EFFECT OF PHYSICAL SOIL PROPERTIES ON COTTON EMERGENCE

Prediction and Quantitative Description

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EFFECT OF PHYSICAL SOIL PROPERTIES ON COTTON EMERGENCE

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SUMMARY

A mathematical model for simulating cotton emergence is presented with accompanying verification. The effects of soil temperature, moisture, physical impedance, and planting depth on emergence are described. A method of estimating maximum expected emergence from planting depth and standard seed germination percentage information is presented. The model provides reliable emergence estimates for situations where the level of each parameter is within given limits. In general, this will encompass a wide range of conditions normally encountered during the planting season across the Cotton Belt. However, in severe climates, where the vigor of the seed changes after planting, the emergence model is not applicable.

INTRODUCTION

The direct cost of planting is small compared with certain other production operations, but the influence of planting lasts for the duration of the season. The stand of seedlings is the initial condition from which the crop grows and matures. Stand uniformity or lack of it in the beginning seedling population greatly affects the management of the crop for the duration of the crop year.

The physical properties of the soil surrounding the seed during germination and emergence affect the magnitude and uniformity of the stand. Bowen [1] identified soil temperature, moisture, compaction over the seed, and aeration as factors that can individually control cotton emergence. These factors are called limiting factors since each can individually prevent emergence if its level is outside the range in which emergence can occur.

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[1] Bowen, H. D. MEASUREMENT OF EDAPHIC FACTORS FOR DETERMINING PLANTER SPECIFICATION. Amer. Soc. Agr. Engin. Trans. 9: 725–735. 1966.

Previous work by the author [2] resulted in the estimation of coefficients in the one-dimensional diffusion equation that are dependent on soil temperature and moisture. These coefficients describe water uptake rate by a germinating seed. Similar coefficients, which describe the rate of cotton hypocotyl elongation, were developed for the well-known sigmoid growth equation. The hypocotyl elongation coefficients are dependent on soil temperature, moisture, and physical impedance. The equations that describe water uptake by the seed and hypocotyl elongation were used in a model for simulating the germination of cottonseed and the subsequent hypocotyl elongation.

The scope of the germination and hypocotyl elongation model was enlarged in the present study by relating mean hypocotyl length to percentage of hypocotyls in a population of germinating cotton seedlings that are greater than specified lengths. When the specific lengths are equated to different planting depths, an estimation can be made of percentage of hypocotyls that are greater than a given planting depth, or, described differently, of percentage emergence. The percentage emergence model has received field verification.

This bulletin briefly describes the model and its verification. Then the model is used as a simulator to show the independent influence that selected physical soil properties have on cotton emergence.

DESCRIPTION OF MODEL

The general logic of the emergence model is summarized in figure 1. Emergence is divided into two separate periods, referred to as germination and hypocotyl elongation. Germination extends from the time of planting until the mean radicle length reaches 3 mm. Germination progress is related to the rate of water absorption by the seed, which is dependent on the level of soil temperature and moisture. The water absorption rate increases between 16° and 38° C, but is assumed to cease below 16° C and level off above 38 C. Germination occurs when the moisture content of the seed exceeds a specific level for a given soil temperature and moisture. The specific moisture levels were determined from empirical data.

Hypocotyl elongation begins with the completion of germination and depends on soil temperature, moisture, and physical impedance. During this phase the average hypocotyl length of the seedling population is described by the model. Temperature

[2] Wanjura, D. F. A MODEL OF COTTON GERMINATION AND EMERGENCE. Unpublished Ph. D. dissertation, University of Arizona, 144 pp. 1971.

limits for hypocotyl elongation are 16° and 40° C. Temperatures outside this range interrupt hypocotyl elongation.

The percentage of emerged seedlings is calculated from a set of regression equations. These equations were developed from experimental data that relate mean hypocotyl length and soil-moisture tension to the percentage of seedlings that exceed specific planting depths. For example, if the model indicates

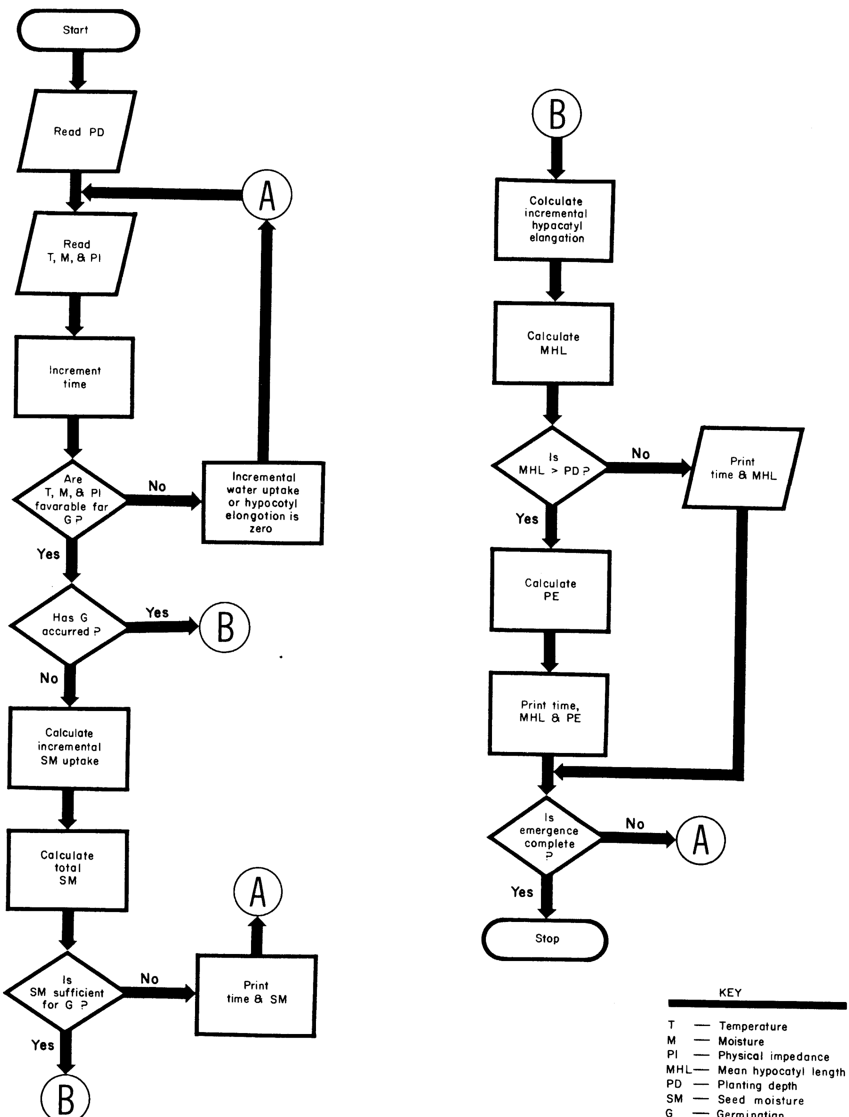

FIGURE 1.—Flow chart of cotton emergence model.

that mean hypocotyl length is 4 cm and that planting depth is 3.8 cm, and if the regression equation calculates that 50 percent of the seedling hypocotyls are equal to or greater than 3.8 cm, then 50-percent emergence has occurred from a 3.8-cm planting depth. Percentage emergence, of course, for the same mean hypocotyl length would be lower if the planting depth were greater.

