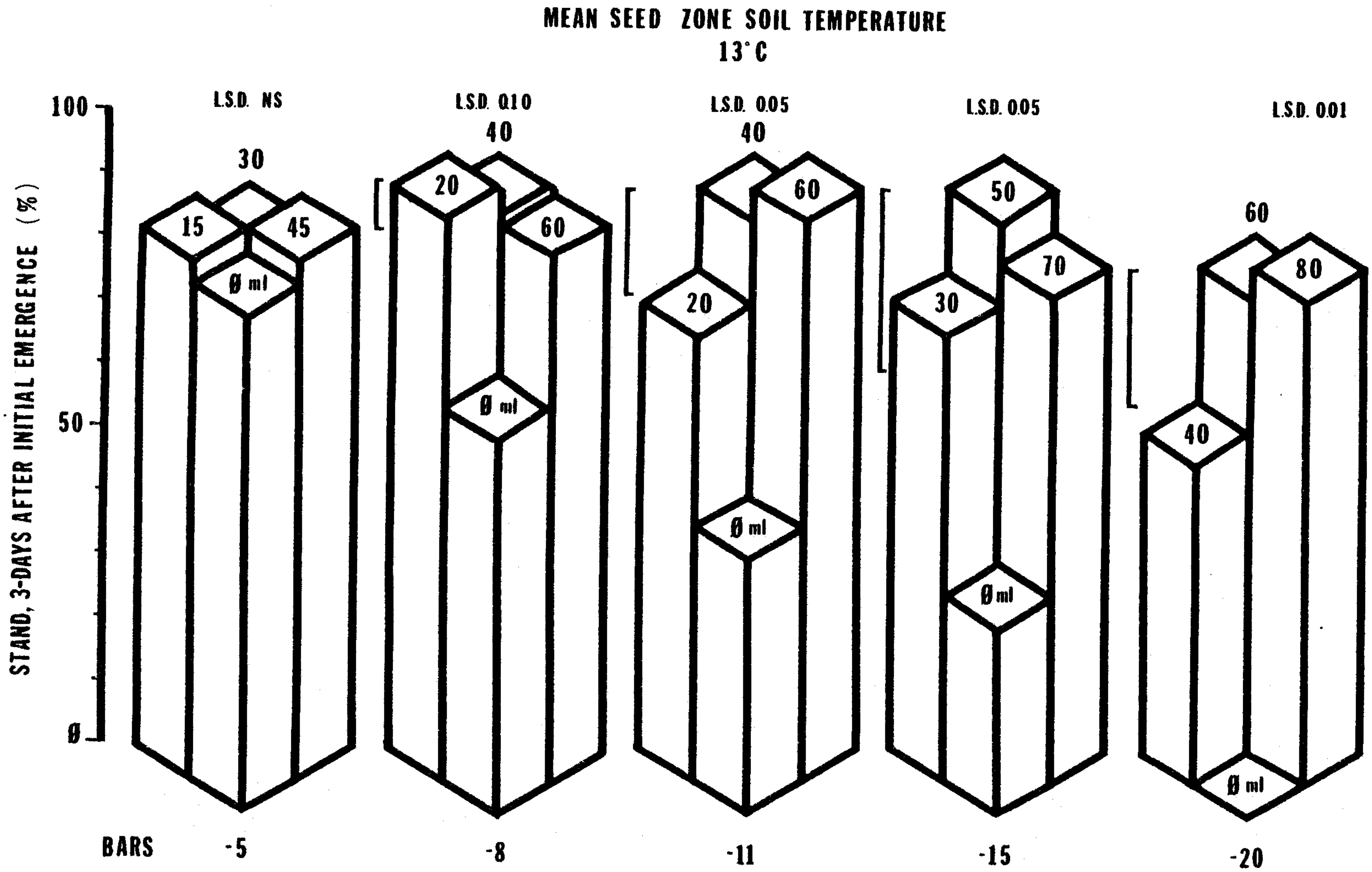

Figure 2. Effects of water injection on percent stand 3 days after initial emergence at five levels of moisture tension at 13°C. The number in each column represents the amount of water applied to the seed zone in milliliters per meter length of row.

