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Title: EFFECT OF SOIL MOISTURE, TEMPERATURE, BULK DENSITY, AND TEXTURE ON EMERGENCE OF THREE WHEAT VARIETIES (TRITICUM AESTIVUM, L.)

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The effects of soil moisture (-2 to -17 bars), temperature (5 to 20°C), bulk density (0.90 to 1.40 gm/cm^3) and texture (Bashaw silty clay and Woodburn silt loam) on germination and seedling emergence of three varieties (Yamhill, Bezostaya, Kirac 66) of wheat (Triticum Aestivum, L.) were evaluated under laboratory and field conditions. Experiments include: 1) germination of three wheat varieties in osmotic solutions made from Carbowax 6000 to evaluate the effect of osmotic potential and temperature on germination, 2) measurement of seedling emergence for three wheat varieties in Bashaw and Woodburn soils as influenced by soil water potential and temperature, 3) measurement of seedling emergence for the three varieties at three planting dates to test the applicability of the laboratory response to field conditions, and 4) measurement of seedling emergence of Kirac 66 as affected by bulk density and soil water potential in Bashaw and Woodburn soils. The effect of seed protein content on germination and emergence was evaluated by using high and low protein samples (16.50 and 7.75 percent, respectively) of Yamhill wheat in the first three experiments.

The number of days required to obtain 50 and 80 percent germination in osmotic solutions and seedling emergence in soil was significantly increased by lowering either temperature or water potential. Although significant interactions were measured, temperature affected germination more than water potential. There was a significant difference in the germination and emergence times of Yamhill, Bezostaya and Kirac 66. Kirac 66 emerged the fastest while Bezostaya consistantly emerged the slowest. Seed protein did not affect germination or seedling emergence of Yamhill variety.

Models were developed using linear regression analysis for the laboratory seedling emergence study to predict the number of days required to obtain 50 and 80 percent emergence in Woodburn soil and 50 percent in Bashaw soil as a function of soil water potential and soil temperature. Since the response to the variables were similar, the models were composite for the three varieties. The models were used to determine soil water potential and temperature combinations which permit emergence to occur within a specified time.

Soil texture and bulk density significantly affected the time required for seedling emergence. More days were required to obtain seedling emergence in Bashaw silty clay than in Woodburn silt loam soil at a given soil water potential primarily because of less seed-soil contact.

Emergence was delayed by bulk densities greater than 1.20 and 0.90 gm/cm^3 in Woodburn and Bashaw soils, respectively, because of increased soil strength.

Data collected from three seeding dates made in the field in general confirmed the findings in the laboratory concerning the effects of soil moisture and temperature. Bezostaya emerged the slowest while Yamhill emerged the fastest. Seed protein content did not affect emergence. Applicability of the laboratory models to field conditions could not be established because of insufficient data.

EFFECT OF SOIL MOISTURE, TEMPERATURE, BULK DENSITY, AND TEXTURE ON EMERGENCE OF THREE WHEAT VARIETIES (TRITICUM AESTIVUM, L)

by

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Typed by Mary Syhlman for MAHMUT BASRI HALITLIGIL

DEDICATED TO MY

BELOVED

FATHER AND MOTHER

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EFFECT OF SOIL MOISTURE, TEMPERATURE, BULK DENSITY, AND TEXTURE ON EMERGENCE OF THREE WHEAT VARIETIES (TRITICUM AESTIVUM, L.)

I. INTRODUCTION

Wheat is one of the primary sources of nutrition for people around the world. Every year the demand for wheat increases because of the continual increase in world population. Although some potential for increasing the amount of land for agricultural production does exist, the most important potential for increasing total agricultural production is through development of technology to increase yields on land already being used for growing crops.

Germination and seedling emergence of wheat are the first two critical stages of growth in dryland production. Obtaining an adequate crop stand for optimum crop production is difficult under many dryland conditions because of adverse soil and other environmental conditions which may limit germination and seedling emergence.

Many soil and other environmental factors affect germination and seedling emergence of a wheat crop. Moisture and temperature influence metabolic activation of the germination seeds. Soil texture and compaction affect the area of contact, matric potential and hydraulic conductivity of the media which in turn effects germination and early growth of crops through limiting water availability.

The objective of this study was to evaluate the effects of soil moisture, temperature, texture, and bulk density on the germination and seedling emergence of three varieties of winter wheat.

II. LITERATURE REVIEW

FACTORS AFFECTING GERMINATION AND SEEDLING EMERGENCE

SOIL MOISTURE

Before a seed can germinate, a hydration process must occur. Water must be absorbed into the endosperm and embryo through the seed coat. The germination process starts just after water content of the seed reaches a critical level if the other factors are optimum for germination. The minimal amount of water which must be present for germination varies depending on species. For example, in maize, rice, soybean and wheat 31, 25, 50, and 40 percent moisture, respectively, must be present on a wet weight basis (Brown, 1965). Also during germination substances must be translocated from the endosperm to the embryo. The diffusion of these substances occurs through water, which consequently results in enzyme formulation and metabolic reactivation (Cooking, 1969). The germination process is complete with the emergence of the radicle from the embryo.

The absorption of water by the seed occurs in two distinct processes: imbibition and uptake of water by the rootlet (Mayer and Poljakoff-Mayber, 1963). Initially after a seed is placed in contact with water, water diffuses toward and into the seed because of the energy level difference between the dry seed and the moist soil. The time required for this process to occur depends upon plant species, composition of the seed, permeability of the seed coat and the availability of water in the soil environment. The second process occurs after the rootlet appears and after the imbibition process has been completed. During this stage water is absorbed by osmosis because of the energy gradient between the soil environment and the cells in the rootlet.

Water moves toward the rootlet within the soil in response to a potential gradient. Soil factors that determine the rate at which seeds can absorb water during the germination and seedling emergence processes are: soil water potential, unsaturated hydraulic conductivity and the area of contact between the seed and the soil. A mathematical description of this movement and the uptake of soil water by germinating seeds was first attempted by Schull (1920), and recently by Hadas (1969) and by Ehrler and Gardner (1971). The soil can transmit water to the seeds at a sufficient rate to allow imbibition to occur even at very low water potentials approaching -15 atmospheres (Hadas, 1969). As the soil water potential decreases the availability of water to the seeds decrease and the time required for water to move to the seed increases. This shows that although the rate of water to the seed is reduced as the soil dries, the water still can be available. Consequently, the rate of germination decreases.

Dasberg et al (1971) found that the distance from which water was taken up by the seeds in soil did not exceed 1 centimeter, regardless of soil water content. He also mentioned that the rate of seedling growth was not affected by initial soil water content, although the shoot growth was strongly affected. On the other hand, very high moisture levels can decrease the germination, because the thickening of the water films around the seeds interfers with oxygen diffusion (Dasberg and Mendel, 1971).

The moisture content of a soil is dependent on both the matric and osmotic components of the soil water potential. A decrease in matric potential involves a decrease in water mobility and hence the availability of water (Hillel, 1971). In contrast, osmotic potential per se does not effect the movement of water in the soil.

Matric potential has been shown to be an important factor in seed germination and seedling emergence due to its effect in controlling the unsaturated hydraulic conductivity of the soil (McWilliams and Phillips, 1971). They stated that the rate of germination and total germination were substantially hindered with decrease in matric potential. Total germination of wheat was not affected by decreasing matric potential to -8 atmospheres, but the rate of germination was reduced as matric potential decreased from -1/3 to -15 atmospheres (Pawlowski and Schaykewich, 1972). Collis-George (1959) found that a matric potential as high as -10 atmosphere was sufficient to retard the germination of Juncus and Medicago species.

Another factor that is controlled by matric potential is the contact area of the seed and the soil (Collis-George and Hector, 1966; Hadas and Russo, 1974). They pointed out that as the matric potential decreases the area of contact becomes less effective. This is a result of the thinning of waterfilm around the soil particles as the matric potential decreases.

The effects of soil matric potential and osmotic potential on seed germination were studied by Ayers (1952). He found that their effects were equal. Also McWilliam and Phillips (1971) showed that if soil moisture diffusivity and area of contact are equal, osmotic and matric potentials have equal effect on the germination of rye-grass seeds over a range of water potential from 0 to -15 bars. On the other hand Gingrich and Russel (1957) observed that a decrease in matric potential had a greater effect on germination and seedling emergence. They attributed this to a decrease in moisture content and hydraulic conductivity. However, osmotic potential does not effect total germination except at high concentrations where toxic effects may occur.

Numerous investigators have conducted germination experiments in osmotic solutions where the water transmission characteristic of the soil is absent. The seed-moisture contact area in these experiments is assumed to be 100 percent. For these studies NaCl, Mannitol or Carbowax salts are used to obtain the desired osmotic pressures. Gingrich and Russel (1957) found different germination and seedling growth results between D-mannitol solution experiments and experiments using soils. McGinnies (1960) studied the germination of range grasses as affected by osmotic potentials ranging from -1/3 to -15 bars. He concluded that as osmotic potential decreased, germination was delayed and its rate was reduced. Knipe and Herbel (1960) and Tadmor, et al., found similar results using range grasses. When alfalfa seeds were germinated in osmotic solutions, the germination was inhibited at -2 to -14 atmospheres (Uhvits, 1946). His explanation for the inhibition was that seeds absorb sufficient amounts of solute to become toxic. He also compared the effects of different solutes (Mannitol and NaCl) on germination. At similar osmotic potentials, water absorption was slower with mannitol solutions than with NaCl solutions. But faster germination rates were obtained with mannitol solutions at lower osmotic potentials because mannitol was less toxic.

Owen (1952) studied the effect of water potential on seed germination using osmotic solutions, however, water transfer was in the vapor rather than liquid phase. He reported that 20 percent of the seeds germinated in 20 days at 20°C with a water potential of -30 bars. The rate of germination was decreased by decreasing water potential. In another experiment he tried to determine whether the failure of some seeds to germinate at lower water potentials was due to inability to attain some critical moisture content. His conclusions indicate that the failure to germinate was mainly due to differences in the reaction of viable seeds rather than the failure to attain a critical moisture content.

SOIL TEMPERATURE

Temperature influences germination and seedling emergence directly and indirectly (Herbel and Sosebee, 1969). It influences germination directly by affecting the rates of metabolic reactions. Temperature indirectly influences germination by affecting the energy level and transport of water in the soil.

After seeds imbibe water, respiration rates increase which are mainly regulated by temperature. Through respiration energy is made available which is used for enzyme formulation and transportation within the seed (Mayer and Poljakoff-Mayber, 1963).

Germination is basically a metabolic reactivation that takes place only between critical maximum and minimum temperatures. Cardinal temperatures for germination and seedling emergence varies among species and often among even varieties.

Cardinal temperatures for wheat have been described differently by various individuals. According to Peterson (1965) the minimum, optimum, and maximum temperatures are 3.5-5.5, 20-25, 35°C respectively, however, Cooking (1969) gives 0-4.8, 25-31, and 31-37°C, respectively. Soil temperatures above 30°C have been reported to adversely effect the germination of wheat varieties (Burleig, Allen and Vogel, 1965). At these temperatures they observed poor seedling emergence. At high temperatures and low soil moisture fungi can hinder germination. On the other hand various pathogenic organisms are capable of causing kernel rot and seedling blight under low temperatures and high soil moisture content (Pinnelle,1949).

Cardinal temperatures have been established for other species. In a study with winter annual legumes, Toole and Hollowell (1939) found that temperatures above 30 to 35°C inhibited total germination. Oberdorf and Hobbs (1970) found that soybeans were sensitive to temperature during imbibition process, and this sensitivity was controlled by initial seed moisture content. The time for the radicle emergence of cotton decreased between the temperatures of 15.6 and 32.2°C (Wanjura and Buxton, 1972).

Numerous investigators have shown that fluctuating temperatures cause faster germination and seedling emergence than constant temperatures. This may be due to the influence of temperature on dormancy of the seeds. Villiers (1972) reported that wheat seeds did not germinate at a constant temperature of 10°C, however, when he fluctuated the diurnal temperature between 5 and 10°C, the seeds did break dormancy and germinate.

Low temperatures influence germination and seedling emergence by slowing water transport within the soil. As temperature is lowered, both the viscosity and surface tension of water increase (Tadmor, Cohen and Harpaz, 1969) and cause slower rates of water movement at similar energy gradients.

The interactions that occur between soil moisture and soil temperature have a great influence on germination and seedling emergence. These interactions are complex because the two factors operate through different modes or mechanisms (Negbi, 1961). Tadmor, Cohen and Harpaz (1969) found that the germination rate of wheat was affected by temperature and water potential, however, the effect of water potential was dependent on temperature. Went (1957) and Evans and Stickler (1961) reported similar temperature and water potential effects on germination and seedling emergence.

SOIL TEXTURE AND BULK DENSITY

The moisture retention and unsaturated hydraulic conductivity characteristics and compactability of soils are influenced by soil texture or particle-size distribution (Hillel, 1971). As a consequence, germination and seedling emergence thus are significantly affected by soil texture.

The amount of water retained by a soil at any given water potential increases with clay content. This is because of the greater surface and number of fine pores present. Associated with the larger amount of water is a greater mobility. The unsaturated hydraulic conductivity, a measure of the mobility of soil water, is many fold higher in clay soils than in sandy soils at any given moisture content between field capacity and permanent wilting point.

Hanks and Throp (1956) measured wheat seedling emergence as affected by soil moisture and bulk density for three soils varying in texture from silty clay loam to a fine sandy loam. Their results showed that final seedling emergence was not influenced by soil moisture content between field capacity and permanent wilting point. When all other factors were optimum, the rate of seedling emergence was related directly to the moisture content. Their data showed that higher bulk densities restricted seedling emergence primarily because of greater soil strength. This phenomenon was more pronounced at lower soil moisture contents indicating a significant moisture and bulk density interaction.

Phillips and Kirkham (1962) found the rate of corn seedling root elongation decreased linearly as the bulk density of Colo clay soil increased from 0.94 to 1.30 gm/cm^3. This indirectly indicates that seedling emergence of corn will decrease as the bulk density increases. As soil compaction increased the coleoptile length of winter wheat was reduced, also total emergence and rate of emergence decreased.

Oxygen concentrations and oxygen diffusion rate can influence germination and emergence of wheat. Winter wheat did not germinate at concentrations below than 1.0 percent, yet only 10 percent oxygen gave maximum emergence (Kaack and Kristen, 1967). They found that the rate of emergence was reduced by reducing the oxygen content or by increasing water content. The low oxygen concentrations and low oxygen diffusion rate are due to inadequate soil structure on soils with high clay content. Slatyer and Rodrigues (1954) indicated that seeds germinated better in a well structured soil.

Soil compaction, generally influences coleoptile length. Kaach and Kristen (1967) found that as soil compaction increased, coleoptile length of winter wheat was reduced. Total emergence and rate of emergence were also decreased.

VARIETAL RESPONSES

The ability of a wheat variety to germinate and emerge is controlled genetically and is an integrated response to all environmental factors, consequently varieties do respond differently to such factors as soil water, temperature, and bulk density. Numerous experiments have been conducted in an attempt to evaluate the effect of low temperature and low soil moisture on emergence of wheat. In laboratory and field experiments Lindstrom (1973) found that the variety McCall emerged faster than the variety NuGaines. However, he indicated that these differences were small and of limited practical importance. Allan et al (1965) found no significant differences in germination rates among 33 semi-dwarf wheat varieties.

