THE INTERRELATION BETWEEN EMERGENCE FORCE AS MEASURED BY A MECHANICAL SEEDLING AND EMERGENCE OF PLANT SEEDLINGS

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Osman A. Shinaishin

1960

This is to certify that the

thesis entitled

The Interrelation Between Emergence
Force as Measured by a Mechanical
Seedling and Emergence of Plant Seedlings

presented by

Osman A. Shinaishin

has been accepted towards fulfillment
of the requirements for

M.S. degree in Agricultural Engineering

Wesley F. Buchele
Major professor

Date Aug 18, 1960

O-169

THE INTERRELATION BETWEEN EMERGENCE FORCE
AS MEASURED BY A MECHANICAL SEEDLING
AND EMERGENCE OF PLANT SEEDLINGS

by

OSMAN A. SHINAISHIN

AN ABSTRACT

Submitted to the College of Agriculture of Michigan
State University of Agriculture and Applied
Science in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

Department of Agricultural Engineering

Year 1960

Approved Wesley F. Buchele

ABSTRACT

The effect of the soil physical condition on seedling emergence is appreciated by crop growers as well as by soil scientists and designers of planters. To determine this effect in clear definite measures is of primary importance for developing better tillage machinery and planters to secure the best possible standings of plants.

Soil strength is one of the important parameters of the soil physical conditions. There are other features, such as aeration, temperature, and others, but they were not included in this research.

Soil strength in turn is a function of soil moisture and compaction pressure as well as the soil's history.

In this research Brookston sandy loam was used to determine the relationship between soil strength and plant emergence. Different moisture contents and different compaction pressures were used. The drying period was varied and the depth of planting was different for the various experiments. In 3 experiments, water had to be added to the soil to induce the seedlings to emerge and to obtain a basis for comparison between the different conditions. The soil was screened and moistened to the desired moisture content. The boxes were planted with sugar beet seeds or corn seeds at the desired depths. Pressure was always

applied both at the seed level and at the surface. Emergence of the seedlings was recorded daily. The emergence force, determined from paired boxes under the same conditions, was measured at different intervals.

Under the controlled laboratory conditions, these tests show that soil strength was always inversely related to the emergence of seedling in each experiment.

A drying period following the planting markedly increased emergence force and decreased seedling emergence. Seedlings emerged better from sugar beet seeds planted at ½-inch depth under no drying conditions than from those planted at 1-inch depth under drying and wetting conditions.

At high moisture contents under no drying conditions almost no difference in the emergence was observed between compaction pressures of ½ psi, 3 psi, but severe reduction in emergence occurred when the planting (under 1.7 psi compaction pressure) was followed by 2 days of drying.

Under non-drying conditions high compaction is more detrimental to seedling emergence at low soil moisture contents (12%) than at higher moisture content (16% and 20%).

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12-21-60

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to his major professor, Dr. W. F. Buchele, whose supervision and dynamic guidance made this study possible.

Sincere thanks are due to Drs. F.W. Snyder, B. A. Stout, and I. E. Morse, members of the guidance committee, for their many helpful suggestions.

The writer greatly appreciates the help of Dr. C. Tatro of the Applied Mechanics Department for supplying the electronic equipment used in the research.

Acknowledgements are also due Mr. James Hendrick, Graduate Assistant in Agricultural Engineering for supplying many useful references, and Mr. George Keller for helping in conducting the experiment.

The writer wishes to express his sincere thanks to Dr. A. W. Farrall, Head of the Agricultural Engineering Department. He kindly approved all the expenses for the project.

Special thanks are extended to Mr. James Cawood for his helpful suggestions and cooperation.

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INTRODUCTION

Soil is the basic, fundamental property of agriculture. It is the bed of seed germination, the cradle of seedling emergence and the supplier of many of the requirements for growth.

To maximize the utilization of the soil, one must understand the relation between soils and plants. Many aspects have been discovered relating the soil to the growth of plants, but much less has been determined about the relation of the soil to the seed and seedling. It is known, however, that much of the effect of the soil on seeds and seedlings is due to its physical characteristics, their support, looseness and their impedance to germination and emergence.