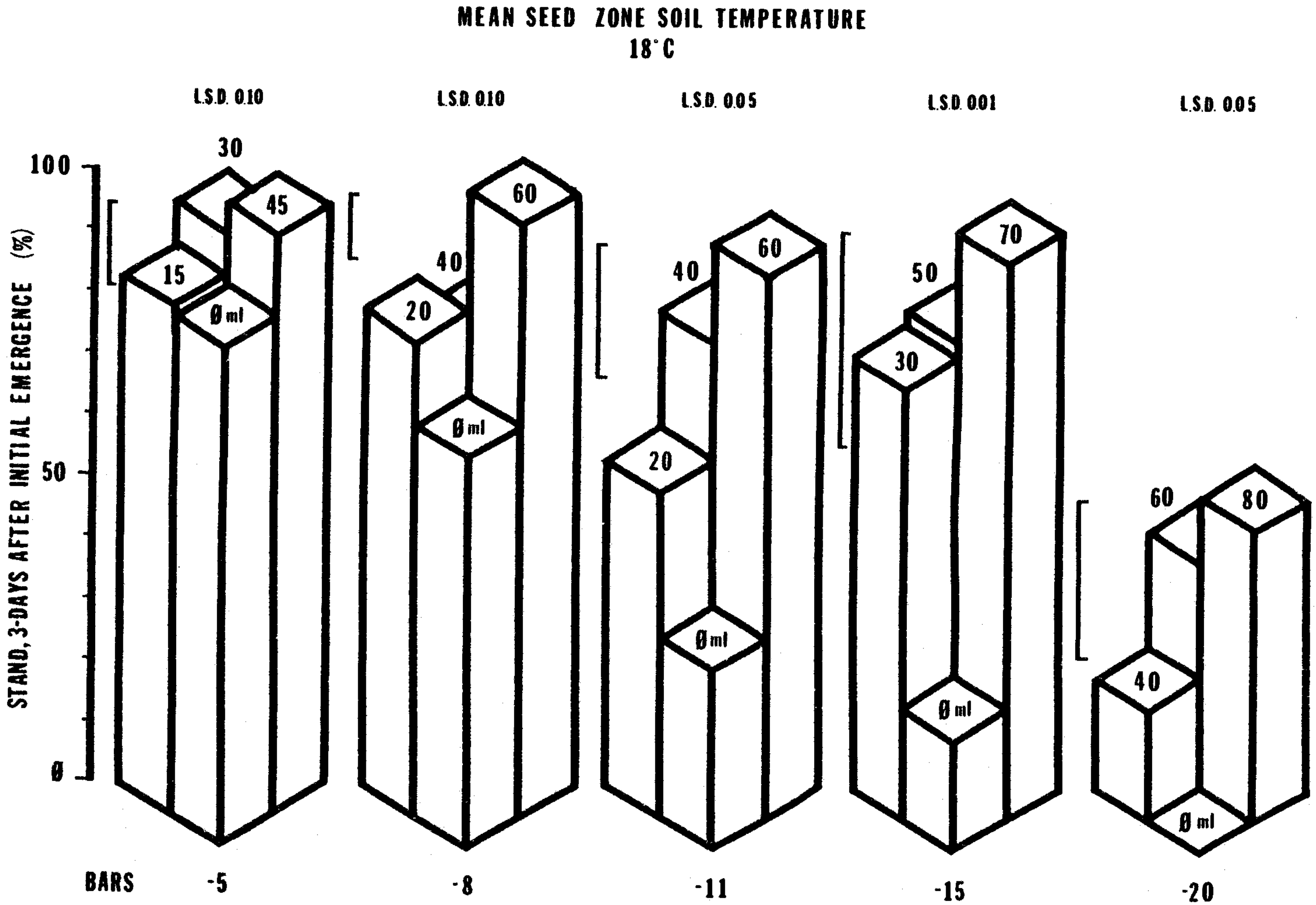

Figure 3. Effects of water injection on percent stand 3 days after initial emergence at five levels of moisture tension at 18°C.

The effect of water injection on the rate of emergence was similar to that on percent stand (Figures 4 and 5). At each of the moisture tensions the treatments receiving water emerged at a significantly faster rate than those treatments without added water. The rate of emergence among the treatments not receiving added water decreased as the soil moisture tension increased. Similar results were reported by Ashraf and Alu-Shakra (1978) who found a significant decrease in the rate of emergence with each 3 atm increase in moisture stress. Onset of emergence was influenced by soil temperature. Initial emergence took place on the sixth day following planting at 18°C and on the ninth day at 13°C.

Water injection appears to alter the seeds' microclimate for a long enough duration to reduce the effects of moisture stress. Examples of the increase in gravimetric water content after adding water are shown in Table 1. The moisture gradient between the moistened seed zone and the bulk soil caused the moisture to move out of the seed zone rather rapidly. The rate of movement increased as the differential water potential between the bulk soil and seed zone soil increased.

A regressional analysis was used to determine the relationship between added water and emergence for both temperatures at each of the moisture levels (Figures 6 and 7). The intersection of the regression with the emergence equal to 80% was designated as that