VERIFICATION OF MODEL

Data for verifying the emergence model were taken from published information and from studies conducted after development of the model. The predicted and observed emergence times are presented in table 1. The model predicts observed initial emergence time very closely at constant temperatures between 19° and 32° C. The model predicts a greater emergence time at 35° and 39°, but agrees with the observation of "no emergence" at 40° C.

A second comparison with the emergence model was made against data from field studies at Lubbock, Tex. In the field study the hours of seed-level soil temperatures greater than 17.8° C were counted to obtain initial emergence time when temperature was the only limiting factor. Table 2 gives model predictions at different mean temperatures for a sinusoidally varying temperature regime. The simulations of specific temperature regimes

TABLE 1.—*Observed and predicted emergence times at constant temperatures*

Soil temperature (° C)	Emergence time	
	Observed [1]	Predicted [2]
	Hours	*Hours*
40	No emergence	No emergence
39	71.2±0.823	305
35	65.4± .574	76
32	72.2± .803	74
28	89.1± .911	89
25	109.6±1.351	110
22	145.7±2.195	142
19	234.3±3.477	221

[1] Observed data from Camp, A. F., and Walker, M. N. SOIL TEMPERATURE STUDIES WITH COTTON. II. THE RELATION OF SOIL TEMPERATURE TO THE GERMINATION AND GROWTH OF COTTON. Fla. Agr. Expt. Sta. Bul. 189: 17–32. 1927. Camp and Walker planted 'Express 432' 3.8 cm deep in sterilized soil with 1.3 to 1.9 cm of ground cork over the soil.

[2] Predicted values are based on 5-percent emergence from 5.0-cm planting depth.

TABLE 2.—*Time required for initial cotton emergence, predicted by percentage emergence model* [1]

Mean temperature (° C)	Emergence time	
	Total	Above 18° C
	Hours	*Hours*
16	338	120
18	218	119
21	154	100
24	119	85
27	102	102
29	95	95
32	109	109
35	112	112
38	119	119

[1] The assumed conditions for the simulations are as follows: Temperature pattern is a sine curve with an amplitude of 8° C, planting depth is 5.0 cm, soil-moisture tension is 0.33 bars, physical impedance is 0.42 kg/cm^2, and seed germination percentage is 90 percent.

in table 2 cannot be directly compared to specific field plantings, but general comparisons are possible. The simulated results show emergence times of 85 to 120 hours of temperatures greater than 18° for regimes with mean temperatures between 16° and 27° C. In the Lubbock study emergence times ranged from 90 to 111 hours at average temperatures between 15° and 27° C. Compared in this manner, the model agrees favorably with the observations in the Lubbock field test.

Finally, field tests conducted during the 1970–71 growing season over a wide area of the Cotton Belt were simulated with the model. Soil temperatures were recorded hourly in the seed zone. Soil moisture was sampled in the seed drill from planting depth to 1.3 cm below. A penetrometer with a blunt, 0.4-cm-diameter probe was inserted at the soil surface and pushed to seed depth. The accumulated resistance registered by the penetrometer was used as the measure of physical impedance. Soil moisture and physical impedance were measured every other day.

In general, the model simulated observed results satisfactorily. Large deviations between model simulation and field observation were not caused by inadequacies of the model. The emergence model does an adequate job of simulating cotton emergence with properly measured inputs of soil temperature, moisture, and physical impedance. In situations where the moisture front dries to seed level or below before emergence, measurements of soil moisture in the seed zone do not measure the soil moisture that the radicle is exposed to as it grows downward. In such situations the model underestimates the amount of emergence because the soil moisture input is not a true measure of that available to the cotton radicle.

The importance of realistic soil-moisture input to the model is illustrated by two examples. In the first example, a test planting made on April 30, 1970, at Auburn, Ala., soil drying was very slow, and moisture tension in the seed zone (from seed level to 1.3 cm below) was less than 0.45 bars during the first 192 hours, followed by a gradual increase to 1.94 bars at 243 hours after planting. A 2.67-cm rainfall fell approximately 10 hours before initial emergence. Soil temperatures at seed level were favorable for emergence except for 6 hours of temperature ranging from 13° to 15° C. Soil compaction over the seed was moderate, resulting in low physical impedance. These favorable conditions resulted in excellent emergence. The simulated emergence curve closely approximates observed emergence points in figure 2.

An example of incorrect soil-moisture input is shown in figure 3. In this test, planted at Lubbock, Tex., on April 28, 1971, no rainfall was received after planting, and moisture tension in the seed zone was less than 0.9 bars before 168 hours, 1.4 bars between 169 and 289 hours, 2.4 bars at 289 hours, and 3 bars after 338 hours of elapsed time. Temperatures were favorable through-

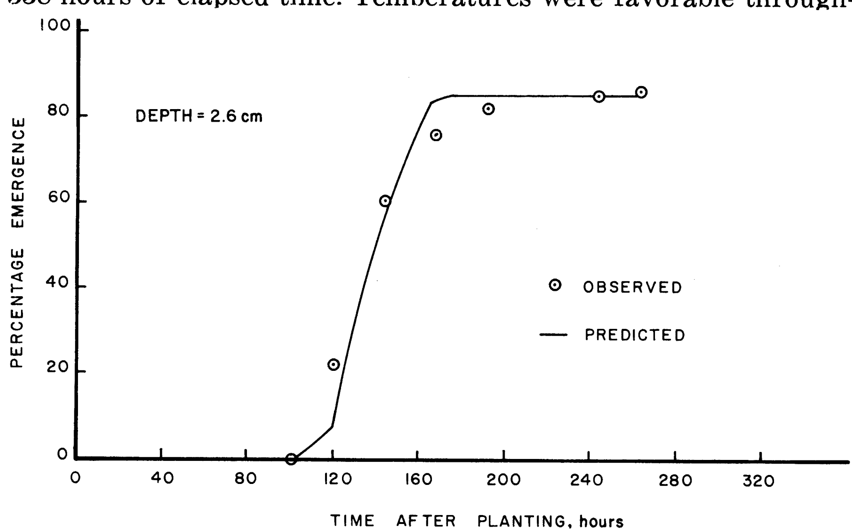

FIGURE 2.—Simulation of cotton emergence from test planted at Auburn, Ala., on April 30, 1970.