It would be reason enough to conduct research to determine exactly the impedance of the soil to emergence just to complete our knowledge about what is taking place below the surface of the soil. But the fact is that we need also to collect information in order to determine the proper ways of tilling our land for best yields. To design a tillage machine we must know in detail the type of seed bed to prepare. Field studies must be supplemented by laboratory studies if needed basic information is to be obtained. This has not yet been accomplished. No single value or group of values exists today which express the optimum conditions for plant growth.

This research is a link in a chain of work being done to analyze the mechanical relation of soil to emerging seedlings and an attempt to place all factors in this relation in mathematical equations usable by designing engineers. It was conducted to determine the effect of soil impedance on seedling emergence under varying conditions and the seedling response to those impedances.

REVIEW OF LITERATURE

The physical factors affecting the emergence of plant seedlings have been studied in detail by soil scientists and agricultural engineers. These factors are as follows:

1. Moisture content
2. Porosity and aeration
3. Temperature
4. The mechanical impedance of the soil

A large amount of research work has been conducted on the first three factors. It is well known that seeds germinate and seedlings emerge only within certain limits of soil moisture content, of porosity and soil temperature. An extensive review of that work on moisture, aeration and temperature effects on germination of seeds and emergence of seedlings was presented by Stout (1959).

The mechanical impedance of soil (due to its strength) to the emerging seedling has long been recognized, and the experienced observer can differentiate between soils concerning their expected impedance to an emerging seedling. Of the several factors that have been demonstrated to affect the strength of the soil and its resistance to penetration, compaction is considered the most important. Compaction increases the bulk density of the soil, decreases pore volume, increases the percentage of small pores volume while decreasing the percentage of large pores volume and thus decreases aeration. Soil compaction has been defined in relative terms rather than absolute values. It is normally thought of in terms of bulk density (bulk weight of material per unit volume). Another concept is in terms of hardness by measuring the resistance to penetration.

Willets (1954) reported an increase of soil strength with aging. He stated that aging (time factor) slightly increases the soil strength. However, he was unable to separate the effect of moisture loss from that of aging. Winkler(1958) speculated that ultraviolet rays and other components of sunlight help increase the soil strength. Gill's experiment (1958) showed that loss of moisture during aging is the reason for the increase of soil strength, and that equal moisture losses in soil samples of same moisture content had identical strength regardless of the time of drying. Morton (1959) obtained similar results and concluded that aging has little or no effect on soil strength particularly when low compaction pressures were applied. Reaves and Nichols (1955) reported an increase in bulk density-at certain applied pressure - with an increase in moisture content (from 9.25 to 17.9%). This increase was small at low pressures (2.5 psi to 5 psi) and large at high pressures (10 psi to 60 psi).

A joint American Society of Agricultural Engineers and Soil Science Society of America Soil Compaction Comcittee (1958) reported that soil moisture is the principal factor determining its mechanical behavior and its cohesive and frictional strength.

Lutz et al., (1946) found a highly significant correlation between penetrability and soil porosity. Parker and Jenny (1945) using a King tube driven 1 inch into the soil reported an increase in bulk density of the cores and an increase in resistance to penetrometers with compactive effort.

To measure soil resistance to penetration many devices have been developed and tested. Shaw et al., (1942) used a recording continuous stress type penetrometer in studies of soil compaction. They decided that soil moisture was the dominant factor influencing the force required to penetrate a given soil type. Culpin (1936) described several penetrometers and the advantages and disadvantages of each.

Browning et al., used a Rototiller soil hardness gauge (developed by Stone and Williams in 1939) to measure the effect of a cover crop on soil compactness. They reported that the results were affected by crusting. This indicates the necessity for extreme care when interpreting data obtained from penetrometers in compaction studies.

Vomocil (1957) mentioned that the penetrometer data can be used as an indication of differences in aeration, permeability to water and mechanical impedance to the growth of plant roots.

The previous review shows that the compaction effect is important on soil physical characteristics. In addition, compaction directly affects seedling emergence.