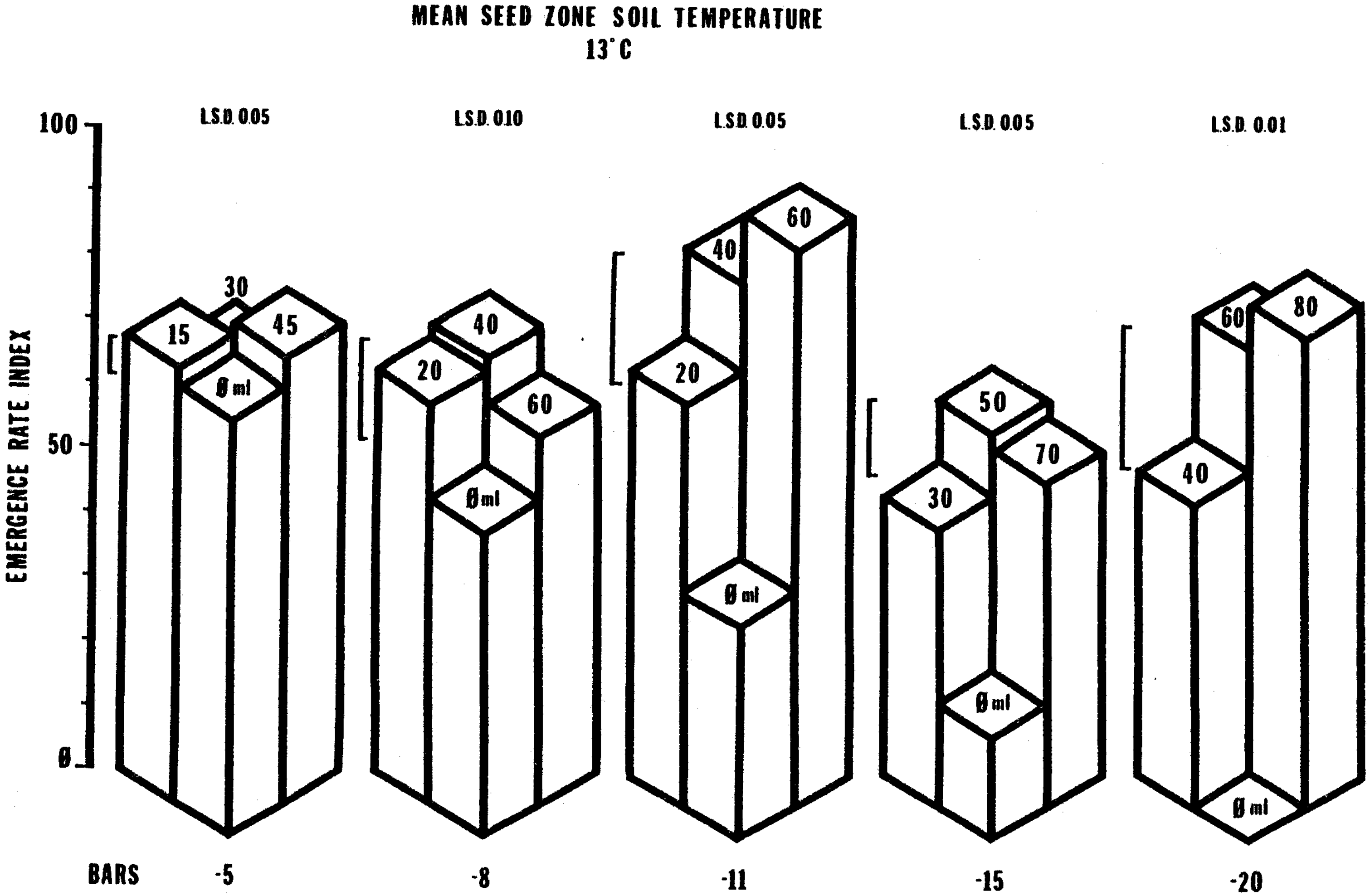

Figure 4. Effects of water injection on the rate of emergence at five levels of moisture tension at 13°C.

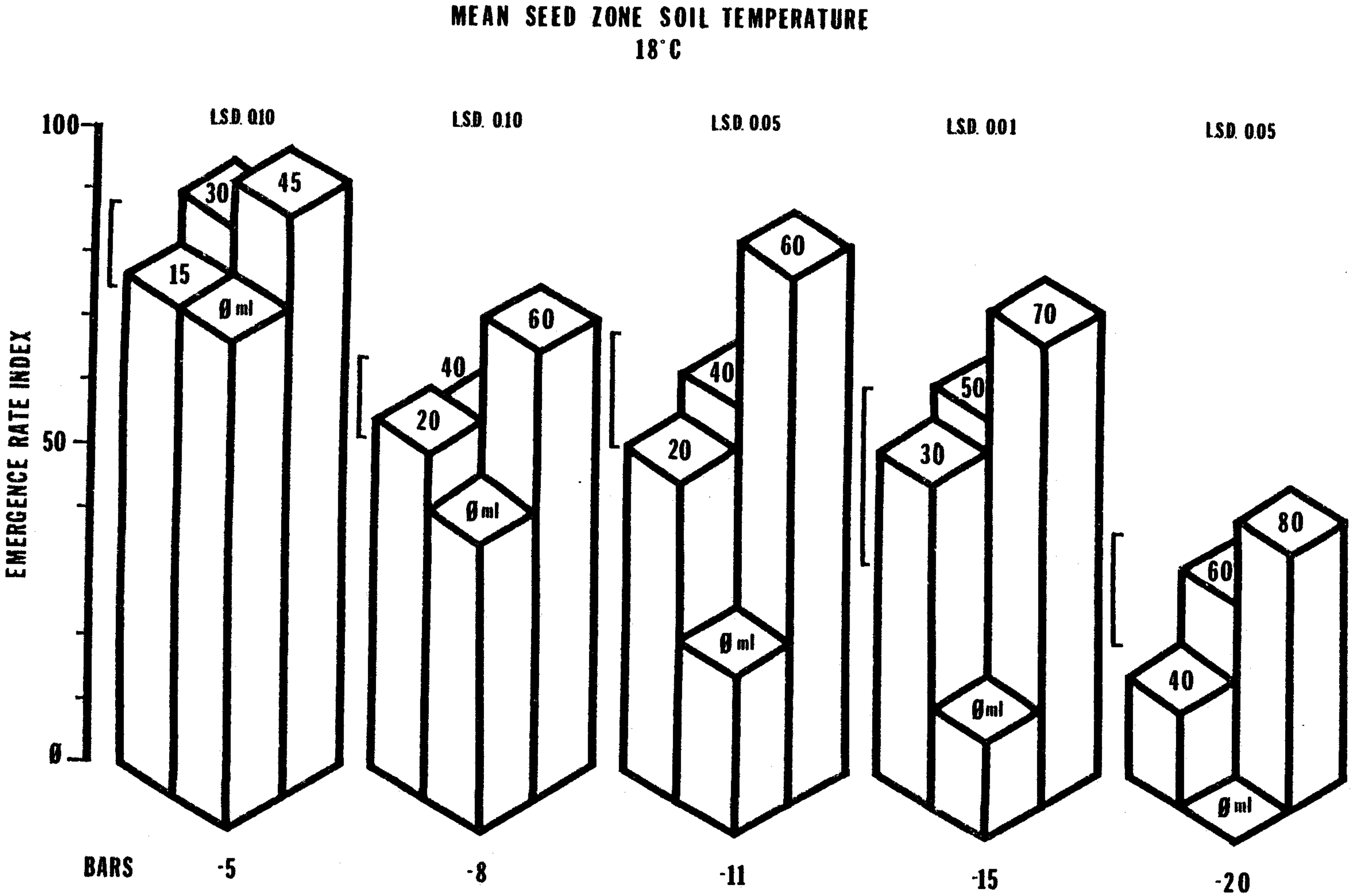

Figure 5. Effects of water injection on the rate of emergence at five levels of moisture tension at 18°C.

Table 1. Seed zone gravimetric water content at two levels of moisture tension and temperature at various time intervals after planting.