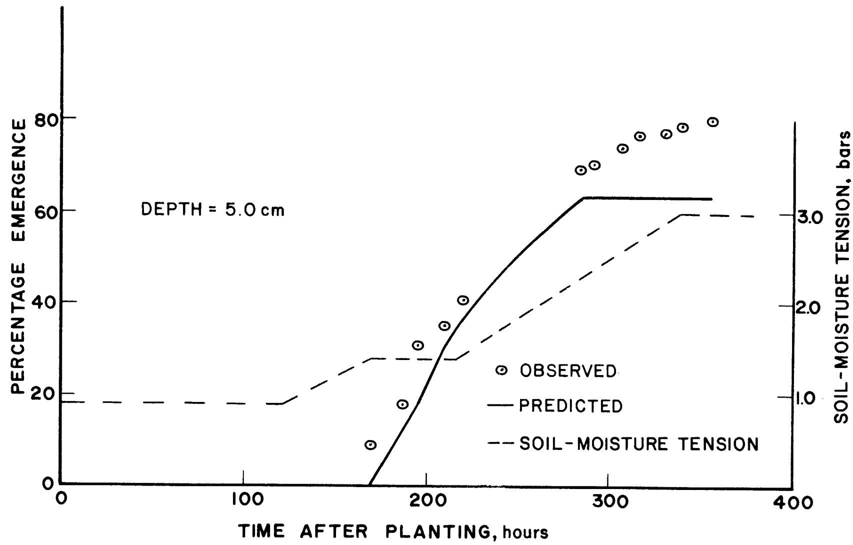

FIGURE 3.—Simulation of cotton emergence from test planted at Lubbock, Tex., on April 28, 1971.

out the emergence period with only 9 hours between 13° and 15° C, and these occurred after 350 hours. Soil compaction was low throughout the emergence period. As shown in figure 3, simulated emergence compares fairly well with field observations until the soil-moisture tension reached approximately 2.5 bars. Afterwards the reported soil-moisture tension caused the model to predict significantly less emergence than was observed. The seedling radicle was actually growing in moist soil, but the seed zone soil moisture, the input to the model, was low. Hence, the model predicted less than actual emergence.

EFFECT OF PHYSICAL SOIL PROPERTIES ON EMERGENCE

It is common knowledge that adequate soil moisture, low physical impedance, and favorable soil temperatures produce a rapid and high percentage of seedling emergence. However, without a simulation model, it is difficult to give numerical value to such qualitative descriptions. Field tests are not a satisfactory method for estimating the primary effects of a single parameter since many parameters are likely undergoing simultaneous change. A mathematical model, however, allows easy and rapid manipulation of inputs; thereby, the effects of single or combined variables can be studied.

The effects of soil temperature, soil moisture, soil physical impedance, and planting depth on cotton emergence were estimated with the model. While one parameter was varied, the other parameters were held at optimum levels. Possible changes in seed vigor due to adverse soil environments were not considered.

The predicted effects are given in graphs (figs. 4–12). In these illustrations, the constant parameter values are given under the heading "Parameters." The temperature regime in all cases varies as a simple sine wave having a 24-hour period. The following symbols are used:

- *D* Planting depth, in centimeters.
- *GP* Standard seed germination percentage.
- *M* Soil-moisture tension, in bars.
- *PI* Physical impedance, in kilograms per square centimeter.
- T_M Daily mean temperature, in degrees Celsius.
- T_S Daily temperature swing (maximum minus minimum temperature), in degrees Celsius.

Temperature

The influence of soil temperature on emergence is shown in figures 4 and 5. The same maximum emergence occurs regardless of mean temperature, except for the mean temperature of 16° C in the 11° C temperature swing (fig. 4). The primary influence of temperature is expressed in the changing rates of emergence: Higher temperatures result in faster rates of emergence.

The daily temperature swing also affects rate of emergence. For high-temperature regimes, such as the 24° and 27° C curves, the 11° C swing produces a faster rate of emergence than does the 22° C swing. The effects of these temperature swings on rate of emergence is reversed at lower temperature regimes such as the 21°, 18° and 16° C curves. A temperature swing of 22° C produces faster emergence for the 21°, 18°, and 16° C curves than for a swing of 11° C. An 11° C swing would be typical of the Southeastern United States, while a 22° C swing would be characteristic of the Far West. The reversed effect of temperature swing at high and low mean temperatures implies that at low mean temperatures (18° C or below) slightly faster emergence should occur in the western areas of the Cotton Belt than in the eastern areas. The main influence of temperature over a wide range is that of regulating the rate, not the magnitude, of emergence.