Ward and Shaykevich (1972) tried to evaluate the different varietal responses by measuring the water diffusivity and hydraulic conductivity of the wheat seeds. They found that if the seed is large, the rate of moisture uptake per unit volume will be slower, so it will require more time for germination. This can be related to the protein content of the seeds. Generally the seeds with higher protein content are smaller than those with lower protein content. One could postulate that varieties with small seed may require less time for germination and hence the seedling emergence may be quicker.

Helmerick and Pfeifer (1954) measured the emergence rate and the coleoptile length of two varieties (Yogo and Cheyenne) in osmotic solutions and in soil. Yogo consistantly had a longer coleoptile and superior emergence. Burleigh, Allan, and Vogel (1965) showed that varieties with long coleoptiles emerged more rapidly than those with short coleoptiles. However, contrary to this, Kaufmann (1968) could not find any variation in the emergence of wheat varieties if differences in coleoptile lengths were taken into consideration.

III. METHODS AND MATERIALS

Three winter wheat varieties (Yamhill, Bezostaya and Kirac 66) were used in the experiments. These varieties were chosen because of the wide range of climatic conditions in which they are grown. Generally, Yamhill is a high yielding variety grown mainly in Oregon under high and low rainfall ranges. Bezostaya and especially Kirac 66 are grown under low rainfall in many parts of the world where they produce well under adverse soil and other environmental conditions. The characteristics of the varieties are summarized in the Appendix, Table 8.

Two soils, Bashaw silty clay and Woodburn silt loam were used to evaluate the effect of soil texture on seedling emergence. These two soil textures were chosen because of differences in clay contents, water holding capacities and compactabilities. Their physical and chemical properties are given in the Appendix, Table 9.

Three laboratory and one field experiments were conducted to evaluate the effect of soil water potential, temperature, texture, and bulk density on the germination and seedling emergence of the three wheat varieties.

Germination Experiment in Osmotic Solutions

Solutions having osmotic potentials of -2, -7, -12, and -17 bars were prepared by mixing Carbowax 6000 (polyethelene glycol) and distilled water. The concentrations of Carbowax 6000 required to produce the specific osmotic potentials were taken from the data of

Barlow (1974), Appendix, Figure 14.

Pieces of blotter paper approximately 10 centimeters square were saturated with the osmotic solutions and placed in shallow plastic trays. Ten seeds were scattered on the blotter paper in each tray. Another piece of blotter paper saturated with the solution was placed on top of the seeds. To prevent the evaporation losses a cover was placed on each tray.

The trays were immediately placed in refrigerated growth chambers where temperature could be controlled ±0.5°C. Temperature treatments were 5°C, 10°C, 15°C and 20°C.

Germination counts were made daily until 90 percent of the seeds had germinated. Germination was considered complete when the radicle length reached 5 millimeters.

The experiment was a randomized, complete-block design with a split-plot arrangement and two replications. After transforming the data using natural logarithms, an analysis of variance was obtained. Tukey's procedure was used to determine significant differences. Models predicting the number of days required to obtain 80 percent germination were developed from the variance analysis by contrast method (Steele and Torrie, 1960).

Laboratory Seedling Emergence Experiment

Moisture retention curves over the range of -1/3 to -15 bars were obtained for the Bashaw silty clay and Woodburn silt loam soils using pressure cooker and pressure plate apparatus (Richard, 1965) (Appendix, Figure 15). Moisture contents at matric potentials of

-2, -7, -12, and -17 bars were determined graphically from the moisture retention curves for the two soils.

Air dry soil was passed through a 2.75 millimeter seive and spread out on laboratory benches. Sufficient water was sprayed onto the soil to increase the moisture content of the desired level. After mixing, the moist soil was placed in closed plastic containers and left for 7 days at room temperature for further equilibrium. Gravimetric samples were then taken to check the moisture content. If needed, additional water or dry soil was added and left to equilibration for an other 7 days to assure that the moisture content was within ± 0.2 percent. Large amounts of soil was prepared in this manner to provide enough experimental soil for one replication of the treatments.

Moist soil was placed in 250 milliliter glass beakers and leveled at a height of 3 centimeters. Ten wheat seeds of uniform size were placed randomly on the surface of the leveled soil. Then 1-centimeter layers of additional moist and air dry soil, respectively, were added. Afterwards the soil was compacted to a 1.0 gm/cm^3 (± 0.05) bulk density. The weight of moist and dry soil needed was determined separately for each beaker. To prevent entry of light the sides and bottom of the beakers were covered by tape. The beakers were covered with plastic to prevent evaporative losses of moisture.

The beakers were placed in a thermostatically controlled water bath in which the soil temperature was controlled within ± 0.5°C. Water was circulated within the bath to assure uniform temperature.

Temperature was controlled by using refrigeration and electrical heating elements. Emergence counts, appearance of hypocotyl, were made daily for each beaker until 80 percent emergence occurred.

Experiment variables included were 1) wheat variety, 2) soil matric potential 3) soil temperature and 4) soil texture. The wheat varieties (Yamhill high protein, Yamhill low protein, Bezostaya and Kirac 66) were subjected to -2, -7, -12, and -17 bar soil matric potentials and soil temperatures of 5, 10, 15 and 20°C for Woodburn soil. The Yamhill variety, with high and low protein sampling was subjected to -2, -7, -12, and -17 bars at soil temperatures of 5, 10, 15, and 20°C for Bashaw soil. Since only two water baths were available three replications were made at different times. There were four observations of each treatment in each replication.

The experiment was a randomized, complete-block design with a split-plot arrangement; temperature being the main plots and soil water potential being the sub-plots.

Models were developed by regression analysis to predict the number of days required to obtain 50 and 80 percent emergence. Models were made for the two germination percentages because 80 percent emergence was not attained on many of the -17-bar soil moisture treatments at 5 and 10°C. After transforming the data by using natural logarithms, the computer was used to obtain an equation by regression analysis which best described the influence of soil moisture and temperature on the time required for seedling emergence (Steele and Torrie, 1960).

Bulk Density Experiment

Bashaw and Woodburn soil were air dried and passed through a 2.75 millimeter seive. Sufficient water was added to the soil to raise the soil matric potential to the desired level. The moist soil was placed in a closed container and given 7 days to equilibrate. Gravimetric samples were taken to determine water content and, if needed, additional water or dry soil was added.

Weights of moist soil needed to fill 250 milliliter glass beakers to a 4.5-centimeter depth when compacted to the desired bulk density were placed in the beakers. Ten wheat seeds were randomly placed on the surface of the soil and covered with the equivalent weight of a 1-centimeter depth of moist soil. Over this was placed the equivalent weight of a 1-centimeter depth of air dry soil. Prior to the seeding and addition of both soil layers, the surface was leveled. The soil was then compacted to a 6.5-centimeter depth to produce the desired bulk density using a hand operated press.

After compaction, the beakers were covered with plastic to prevent loss of water through evaporation. Plastic tape was placed on the side and bottom of each beaker to exclude light. Then the beakers were placed in a 20°C ± 1°C constant temperature room. Seedling emergence was recorded daily until 80 percent of the seeds had emerged.

Experimental variables included were: 1) soil matric potential, 2) bulk density, and 3) soil texture. Kirac 66 was subjected to -1, -4, -7, and -10 bars soil matric potentials and bulk densities of

0.9, 1.00, 1.10, 1.20, and 1.30 gm/cm^3 for Bashaw soil and 0.9, 1.00, 1.10, 1.20, 1.30 and 1.40 gm/cm^3 for Woodburn soil. Three replications of each treatment were made simultaneously.

The experiment was a completely randomized design with 4 x 5 factorial arrangement for Bashaw soil and 4 x 6 factorial arrangement for Woodburn soil. Data was statistically evaluated using analysis of variance. Tukey's procedure was used to determine significant differences between treatment means (Steele and Torrie, 1960).

Field Seedling Emergence Experiment

Wheat seedings were made in the field at three different dates to obtain different soil moisture and temperature regimes. Two of them were made near Corvallis, Oregon, on a Woodburn silt loam soil and one was made in Central Oregon on a Madras loam soil. Locations and time of planting were selected to provide a range of soil moisture and temperature conditions to determine whether the models developed from the laboratory experiments was applicable under field conditions.

The three wheat varieties used in the laboratory experiments were planted by hand or with a belt seeder at a depth of 5 centimeters at each seeding date. After covering the seeds, the soil was compacted to a bulk density of approximately 1.0 gm/cm^3. For each variety, four replications of 30 seeds were planted at each planting date. Emergence counts were made daily as well as maximum and minimum soil temperatures in the seed zone. Soil moisture samples at the 0 to 15-centimeter depth was taken when the seeds were planted and when 80 percent seedling emergence was obtained and converted to water potential using soil moisture retention curves.

The experiment was a randomized, complete-block design with a split-plot arrangement; seeding dates being the main plots and varieties being the sub-plots. Data was analyzed statistically using analysis of variance. Tukey's procedure was used to determine significant differences between treatment means (Steele and Torrie, 1960).

IV. RESULTS

SOLUTION EXPERIMENT

The number of days required to obtain 80 percent seed germination (D_{80}) for each of the four varietal treatments as influenced by osmotic water potential and temperature is given in Table 1 (see Appendix, Table 10 , for variance analysis).

Significant differences were measured amoung the four wheat treatments. Kirac 66 generally germinated first regardless of the osmotic water potential and temperature while Bezostaya, consistantly germinated last. The differences in germination times were less than 1 day except at 5°C. At 5°C, however, Kirac 66 required 2 days less time to germinate than did Bezostaya.

The protein content of the Yamhill variety did not influence germination. Seeds with 16.50 percent protein did not germinate any faster than the seeds having 7.75 percent protein. These results suggest that manipulating seed protein content through fertilizing or cultural practices has limited potential for altering the time required for wheat to germinate.

Average D_{80} values for the varieties shows that a significant temperature by osmotic water potential response was obtained. Lowering either temperature or osmotic water potential significantly delayed germination, but lowering both resulted in a greater delay. When the temperature was 20°C, lowering the osmotic water potential from -2 to -17 bars increased D_{80} from 2.3 to 6.5 days. However, when the temperature was 5°C, lowering the osmotic water potential

TABLE 1. Effects of osmotic potential and temperature on the observed number of days required to attain 80 percent germination(D_{80}) for Yamhill high and low protein, Bezostaya, and Kirac 66 wheat.

Temperature °C	Varietal Treatments	Osmotic Potential, Bars -2	-7	-12	-17
		days to D_{80}			
5	Yamhill, high protein	12.8	15.2	18.1	20.0
	Yamhill, low protein	12.7	15.1	18.0	19.3
	Bezostaya	13.3	15.2	20.2	20.6
	Kirac 66	11.7	13.6	18.0	17.7
	Average	12.7	14.8	18.6	19.4
10	Yamhill, high protein	6.5	7.6	9.3	11.5
	Yamhill, low protein	6.5	7.7	11.5	11.2
	Bezostaya	6.6	7.8	11.3	12.3
	Kirac 66	6.5	7.8	9.5	11.5
	Average	6.5	7.7	10.4	11.6
15	Yamhill, high protein	3.0	4.3	7.2	10.3
	Yamhill, low protein	2.7	4.5	6.3	10.8
	Bezostaya	3.2	4.5	7.1	9.0
	Kirac 66	2.8	4.2	5.8	9.1
	Average	2.9	4.4	6.6	9.8
20	Yamhill, high protein	2.3	4.0	5.3	7.1
	Yamhill, low protein	2.1	3.8	6.2	6.3
	Bezostaya	2.2	4.0	5.6	7.0
	Kirac 66	2.6	3.2	4.8	5.7
	Average	2.3	3.7	5.5	6.5

Tukey's $w_{(0.01)}$ = 0.5 (for same level of temperature)

Tukey's $w_{(0.01)}$ = 1.7 (for same or different levels of moisture) from -2 to -17 bars increased D_{80} from 12.6 to 19.4 days. This indicates that the influence of osmotic water potential is not as pronounced at warmer temperatures as it is at colder temperatures. However, lowering the temperature to 10°C did not affect germination nearly as did lowering to 5°C.

Since the response of the four varietial treatments to osmotic water potential and temperature variables were similar, a composite model was developed to predict D_{80} as a function of temperature (T) and osmotic water potential (OWP) (see Appendix, Table 11, for variance analysis). The equation is:

$$\ln (D_{80}) = 2.01094 - 0.2273 (T) - 0.1385 (OWP) + 0.01967 (T \times OWP). \quad (1)$$

Figure 1 shows the D_{80} values as predicted by the model agree well with the observed D_{80} values over the temperature and osmotic potential ranges studied. The equation shows germination is influenced more by temperature than by osmotic potential because the temperature coefficient is larger (more than 1.5 times) than the osmotic potential coefficient. This is depicted best by response surface shown in Figure 2 which was generated using the regression equation.