Seedlings have a limited capacity of penetration. Lutz (1951) stated that the seedlings of almost all common plants will die if the seed is germinated under a stone 2-3 inches in diameter. It was reported that where a crust has formed, emergence of seedlings was extremely poor due to the strength of the crust. Veihmeyer and Hendrickson (1948) concluded that roots would not penetrate any soil when the apparent density was 1.9 or above. This was not due to a lack of aeration but to soil strength. In most types of soils, however, the limiting densities were much lower.

Morton (1959) gave an extensive literature review on soil strength measurement. He studied the soil impedance to penetration, as measured by strain gages when using probes of different diameters, and varied the following combination of factors: Moisture content, compaction, and period of drying. He was able to establish force and energy levels of impedance for certain probes to penetrate a 3-inch layer of Brookston sandy loam soil. He concluded the following:

1. Penetration energy increased directly with soil compaction.

2. Penetration energy increased as initial soil moisture content increased if there was drying.

3. Penetration energy increased directly with length of drying period of the soil, but not with aging if no drying took place.

Lutz (1951), however, suggests that the relative resistance values found with machines on different soils might not apply to plant roots because the root tip is moist (it lubricates the surface of the point contact with the soil and facilitates penetration). In fact roots transfer water between soil layers. In addition, roots have some elastic properties and tend to bend in the direction of loose soil.

STATEMENT OF THE PROBLEM

From the above review, it is clear that the physical conditions of the soil are interrelated. The relationship between the physical conditions of the soil and seedling emergence has been observed and experienced in many cases of poor germination, poor stands of crops and as a result, poor yield.

The objectives of this study are stated in the following points:

1. The hypothesis that "The rate of emergence and the final stand of seedlings is inversely related to the emergence force" was tested. To test this hypothesis,

the soil moisture content, compaction pressure and drying time must be adjusted to give identical emergence forces for seedlings planted under combinations of the above three factors.

2. To determine whether the factors affecting the physical condition of the soil (moisture, pressure, aging and drying) do influence seedling emergence independently. For example, does moisture content of the soil have a certain effect on emergence regardless of the other factors, or do they all contribute, within limits, to a single condition (which we may call impedance or resistance) affecting germination and emergence?

3. To determine the usefulness of the probe used by Morton (1959), and termed "mechanical seedling", as an indication of the actual conditions encountered by the seedlings.

THEORETICAL CONSIDERATION

Newton's first law of motion states that a body left to itself will maintain its velocity unchanged.

From his third principle there is to every action an equal and opposite reaction, and for a motion to continue at a constant rate against a resistance, the body will have to exert a force equal and opposite to the resistive force. It is also an accepted fact that exerting this force requires an amount of energy equal in magnitude to the average force times the distance traveled.

Seedling emergence can be viewed in the light of the above laws. The growing seedling supplies energy for several purposes that can be summed in the following equation:

$$E_t = E_g + E_r + E_e + E_u$$

where E_t = Total energy expended from the seed.

E_g = Energy of growth, includes energy used in cell division and to move the center of weight of the seedling upwards.

E_r = Energy of respiration.

E_e = Energy of emergence.

E_u = Different energies used elsewhere.

The energy of emergence is expended by the seedling tip while reacting against the soil resistance to the motion of the seedling. It is a function of the following:

1. The strength of the soil or its resistance to penetration. This resistance depends on the soil moisture and compaction.
2. The distance the seedling has to move against that resistance.
3. The diameter of the seedling.

The force exerted by the seedling tip is a result of the turgor pressure in the surface cells. The higher the turgor pressure, the more capable the seedling is in penetrating soils. The larger seeds have more energy stored as carbohydrates, proteins, and fats, but they usually have larger seedling diameters and the resistance to penetration would be higher. That presumably explains the failure of a bean seedling to emerge under soil conditions where a corn seedling may emerge with less energy stored in the seed. The soil as a medium for the seedling's growth has varying characteristics that change its impedance to emergence. Most agricultural soils are plastic in nature. The soil generally shears under seedling pressure before emergence takes place.

Earlier studies made on the soil resistance to shear in land locomotion research showed a tendency for the resistance to increase as the moisture decreases and as the compaction pressure increases. Thus, we may expect a decrease in the rate and total seedling emergence as the soil moisture decreases or compaction pressure increases. This trend was demonstrated by most of the data gathered during this research.

