THE EFFECT OF BULK DENSITY AND SOIL

WATER PRESSURE ON GRASS

SEEDLING EMERGENCE

By

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Bachelor of Science

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1963

Submitted to the faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1966

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ACKNOWLEDGMENTS

The author is grateful to the Agronomy Department of Oklahoma State University for the facilities provided for this study, and to the many persons involved who have provided guidance and inspiration.

Special thanks and grateful appreciation are extended to Dr. John F. Stone, my adviser, for his consideration and valuable counsel in the assembling and reviewing of this thesis. An expression of gratitude is also extended to the other members of the committee, Dr. Wayne W. Huffine, Dr. J. W. Lynd, and Dr. R. D. Morrison. Recognition is given to Dr. J. R. Gingrich of Agricultural Division of Olin for his guidance during the initial parts of the study and to the Oklahoma State Highway Department for funds provided for the purchase of equipment.

The writer also wishes to thank Mrs. Gary Roach for typing the final copy of this manuscript.

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CHAPTER I

INTRODUCTION

Effects of soil crusting on seedling emergence have received considerable attention from research workers in recent years. Most of the work has been done with larger seeded crops and little information is available for small seeded grasses.

The purpose of this study is to relate grass seedling emergence to certain conditions of soil water pressure, bulk density, soil crust strength, and oxygen diffusion rate.

CHAPTER II

LITERATURE REVIEW

Several methods have been devised to study the hardness or strength of soil crusts. Richards' (14)[1] modulus of rupture procedure has been used by several research workers (3, 8, 9, 15). Hanks and Thorp (9) measured wheat seedling emergence on three soils varying in texture from a silty clay loam to a fine sandy loam with different combinations of soil moisture, bulk density, oxygen diffusion rate, and crust strength. They concluded that bulk density was related indirectly to seedling emergence in that any change in bulk density changed other factors such as oxygen diffusion rate and crust strength. The limiting crust strength for wheat seedling emergence was between 200 and 500 millibars as measured by the modulus of rupture and appeared to decrease as the amount of available moisture decreased. In a different study, Hanks and Thorp (8) studied seedling emergence of wheat, grain sorghum, and soybeans. They found that for a given crust strength, seedling emergence was lowest where the soil moisture content was lowest. At constant moisture contents, seedling emergence decreased with increasing crust strength. Partial seedling emergence was received at crust strengths as high as 1400 millibars as measured by the modulus of rupture. Hanks and Thorp (8)

[1]Figures in parenthesis refer to Literature Cited.

were of the opinion that the reduced emergence at the lower moisture contents may be associated with the rate of emergence. They felt that other factors such as seedling turgor and guttation may be important but were unable to detect an increase in moisture in the soil crust after emergence.

Doneen and MacGillvray (5) found that most vegetable seeds gave good germination over the entire range of available moisture and that they germinated in a shorter period of time at high soil moistures than at low.

Richards (14) using a fine sandy loam found no decrease in emergence of beans at a crust strength of 108 millibars as measured by the modulus of rupture under field conditions. Emergence decreased until at 273 millibars no emergence occurred.

Carnes (3) produced soil crusts in the laboratory and found that moisture, rate of drying, and compaction of soil beneath the seeds had an effect either on the modulus of rupture or the seedlings' ability to emerge.

Parker and Taylor (13) studied the relation between soil strength and grain sorghum emergence on six different soils. A Chatillon penetrometer was used to measure the soil crust strengths. With four of the six soils tested, small amount of compaction apparently increased seedling emergence, but emergence was progressively decreased by increases in soil strength above three bars. No emergence occurred at soil strengths above 13 bars for one soil while no emergence occurred above 18 bars for the other five soils used. They concluded that the rate of emergence was affected by soil strength, soil water pressure, and soil temperature and that there was only a minor effect of planting depth on the relationship between grain sorghum seedling emergence and soil strength.

Taylor (17) devised a nonporous wax surface crust technique to study seedling emergence of wheat, grain sorghum, and guar. No emergence occurred when the wax penetration numbers (1) were 27.0 or less. There were no differences between species in their ability to emerge through wax crusts. For the wheat and grain sorghum, accumulations of water as great as ¼ cm^3 per plant were trapped in the wax crusts. Although this accumulation of water did not change the strength of the wax crust it would have changed the strength of a soil crust.

Domby and Kohnke (4) investigated the influence of soil crusts on gaseous diffusion and concluded that unless the surface is completely impervious the rate of diffusion through a soil does not depend solely on the properties of this layer. They found that when various proportions of the soil surface were sealed with paraffin, the rate of diffusion was not reduced in proportion to the area covered. The effects of soil crusts upon diffusion depended to a very great extent on the soil moisture content.

The platinum microelectrode has been used by several workers to evaluate the rate of oxygen diffusion through the soil (9, 10, 11, 16, 18). It is important to keep in mind some of the factors that influence the oxygen diffusion rate measurement that are not considered in the calculations when reviewing the literature (2). The more important factors are the time allowed for establishment of a steady state, the voltage potential applied, soil moisture, salt content of the soil, temperature, and the diameter of the electrode used. Also poisoning of the electrode can occur if the electrode is left in the soil for extended periods of time.

Hanks and Thorp (9) measured wheat seedling emergence on soils with different textures, bulk densities, and moisture contents. They found that an oxygen diffusion rate of about 75 to 100 X 10^{-8} gm/cm^2min was necessary for the emergence of wheat. Readings were taken at the end of three minutes using an 18-gauge electrode and a potential of -0.8 volts.

Erickson and Van Doren (6) showed a marked reduction in the emergence of peas in soils at oxygen diffusion rates of 36 to 45 and 51 to 60 X 10^{-8} gm/cm^2min. Oxygen diffusion rates of 61 to 70 X 10^{-8} gm/cm^2min doubled the emergence as compared with those soils of lower oxygen diffusion rates.

Stolzy and Letey (16) reviewed the published literature on oxygen diffusion rate experiments and presented relationships of oxygen diffusion rate and plant responses. They concluded that emergence data in relation to oxygen diffusion rates indicate that plants have a much greater need for better soil aeration during emergence than after they become established. Oxygen diffusion rates of at least 50 to 70 X 10^{-8} gm/cm^2min are needed for good emergence.

It is important to point out the variability in information on plant response and oxygen diffusion rate. Much remains to be discovered in order to understand how soil oxygen affects the plant from germination to maturity.