Water added	Days after planting at 13 °C			
	0	2	4	6
(ml/m row)	(%)	(%)	(%)	(%)
	-5 bars tension			
0	9.0	9.1	9.2	9.2
15	11.6	10.2	10.1	9.8
30	15.1	11.8	12.0	10.5
45	16.4	12.9	12.8	11.0
	-15 bars tension			
0	7.1	7.1	7.0	6.9
30	14.5	9.7	8.9	8.7
50	16.2	11.0	9.8	9.0
70	17.8	11.0	10.2	9.4
	Days after planting at 18 °C			
	0	3	6	9
	-5 bars tension			
0	9.1	9.1	8.0	8.4
15	13.1	10.6	8.2	8.2
30	13.0	11.1	9.2	9.1
45	15.3	11.8	9.8	9.3
	-15 bars tension			
0	7.1	6.9	6.4	5.3
30	14.2	8.9	7.0	5.5
50	15.8	9.7	8.2	6.0
70	17.1	10.3	8.6	6.5

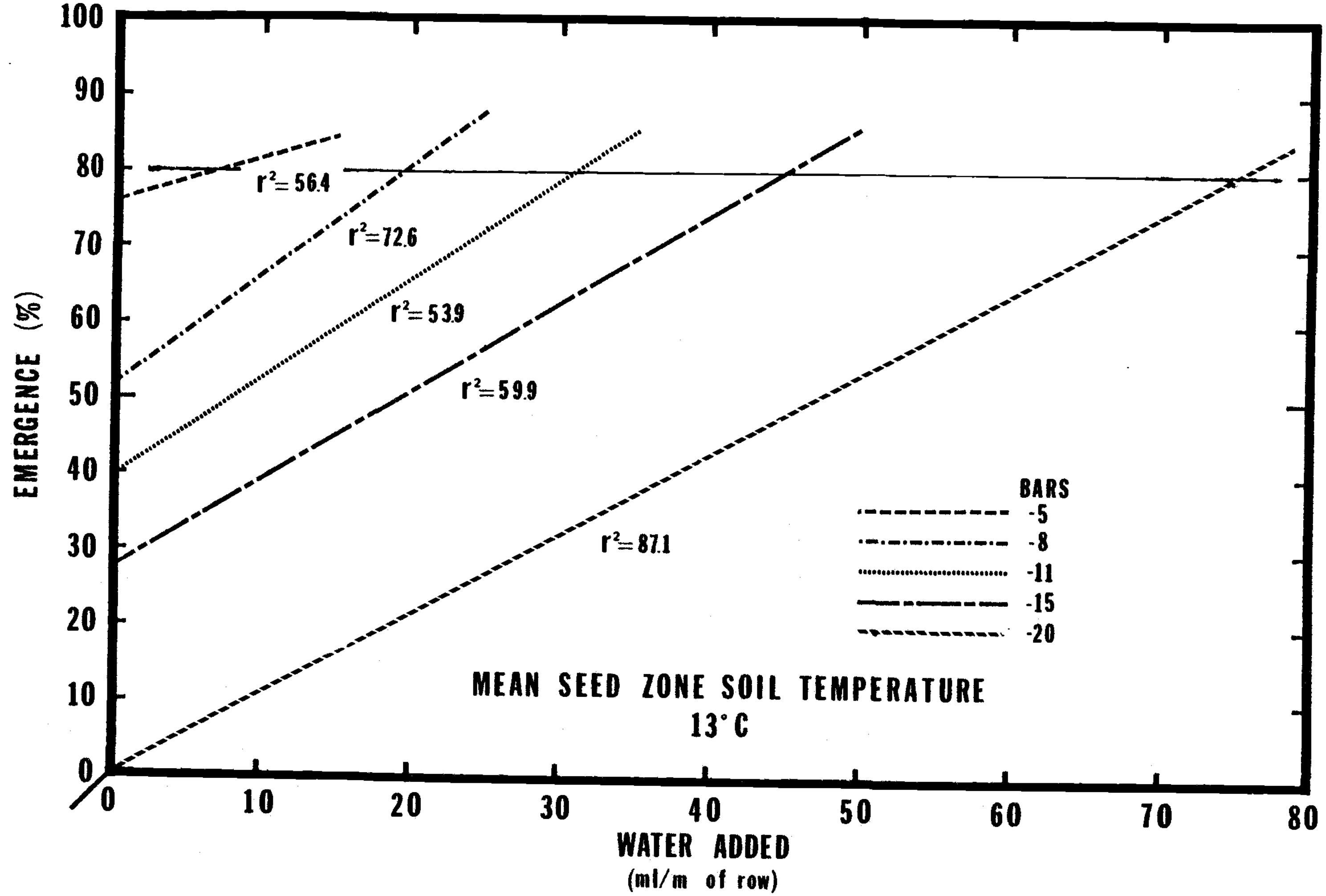

Figure 6. Regression relationships of water added to emergence at five levels of soil moisture tension at 13°C.