Bending of the seedlings occurred when certain compaction pressures were used. The theory of buckling under critical loads may be applied to these cases.

It has been noticed that in many cases the seeds germinated and the roots grew but the seedling did not emerge. This may be due to the fact that drying is a function of time and the drying wave started at the surface and moved downward at a variable velocity.

MATERIALS AND APPARATUS

The materials used in this research consisted of the following:

1. A U.S. No. 16 screen for screening the soil.
2. Jars of about 3000 gram capacity for mixing water and soil.
3. Barrels of about 40 kilogram capacity for further mixing the soil for even distribution of moisture.
4. Plastic sample boxes of about 5 x 7 x 4 inches dimensions with 9 holes in the bottom of each box. The height of soil in box after applying the pressure was 3 inches.
5. Apparatus for packing the soil consisted of a hydraulic system to apply the force which was transmitted to the soil through a ring and a plate of 5 x 7 inches.

   The pressure applied was indicated on a dial that was calibrated earlier and has a sensitivity of 0.025 psi under the conditions of the experiment.
6. A controlled environment room with a $\frac{1}{2}$ ton air conditioning unit to keep the temperature between 66 - 68° F. The relative humidity

was kept between 75 - 80 percent by spraying water on the floor of the room. A hygrometer was used to continuously indicate the relative humidity. All samples were kept in the controlled environment room during the time of experiment. **(Figure 1)**

7. A penetrometer was used for measuring the mechanical impedance of soil to emergence. The apparatus was used by C. T. Morton (1959) to measure the force exerted during the emergence of a mechanical seedling. It consisted of a probe of a known standard diameter mounted on a simply supported beam. The probe and the beam were stationary, and the soil sample box, carried on a plexiglass platform was lowered onto the probe. This force was transmitted to the center of the beam. Four SR-4 strain gages were mounted on the beam to give maximum sensitivity. The strain gages signals were amplified by a Brush Amplifier Model 520 and recorded on a 2-channel oscillograph. Figure 2 is a view of the system.

The mechanical details of the lifting and lowering mechanism for the platform were presented by Morton (1959).

Figure 1: The Air Conditioned Room With ½-Ton Capacity Air Conditioner

Figure 2: View of the Penetrometer System Showing the Rigid Support for the Simply Supported Beam

PROCEDURE IN USING THE APPARATUS

1. The soil was weighed and placed in the jars, calculated amounts of water were added to produce the desired moisture contents. (in one experiment the soil was sterilized first with live steam for 45 minutes). The jars were shaken for a few minutes daily for 3 days, screened and kept in barrels for 3 more days before using.

2. Moisture content checks were made after 6 days The soil was placed in the boxes and the calculated force applied by the hydraulic system to produce the desired compaction pressure. In most cases when the pressure was more than 1 psi the pressure had to be applied twice (once at about 2 inch height and once at 3 inch height) due to the limited height of the box. In all planted boxes, pressure was applied at seed level (½-inch depth in some experiments and 1-inch in the rest), and at the surface.

3. When measuring the emergence energy, a penetration speed of about 4 inches per minute was used. The probe was allowed to penetrate the soil beyond the surface until the force indicated on the recorder reached zero or became constant and negligible, this occurred at ½-inch above surface. The sensitivity was maximized by adjusting the amplification to get the maximum deflection per unit force.

4. The energy expended during emergence was taken as the integral of the force differential produced times the distance traveled by the probe from the seed level till the end of the recording. This was taken as the area under the curve of force versus distance on the recording paper after adjusting the units to produce a value in terms of energy units (inch-pound) as follows:

If an attenuator setting of 20 gives 20 lines per 1 pound, the distance traveled by the recording pen on the paper was 1 inch, while the area traveled by the probe tips from the seed level was $1\frac{1}{2}$ inch, to adjust the y axis (force axis), we notice the following:

1 inch = 25.4 mm = 2.54 pounds.

To adjust the X axis (distance axis) we notice the following:

1 inch on the chart = 1.5 inch traveled.

Actual energy = area on recording paper X 1.5 X 2.54.