CHAPTER III

MATERIALS AND METHODS

Soil. The soil used came from a profile originally classed as Vernon clay. It was sampled from a disturbed site on Interstate 35, one mile north of Highway 51 intersection. The area, as it exists in the field, is a mixture of surface and subhorizon material and is void of vegetative growth. The mechanical analysis was determined by the pipette method (Table I).

TABLE I

MECHANICAL ANALYSIS OF DISTURBED SOIL SAMPLE

% Sand >50u	% Coarse Silt 20u to 50u	% Fine Silt 2u to 20u	% Clay < 2u
7.73	4.10	32.40	54.91

Soil Moisture Contents. The soil moisture contents were determined for each combination of bulk density and soil water pressure using a ceramic pressure plate apparatus. These are presented in Figure 1. The equations for the lines and the $\hat{Y}$ values were obtained by using least squares regression analyses. Moisture contents for the 1.8 gm/cm^3 bulk densities were determined in addition to the 1.4, 1.5, 1.6, and 1.7 gm/cm^3 bulk densities in an attempt to get a better estimate of the regression.

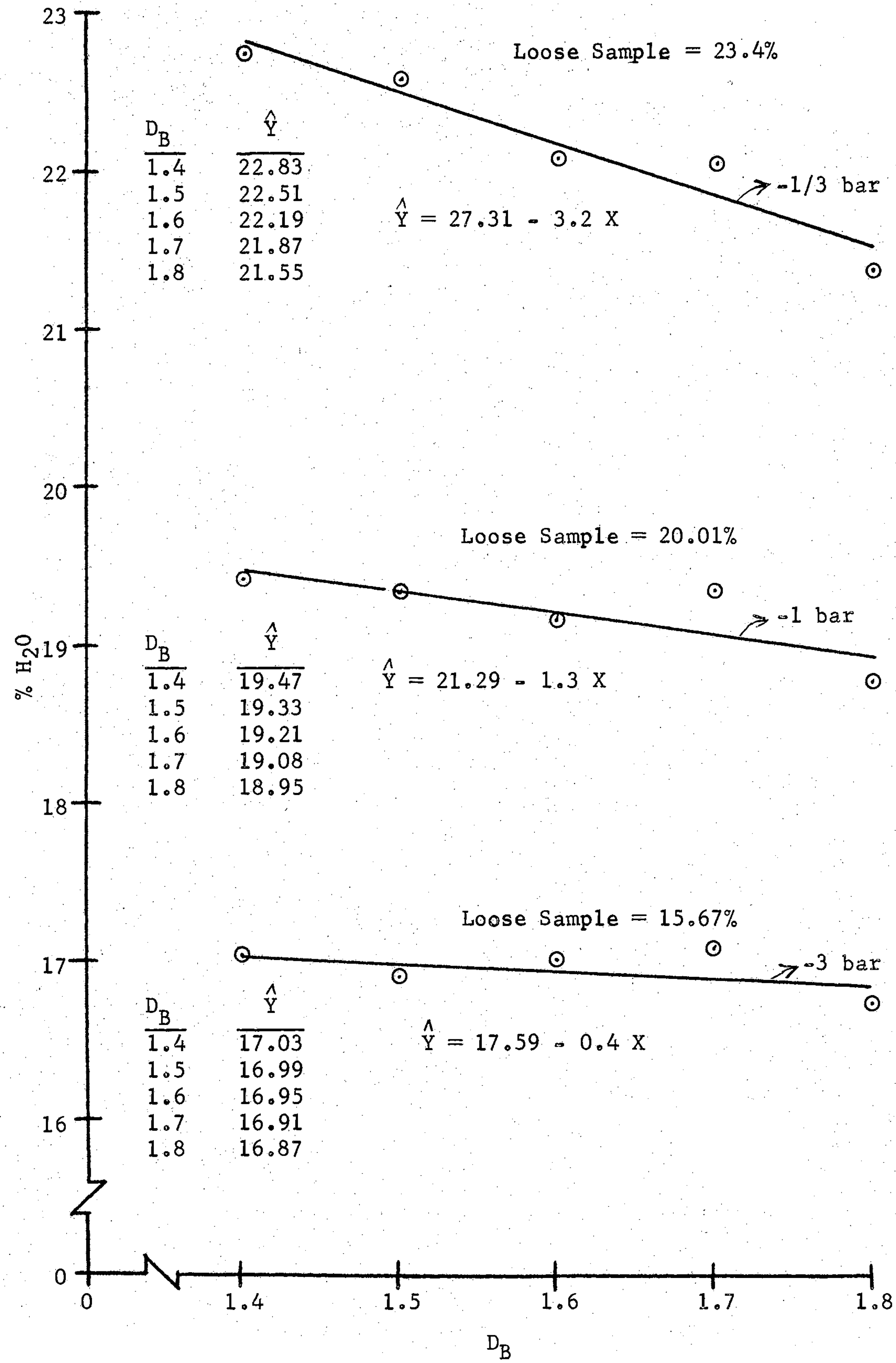

Figure 1. Soil Moisture Contents for all Combinations of Bulk Density and Soil Water Pressure.

Soil Core Preparation. The soil cores were prepared in tin-plated steel cans, 9.8 cm in diameter by 11.5 cm high. The required amount of water to achieve the desired soil water pressure was placed in the can, then the appropriate weight of air dry soil that had previously passed through an 8-mesh sieve was added to obtain the desired bulk density for 275 cm^3 volume. The soil surface was then smoothed to assure a uniform depth of seed placement. Fifty seeds were then placed on the soil surface with no seeds being placed within 1 cm of the outside edge or within a 2.5 cm diameter circle in the center. Soil for the remaining 25 cm^3 volume was then added to cover the seeds. After 48 hours the soil cores were compressed to 300 cm^3 volume by using a Carver hydrualic press. A lead plate that had been molded to fit the contours of the bottom of the cans was used to support the bottom of the cans. A circular aluminum piston was inserted in the top of the cans to compress the cores. The final 300 cm^3 volume was obtained by gauging from the top of the cans to the top of the aluminum plate. This resulted in a depth of seed placement of approximately 0.3 cm and final core dimensions of 9.8 cm diameter and 4.0 cm height.