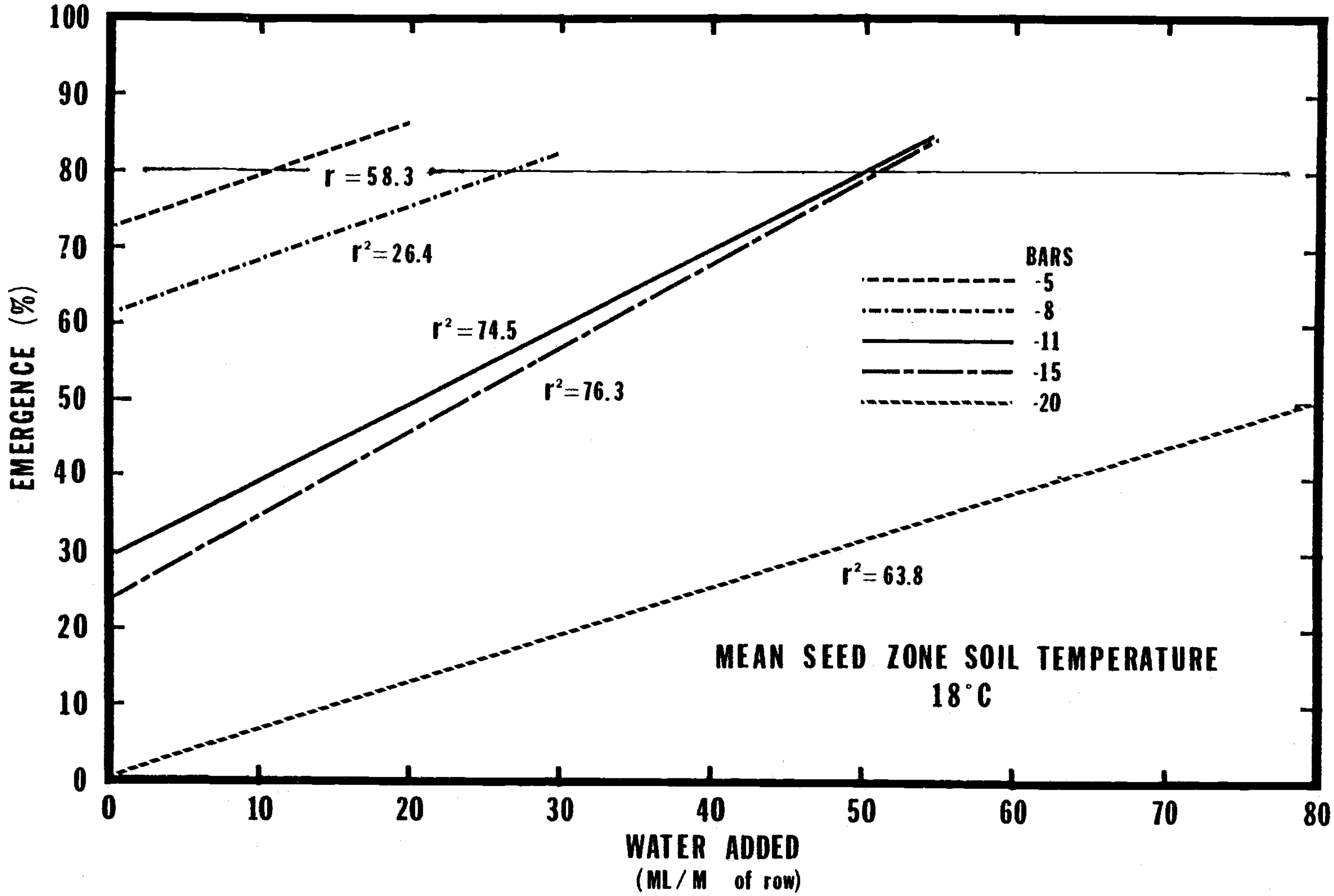

Figure 7. Regression relationships of water added to emergence at five levels of soil moisture tension at 18°C.

amount of water necessary to insure 80% emergence 3 days after initial emergence. For example, at 13°C soil temperature the regression at -11 bars tension crosses 80% emergence at 32 ml on the X axis. This indicates that at -11 bars tension it would require at least 32 ml of water per meter length of row to obtain approximately 80% emergence 3 days after initial emergence.

Figures 6 and 7 show that the slope of the regression at 18°C, -20 bars and 13°C, -5 bars approaches zero, indicating that these moisture tensions are probably the transitional zones for effective water injection. These results substantiate the information obtained in the preliminary study. Each of the moisture tension functions intermediate to these had a positive slope, demonstrating the effectiveness of the water injection treatments.

The values obtained from the linear regression were used to construct the curves shown in Figure 8. This graph illustrates the quantities of water required to reach 80% emergence 3 days after initial emergence for those parameters of soil temperature and moisture tension shown. The left column represents the milliliters of water required per meter of row. The right column is the liters of water/hectare required for three row spacings. As the row spacing widens the quantity of water required on a unit area basis decreases, even though the actual amount of water applied to the furrow remains the same. In fact, widening the row spacing from 25 to 45 cm reduces