LABORATORY EMERGENCE EXPERIMENT

The number of days required to obtain 50 percent seedling emergence (D_{50}) as influenced by temperature and soil water potential for the three wheat varieties is given in Tables 2 and 3 for Woodburn and Bashaw soils, respectively. For most temperatures

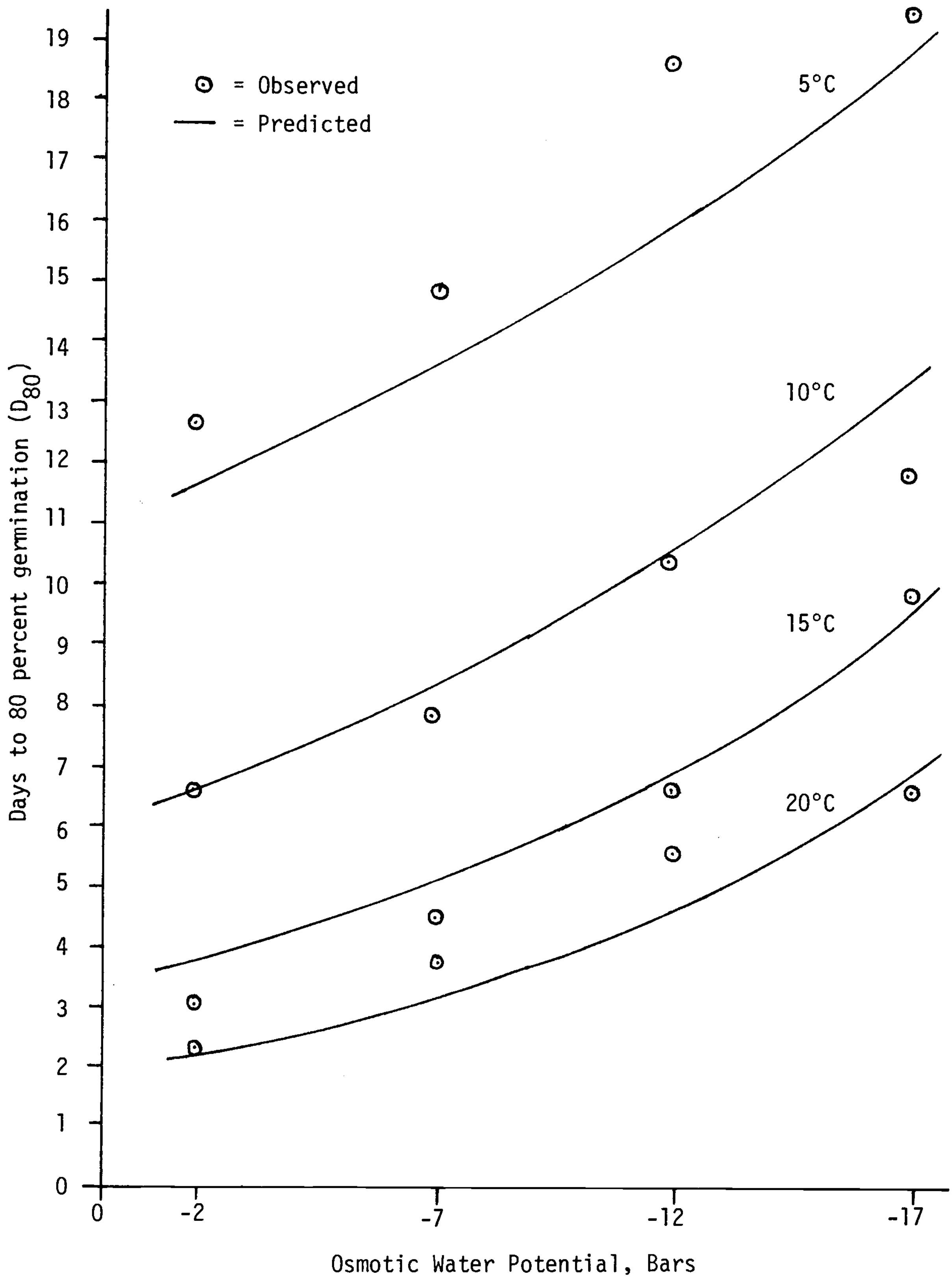

FIGURE 1. Predicted number of days required to obtain 80 percent germination (D_{80}) as influenced by osmotic water potential and temperature.

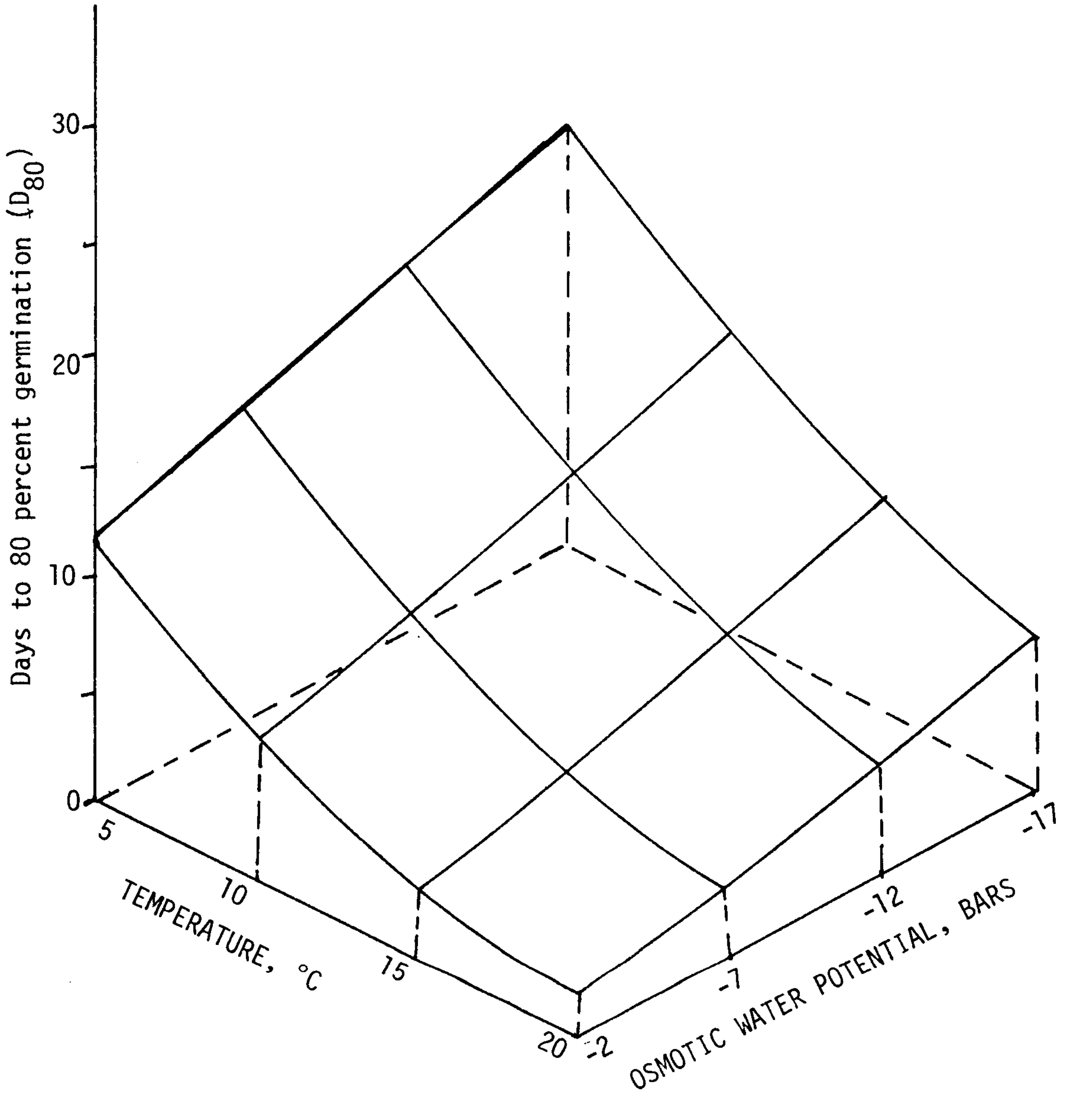

FIGURE 2. Effect of osmotic potential and temperature on number of days required to obtain 80 percent germination (D_{80}) as predicted by equation (1).

TABLE 2. Effect of soil water potential and temperature on the observed number of days required to obtain 50 percent seedling emergence (D_{50}) for Yamhill (high and low protein), Bezostaya, and Kirac 66 varieties grown in Woodburn soil.

Temperature °C	Varietal Treatments	Soil Water Potential, Bars -2	-7	-12	-17
		---------- days to D_{50}			-------------
5	Yamhill, high protein	21.1	23.5	27.1	32.1
	Yamhill, low protein	21.7	24.9	26.4	32.3
	Bezostaya	23.1	25.8	27.8	32.0
	Kirac 66	21.9	25.0	27.0	33.8
	Average	21.9	24.7	27.0	32.5
10	Yamhill, high protein	10.9	12.2	14.4	20.4
	Yamhill, low protein	10.3	12.0	13.9	20.1
	Bezostaya	10.6	12.6	15.2	21.2
	Kirac 66	10.6	12.6	15.3	20.6
	Average	10.6	12.3	14.7	20.6
15	Yamhill, high protein	6.4	7.0	8.0	10.0
	Yamhill, low protein	6.1	7.1	8.1	9.3
	Bezostaya	6.7	7.6	7.8	11.8
	Kirac 66	6.4	7.2	7.8	9.5
	Average	6.4	7.2	7.9	10.1
20	Yamhill, high protein	4.0	4.6	5.4	9.7
	Yamhill, low protein	3.9	4.3	5.0	9.7
	Bezostaya	4.5	4.8	6.5	10.3
	Kirac 66	4.0	4.6	6.2	9.5
	Average	4.1	4.5	5.8	9.7

TABLE 3. Effect of soil water potential and temperature on the observed number of days required to obtain 50 percent seedling emergence (D_{50}) for Yamhill high and low protein wheat grown in Bashaw soil.

Temperature °C	Varietal Treatment	Soil Water Potential, Bars -2	-7	-12
		days to D_{50}		
5	Yamhill, high protein	20.8	24.6	29.3
	Yamhill, low protein	21.2	23.9	28.3
	Average	21.0	24.0	28.8
10	Yamhill, high protein	10.9	17.5	21.9
	Yamhill, low protein	9.3	15.5	20.7
	Average	10.2	16.5	21.3
15	Yamhill, high protein	6.8	11.2	13.0
	Yamhill, low protein	6.2	10.4	12.5
	Average	6.5	10.8	12.7
20	Yamhill, high protein	4.1	5.8	7.3
	Yamhill, low protein	4.2	6.0	7.2
	Average	4.1	5.9	7.2

and soil water potentials the differences in seedling emergence among varietal treatments were less than two days. Kirac 66 tended to germinate fastest while Bezostaya was slowest.

Emergence in Bashaw soil was greatly influenced by temperature and soil water potential. Decreasing the temperature and soil water potential, significantly increased D_{50}. When soil water potential was held at -2 bars, lowering the temperature from 20 to 5°C increased D_{50} from 4.1 to 21.0 days. However, when the soil water potential was -17 bars, the change of 20 to 5°C increased D_{50} from 10.3 to 31.2 days.

Similar effects on D_{50} were observed between these temperature and soil water potentials in Woodburn soil. At a temperature of 20°C, lowering the soil water potential from -2 to -17 bars increased D_{50} from 4.1 to 9.6 days. However, when the temperature was 5°C the change of -2 to -17 bars in soil water potential increased D_{50} from 21.9 to 32.5.

These results show that temperature influenced emergence more than soil water potential. Also, there is a significant interaction between temperature and soil water potential.

The influence of temperature and soil water potential on the number of days required to obtain 80 percent seedling emergence (D_{80}) for the four varietal treatments for Woodburn soil is given in Table 4. The response of the four varietal treatments was similar at all temperature and soil water potential combinations.

TABLE 4. Effect of soil water potential and temperature on the number of days required to obtain 80 percent emergence (D_{80}) of Yamhill high and low protein, Bezostaya, and Kirac wheat grown in Woodburn soil.

Temperature °C	Varietal Treatments	Soil Water Potential, Bars -2	-7	-12
		days to D_{80}		
5	Yamhill, high protein	22.5	25.4	28.3
	Yamhill, low protein	22.9	25.4	28.3
	Bezostaya	24.9	28.3	29.3
	Kirac 66	23.6	26.1	29.1
	Average	23.5	26.3	28.8
10	Yamhill, high protein	11.3	13.1	16.0
	Yamhill, low protein	10.9	13.0	15.0
	Bezostaya	11.7	13.9	16.8
	Kirac 66	11.4	13.4	16.8
	Average	11.3	13.4	16.2
15	Yamhill, high protein	7.3	7.8	9.2
	Yamhill, low protein	7.3	8.0	8.8
	Bezostaya	7.5	8.4	8.7
	Kirac 66	7.4	7.7	8.5
	Average	7.4	7.9	8.7
20	Yamhill, high protein	4.3	4.9	6.3
	Yamhill, low protein	4.1	4.8	6.4
	Bezostaya	5.0	5.3	7.8
	Kirac 66	4.6	5.4	6.3
	Average	4.5	5.1	6.8

When the averages of the four varietal treatments are examined it is evident that decreasing the temperature and soil water potential significantly delayed emergence. When the temperature was 20°C, lowering the soil water potential from -2 to -12 bars increased D_{80} from 4.5 to 6.8 days. However, when the temperature was 5°C the change of soil water potential from -2 to -12 bars increased D_{80} from 23.5 to 28.8 days. This, again, indicates that temperature influenced seedling emergence more than did soil water potential.

The effect of soil texture on seedling emergence can be seed by comparing average D_{50} values for the two Yamhill seed treatments (Table 5). When the soil water potential was -2 bars or soil temperature was 5°C there was no difference in D_{50} for the two soils. However, at higher temperatures or lower potentials, D_{50} was greater for the Bashaw soil. For temperatures of 10 and 15°C over the range of -7 to -12 bars soil water potentials, D_{50} was 4 to 7 days greater for the Bashaw soil.

Since the data showed the response of the four seed treatments was similar in both soils over the ranges of soil water potential and temperature included in the study, composite equations were developed by linear regression analysis to predict the time required to obtain 50 and 80 percent emergence (D_{50} and D_{80}, respectively) for the Woodburn soil and 50 percent emergence (D_{50}) for the Bashaw soil as a function of soil water potential (SWP, Bars) and temperature (T, °C). The equations and R^2 values are:

TABLE 5. Effect of soil water potential and temperature on the observed number of days required to obtain 50 percent emergence (D_{50}) for Yamhill high and low protein wheat in Bashaw and Woodburn soils.

Temperature °C	Soil	Soil Water Potential, Bars -2	-7	-12
		------ days to D_{50}	---------	
5	Woodburn	21.4	24.2	26.7
	Bashaw	21.0	24.0	28.9
10	Woodburn	10.6	12.1	14.1
	Bashaw	10.1	16.6	21.4
15	Woodburn	6.2	7.0	8.0
	Bashaw	6.5	10.8	12.8
20	Woodburn	3.9	4.5	5.2
	Bashaw	4.1	5.9	7.3

$$\ln (D_{50}) = 3.757 - 0.03849 \text{ (SWP)} - 0.1837 \text{ (T)} + 0.003131 (T^2) \qquad R^2 = 0.92 \qquad (2)$$

for 50 percent emergence in Woodburn soil,

$$\ln (D_{80}) = 3.838 - 0.02691 \text{ (SWP)} - 0.1662 \text{ (T)} + 0.00237 (T^2) \qquad R^2\ 0.94 \qquad (3)$$

for 80 percent emergence in Woodburn soil and

$$\ln (D_{50}) = 3.327 - 0.05669 \text{ (SWP)} - 0.09884 \text{ (T)} \qquad R^2 = .91 \qquad (4)$$

for 50 percent emergence in Bashaw soil. The variance analysis for the three equations and predicted values are given in Appendix, Tables 12, 13 and 14. The predictive equations for D_{80} in Woodburn soil and D_{50} in Bashaw soil are valid only for the -2 to -12 bars range of soil water potential because an insufficient number of emergence observations were available to accurately estimate the time required at -17 bars. It should be noted that the predictive equations may underestimate the time required for seedling emergence where both temperature and soil water potential are low since fewer observations were included in the mean values used to develop the predictive equations. Because of the large number of observations which each mean represented, this underestimation should be minimal.