Moisture Losses. Moisture losses were minimized by covering the cans with a thin transparent plastic[2]. A glass rod was inserted into the center of the soil cores to hold the center of the plastic cover approximately 4 cm above the top of the cans forming a cone. This prevented condensed moisture on the underneath side of the cover from dripping on the soil surface. Rubber bands were used to secure the

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[2]Handi-Wrap, Dow Chemical Company, Midland, Michigan.

plastic covers to the outside of the cans.

Seedling Emergence Counts. Emergence counts of the seedlings were made at the end of 1, 2, and 3 weeks. Only the total emergence counts at the end of 3 weeks were subjected to statistical analyses.

Soil Strength Measurements. Unconfined compression strength measurements were taken by using a Chatillon 719-40 penetrometer[3]. Six readings per core were taken after the 3-week germination and emergence period by forcing the 0.833 cm diameter tip into the core to a depth equal to the diameter. The penetrometer was mounted on a drill press to make it possible to apply increasing amounts of force at a more uniform rate than could be done by manual manipulation of the penetrometer.

Oxygen Diffusion Rates. The oxygen diffusion rates were measured by the platinum microelectrode method of Letey and Stolzy (12). An applied potential of -0.65 volts was used with a 22-gauge platinum microelectrode. The current readings were taken with a Keithley Model 150A DC microvoltammeter. Ten readings per core were taken on a set of cores different from the ones used to make the emergence and strength measurements. The cores were prepared in the same manner with the exceptions that the soil for 300 cm^3 volume was placed in the can at one time and that the cores were not compressed until after 96 hours. The oxygen diffusion rate was then determined 48 hours after compaction with 5 minutes being allowed for a steady state condition to develop after the electrode was placed in the soil core.

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[3] Manufactured by John Chatillon and Sons, 85 Cliff Street, New York 38, New York.

The oxygen diffusion rates were calculated by

$$\text{ODR} = \frac{i \text{ X } 10^{-6} \text{ X } 60 \text{ X } 32 \text{ X } 10^{6}}{4 \text{ X } 96{,}500 \text{ X } A}$$

where $i \text{ X } 10^{-6}$ is the current in microamperes, 4 is the number of electrons required for the reduction of one molecule of oxygen, 96,500 is Faraday's constant, and A is the surface area of the platinum electrode in cm^2. The factors 60 and $32 \text{ X } 10^6$ are included in order to express the results in terms of minutes and micrograms. The results were expressed as gm X $10^{-8}/cm^2 min$ to avoid reporting extremely small values.

Statistical Analysis. Two univariate analyses, emergence and strength respectively, were made on a factorial arrangement of two treatments, bulk density and soil water pressure. The analysis was performed for each grass separately. The experiment was laid out in a randomized complete block design. The correlation coefficients between strength and emergence were calculated by

$$r = \frac{\text{Cov}(Y_1, Y_2)}{\sqrt{\text{Var } Y_1} \quad \sqrt{\text{Var } Y_2}}$$

where Var Y_1 is the error mean square for emergence, Var Y_2 is the error mean square for strength, and $\text{Cov}(Y_1,Y_2)$ is the covariance of emergence and strength. The covariance of emergence and strength was calculated by

$$\text{Var}(Y_1 + Y_2) = \text{Var } Y_1 + \text{Var } Y_2 + 2\text{Cov}(Y_1,Y_2)$$

where Var Y_1 and Var Y_2 are the error mean squares for emergence and strength and $\text{Var}(Y_1+Y_2)$ is the error mean square for emergence plus strength.

Environmental Conditions. The method of Gingrich (7) was used to provide controlled soil temperature conditions in the greenhouse. A 12-hour photoperiod was employed with a day temperature of 35° C. and a night temperature of 20° C.

Plants. Seeds of common bermudagrass (*Cynodon dactylon* (L.) Pers.) and weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees.) were used in this study.

CHAPTER IV

RESULTS AND DISCUSSION

The seedling emergence of common bermudagrass and weeping lovegrass as effected by bulk density and soil water pressure was investigated. Soil cores were prepared at bulk densities of 1.4, 1.5, 1.6, and 1.7 gm/cm^3 in combination with soil water pressures of -1/3, -1, and -3 bars. Soil strength and oxygen diffusion rate measurements were taken to establish the role of these two factors on grass seedling emergence.

Seedling emergence at the -3 bar soil water pressures for all levels of bulk density is low for both common bermudagrass and weeping lovegrass as shown in Figures 2 and 6. In Figure 2, bermudagrass emergence is high and ranges from 70 to 75% at the -1 bar pressures. It is also high at the -1/3 bar pressures with the exception of the 1.5 gm/cm^3 bulk density. The strength and oxygen diffusion rate measurements (Figures 3 and 4) do not provide the needed explanation for this drop in emergence even though the oxygen diffusion rate of 12.9 X 10^{-8} gm/cm^{2}min (Figure 4) may be approaching some critical point. As shown in Figure 6, a relatively constant emergence for lovegrass of approximately 80% was obtained at the -1 bar pressures. For the -1/3 bar pressures in Figure 6 approximately 80% emergence was obtained at the 3 lower levels of bulk density. At a bulk density of 1.7 gm/cm^3 and -1/3 bar pressure lovegrass emergence drops to 72.67%. The oxygen diffusion rate for this point drops to 9.7 X 10^{-8} gm/cm^{2}min which may be close to some critical point. In the analysis of variance for bermudagrass emergence (Table II) the F tests indicate that reps and bulk density are not significant at the 0.05 level. Soil water pressure is indicated to be highly significant at the 0.01 level. Although the interaction between bulk density and pressure is indicated to be significant at the 0.05 level, physical significance of it is questionable. In many instances where one finds large main effect differences it is generally accompanied by interactions. Therefore, the interaction is quite small in comparison with the main effect of pressure. In the analysis of variance for lovegrass emergence (Table II) the F tests indicate that reps, bulk density, and the interaction between bulk density and pressure are not significant at the 0.05 level but that pressure is highly significant at the 0.01 level.

In general, Figures 3 and 7 indicate that soil strength increases with increasing bulk density for a given level of soil water pressure. Strength also increases with increasing soil water pressure for a given level of bulk density. Where exceptions do occur in Figures 3 and 7 they are not significant and may be considered random errors in the experiment. In the analysis of variance for strength on the bermudagrass and lovegrass (Table II) the F tests indicate that bulk density, soil water pressure, and the interaction between bulk density and pressure are significant at the 0.01 level. In Figures 3 and 7 these interactions are visible. In Table II for the bermudagrass data the F test for reps does not indicate significance at the 0.05 level but for the lovegrass data the F test does indicate significance at the 0.05 level for reps. This may be due to the relatively large amount of variation that is present in the strength determinations. The coefficients of variation for bermudagrass and lovegrass were 18.1% and 19.3% respectively.