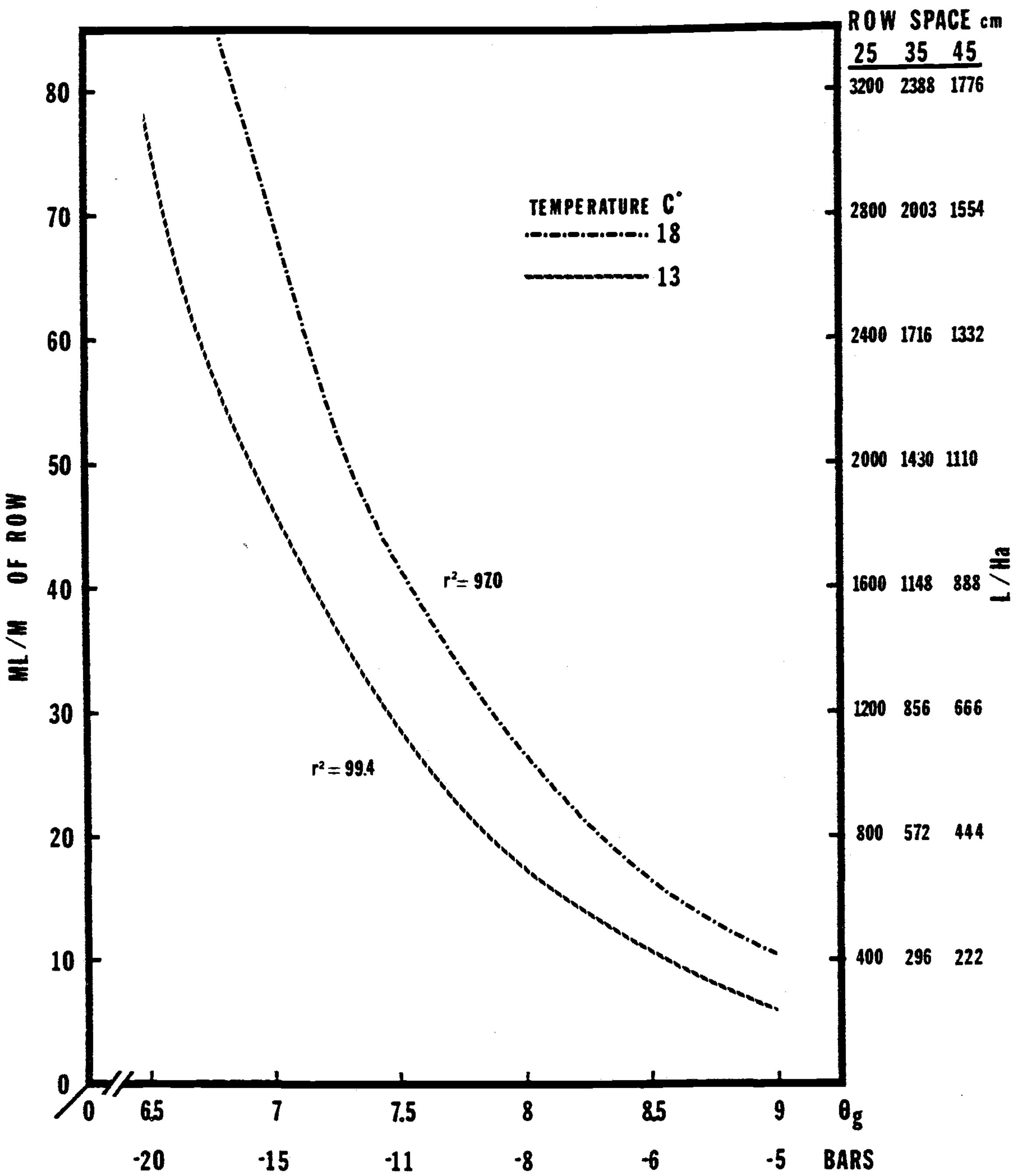

Figure 8. The amount of water required to obtain 80% emergence 3 days after initial emergence at two soil temperatures.

the water requirement almost by half on a unit area basis. Common row spacings in the area under study are usually between 25 and 35 cm. Studies conducted at Lind, Washington, however, have shown that yield levels can be maintained by widening the row spacing from 35 cm to 52 cm if other factors such as weed control are equal.

It is evident from Figure 8 that lowering the seed zone soil temperature decreased the amount of moisture necessary for emergence. This could be due in part to the fact that at the higher soil temperature the soil moisture loss was greater during the first 6 days than at the lower temperature (see Table 1). At the lower soil temperature the bulk soil moisture content remained fairly constant. This loss in soil moisture content could have influenced the emergence rate and percent stand so that the curve at 18°C overestimates what would be necessary had this loss in moisture not occurred.

To keep the rates of water within a practical range and to insure seedling survival after emergence, the basic premise of water injection must include placing the seed into the residual moisture with water added only as an aid to emergence. Considering the amount of water required to insure emergence at moisture tensions of -15 bars or greater and because seedling roots of wheat will not penetrate soil at these moisture tensions (Salim _et al_. 1965), the practical range of water injection appears to be between -5 and -14 bars. In the field the soil moisture content increases with increasing depth. Under field conditions seedlings could draw upon residual soil moisture until effective fall rains were received. The Lower Columbia Basin receives approximately 70% of the annual precipitation between the months of November and March. Hence, the probability of effective fall rains is greatly increased by the end of October. It is interesting to note that in the laboratory 14 days after initial emergence there were no visible signs of seedling stress at -15 or -20 bars tension.

The data from this study indicate that adding water in a narrow band at seeding has the potential to enhance stand establishment under sub-optimal soil moisture conditions. Field trials are needed to determine if the information obtained in the laboratory is applicable to field conditions.

LITERATURE CITED

Allan, R.E., O.A. Vogel, and C.I. Peterson. 1962. Seedling emergence rate of fall-sown wheat and its association with plant height and coleoptile length. Agron. J. 54:347-350.

Anonymous. 1968. Weed control in sugar beets: water injection versus planting dry. Agricultural Exp. Sta., University of Wyoming, Laramie. PR 27.

Ashraf, C.M. and S. Alu-Shakra. 1978. Wheat seed germination under low temperatures and moisture stress. Agron. J. 70:135-139.

Derici, M.R. 1971. Crop establishment under limited soil moisture conditions. M.S. thesis. Univ. of California, Davis.

Lindstrom, M.J., R.I. Papendick, and F.E. Kaehler. 1976. A model to predict winter wheat emergence as affected by temperature, water potential, and depth of planting. Agron. J. 68:137-140.

Russelle, M.P. 1979. Soil moisture and temperature relationship under fallow in eastern Oregon. M.S. thesis. Oregon State Univ., Corvallis.

Salim, M.H., G.W. Todd, and A.M. Schlehuber. 1965. Root development of wheat, oats and barley under conditions of soil moisture stress. Agron. J. 57:603-607.

BIBLIOGRAPHY

Allan, R.E., O.A. Vogel, and C.I. Peterson. 1962. Seedling emergence rate of fall-sown wheat and its association with plant height and coleoptile length. Agron. J. 54:347-350.

Anonymous. 1968. Weed control in sugar beets: water injection versus planting dry. Agriculture Exp. Sta., University of Wyoming, Laramie. PR 27.