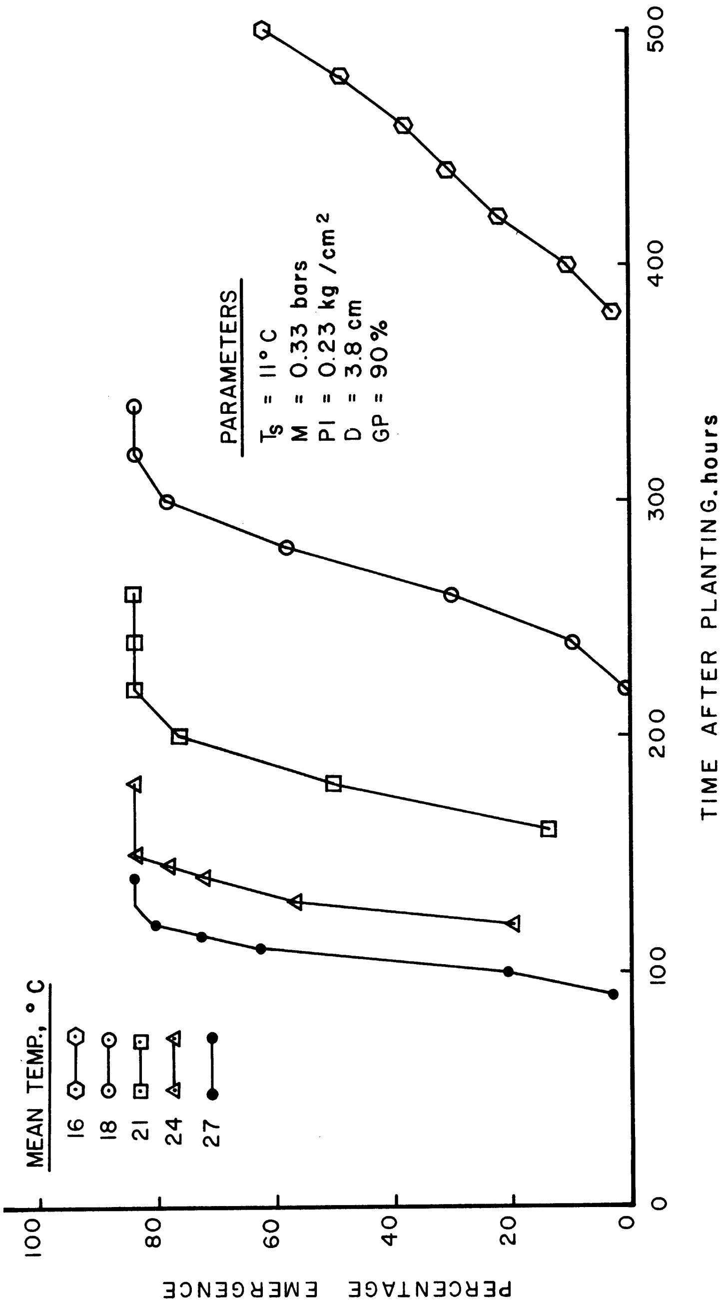

FIGURE 4.—Predicted cotton emergence from sinusoidal temperature regimes having different mean temperatures with a common daily temperature swing of 11° C.

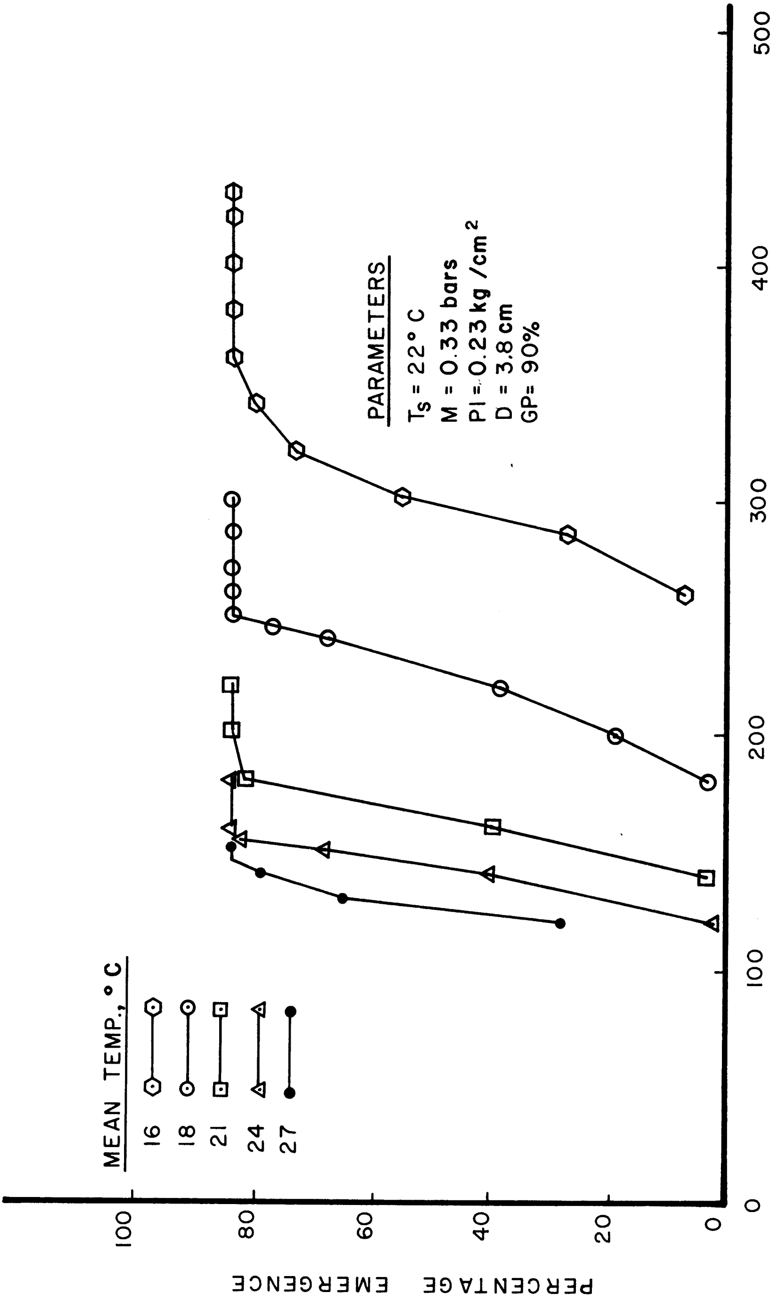

FIGURE 5.—Predicted cotton emergence from sinusoidal temperature regimes having different mean temperatures with a common daily temperature swing of 22° C.

Moisture

Soil moisture influences both the magnitude and rate of emergence. Maximum emergence decreases almost linearly with increasing soil-moisture tension (fig. 6). Rates of emergence at 0.33- and 1-bar moisture tensions are similar, but a pronounced slowdown occurs at moisture tensions of 3 and 6 bars. Ideally, soil-moisture tension at seed depth should be near field capacity at planting. The optimum soil moisture range for emergence occurs when the soil-moisture tension around the radicle is 1 bar or less. Emergence should cease if soil-moisture tension approaches 3 bars or more.

Soil Physical Impedance

The main effects of physical impedance on emergence are shown in figure 7. Physical impedance is considered to be cumulative as hypocotyl length increases, reaching its maximum value just before seedling emergence. The physical impedances in figure 7 represent conditions ranging from low to extremely high. As physical impedance increases, emergence percentage decreases, and time to reach a given level of emergence increases.

The simulation in figure 7 depicts a situation where soil compaction is uniform with depth and cumulative physical impedance increases linearly from seed level to the soil surface. Other simulations were run for linearly increasing physical impedances that began at three-fourths and one-half of planting depth. These correspond to soil-crust thicknesses one-fourth and one-half of planting depth, whereas the soil-crust thicknesses in figure 7 equal planting depth. There were no differences in emergence rate or magnitude among crust thicknesses at physical impedance levels of 0.42 and 0.70 kg/cm^2. At 0.98 and 1.41 kg/cm^2 emergence rate and magnitude decreased with increasing crust thickness.