Or more generally:

Energy in inch-pound =

$$\frac{\text{area} \cdot \text{distance traveled by probe} \cdot (2.54)}{\text{X (distance on the chart)} \cdot \text{line per pound}}$$

5. Soil moisture was expressed as a percentage (dry basis). A relation between soil moisture content and soil moisture tension can be found in Appendix one.

PRESENTATION AND DISCUSSION

OF EXPERIMENTAL RESULTS

The experiments in this thesis were conducted in the Research Laboratory and the Food Engineering Laboratory of the Agricultural Engineering Building. The soil used was a Brookston sandy loam with a mechanical analysis, given by Stout (1959), as follows:

Sand	63%	by	weight
Silt	23%	"	"
Clay	14%	"	"

The experiments will be presented in a chronological order.

EXPERIMENT 1

Emergence of sugar beet seedlings under different conditions of soil moisture and compaction-no drying:

The plastic boxes were packed with soil in three different treatments as follows:

Treatment	Moisture content percent	Compaction psi
1.	12	16
2.	16	8
3.	20	1.7

The above combinations of moisture and compaction pressure were selected by examining the graphs of emergence energy in Morton's work (1959) to give approximately equal emergence energies and forces when kept for a period of 6 days under drying conditions.

The designated pressures were applied both at the seed level (½-inch depth) and at the surface. Each treatment had 12 boxes distributed as follows: Four boxes planted with dry sugar beet seed-balls at ½-inch depth, 40 seeds evenly spaced in each box. Four boxes were planted with sugar seed balls soaked for 3 hours and planted at ½-inch depth. Four boxes packed with soil for measuring the emergence force and energy of the mechanical seedling. The boxes were covered and placed in the air-conditioned room. Emergence was recorded daily and the results are given in Table I. The emergence energy of the mechanical seedling was measured and recorded 0 and 8 days after packing the soil, the results are given in Table II.

All moisture contents are expressed as the percentage moisture of the soil on a dry weight basis.

Table I

Accumulative Percentage Emergence of

Sugar Beet for Experiment 1

Compaction	Moisture Content	Seed	Days after planting						
			4	5	6	7	8	9	15
psi	%		percentage emergence						
16	12	dry	1	7	22	26	26	30	33
		soak	1	11	22	26	27	29	31
8	16	dry	34	62	69	71	73	74	74
		soak	37	58	61	65	66	66	67
1.7	20	dry	12	24	37	38	40	41	45
		soak	26	41	48	50	54	55	60

Table II

Emergence Force and Energy Required of the

Mechanical Seedling in Experiment 1

Time	12% M.C.-16psi		16% M.C.-8psi		20% M.C.-1.7psi	
	Force lb.	Energy in.-lb.	Force lb.	Energy in.-lb.	Force lb.	Energy in.-lb.
0 day	1.18	0.61	1.28	0.62	0.55	0.35
8 days	2.10	0.85	1.40	0.65	1.70	1.10