Since the values and ranges of the temperature and soil water potential variables are of similar magnitude, the coefficients of the variables clearly indicate that seedlings emergence is inhibited more by temperature than by soil water potential. Figures 3, 4, and 5 which show the predicted number of days to obtain 50 and 80 percent emergence

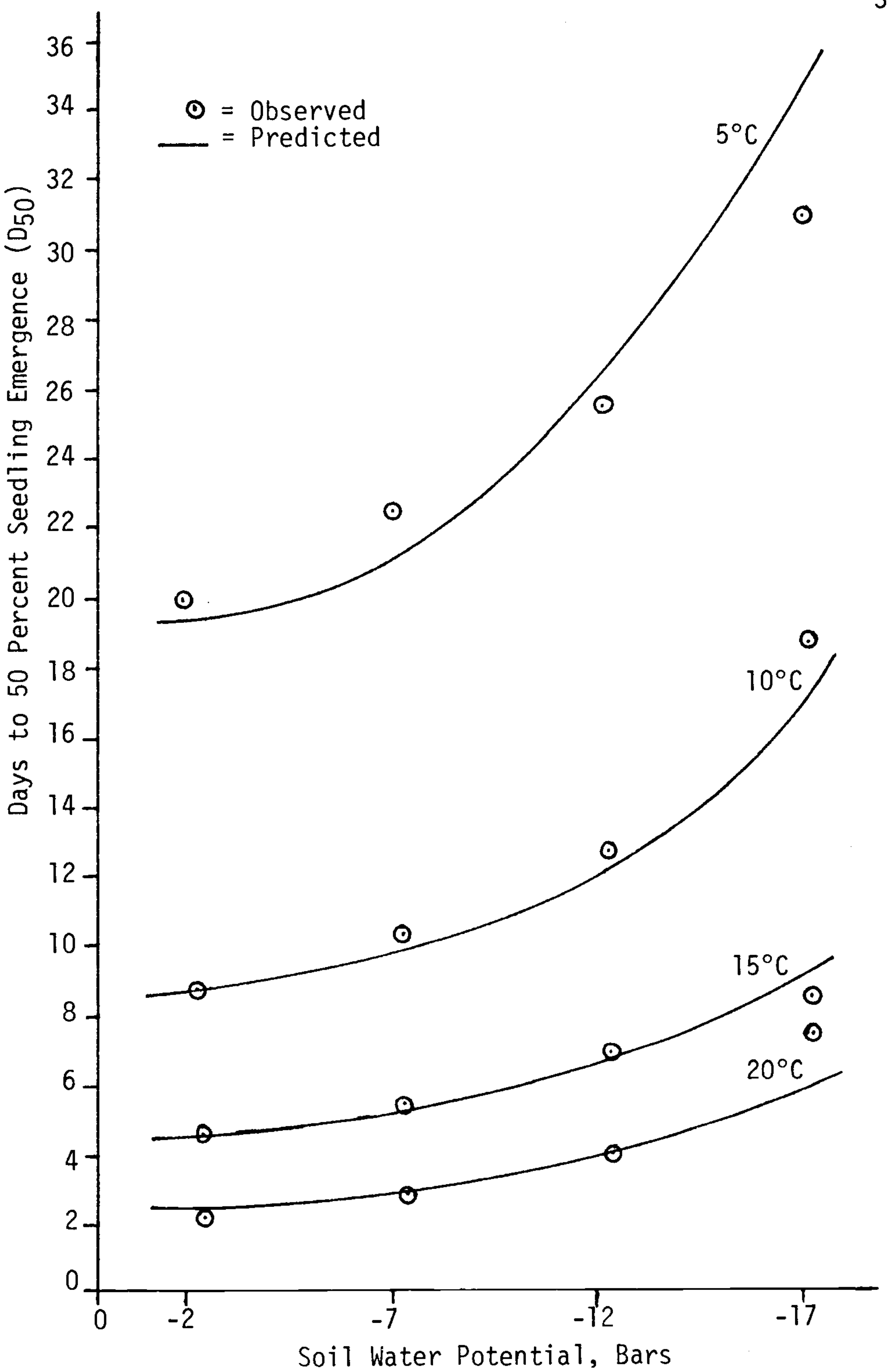

FIGURE 3. Predicted number of days required to obtain 50 percent emergence (D_{50}) as influenced by soil water potential and temperature for Woodburn soil.

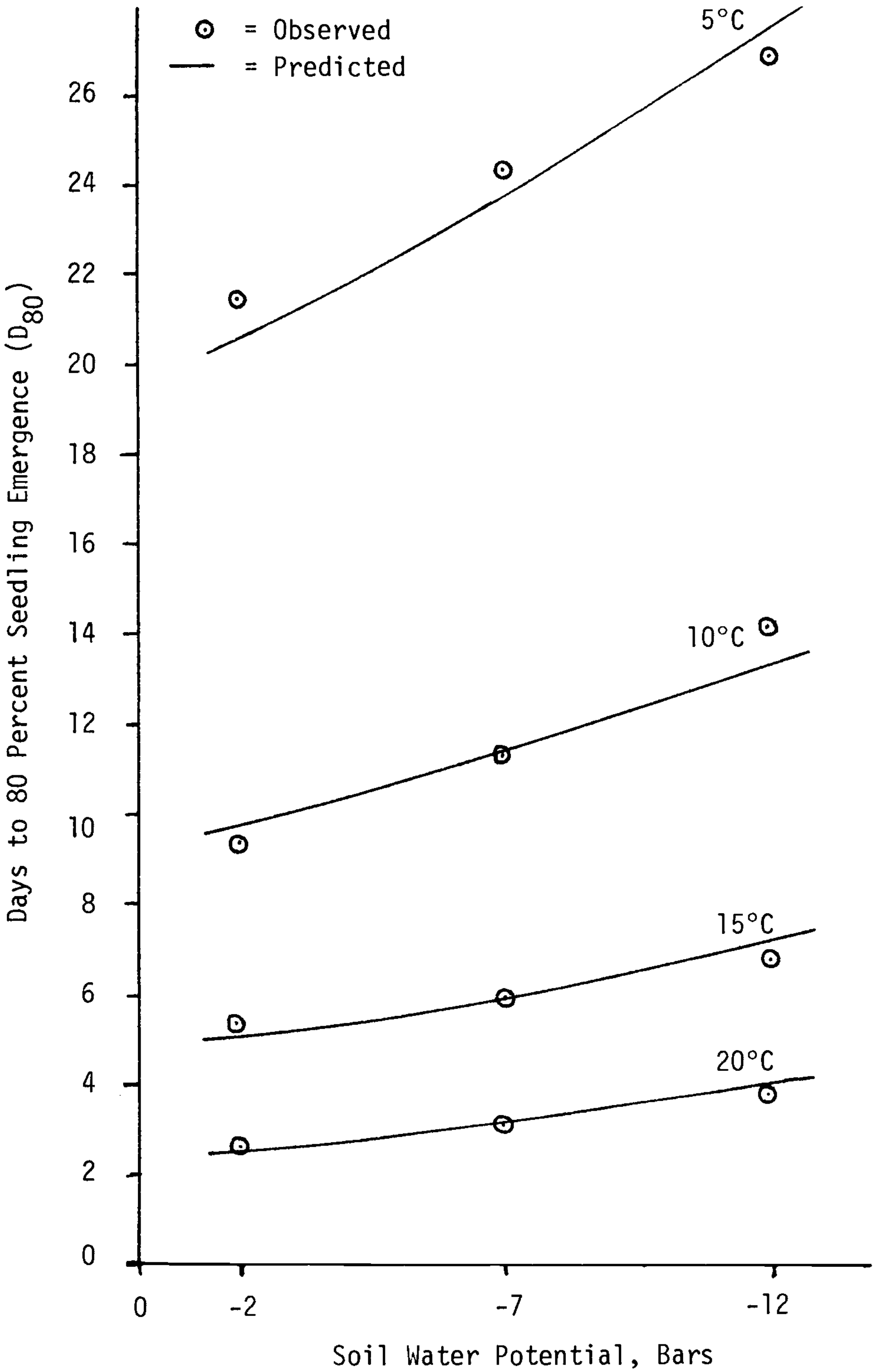

FIGURE 4. Predicted number of days required to obtain 80 percent emergence (D_{80}) as influenced by soil water potential and temperature for Woodburn soil.

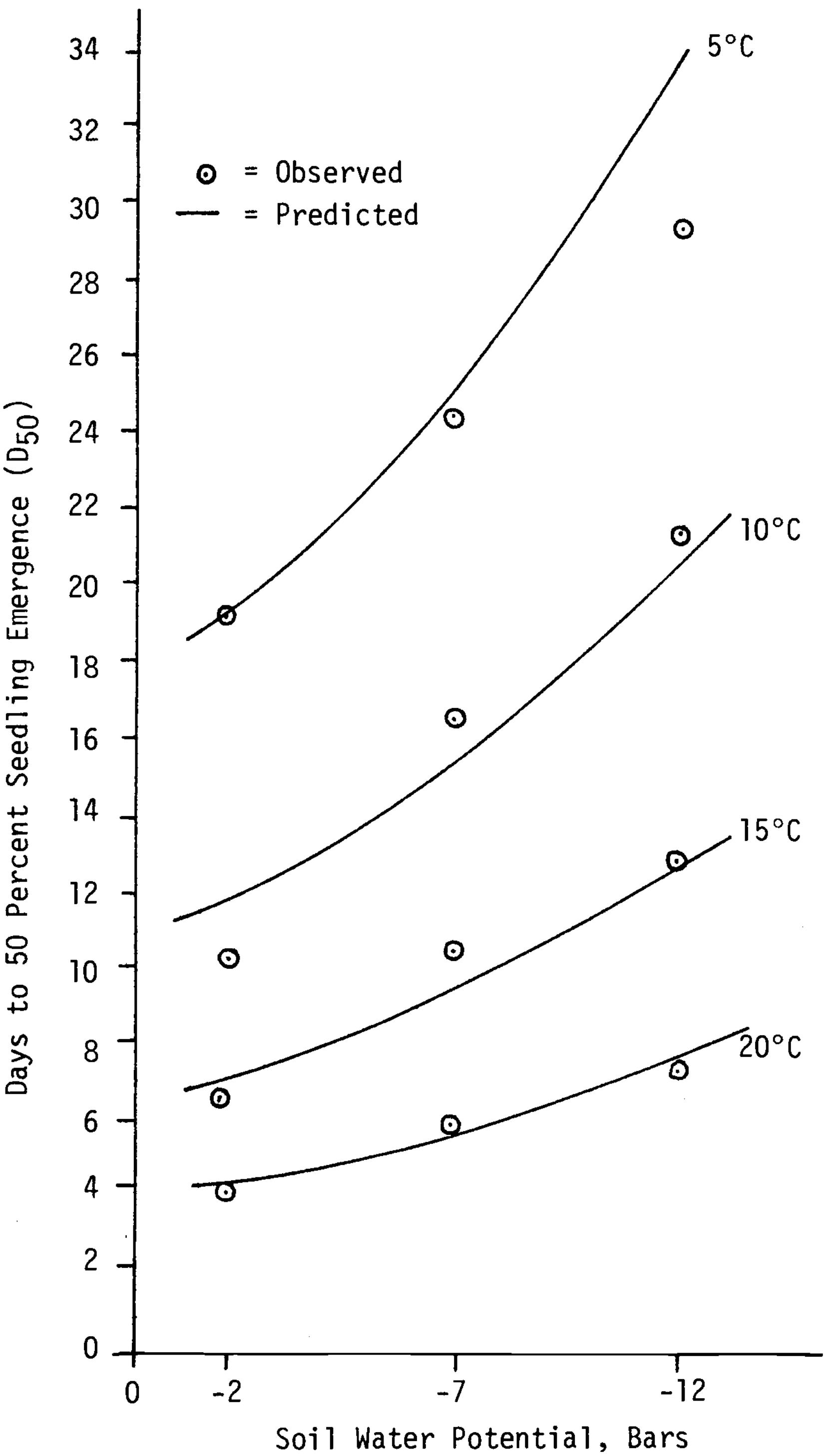

FIGURE 5. Predicted number of days required to obtain 50 percent emergence (D_{50}) as influenced by soil water potential and temperature for Bashaw soil.

in Woodburn soil and 50 percent emergence in Bashaw soil. These figures show that the predictive equations agree with the means of the observed values. The standard deviation of the observed number of days is given in Table 6 to give an indication of the variation which occurred in the experiment.

Three-dimensional response surfaces showing the effect of temperature and soil water potential on the number of days required for 50 and 80 percent seedling emergence (D_{50} and D_{80}, respectively) in Woodburn soil and 50 percent seedling emergence (D_{50}) in Bashaw soil are presented in Figures 6, 7, and 8. These clearly show seedling emergence is inhibited more by low temperature than by low soil water potential.

BULK DENSITY EXPERIMENT

Seedling emergence was significantly different for the Bashaw silty clay and Woodburn silt loam soils at similar soil moisture potentials and bulk densities (Figures 9 and 10). Days required for 80 percent seedling emergence (D_{80}) for both soils and the variance analysis are given in Appendix, Tables 15, 16 and 17, respectively.

For Woodburn soil, increasing the bulk density from 0.90 to 1.20 gm/cm^3 did not influence seedling emergence. As the bulk density increased to 1.30 gm/cm^3 emergence was delayed slightly. However, a bulk density of 1.40 gm/cm^3 approximately doubled the time needed for emergence. At -10 bars, D_{80} was 6.6 and 12.1 days

TABLE 6. The standard deviations of the observed number of days to 50 and 80 percent seedling emergence in Woodburn soil and 50 percent seedling emergence in Bashaw soils.