Planting Depth

The influence of planting depth on emergence in a favorable soil environment is shown in figure 8. As with soil moisture and physical impedance, changing the planting depth also changes the magnitude of emergence and the time to reach a particular level of emergence. Deep-planted cottonseed will produce less emergence than seed from a shallow depth, provided soil moisture is optimum at both depths. Often it is necessary to increase planting depth in order to insure that sufficient moisture will be available to the seedling during emergence. Consequently, field-planting depth should be a compromise where the advantage of planting shallow is balanced against the likelihood of drying out at a

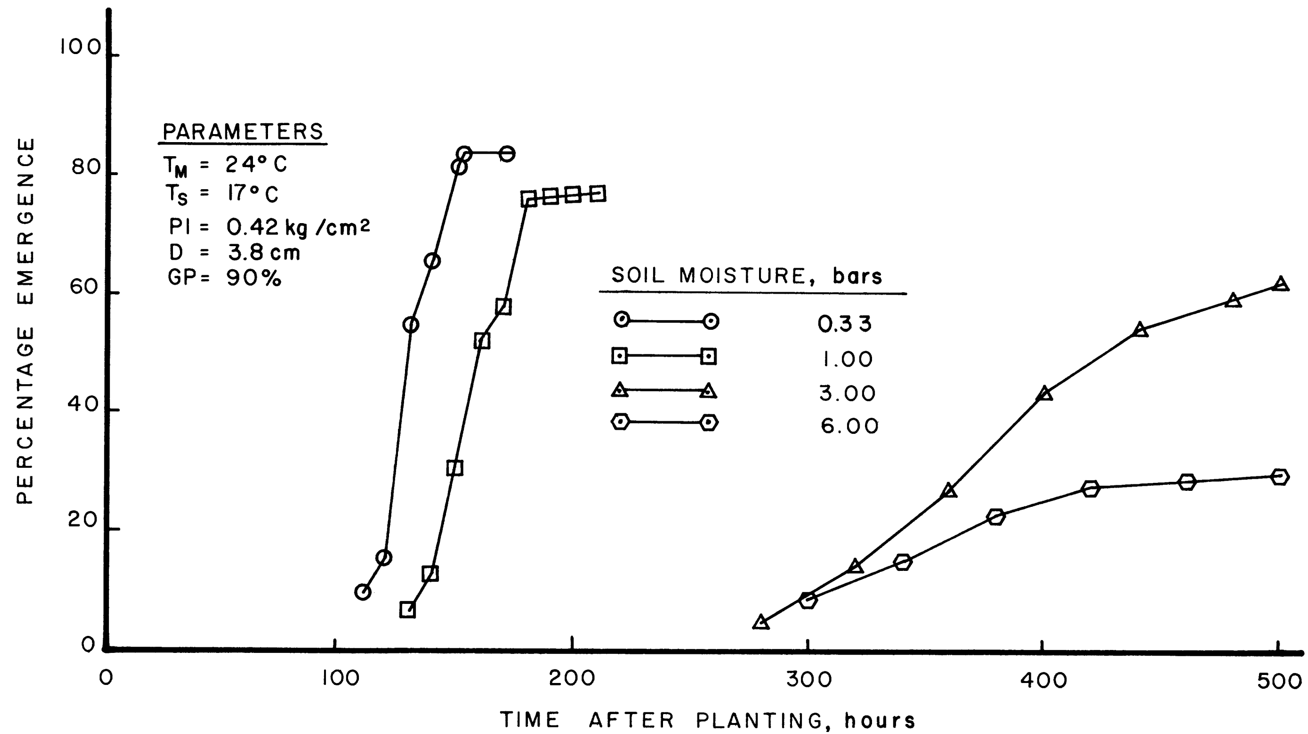

FIGURE 6.—Simulated effects of soil-moisture tension on cotton emergence where other physical soil parameters are at optimum levels.

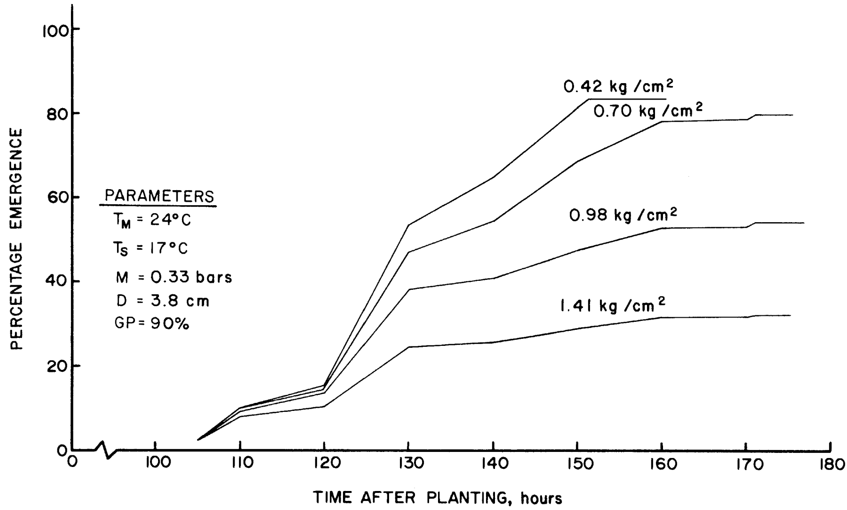

FIGURE 7.—Simulated effect of soil physical impedance on cotton emergence where other soil physical parameters are at optimum levels. Impedance levels represent cumulative resistance from seed level to the soil surface for a uniformly compact soil.

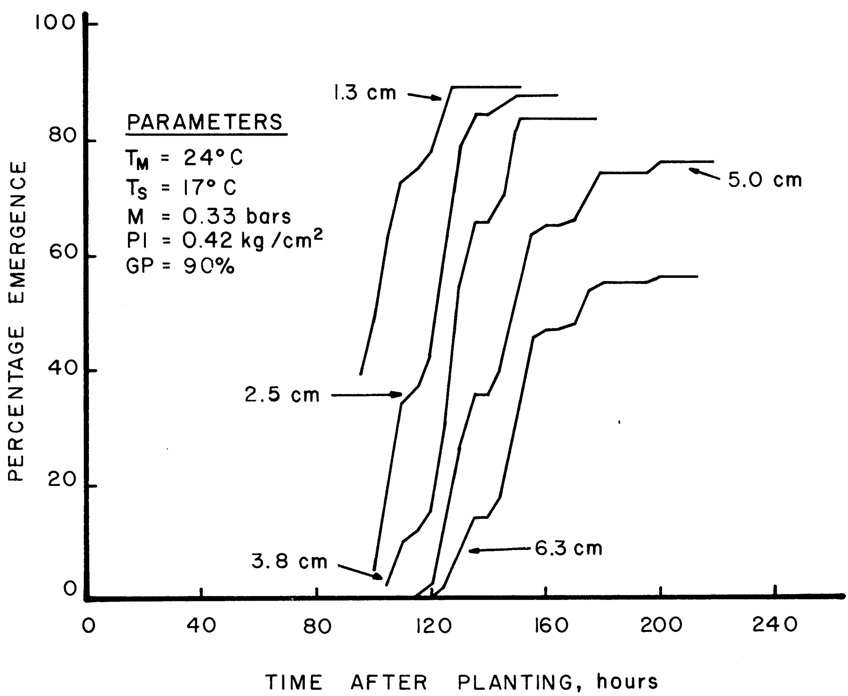

FIGURE 8.—Effect of planting depth on cotton emergence where other physical parameters are at optimum levels.

shallower depth. Established planting depths in different areas of the Cotton Belt have evolved as the best compromise between available soil moisture and the benefits of shallow planting.