Figures 3 and 4 portray graphically the emergence of

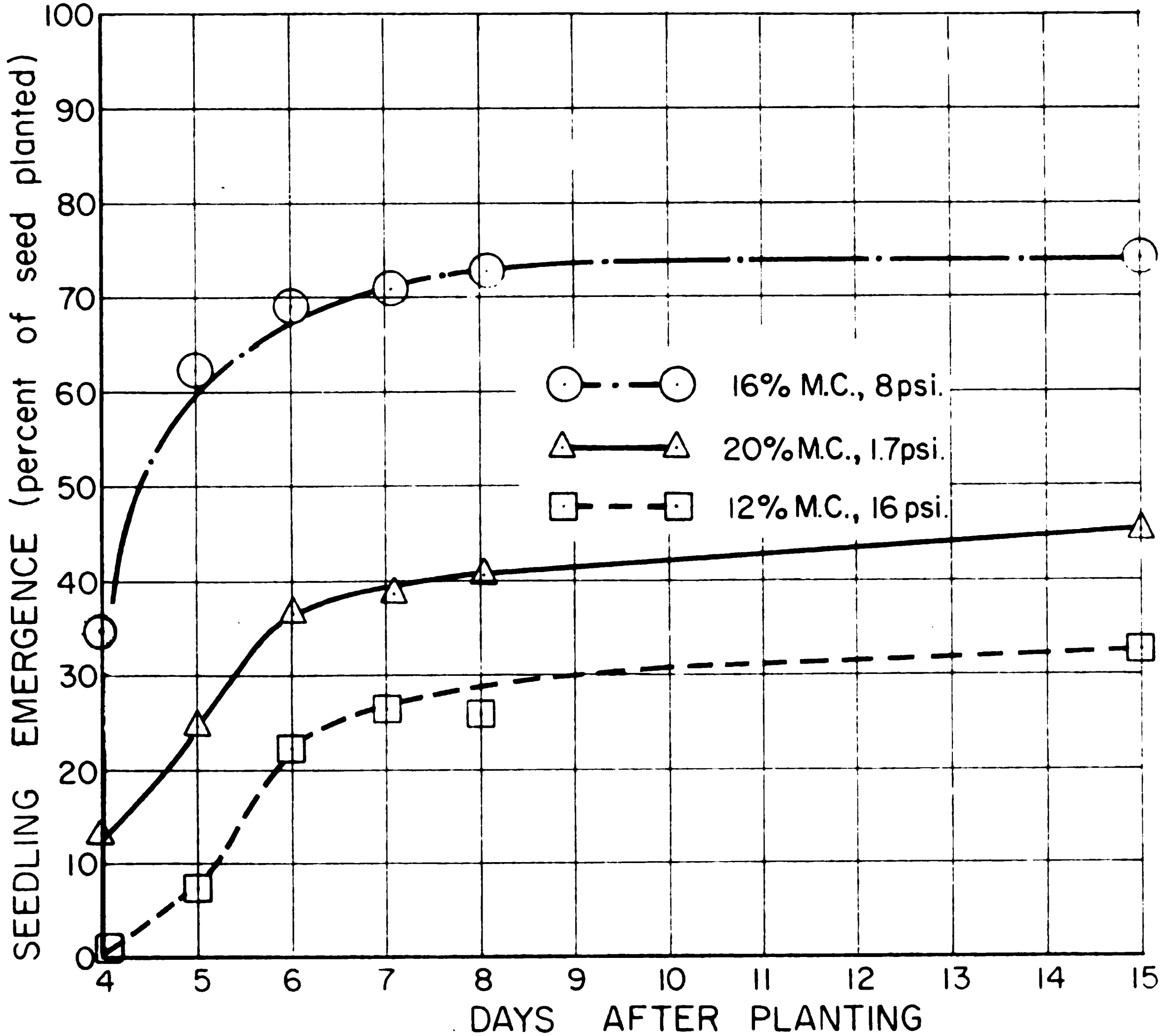


Figure 3: The Emergence of Sugar Beet Seeds Versus Time -- No Drying

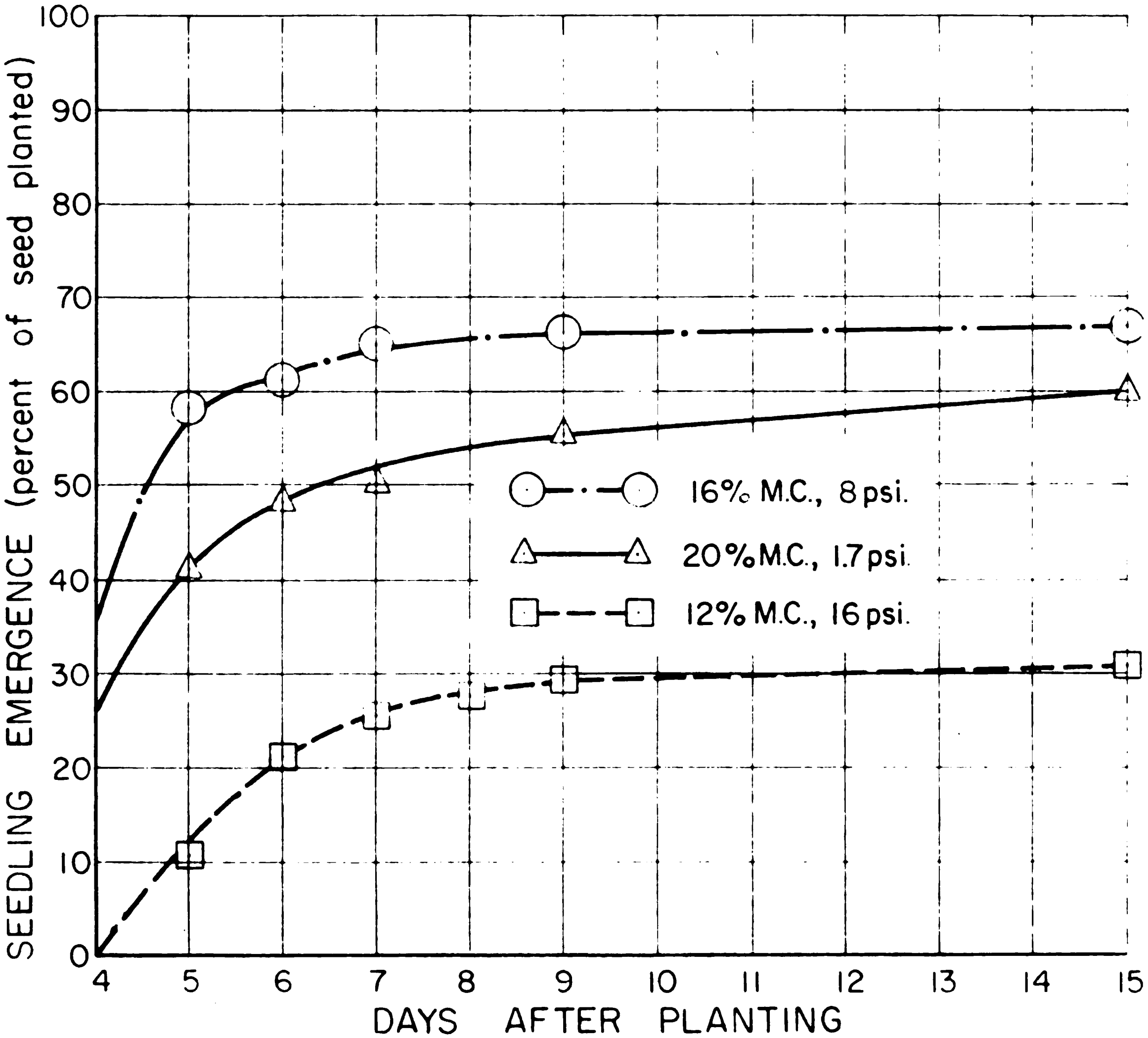


Figure 4: The Emergence of Soaked Sugar Beet Seeds Versus Time - No Drying

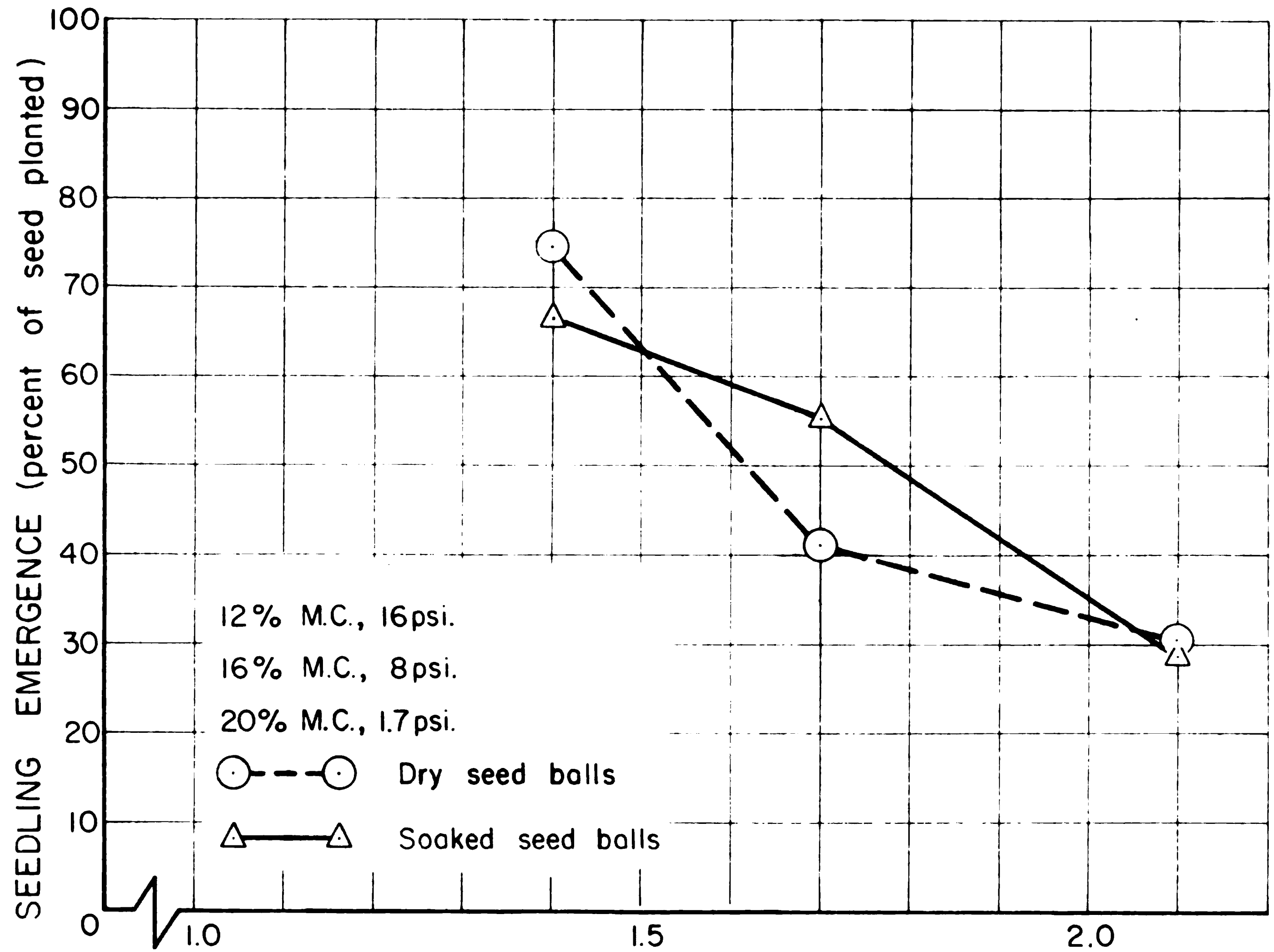


Figure 5: The Relationship Between the Maximum Emergence Force and the Emergence of Sugar Beet Seedlings -- No Drying

the different treatments as a function of time. Figure 5 shows the final seedling emergence versus the emergence force. Emergence force is used in this case because it has been observed that the curves of the emergence energies and emergence forces are almost of the same shape, and