Soil and Emergence Percentage	Temperature °C	Soil Water Potentials, Bars -2	-7	-12	-17
		------------- days		-------------	
Woodburn, 50 percent	5	1.6	3.4	3.1	2.3
	10	0.9	1.1	1.5	5.6
	15	0.9	0.6	1.7	1.8
	20	0.9	1.0	1.9	2.9
Woodburn, 80 percent	5	2.1	3.6	3.7	---
	10	0.9	1.3	2.1	---
	15	0.7	0.5	1.5	---
	20	0.8	1.2	1.7	---
Bashaw, 50 percent	5	1.1	1.1	5.6	---
	10	1.1	3.5	4.1	---
	15	0.6	1.8	2.2	---
	20	0.8	1.7	1.7	---

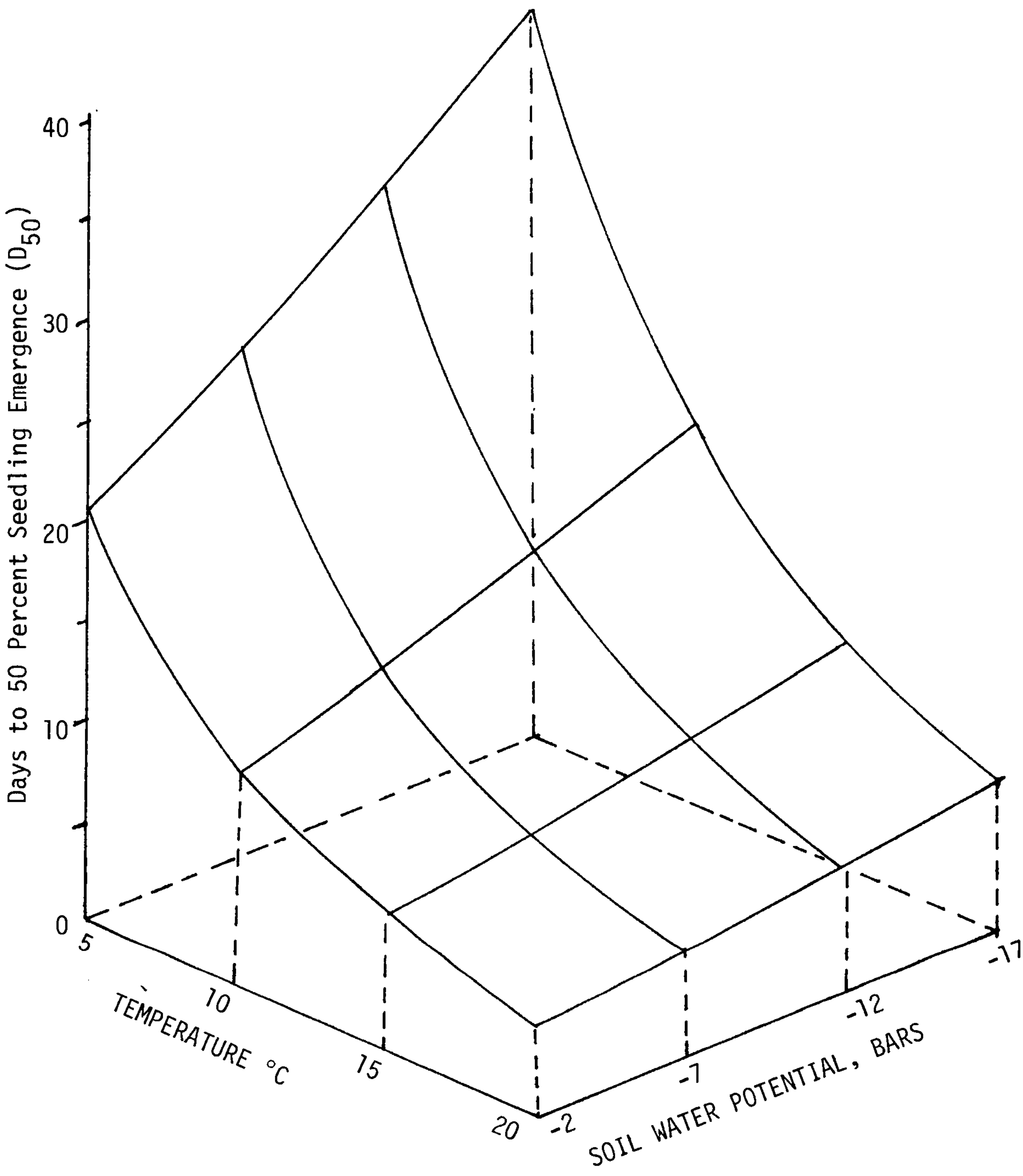

FIGURE 6. Effect of soil water potential and temperature on number of days required to obtain 50 percent seedling emergence (D_{50}) in Woodburn soil as predicted by equation (2).

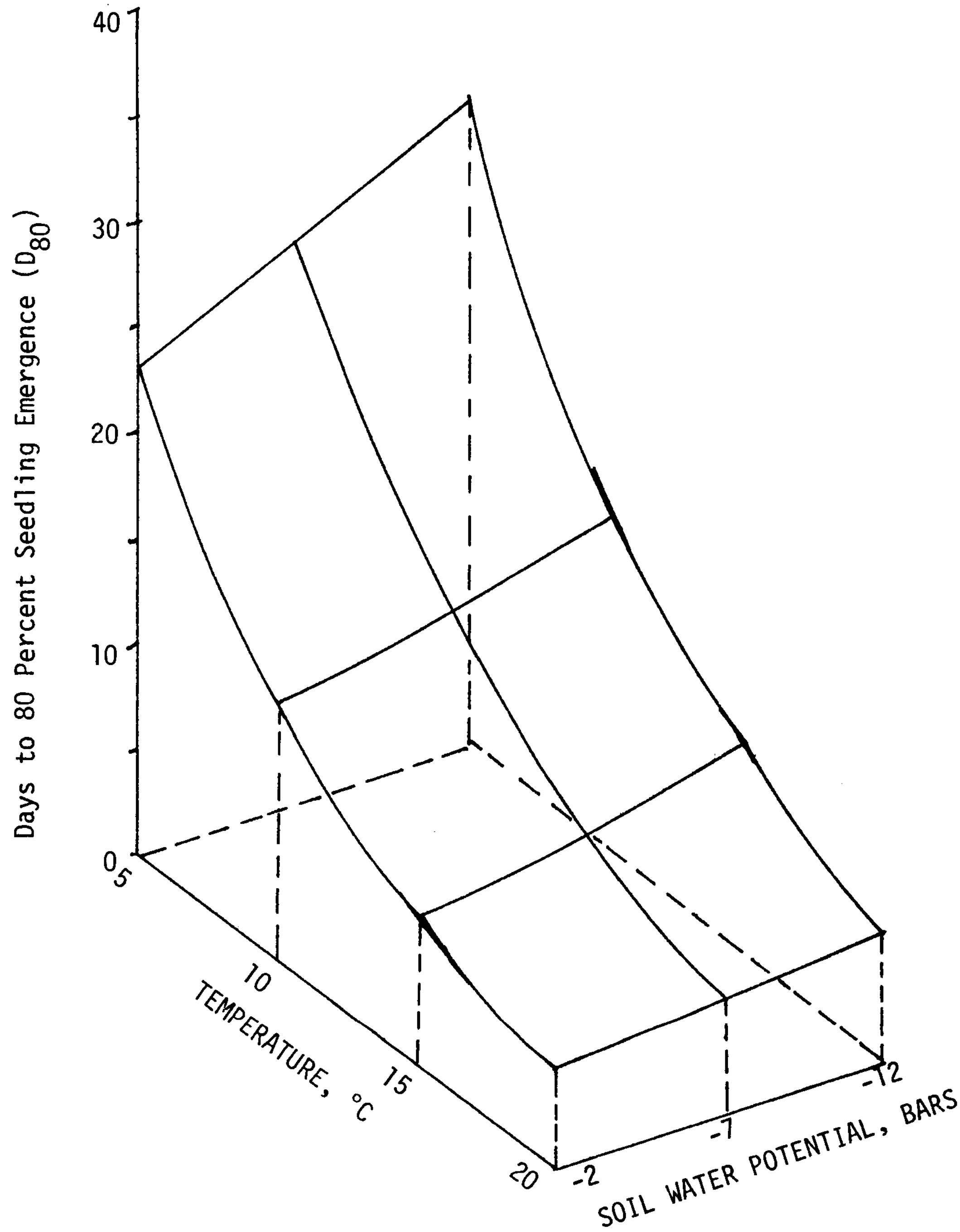

FIGURE 7. Effects of soil water potential and temperature on number of days required to obtain 80 percent seedling emergence (D_{80}) in Woodburn soil as predicted by equation (3).

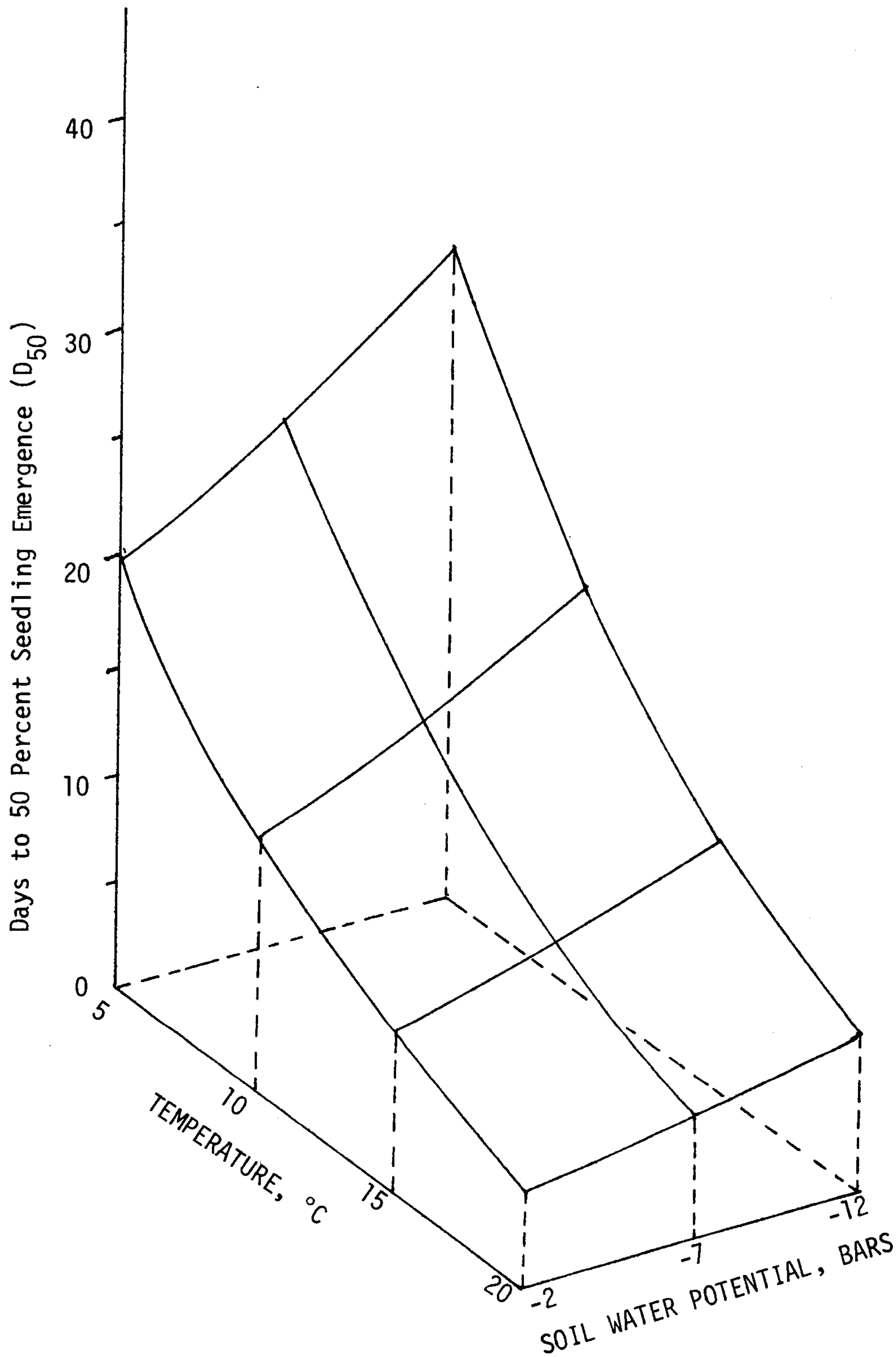

FIGURE 8. Effect of soil water potential and temperature on number of days required to obtain 50 percent seedling emergence (D_{50}) in Bashaw soil as predicted by equation (4).

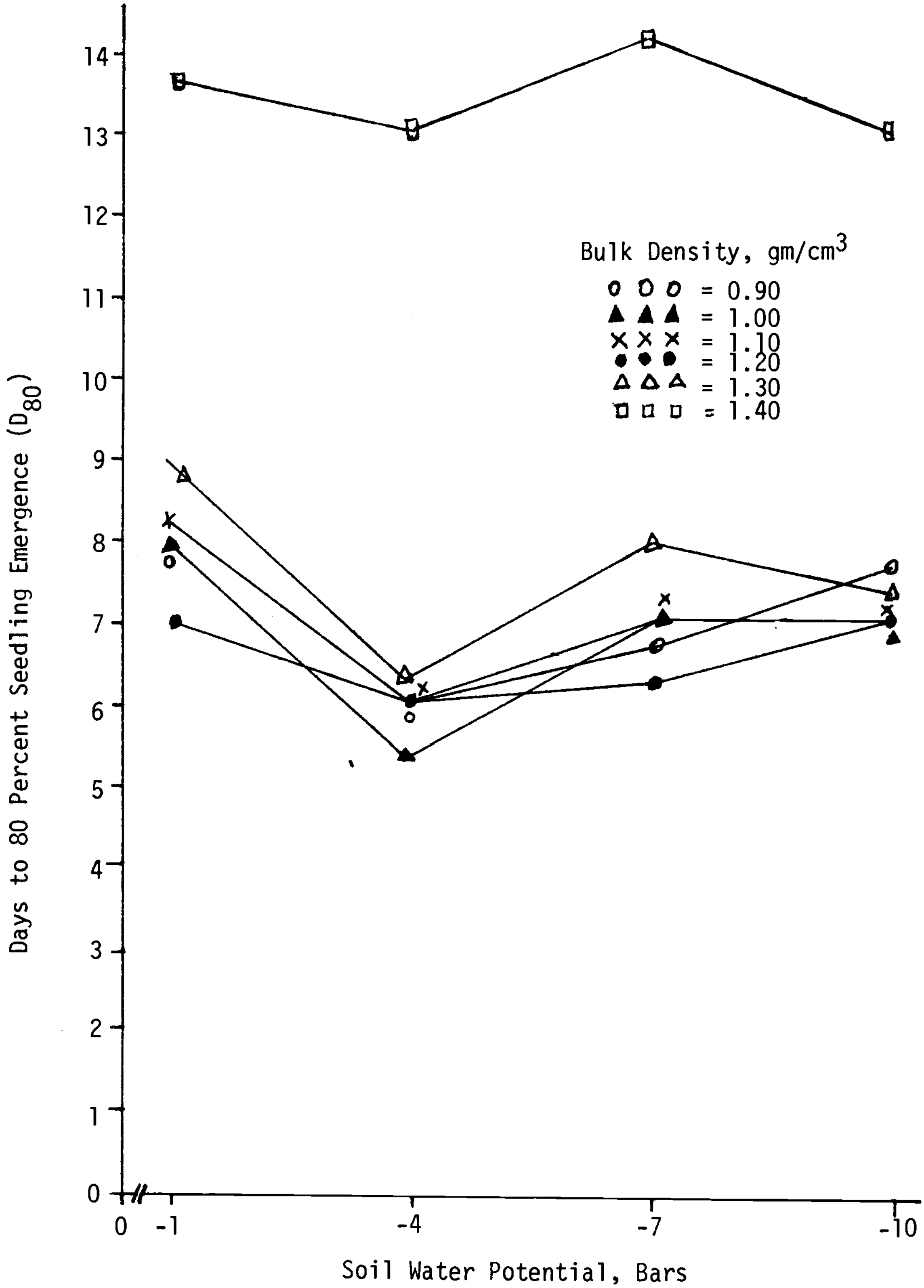

FIGURE 9. Influence of soil water potential and bulk density on number of days required to obtain 80 percent seedling emergence (D_{80}) in Woodburn silt loam.