Comparison of Planting Depth and Physical Impedance

Increasing depth can be viewed as presenting greater physical impedance. To illustrate this, simulations were run for a combination of planting depths and physical impedances (figs. 9 and 10). The similarity of the curves in the two figures indicate that physical impedance and planting depth exert similar effects on cotton emergence. However, the influences of planting depth and physical impedance on emergence are not independent. A marked interaction between depth and physical impedance on emergence is evident in figures 9 and 10. The reduction in maximum percentage emergence at constant physical impedance becomes increasingly greater as depth increases (fig. 9). Likewise, the reduction caused by a specific level of physical impedance in figure 10 is dependent on planting depth. A series of parallel curves would result if interaction were not present.

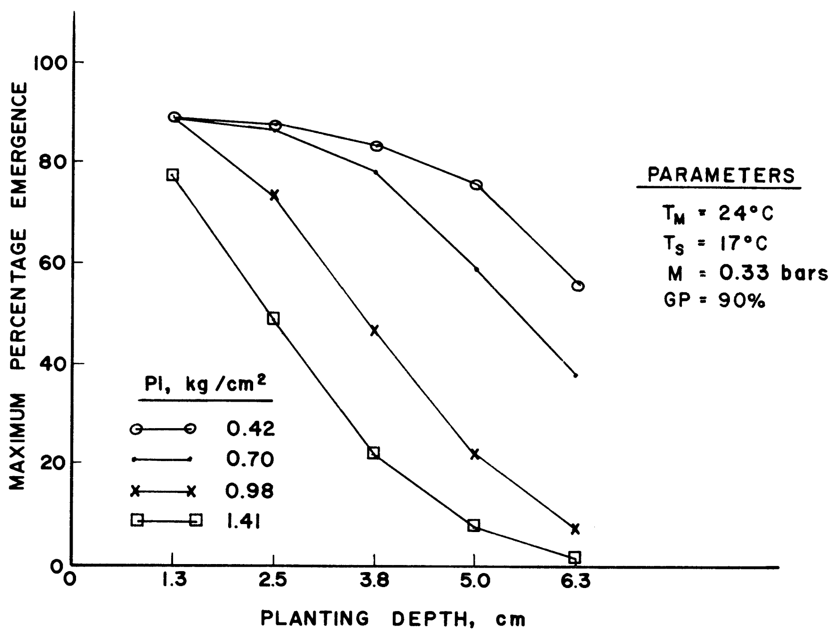

FIGURE 9.—Influence of constant levels of cumulative physical impedance on cotton emergence for different planting depths.

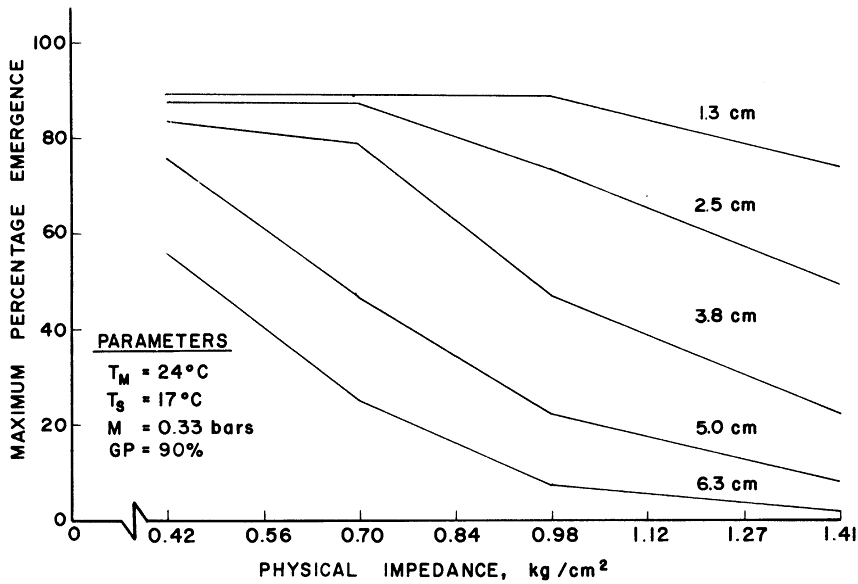

FIGURE 10.—Influence of several planting depths on cotton emergence for different levels of cumulative physical impedance.

Rising Versus Falling Temperature Regimes

Cotton planting early in the season is often complicated by unstable weather conditions. In another simulation a planting followed by a period of rising temperatures and then by a period of falling temperatures (warm-cold regime) was contrasted with a planting followed by falling temperatures and then by a period of rising temperatures (cold-warm regime). The warm-cold simulation (fig. 11) indicates that initial emergence from a 1.3-cm planting depth occurs about 192 hours after planting and reaches a maximum emergence of 84 percent. Severe reductions in emergence are indicated for the other assumed planting depths.

The cold-warm regime causes a delay in initial emergence until about 288 hours after planting at the 1.3-cm depth; however, the predicted maximum emergence increases slightly to 88 percent (fig. 12). Emergence from other depths occurs at slower rates, but for each depth maximum emergence is significantly greater than for the equivalent depth shown in figure 11. Thus, neglecting differences in seed deterioration that might occur in the two temperature regimes, a cold-warm regime should give greater maximum emergence and a more uniform seedling stand since the plants would be emerging over a shorter time span than they would in a warm-cold regime.

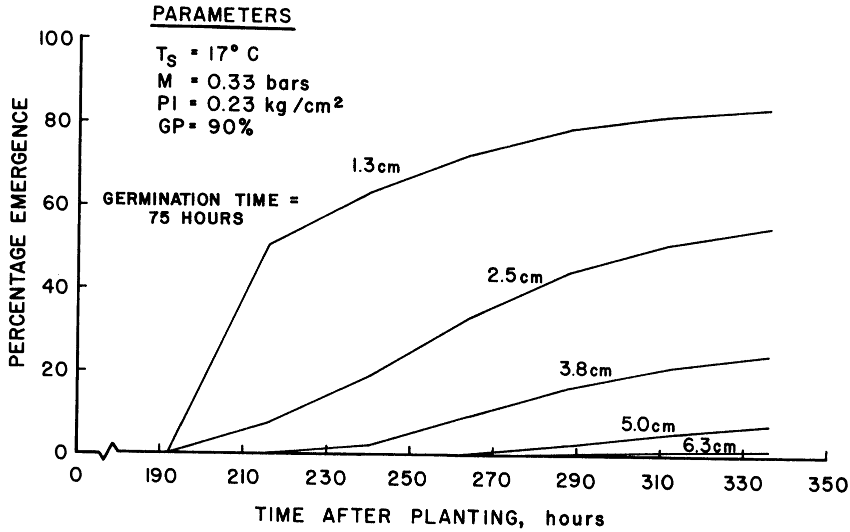

FIGURE 11.—Simulated cotton emergence resulting from a warm-cold temperature regime. Twenty-four hours after planting the mean daily temperature rose 1.1° C per day for 4 days, followed by a decrease of 1.1° C per day.