Ashraf, C.M. and S. Alu-Shakra. 1978. Wheat seed germination under low temperatures and moisture stress. Agron. J. 70:135-139.

Ayers, A.D. 1952. Seed germination as affected by soil moisture and salinity. Agron. J. 44:82-84.

Burleigh, J.R., R.E. Allen, and O.A. Vogel. 1964. Effects of temperature on coleoptile elongation in eight wheat varieties and selections. Agron. J. 56:523-524.

Burleigh, J.R., R.E. Allan, and O.A. Vogel. 1965. Varietal differences in seedling emergence of winter wheat as influenced by temperature and depth of plants. Agron. J. 57:195-198.

Collis-George, N. and J.E. Sands. 1959. The control of seed germination by moisture as a soil physical property. Australian J. Agr. Res. 10:628-630.

Connveme, I.C. and H.M. Laude. 1972. Heat-induced growth retardation and attempts at its prevention in barley and wheat. J. Agr. Sci. 79:331-333.

Conway, M.P. 1978. Temperature and moisture effects on stand establishment of seven winter wheat cultivars and selected progeny (Triticum aestivum L. em Thell). M.S. thesis. Corvallis, Oregon State University.

Dasberg, S. 1971. Soil water movement to germinating seed. J. Exp. Bot. 22:992-998.

Derici, M.R. 1971. Crop establishment under limited soil moisture conditions. M.S. thesis. Davis, University of California.

Gul, A. and R.E. Allen. 1976. Stand establishment of wheat lines under different levels of water potential. Crop Sci. 16:611-615.

Gulliver, R.L. and W. Heydecker. 1973. Establishment of seedlings in a changeable environment. p. 433-462. In W. Heydecker (ed.). Seed Ecology. Proc. 19th Easter School in Agric. Sci. Univ. of Nottingham, 1972.

Hadas, A. 1969. Effects of soil moisture stress on seed germination. Agron. J. 61:325-327.

Hadas, A. 1970. Factors effecting seed germination under soil moisture stress. Israel J. Agr. Res. 20:3-13.

Hadas, A. and D. Russo. 1974a. Water uptake by seeds as affected by water stress, capillary conductivity and seed-soil water contact. I. Experimental Study. Agron. J. 66:643-647.

Hadas, A. and D. Russo. 1974b. Water uptake by seeds as affected by water stress, capillary conductivity and seed-soil water contact. II. Analysis of Experimental Data. Agron. J. 66:647-652.

Halitligil, M.B. 1975. Effect of soil moisture, temperature, bulk density and texture on emergence of three wheat varieties (Triticum aestivum L.). M.S. thesis. Corvallis, Oregon State University.

Helmerick, R.H. and R.P. Pfeifer. 1954. Differential varietal responses of winter wheat germination and early growth to controlled limited moisture conditions. Agron. J. 46:560-562.

Hunter, K. and K.J. Kristen. 1967. Emergence and seedling growth related to oxygen content and O.D.R. in different soils. Agron. J. 59:541-544.

Mayer, A.M. and A. Poljakoff-Mayber. 1963. The germination of seeds. Pergamon Press, New York. p. 236.

McGinnes, W.J. 1960. Effects of moisture stress and temperature on germination of six range grasses. Agron. J. 52:159-162.

Noggle, G.R. and G.J. Fritz. 1976. Introductory Plant Physiology. Prentice-Hall, Inc., New Jersey.

Owen, P.C. 1952. The relation of germination of wheat to water potential. J. Exp. Bot. 3: 188-203.

Pawlowski, M.C. and C.F. Shaykewich. 1972. Germination of wheat as affected by soil water stress. Can. J. Plant. Sci. 52:619-623.

Peterson, R.F. 1965. Wheat: botany, cultivation, and utilization. Interscience Publishers, Inc., New York. 422 p.

Russelle, M.P. 1979. Soil moisture and temperature relationships under fallow in eastern Oregon. M.S. thesis. Corvallis, Oregon State University.

Salim, M.J., G.W. Todd, and A.M. Schlehuber. 1965. Root development of wheat, oats and barley under conditions of soil moisture stress. Agron. J. 57:603-607.

Singh, O.S. and K.S. Gill. 1972. Some physiological aspects of the effects of kinetin, depth of seeding and soil temperature on seedling establishment and metabolism of dwarf wheat. Indian J. Agric. Sci. 42:205-210.

Tadmor, N.H., Y. Cohen, and Y. Harpaz. 1969. Interactive effects of temperature and osmotic potential on germination of range plants. Crop Sci. 9:771-774.

Valovich, E.M. and V.G. Grif. 1974. On the minimal temperature of seed germination. Sov. Plant Physiol. 21:1042-1047.

Ward, J. and C.F. Shaykevich. 1972. Water absorption by wheat seeds as influenced by hydraulic properties of soil. Can. J. Soil Sci. 52:99-105.

APPENDIX

Appendix Table 1. Mean squares from the analysis of variance for emergence 3 days after initial emergence (stand) and the emergence rate index (E.R.I.) at -5 bars tension for both 13 and 18^{o}C mean seed zone soil temperatures.

Source	Stand			E.R.I.		
	df	13^{o}C	18^{o}C	df	13^{o}C	18^{o}C
Replications	2	0.87	1.54	2	141.17	0.25
Treatments	3	3.11	17.44*	3	72.41**	292.22**
Reps. x Treats.	6	1.15	4.81	6	18.36	49.80
Error	12	3.33	3.75	-	-	-
Total	23			11		
CV		0.07	0.15		0.11	0.08

*Significant at the 10% level.

**Significant at the 5% level.

Appendix Table 2. Mean squares from the analysis of variance for emergence 3 days after initial emergence (stand) and the emergence rate index (E.R.I.) at -8 bars tension for both 13 and 18°C mean seed zone soil temperatures.