Oxygen diffusion rates were not determined in the -3 bar pressures. The oxygen diffusion rate measurements as presented in Figure 4 are fairly constant and low for all levels of bulk density at the -1/3 bar soil water pressures. The low oxygen diffusion rate of 9.7×10^{-8} gm/cm^2 min at a bulk density of 1.7 gm/cm^3 and -1/3 bar pressure does not appear to limit the emergence of either grass. At the -1 bar pressures the oxygen diffusion rate is highest at the 1.5 gm/cm^3 bulk density with the 1.4 and 1.7 gm/cm^3 bulk densities being lowest and approximately equal. All of the oxygen diffusion rates at the -1 bar pressures are above 39.7×10^{-8} gm/cm^{2}min. The low reading at the 1.4 bulk density may be due to incomplete wetting of the platinum electrode.

Figures 5 and 8 indicate that at the end of one week the -1/3 bar pressures give the highest emergence for both weeping lovegrass and bermudagrass. The -1 bar pressures tend to catch up with the -1/3 bar suctions until at the end of three weeks the -1 bar pressures are approximately equal to the -1/3 bar pressures for both grasses. Essentially no emergence was obtained at the -3 bar pressures at the end of one week for either grass. At the end of three weeks none of the -3 bar pressures had greater than 20% emergence for bermudagrass or greater than 44% emergence for lovegrass.

For the range of bulk densities and soil water pressures investigated the correlation coefficients between strength and emergence were

-0.0058 for bermudagrass and -0.0679 for lovegrass. These correlation coefficients are quite low. This may be partially explained by the fact that none of the strengths that were developed inhibited emergence. It would be possible to obtain higher correlations if each level of soil water pressure were considered separately but this would not give an overall indication of the reliability of the strength measurements.

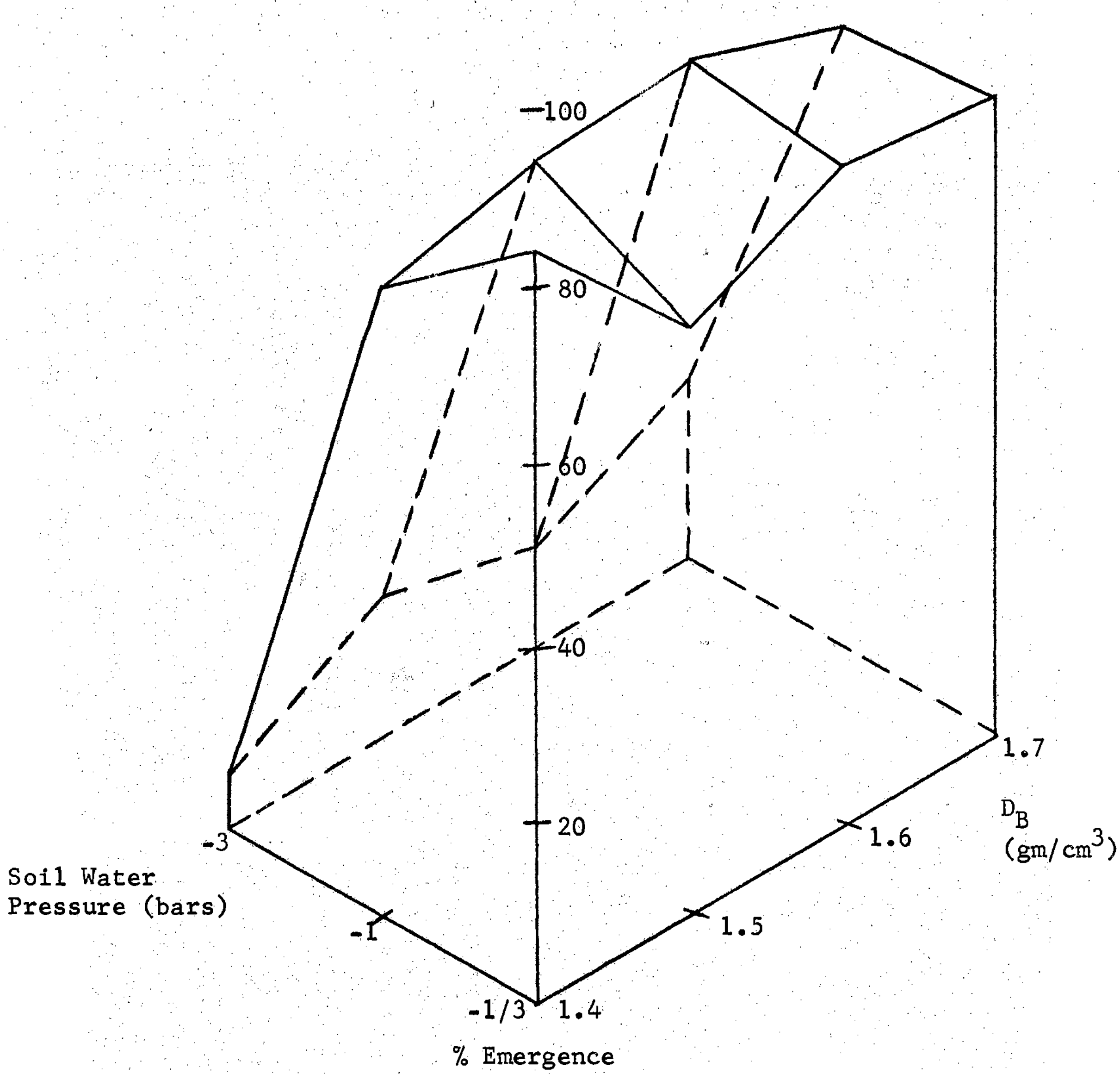

Figure 2. Common Bermudagrass Seedling Emergence as Influenced by Bulk Density and Soil Water Pressure.