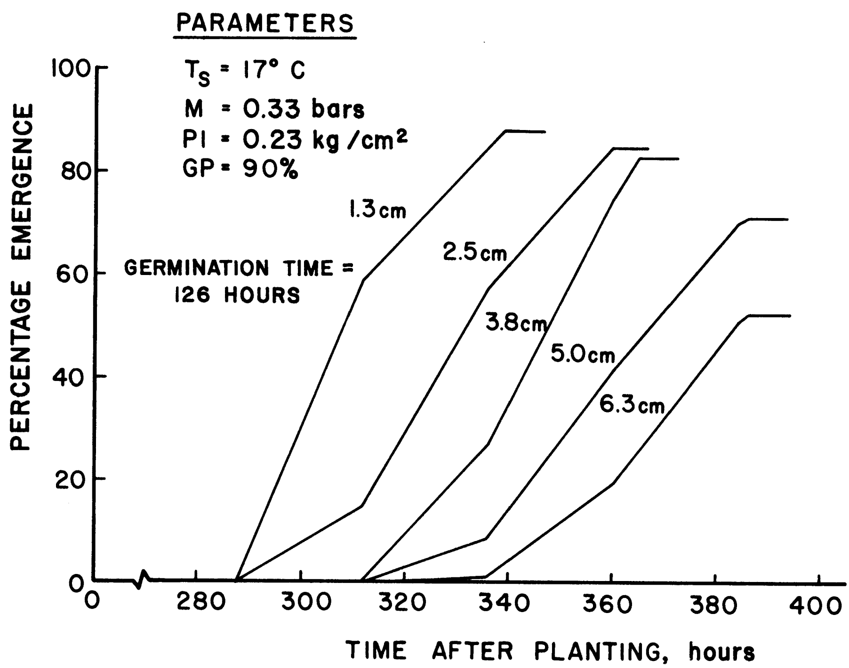

FIGURE 12.—Simulated cotton emergence resulting from a cold-warm temperature regime. Twenty-four hours after planting the mean daily temperature decreased 1.1° C per day for 4 days, followed by an increase of 1.1° C per day.

ESTIMATING PERCENTAGE EMERGENCE

The ability to predict emergence in different weather conditions is potentially a useful tool for the cotton producer and researcher interested in developing improved techniques or equipment for planting cotton. The basic relationship in the predictive method in figure 13 is the dimensionless ratio: emergence percentage divided by germination percentage plotted against planting depth. The relationship in figure 13 was developed from the 0.42 kg/cm^2 curve in figure 9 by dividing the maximum emergence percentages for each of the planting depths by the standard seed germination percentage. Thus the curve in figure 13 is independent of seed germination percentage. The curve in figure 13 is limited to optimum soil conditions.

One needs to know the planting depth and standard seed germination percentage to use figure 13. For example, if planting depth is 3.8 cm, the ratio taken from the curve would be 0.93. By multiplying germination percentage by 0.93 one could estimate the maximum emergence percentage under optimum condi-

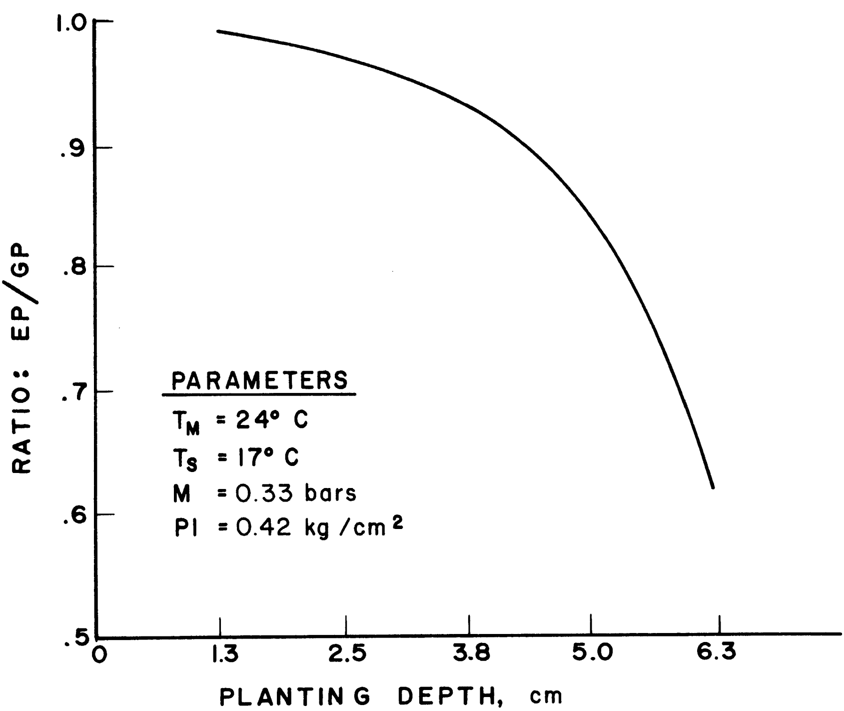

FIGURE 13.—Relationship between the ratio of maximum emergence percentage/standard germination percentage and planting depth under optimum environmental conditions.

tions. If the standard seed germination percentage is 90 percent, maximum emergence percentage would be 84. The validity of the relationship shown in figure 13 was tested with emergence data (table 3). The predicted results compare very favorably with field observations, with the exception of Clemson, S.C., and Lubbock, Tex., in 1970. In the other comparisons the predicted results were within plus or minus 8 percent of maximum observed emergence.

The relationship shown in figure 13 is an easy method for estimating how much emergence to expect if all conditions are optimum. This can be used by a producer to estimate how many pounds of seed to plant. Late in the season he might expect conditions to be near optimum and could expect emergence close to that indicated by figure 13; however, early in the season he could expect emergence to be lower. For the individual involved in developing planting equipment, figure 13 can serve to estimate how close emergence from a particular planting test comes to the theoretical maximum. This information, along with a soil temperature, moisture, and physical impedance, can be used to determine whether reduced emergence was caused by unfavorable physical soil conditions. A knowledge of weather conditions will then make it possible to attribute unfavorable soil environment to above-ground environment or perhaps to the planting equipment or planting technique used.