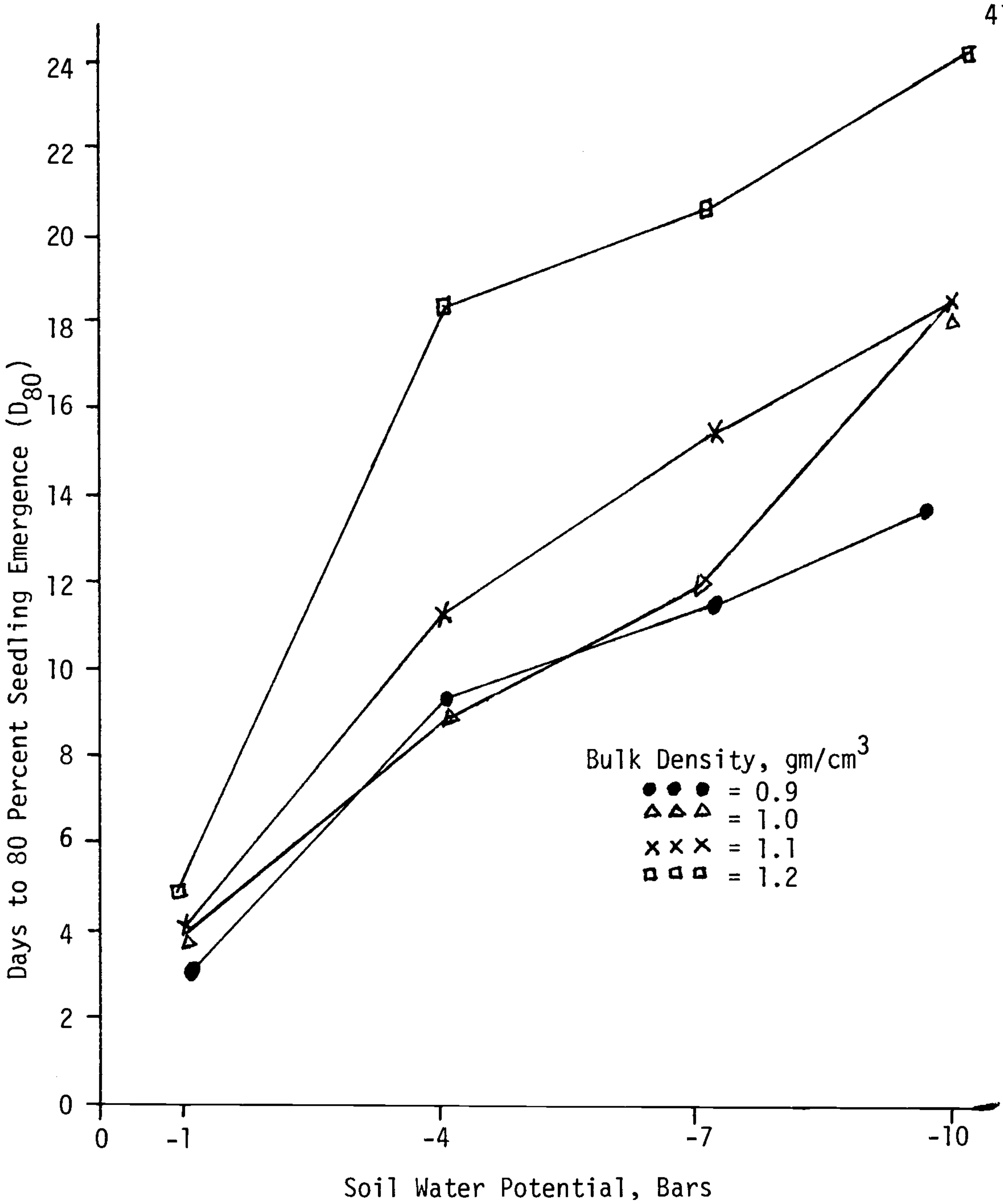

FIGURE 10. Influence of soil water potential and bulk density on days required to obtain 80 percent seedling emergence (D_{80}) in Bashaw silty clay soil.

for bulk densities of 1.30 and 1.40 gm/cm^3, respectively.

Soil water potential influenced seedling emergence in the Woodburn soil. For bulk densities less than 1.30 gm/cm^3, increasing the soil water potential from -4 to -1 bars increased D_{80} by 1 to 3 days. No explanation can be given for this response. However, as soil water potential was reduced from -4 to -10 bars, D_{80} tended to increase as in the laboratory emergence experiment. For a bulk density of 1.40 gm/cm^3, moisture did not influence D_{80}. These data show that in Woodburn soil, bulk densities greater than 1.20 gm/cm^3 affect seedling emergence more than soil water potential in the range of -1 to -10 bars.

The bulk density by soil water potential interaction was nonsignificant for the Woodburn soil. Although bulk density had a great influence on emergence, this influence was not affected by different soil water potentials.

For Bashaw soil, D_{80} was the same for 0.9 and 1.0 gm/cm^3 bulk densities at similar soil water potential levels. However, increasing the bulk density to 1.10 and 1.20 gm/cm^3 substantially increased D_{80} at similar soil water potentials. Eighty percent emergence was not even attained in 35 days with a 1.30 gm/cm^3 bulk density except at -1 bar.

Soil water potential significantly influenced emergence in the Bashaw soil. For all bulk densities, D_{80} increased as the soil water potential decreased. Decreasing the water potential from -1 to -10 bars increased D_{80} about 3 fold - from 5 to 16 days at 0.9 gm/cm^3

bulk density. Similar responses were observed at higher bulk densities.

The interaction between bulk density and soil water potential was also significant. As the water potential of the soil decreased, raising bulk density increased D_{80} at an increasing rate. At -1 bar soil water potential, changing the bulk density from 0.90 to 1.30 gm/cm^3 increased D_{80} by 2 days, while at -10 bars, the same change in bulk density increased D_{80} by 10 days. These data show that seedling emergence is inhibited more by high bulk density in heavy textured soils than in medium textured soils.

Field Emergence Experiment

The average number of days required to obtain 80 percent seedling emergence (D_{80}) for the four seed treatments at the three seeding dates is given in Table 7. Also given are average soil water potentials during experiments and daily mean seed zone temperatures. The variance analysis of the field experiments is given in Appendix, Table 18.

There was a significant difference among the four seed treatments in regards to time required to obtain 80 percent seedling emergence. Yamhill high and low protein emerged first while Bezostaya emerged last. Since there was no difference in the emergence time of Yamhill high and low protein wheat, seed protein did not influence seedling emergence.

Soil water potential and seed-zone temperature significantly influenced field emergence of wheat. As the soil water potential

TABLE 7. Observed number of days required to obtain 80 percent seedling emergence (D_{80}) of four varietal treatments at three seeding dates.

Soil and Seeding Dates	Soil Water Potential (Bars)	Mean Daily Temp. (°C)	Varietal Treatment	Days For emergence 80 percent
25-4-1974 Woodburn	-2	15.3	Yamhill high protein	8.3
			Yamhill low protein	8.5
			Bezostaya	9.0
			Kirac 66	8.9
			Average	8.6
27-7-1974 Woodburn	-7	17.6	Yamhill high protein	17.0
			Yamhill low protein	17.2
			Bezostaya	18.6
			Kirac 66	18.3
			Average	17.8
1-9-1974 Madras	-2	11.6	Yamhill high protein	14.5
			Yamhill low protein	14.8
			Bezostaya	15.2*
			Kirac 66	14.9
			Average	14.8

* 75 percent seedling emergence

Tukey's $w_{(0.01)}$ = 1.5 for varietal treatments within seeding dates

Tukey's $w_{(0.01)}$ = 3.1 for seeding dates decreased from -2 to -7 bars (at nearly the same seed-zone temperatures) D_{80} increased almost two fold - from 8.6 to 17.8 days. However, when soil water potential was held constant (-2 bars) but mean daily seed zone temperature was lowered from 15.3°C to 11.6°C, D_{80} increased from 8.6 to 14.8.

V. DISCUSSION

Establishing a winter wheat crop in arid regions having winter rainfall is often difficult because the crop may be seeded in dry soil prior to the start of winter rainfall. This is especially true for areas where annual cropping is practiced since the previous crop has extracted all of plant available moisture. A similar condition often occurs when a fallow system is used to store moisture because the moisture near the soil surface is lost through evaporation during the dry, hot summer months.

Every year as dryland wheat growers prepare to seed wheat the questions of whether there is sufficient moisture present in the soil to germinate the seed and the time required for a wheat crop to emerge for a given level of soil moisture and soil temperature must be answered.

Data collected in the solution experiment where three varieties of wheat were germinated in Carbowax 6000 solutions with water potentials ranging from -2 to -17 bars and temperatures of 5 to 20°C show the time required for germination is significantly increased by low water potential and temperature. From the regression model which was developed, it's evident that temperature has a greater effect on the length of time required for germination than does water potential. Similar results have been observed for wheat by Lindstrom (1973). There also was significant interaction between osmotic potential and temperature. By examining these two factors independently one can conclude that the low osmotic potential slows the rate of absorption and increases the water stress within the seeds and hence delays germination. Low temperature slows the germination as well as other physiological activities because of a reduction in enzyme activity and decrease in water diffusivity through the seed coat.

There were significant differences among the three wheat varieties in regards to time required for germination. Kirac 66 germinated significantly faster than Yamhill or Bezostaya varieties. Bezostaya generally germinated the slowest. Seed protein content had no effect on the Yamhill wheat. Germination times were identical for Yamhill wheat containing 16.50 and 7.75 percent protein. This suggests that, at least, for the Yamhill variety, manipulating the protein content by increasing rates of nitrogen fertilization will not effect the time required for germination. These data are in contrast to the data of Said Kamal (1953), who reported that for winter wheat high seed protein hastened germination. The results do agree with general field observations made in Oregon that Kirac 66 does germinate faster than most varieties under adverse soil and temperature conditions (Kronstad, 1974). Kirac 66 could be used as a source of genetic material for improving germination of wheat under adverse temperature and soil moisture conditions.

The laboratory emergence experiment evaluating the effect of soil water potential and temperature on the time required for emergence of three wheat varieties in Bashaw silty clay and Woodburn silt loam soils, showed that time required for seedling emergence is significantly increased by low soil water potential and soil temperature. Soil temperature was found to have a greater influence on seedling emergence than did soil water potential. Similar results have been reported by Lindstrom (1973). There was also a significant interaction between soil water potential and temperature. This indicates that the late seedings in dryland farming areas when soil temperature is quite low should be avoided.

The data collected in this study and most others similar to it clearly show wheat emergence is inhibited more by low temperature than low soil water potential. However, only Lindstrom (1973) was able to show which combinations of temperature and soil water potential would result in seedling emergence in a given time. To better evaluate the combinations which would result in emergence within a specified number of days, iso-seedling emergence time curves were generated with the composite predictive equations obtained from the laboratory experiment. Iso-seedling emergence curves of 5, 10, 15, 20, 25 and 30 days are presented in Figures 11 , 12 , and 13 for 80 and 50 percent emergence (D_{80} and D_{50}, respectively) in Woodburn soil and 50 percent emergence (D_{50}) in Bashaw soil, respectively. These curves clearly show trade-offs can be made in temperature and soil water potential. More opportunity exists for doing this in the Bashaw soil then in the Woodburn soil.

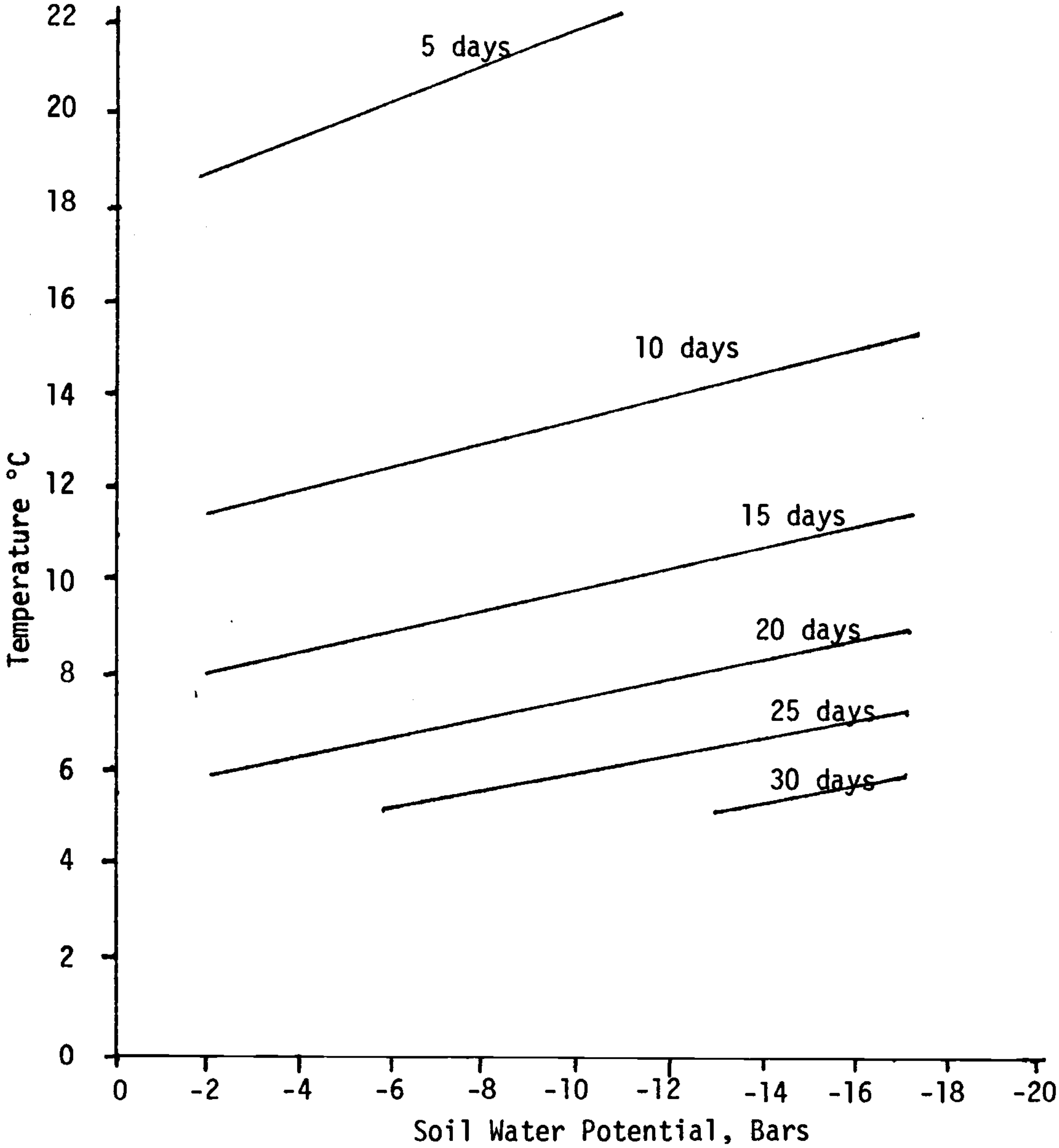

FIGURE 11. Iso-seedling emergence time in days as a function of soil water potential and temperature for 80 percent emergence in Woodburn soil.