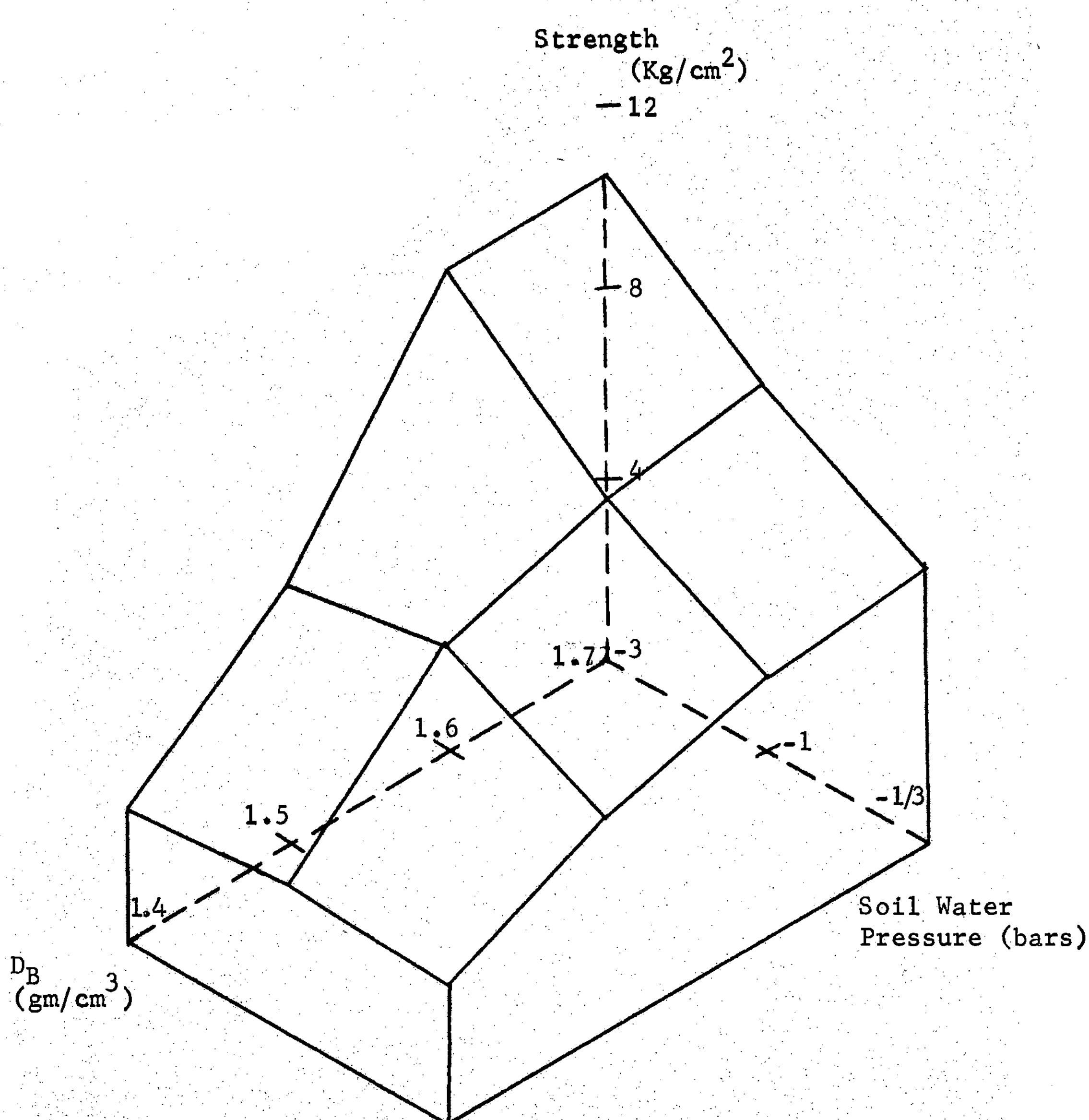

Figure 3. Strength as Affected by Bulk Density and Soil Water Pressure for Common Bermudagrass.