TABLE 3.—*Comparison of field emergence and predicted emergence, from the* EP/GP-*depth curve (fig. 13) for optimum soil environmental conditions*

Location	Planting depth	*EP/GP*	Maximum emergence: Observed	Maximum emergence: Predicted	Difference [1]
	Cm		*Percent*	*Percent*	*Percent*
1970					
Clemson, S. C	3.2	0.95	99.7	82.7	20.6
Chickasha, Okla	3.8	.93	81.3	86.5	−6.0
Auburn, Ala	2.6	.97	86.3	85.4	1.1
Lubbock, Tex	5.0	.84	100.0	78.1	28.0
1971					
Baton Rouge, La	2.5	.97	91.7	87.0	5.4
Do	2.8	.96	92.6	86.0	7.7
St. Joseph, La	5.0	.84	77.8	75.6	2.9
State College, Miss	3.8	.93	75.5	81.0	−6.8
Lubbock, Tex	5.0	.84	80.8	75.0	7.7
Auburn, Ala	3.0	.95	96.5	89.3	8.1

[1] Observed emergence minus predicted emergence divided by predicted emergence: $(O-P)/P$.

Relationships similar to the information in figure 13 are developed in figures 14 and 15 for different levels of soil compaction and soil-moisture tension. The procedure for using figures 14 and 15 is the same as that used in figure 13. Estimates derived from figures 14 and 15 are only applicable for the conditions specified in the figures and the specific curves within the figures.

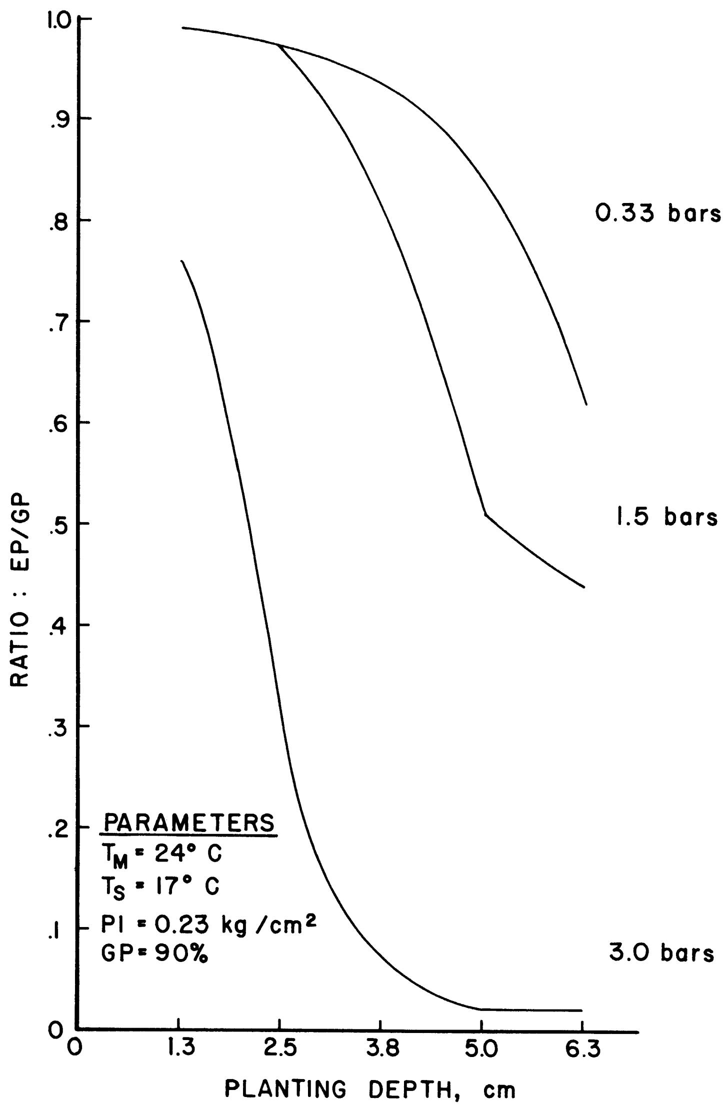

FIGURE 14.—Relationship between the ratio of maximum emergence percentage/standard germination percentage and planting depth for different soil-moisture tensions.

Although figures 14 and 15 have not been verified with field data, they are believed to be accurate. The information presented in the figures is based on simulations with a model that received verification for conditions where soil environment is optimum (fig. 13). and overall verification from extensive field emergence tests. It is most important that the soil parameters be accurately measured so that the proper curve within a figure can be used.

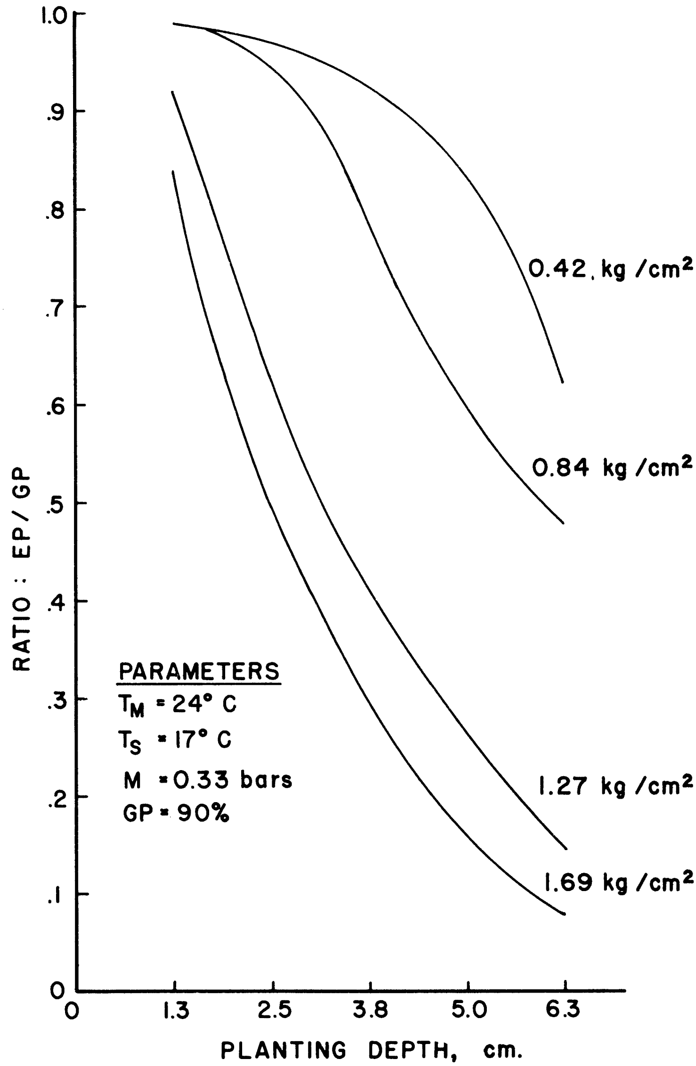

FIGURE 15.—Relationship between the ratio of maximum emergence percentage/standard germination percentage and planting depth for different levels of soil physical impedance.

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