Source	Stand			E.R.I.		
	df	13°C	18°C	df	13°C	18°C
Replications	2	36.04	23.79	2	410.08	706.33
Treatments	3	18.50*	12.48*	3	370.66*	434.75**
Reps. x Treats.	6	8.00	3.23	6	110.41	49.00
Error	12	1.54	2.70	-	-	-
Total	23			11		
CV		0.22	0.12		0.18	0.12

*Significant at the 10% level.

**Significant at the 5% level.

Appendix Table 3. Mean squares from the analysis of variance for emergence 3 days after initial emergence (stand) and the emergence rate index (E.R.I.) at -11 bars tension for both 13 and 18°C mean seed zone soil temperatures.

Source	Stand			E.R.I.		
	df	13°C	18°C	df	13°C	18°C
Replications	2	65.05	19.54	2	1071.75	424.08
Treatments	3	108.44***	125.61***	3	2044.08***	2078.30***
Reps. x Treats.	6	8.65	7.48	6	108.08	83.30
Error	12	1.16	5.58	-	-	-
Total	23			11		
CV		0.23	0.27		0.16	0.17

***Significant at the 1% level.

Appendix Table 4. Mean squares from the analysis of variance for emergence 3 days after initial emergence (stand) and the emergence rate index (E.R.I.) at -15 bars tension for both 13 and 18°C mean seed zone soil temperatures.

Source	Stand			E.R.I.		
	df	13°C	18°C	df	13°C	18°C
Replications	2	58.16	20.04	2	771.08	444.33
Treatments	3	133.48***	147.70***	3	1319.68***	2188.55***
Reps. x Treats.	6	12.77	7.87	6	40.63	87.88
Error	12	1.45	6.37	-	-	-
Total	23			11		
CV		0.31	0.27		0.15	0.04

***Significant at the 1% level.

Appendix Table 5. Mean squares from the analysis of variance for emergence 3 days after initial emergence (stand) and the emergence rate index (E.R.I.) at -20 bars tension for both 13 and 18°C mean seed zone soil temperatures.

Source	Stand			E.R.I.		
	df	13°C	18°C	df	13°C	18°C
Replications	2	4.29	31.29	2	96.08	393.75
Treatments	3	194.93***	70.37***	3	3331.00***	902.88***
Reps. x Treats.	6	3.18	9.95	6	59.41	85.97
Error	12	6.70	2.45	-	-	-
Total	23			11		
CV		0.15	0.49		0.12	0.31

***Significant at the 1% level.

Appendix Table 6. Emergence percentage 3 days after initial emergence at five levels of moisture tension and two soil temperatures.

Moisture tension (bars)	Temperature (°C)	Water added (ml/m row) 0	15	20	30	40	45	50	60	70	80
-5	13	72	81		78		81				
	18	76	82		94		94				
-8	13	53		88		88			82		
	18	60		80		80			96		
-11	13	35		70		88			88		
	18	24		53		77			88		
-15	13	24			70			88		76	
	18	13			70			77		88	
-20	13	0				53			76		76
	18	0				18			42		47

Appendix Table 7. Emergence rate index at five levels of moisture tension and two soil temperatures.

Moisture tension	Temperature	Water added (ml/m row)									
		0	15	20	30	40	45	50	60	70	80
(bars)	(^oC)										
-5	13	72	76		89		92				
	18	59	68		68		68				
-8	13	42		62		68			67		
	18	41		54		57			70		
-11	13	29		63		82			86		
	18	20		50		63			82		
-15	13	11			42			59		52	
	18	10			50			60		73	
-20	13	0				47			71		73
	18	0				15			32		40

Appendix Table 8. Seed zone gravimetric water content at three levels of moisture tension and 13°C at various time intervals after planting.

Water added	Days from planting			
	0	2	4	6
(ml/m row)	(%)	(%)	(%)	(%)
	-5 bars tension			
0	9.0	9.1	9.2	9.2
15	11.6	10.2	10.1	9.8
30	15.1	11.8	12.0	10.5
45	16.4	12.9	12.8	11.0
	-8 bars tension			
0	8.2	8.6	8.8	8.3
20	12.6	11.0	10.5	9.4
40	15.1	11.8	12.1	10.4
60	17.4	12.4	12.4	11.2
	-15 bars tension			
0	7.1	7.1	7.0	6.9
30	14.5	9.7	8.9	8.7
50	16.2	11.0	9.8	9.0
70	17.8	11.0	10.2	9.4

Appendix Table 9. Seed zone gravimetric water content at five levels of moisture tension and 18°C at various time intervals after planting.

Water added	Days from planting			
	0	3	6	9
(ml/m row)	(%)	(%)	(%)	(%)
	-5 bars tension			
0	9.1	9.1	8.0	8.4
15	13.1	10.6	8.2	8.2
30	13.0	11.1	9.2	9.1
45	15.3	11.8	9.8	9.3
	-8 bars tension			
0	8.0	8.8	7.1	5.6
20	11.8	9.0	7.5	6.0
40	15.4	10.2	8.3	6.4
60	16.2	10.4	9.0	6.8
	-11 bars tension			
0	7.6	6.0	5.8	5.6
20	16.0	9.5	6.2	5.8
40	16.3	9.9	6.9	6.1
60	16.8	10.5	7.9	7.2
	-15 bars tension			
0	7.1	6.9	6.4	5.3
30	14.2	8.9	7.0	5.5
50	15.8	9.7	8.2	6.0
70	17.1	10.3	8.6	6.5
	-20 bars tension			
0	6.5	6.1	5.1	4.4
40	15.2	8.6	5.3	4.7
60	17.3	9.5	6.0	4.7
80	17.3	9.8	6.8	5.0