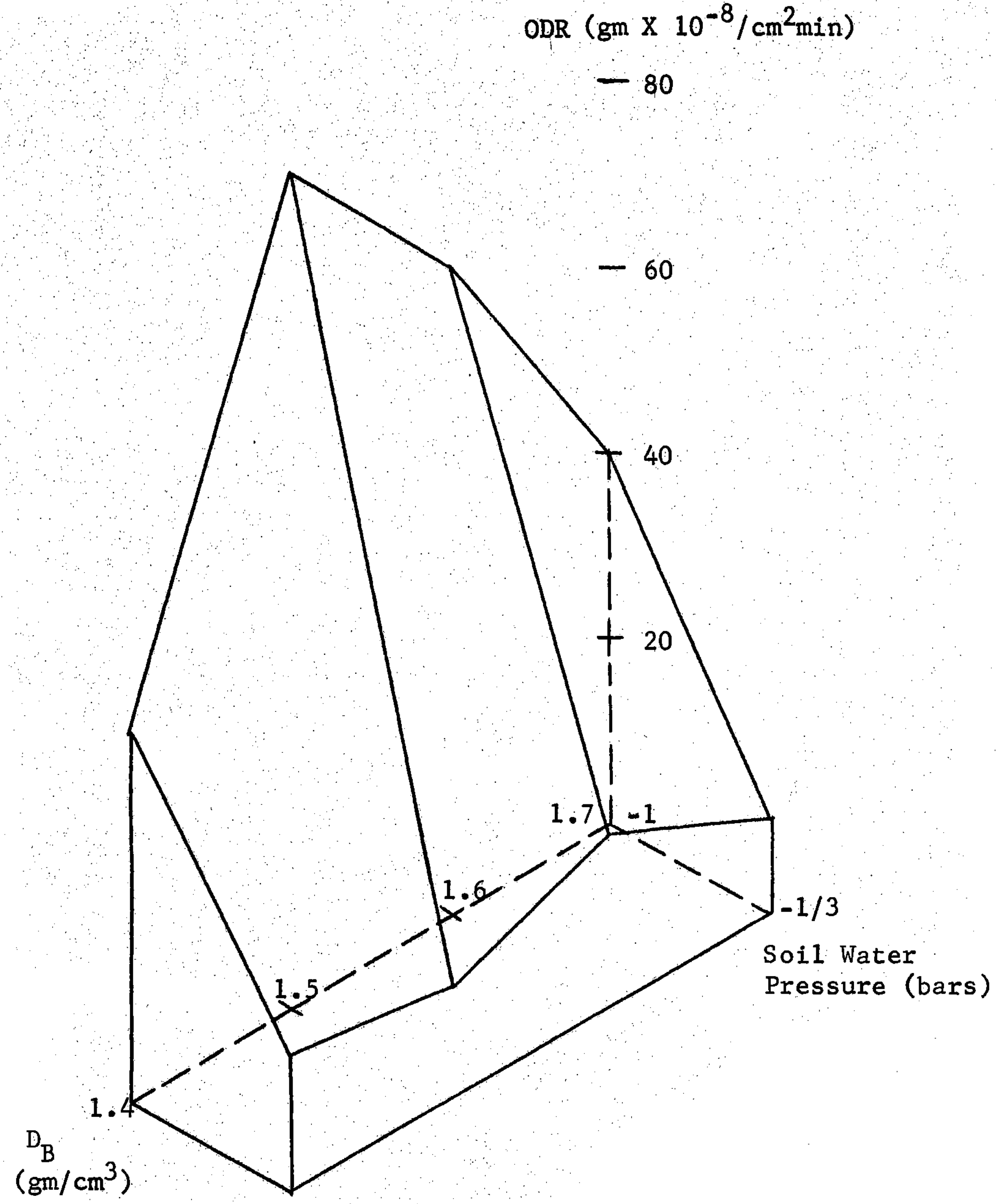

Figure 4. Oxygen Diffusion Rate as Affected by Bulk Density and Soil Water Pressure.

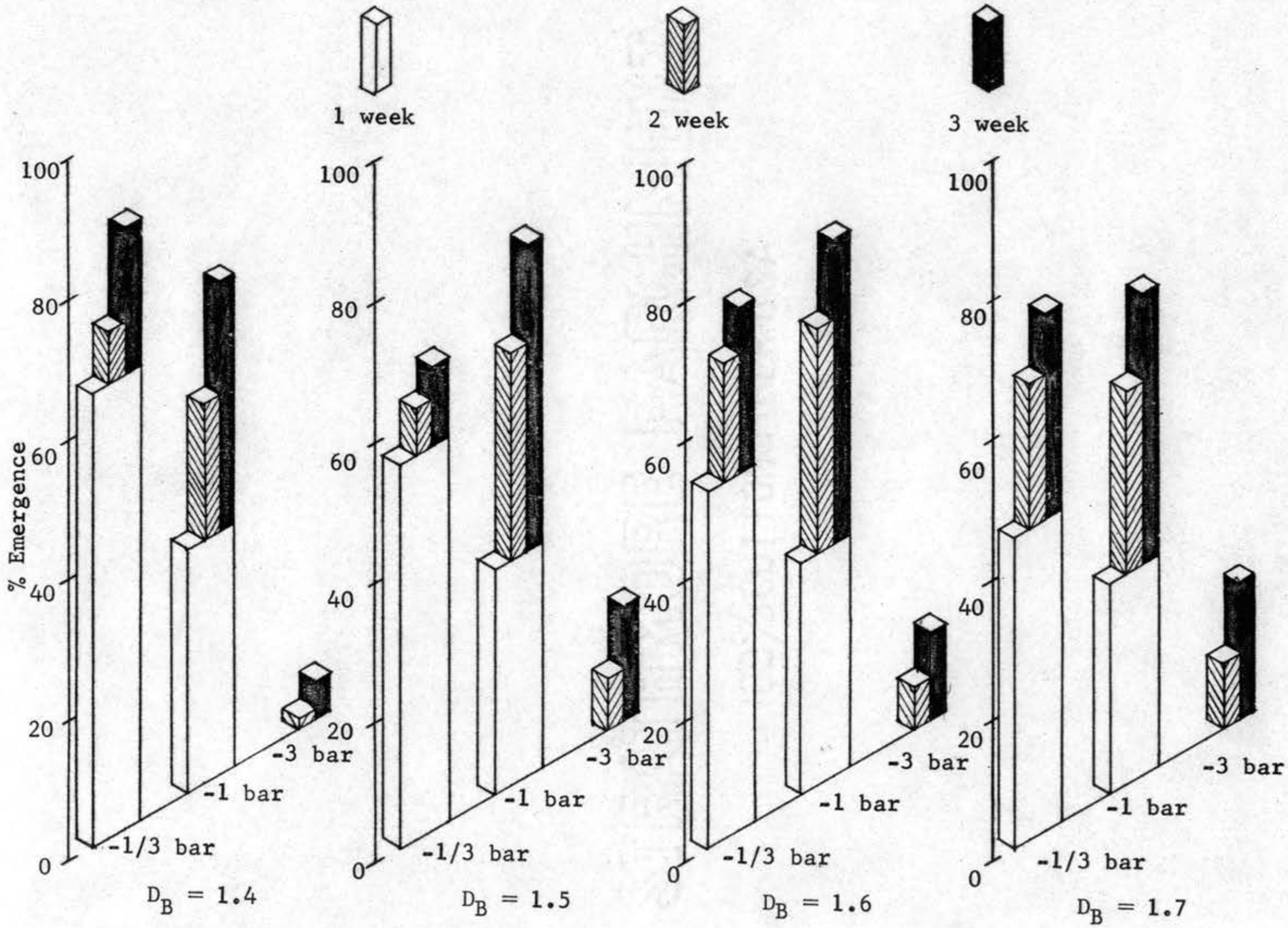

Figure 5. Weekly Seedling Emergence Counts of Common Bermudagrass for all Levels of Bulk Density and Soil Water Pressure.