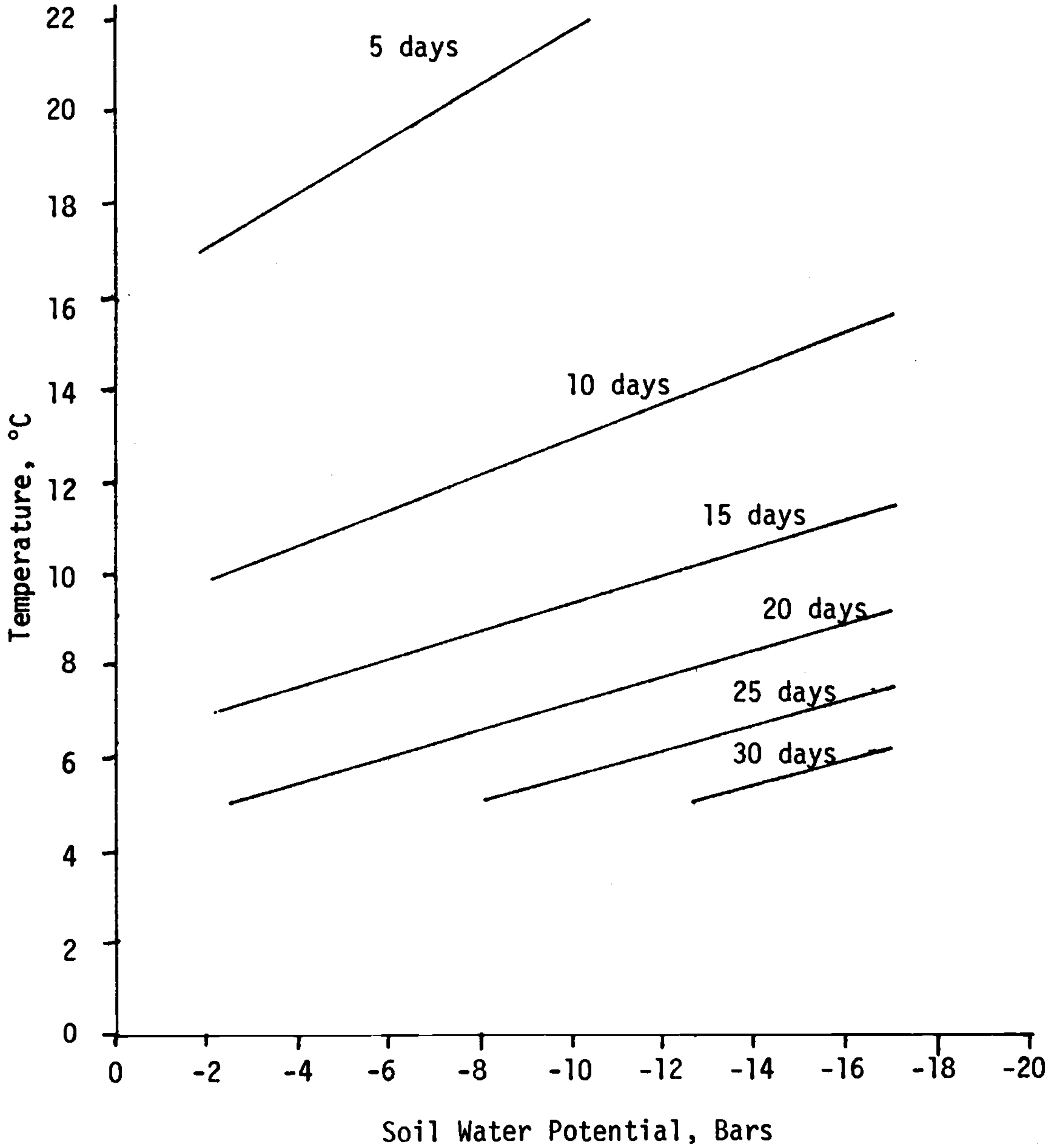

FIGURE 12. Iso-seedling emergence times in days as a function of soil water potential and temperature for 50 percent emergence in Woodburn soil.

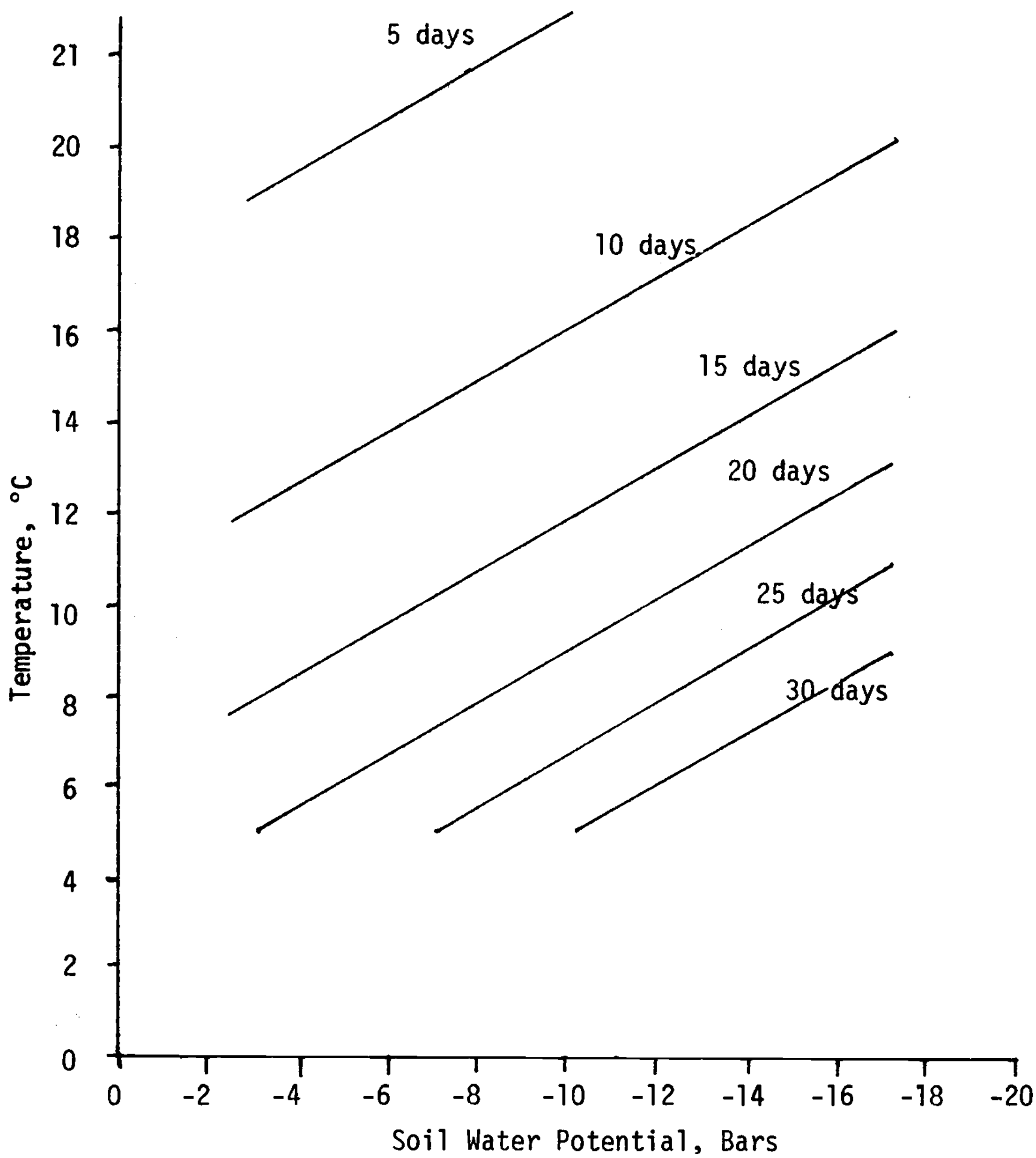

FIGURE 13. Iso-seedling emergence time in days as a function of soil water potential and temperature for 50 percent emergence in Bashaw soil.

Seedling emergence was also found to be affected by soil textures. Wheat emerged slightly faster in Woodburn silt loam than in Bashaw silty clay at the similar water potentials and temperatures. This is due to soil moisture content, hydraulic conductivity and wetted seed-soil area of contact differences between the two soil textures. As the soil moisture content is reduced the hydraulic conductivity decreases and slows the rate of water movement to the seed and hence delays germination and seedling emergence. Under unsaturated soil conditions the hydraulic conductivity of soils generally increases with clay content. From this one would predict faster seedling emergence in Bashaw silty clay than in Woodburn silt loam, however, the reverse was observed. This reversal is attributed to wetted seed-soil area of contact. This factor is important because any reduction in wetted seed-soil area of contact reduces the rate of water uptake by the seeds and consequently delays germination (Collis-George and Hector, 1966; Dasberg and Mendel, 1971; and Hadas and Russo, 1974). Because of the higher clay content, Bashaw silty clay soil former larger and stronger soil aggregates. Thus, when the wheat was seeded, there was a much smaller area of contact between the soil and seed as well as between the soil aggregates.

Matric potential has a strong effect in controlling the wetted seed-soil area of contact. Pawlowski and Shaykevich (1972) showed a decrease in germination rate of wheat as the matric potential decreased. However, when the matric component of water potential is absent, as in the solution germination experiments, the seeds have a very high wetted seed-soil area of contact, so the rate of water uptake by the seeds is not as limited.

Another soil condition which may limit germination and seedling emergence of wheat is bulk density. After a seed is planted, the soil should be compacted slightly on the seeds to assure sufficient seed-to-soil contact. However, excessive compaction can be detrimental because high soil-strength can inhibit shoot elongation and seedling emergence.

Laboratory experiments showed that for the Woodburn silt loam and Bashaw silty clay soils, seedling emergence was delayed by bulk densities greater than 1.20 and 1.10 gm/cm^3, respectively. Similar results have been reported by Hanks and Throp (1956, 1967) and Phillips and Kirkham (1962). These data show that more caution must be taken in compacting heavy textured soils which have large stable aggregates to improve seed-soil contact than medium textured soils which have a relatively weak structure.

The observed number of days required to obtain 80 percent seedling (D_{80}) in the field experiment in general agreed with the values predicted by the regression equation developed from the laboratory emergence experiments. The equation predicted that lowering the temperature from 15 to 11°C at a -2 bars soil water potential should increase D_{80} from approximately 7 to 12 days - nearly a two fold - about the same as was observed in the field. The fact that seeds required 2 days longer to emerge in the field could be attributed primarily to deeper seeding depth. However, when the soil water potential was lowered from -2 to -7 bars in the field, D_{80} increased from 8 to 17 days - a greater delay than what was observed in the laboratory. Many more field observations would be needed to fully evaluate the applicability and accuracy of the predictive equations in the field situations. It is likely that the laboratory regression equation will need modification if it is to be applicable to the field where some other factors may influence seedling emergence.

Varietal response to soil water potential and temperature variables in the field was similar to that measured in the laboratory. Bezostaya wheat tended to emerge the slowest, the same as observed in the laboratory. However, Yamhill tended to emerge faster in the field than did Kirac 66, the fastest emerger in the laboratory experiment. No reason can be given for why Yamhill emerged faster than Kiracc 66 in the field except, possibly that Yamhill wheat is less sensitive than Kirac 66 to fluctuating temperatures. As in the laboratory experiments, seed protein content did not significantly affect seedling emergence, however, Yamhill wheat having 16.50 percent protein did tend to emerge approximately 0.3 days sooner than Yamhill wheat having 7.75 percent protein.

VI. SUMMARY

Three laboratory and one field experiments were conducted to determine the influence of water potential (-2 to -17 bars), temperature (5 to 20°C), bulk density (0.90 to 1.40 gm/cm^3) and texture (Bashaw silty clay and Woodburn silt loam) on the germination and emergence of three varieties (Yamhill, Kirac 66 and Bezostaya) of winter wheat (Triticum Aestivum, L.). A solution experiment using osmotic solutions were used to determine the effect of low water potential and temperature on the germination of the three varieties. One laboratory experiment evaluated the effect of temperature, soil water potential and soil texture, as well as interactions, on the emergence of the three varieties of wheat. Three field seeding of the three wheat varieties were made in soils having different soil moisture and temperature combinations to determine if the laboratory data was applicable to the field condition. High and low protein samples of Yamhill wheat were included in laboratory and field experiments to evaluate the effect of seed-protein content on germination and emergence. A fourth laboratory experiment evaluated the effect and interaction of soil bulk density, texture, and water potential on the emergence of Kiracc 66 wheat.

The number of days required to obtain 50 and 80 percent germination in osmotic solutions and seedling emergence in soil was significantly increased by lowering either temperature or water potential. Lowering temperature delayed germination and emergence more than did lowering water potential, but even greater delays occurred by lowering both factors. There was a significant difference in germination and emergence times of Yamhill, Bezostaya and Kirac 66. Bezostaya consistantly emerged the slowest. Seed protein did not affect germination or seedling emergence of Yamhill variety.

Models were developed using linear regression analysis for the laboratory seedling emergence study to predict the number of days required to obtain 50 and 80 percent emergence (D_{50} and D_{80}, respectively) in Woodburn soil and 50 percent in Bashaw soil as a function of soil water potential (SWP, Bars) and soil temperature (T, °C). Since the three varieties respond similarly to the temperature and moisture variables the models were based upon average varietal response and are:

$$\ln (D_{50}) = 3.757 - 0.03849 \text{ (SWP)} - 0.1837 \text{ (T)} + 0.00313 \text{ (T}^2) \qquad R^2 = 0.92 \qquad (1)$$

for 50 percent emergence in Woodburn soil,

$$\ln (D_{80}) = 3.838 - 0.02691 \text{ (SWP)} - 0.1662 \text{ (T)} + 0.00237 \text{ (T}^2) \qquad R^2 = 0.94 \qquad (2)$$

for 80 percent emergence in Woodburn soil and

$$\ln (D_{50}) = 3.327 - 0.05669 - 0.5669 \text{ (SWP)} - 0.09884 \qquad R^2 = 0.91 \qquad (3)$$

for 50 percent emergence in Bashaw soil. The models were used to determine soil water potential and temperature combinations which permit emergence to occur within a specified time.

Soil texture and bulk density significantly affected the time required for seedling emergence. More days were required to obtain seedling emergence in Bahaw silty clay than in Woodburn silt loam soil at a given soil water potential primarily because of less seed-soil contact. In silt loam soil, emergence was delayed by bulk densities greater than 1.20 gm/cm^3. In silty clay soil, time required for emergence increased as bulk density increased over the range of 0.90 to 1.30 $gram/cm^3$. The bulk density by soil moisture interaction was much greater for the silty clay soil. Bulk density delayed emergence primarily because of increased soil strength.

Data collected from three seeding dates made in the field confirmed the findings made in the laboratory. The time required for emergence was similar for these three varieties and for the two levels of seed protein content. Yamhill tended to emerge the fastest while Bezostaya emerged the slowest. Lowering soil water potential and temperature delayed emergence and although field and laboratory emergence times in general agreed, the applicability of the laboratory models to field conditions could not be established because of insufficient data.