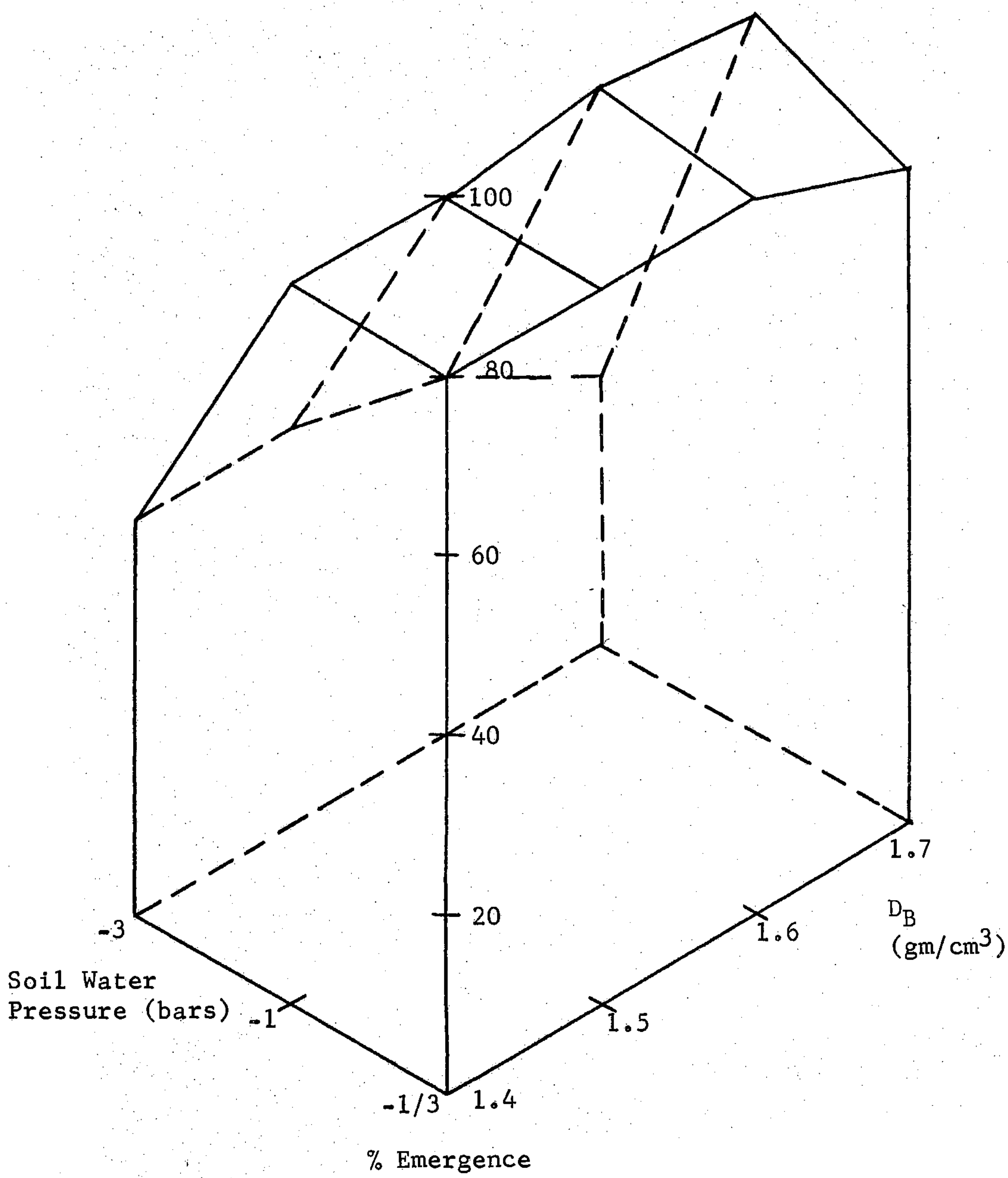

Figure 6. Weeping Lovegrass Seedling Emergence as Affected by Bulk Density and Soil Water Pressure.

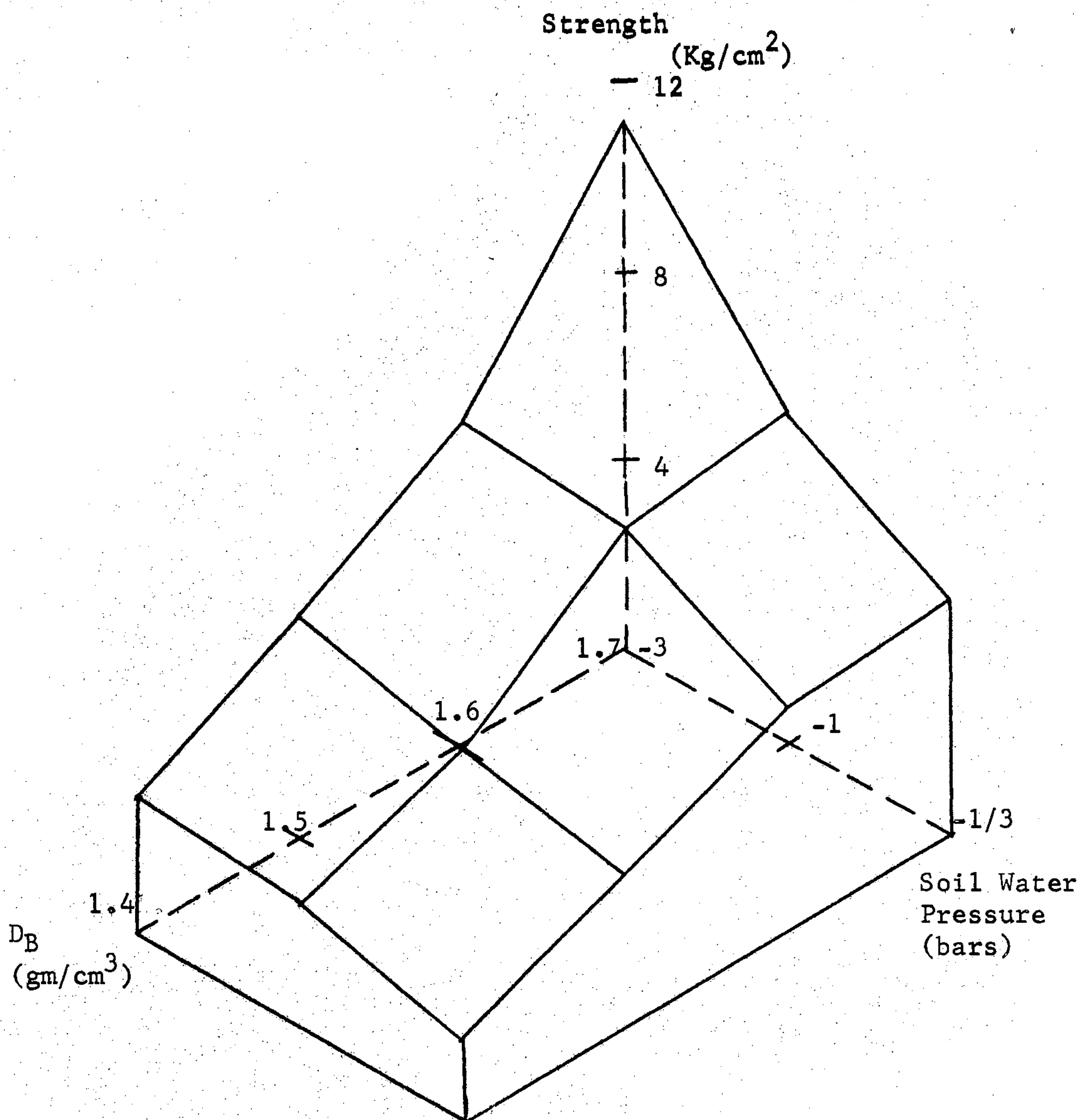

Figure 7. Soil Strength as Affected by Bulk Density and Soil Water Pressure for Weeping Lovegrass.

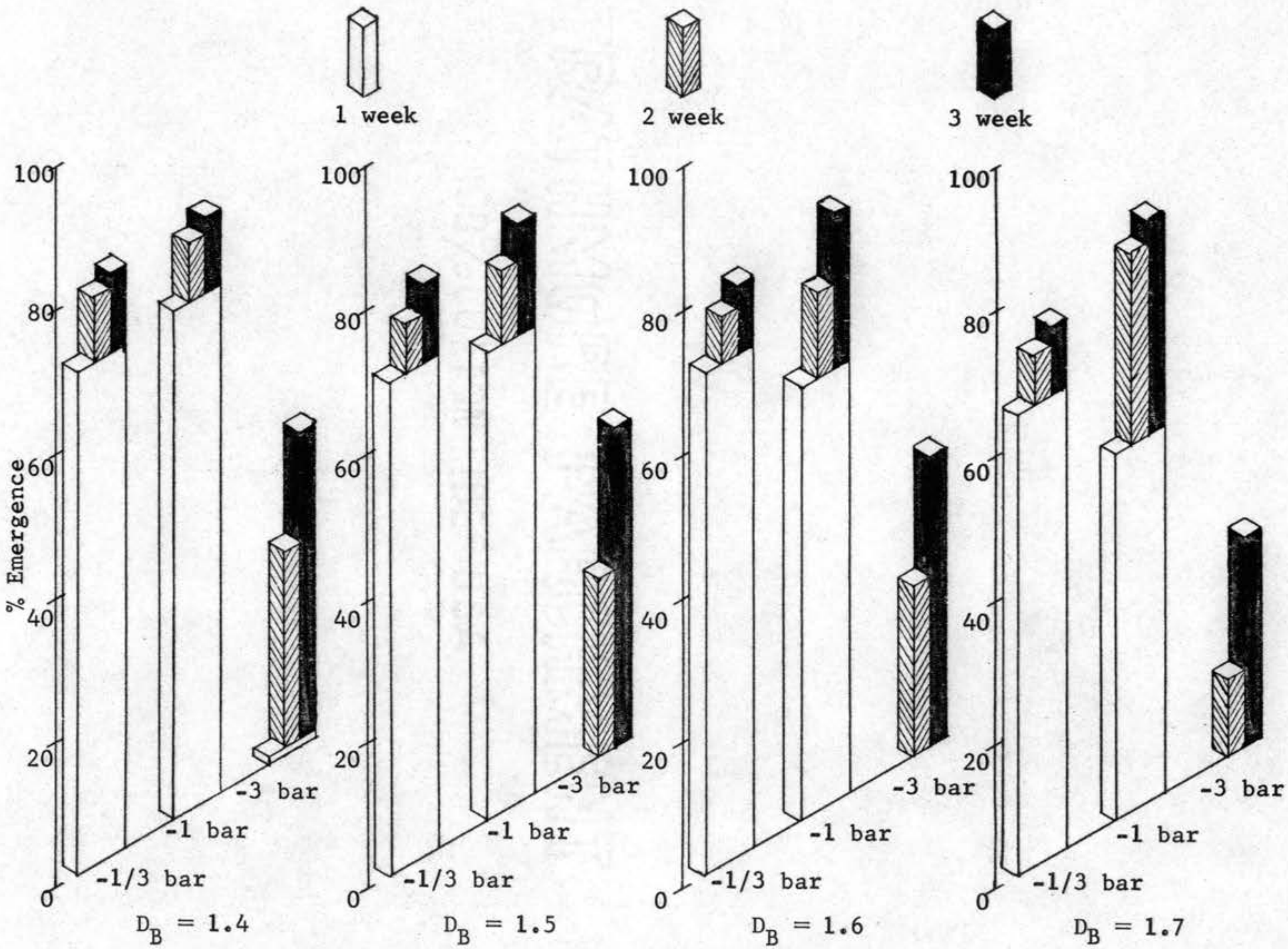

Figure 8. Weekly Seedling Emergence Counts of Weeping Lovegrass for all Levels of Bulk Density and Soil Water Pressure.

TABLE II

ANALYSES OF VARIANCE OF SOIL STRENGTH AND RELATED SEEDLING EMERGENCE FOR COMMON BERMUDAGRASS AND WEEPING LOVEGRASS

Source	df	Common Bermudagrass		Weeping Lovegrass	
		Seedling Emergence Mean Square	Soil Strength Mean Square	Seedling Emergence Mean Square	Soil Strength Mean Square
Total	35				
Reps	2	171.45-NS	323.36-NS	28.00-NS	903.25*
D_B	3	4.26-NS	10279.14**	102.67-NS	10093.58**
Pressure	2	14214.78**	3727.53**	6427.00**	4485.58**
D_B X Pressure	6	163.81*	1013.97**	35.45-NS	971.14**
Error	22	56.29	248.63	85.70	188.25
CV		14.1%	18.1%	14.1%	19.3%

* indicates significance at the 0.05 level.
** " " " " 0.01 "
NS - not significant at the 0.05 level.

CHAPTER V

SUMMARY AND CONCLUSIONS

Moisture is the most important factor influencing the emergence of common bermudagrass and weeping lovegrass seedlings for the range of bulk density and soil water pressure investigated. The low emergence of not more than 20% for bermudagrass and not greater than 44% for lovegrass at the -3 bar pressures may have been higher if more than 3 weeks had been allowed for the germination and emergence period. Both grasses gave approximately the same emergence at the -1/3 and -1 bar pressures.

Considerable variation was present in the soil strength determinations. None of the strengths up to 11.2 Kg/cm^2 that were developed in the combinations of bulk density and soil water pressure appeared to limit the emergence of either grass. Very low correlation coefficients between strength and emergence of -0.0058 for bermudagrass and -0.0679 for lovegrass were obtained.

None of the oxygen diffusion rates appeared to limit emergence of either grass. No critical oxygen diffusion rate can be named but it probably was below 9.7×10^{-8} $gm/cm^2 min$ for both grasses.

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