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APPENDIX

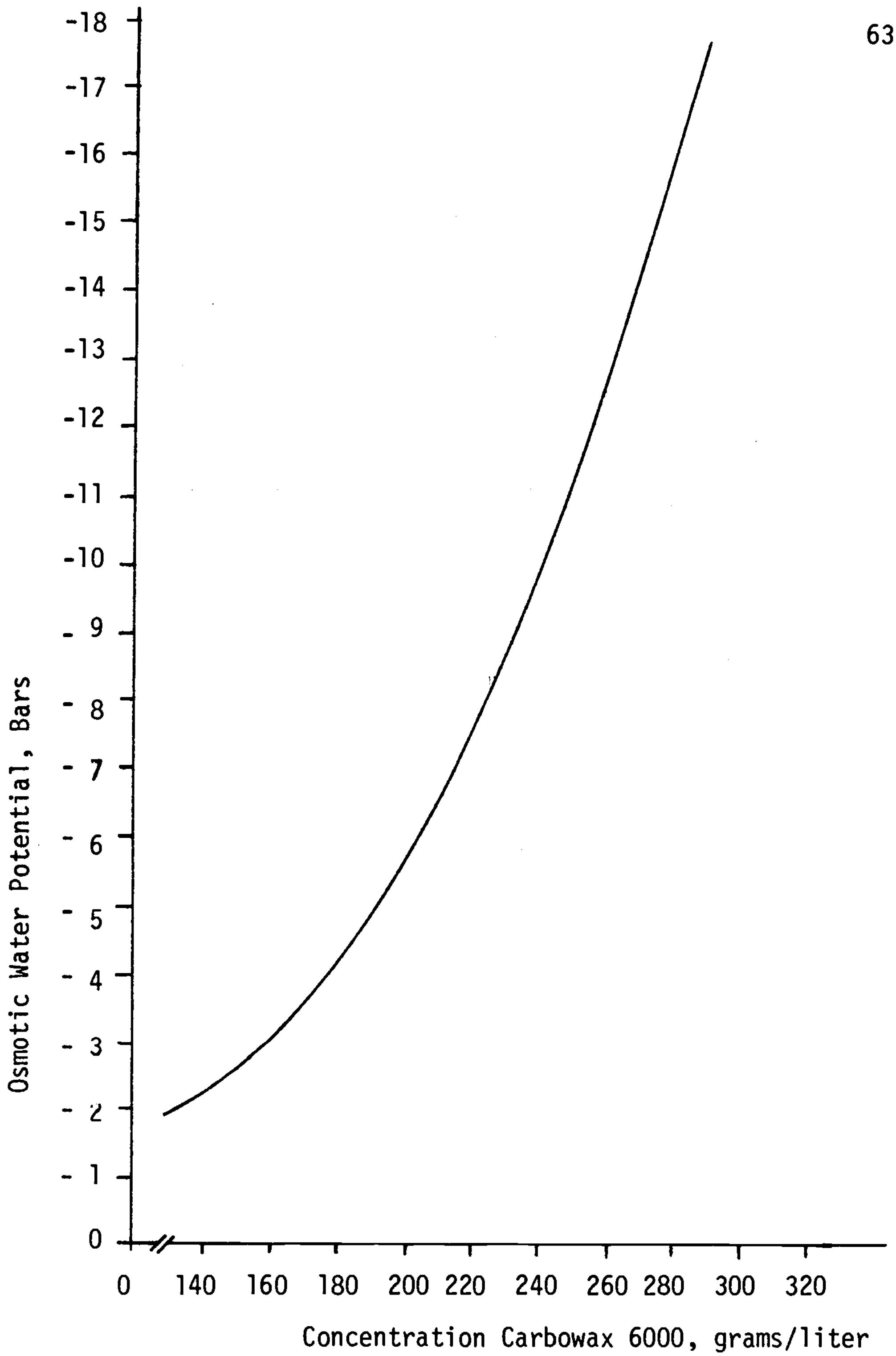

FIGURE 14. Effect of Carbowax concentration on osmotic potential (Barlow, 1974).

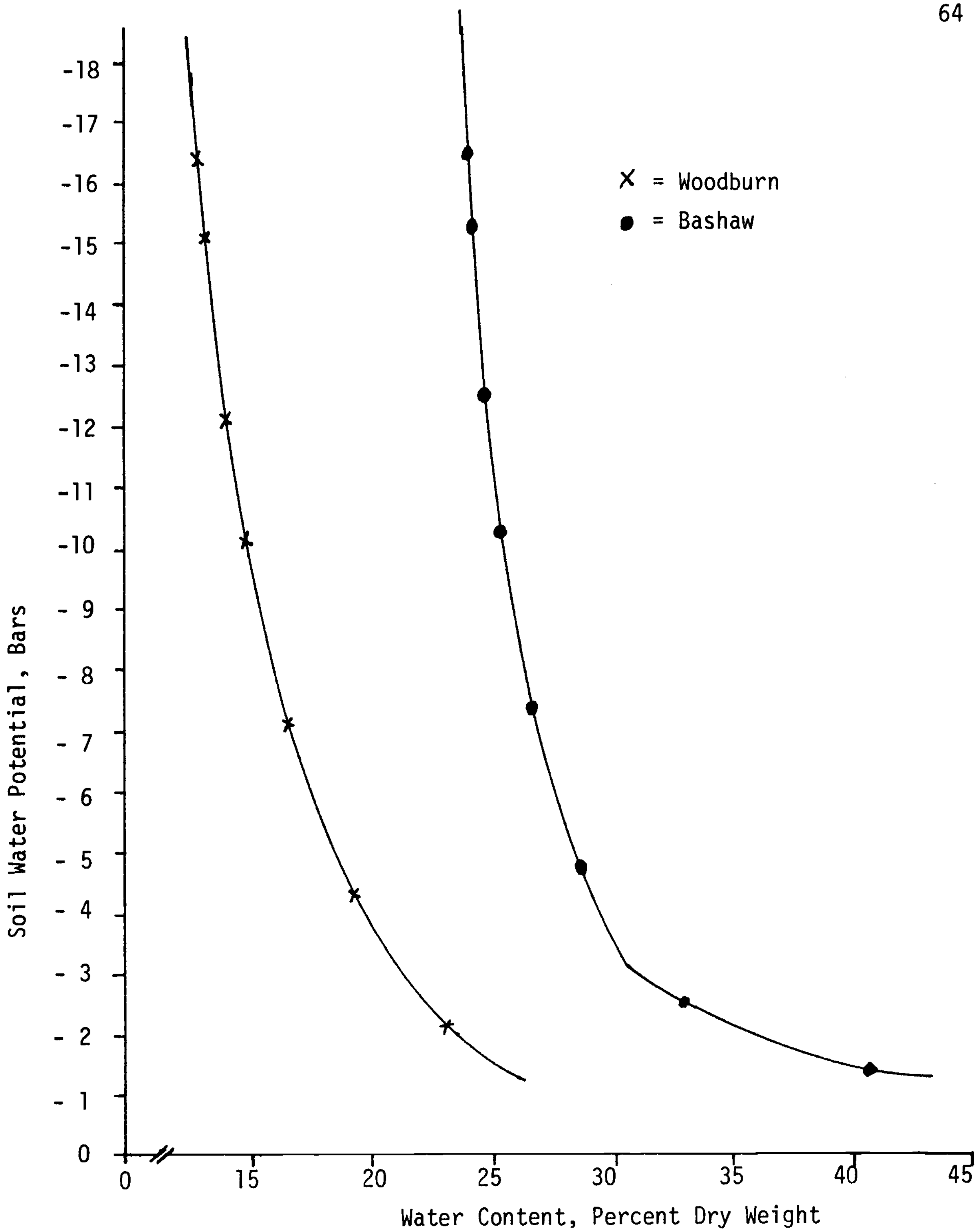

FIGURE 15. Soil moisture retention curves for Bashaw silty clay soil and Woodburn silt loam soils.

TABLE 8. Characteristics of Winter Wheat Varieties.

1. Yamhill: Medium height, soft, white beardless, high yielding winter wheat variety, resistant to strip rust and mildew, susceptible to smut. Developed by Warren Kronstad in Oregon, U.S.A.

2. Bezostaya: Tall, beardless, hard red winter wheat, susceptible to septoria, moderately susceptible to stripe rust and mildew. Good milling quality. Developed in Russia by L. Lukyenenko.

3. Kirac 66: Tall, bearded, soft winter wheat, shattering and drought resistance. Moderately resistance to stripe rust, and septoria; susceptible to mildew. Good milling and baking quality. Developed in Eskisehir, Turkey, by Rifat Gerek.

TABLE 9. Some properties of Bashaw and Woodburn soils.

Properties	Bashaw	Woodburn
Sub group name	Typic Pelloxerets	Aquultic Argixerolls
Family name	(Very fine, montmorillonitic mesic)	(Very fine, mixed, mesic)
Texture	silty clay	silt loam
Sand (%)	13.16	2.95
Silt (%)	43.35	80.37
Clay (%)	43.49	16.68
pH	6.30	6.60
P (ppm)	128.0	99.0
K (ppm)	156.0	222.0
Ca (meq/100 gram)	32.0	13.3
Mg (meq/100 gram)	13.0	0.99
Na (meq/100 gram)	0.28	0.13
B (ppm)	0.62	0.30
Salts (mmhos/cm)	0.40	1.70
Organic Matter, (%)	4.20	1.70
NO_3 - N (ppm)	6.70	1.30
NH_3 - N (ppm)	9.40	2.80

TABLE 10. Variance analysis for number of days required to obtain 80 percent germination (D_{80}) in solution experiment.

Source	d.f.	M.S.	F
Temperature (T)	3	45.5382	30.6**
Replication (R)	1	0.21658	
R x T	3	1.48813	396.00**
Moisture (M)	3	16.5844	396.00**
T x M	9	0.78867	18.85**
Variety (V)	3	0.22187	5.30*
T x V	9	0.019451	.466 N.S.
M x V	9	0.042129	1.01 N.S.
T x M x V	27	0.036983	.884 N.S.
T x M x V x R	60	0.0418394	
Error	384	0.01033	
Total	511		

** Significant at 1 percent level.
* Significant at 5 percent level.

TABLE 11. Variance analysis by contrast methods procedure for predictive equation in osmotic solution experiment.

TEMPERATURE (T)						
Contrast	L_i	rD_i	b_i	SS_i	SS Overall	F_i
Linear	-581.86	2560	-0.2273	132.25	136.61	88.9**
Quadratic			N.S.			
OSMOTIC WATER POTENTIAL (OWP)						
Contrast						
Linear	354.56	2560	0.1385	49.11	49.75	1173.7**
Quadratic			N.S.			
T X OWP						
Contrast						
L X L	251.808	12800	0.01967	4.954	.7098	118.4**

** Significant at 1 percent level.

$$\ln(D_{80}) = 2.01094 - 0.2273\,(T) - 0.1385\,(OWP) + 0.01967\,(T \times OWP)$$

TABLE 12. Variance analysis of regression equation developed to predict the number of days required to obtain 50 percent seedling emergence (D_{50}) and predicted values for Woodburn soil.

$$\ln(D_{50}) = 3.7576 - 0.038496\,(SWP) - 0.18372\,(T) + 0.0031312\,(T^2)$$

SWP = Soil Water Potential, Bars

T = Temperature, °C

$R^2 = 0.921$

ANOVA

Source	d.f.	M.S.	F
Regression	3	24.6869	719.3**
Residual	186	0.03432	
Total	189	0.42563	

** Significant at 1 percent level.

Predicted number of days required to obtain 50 percent seedling emergence.

Temperature °C	Soil Water Potential, Bars -2	-7	-12	-17
	---------- days to D_{50} ----------			
5	21.1	23.0	27.9	37.7
10	10.6	11.6	14.1	18.9
15	6.2	6.8	8.2	11.2
20	4.3	4.7	5.7	7.7

TABLE 13. Variance analysis of regression equation developed to predict the number of days required to obtain 80 percent seedling emergence (D_{80}) and predicted values for Woodburn soil.

$$\ln (D_{80}) = 3.8346 - 0.026914\,(SWP) - 0.16615\,(T) + 0.0023729\,(T^2)$$

SWP = Soil Water Potential, Bars

T = Temperature, °C

$R^2 = 0.941$

ANOVA

Source	d.f.	M.S.	F
Regression	3	17.5333	739.8**
Residual	139	0.02372	
Total	142	0.39364	

** Significant at 1 percent level.

Predicted number of days required to obtain 80 percent seedling emergence

Temperature °C	Soil Water Potential, Bars -2	-7	-12
	---------------- days to D_{80}	----------------	
5	22.6	25.8	29.6
10	11.8	13.5	15.4
15	6.9	7.9	9.0
20	4.6	5.2	5.9

TABLE 14. Variance analysis of regression equation developed to predict the number of days required to obtain 50 percent seedling emergence (D_{50}) and predicted values for Bashaw soil.

$$\ln (D_{50}) = 3.327 - 0.05669\ (SWP) - 0.098854\ (T)$$

(SWP) = Soil Water Potential, Bars

T = Temperature °C

R^2 = 0.934

ANOVA

Source	d.f.	M.S.	F
Regression	2	12.9219	489.5**
Residual	69	0.0264	
Total	71	0.3896	

** Significant at 1 percent level

Predicted number of days required to obtain 50 percent seedling emergence.

Temperature °C	Soil Water Potential, Bars -2	-7	-12
	days to D_{50}		
5	19.0	25.3	33.6
10	11.6	15.4	20.5
15	7.0	9.4	12.5
20	4.3	5.7	7.6

TABLE 15. Average number of days required to obtain 80 percent seedling emergence in Bashaw and Woodburn soils for different bulk densities.

Soil	Bulk Density gm/cm^3	Soil Water Potential, Bars -1	-4	-7	-10
		days to D_{80}			
Bashaw	0.9	5.0	11.3	13.3	16.0
	1.0	6.0	11.0	14.0	20.7
	1.1	6.0	13.7	17.3	20.7
	1.2	7.0	20.7	22.7	26.0
	1.3	9.0	*	*	*
Woodburn	0.9	7.3	5.0	5.7	6.7
	1.0	7.0	4.3	6.0	6.0
	1.1	7.3	5.0	6.0	6.0
	1.2	6.0	5.0	5.3	6.0
	1.3	8.0	5.3	7.0	6.3
	1.4	12.7	12.0	13.3	12.0

Tukey's $w_{(0.01)}$ = 4.45 (for Bashaw soil)

Tukey's $w_{(0.01)}$ = 0.95 (for Woodburn soil)

* 80 ercent mergence not obtained

TABLE 16. Variance analysis for number of days required to obtain 80 percent seedling emergence in bulk density experiment for Woodburn soil.

Source	d.f.	M.S.	F
Replication (R)	2	2.8958	
Moisture (M)	3	381.1111	175.33**
R x M	6	2.1735	
Bulk Density (BD)	3	76.5556	32.14**
M x BD	9	6.6296	2.78*
Error	24	2.3819	
Total	47		

** Significant at 1 percent level.

* Significant at 5 percent level.

TABLE 17. Variance analysis for number of days required to obtain 80 percent seedling emergence in bulk density experiment for Bashaw soil.

Source	d.f.	M.S.	F
Replication (R)	2	0.79167	
Moisture (M)	3	7.14815	6.15**
R x M	6	1.16204	
Bulk Density (BD)	5	73.70000	169.03**
M x BD	15	0.80370	1.84 N.S.
Error	40	0.436111	
Total	71		

** Significant at 1 percent level.

TABLE 18. Variance analysis for the number of days required to obtain 80 percent seedling emergence in field seedling emergence experiment.

Source	d.f.	M.S.	F
Seeding Date (D)	2	345.09	92.02**
Replication (R)	3	0.67	
D x R	6	3.75	
Variety (V)	3	2.82	7.23**
D x V	6	0.32	N.S.
Error	27	0.20	
Total	47		

** Significant at 1 percent level.