because force was measured with less chances of errors than energy. From Figure 5, the emergence decreases when the emergence force, as measured by the mechanical seedling, increases. This holds for both the dry planted sugar beet seeds and the soaked seeds.

EXPERIMENT 2

Emergence of sugar beet and corn seedlings from soil exposed to drying conditions:

In this experiment the boxes were packed with soil in one of the three following conditions:

Treatment	Moisture Content %	Pressure psi
4	18	1.8
5	18	2.8
6	18	3

Twelve boxes of each treatment were prepared. These pressures were selected from the graphs given by Morton (1959). They were intended to give the highest emerging force for the 2.8 psi when dried for 12 days and the medium for 3 psi when dried for 6 days and the lowest for the 1.8 psi when dried 6 days.

Four boxes were planted ½-inch deep with 40 sugar beet seed balls, 4 boxes were planted ½-inch deep with 20 corn seeds, and 4 boxes not planted but used for measuring emergence force and energy. All boxes, after being compacted, were placed uncovered in the air conditioned room. No emergence occurred during the first 15 days under the drying conditions. Emergence forces were measured and recorded after 6 days and 15 days of planting. On the 16th day all the boxes, except for the 2.8 psi treatment, were wetted with water from the bottom of the boxes. The tape over the holes was removed and the boxes were placed in water about 1 inch deep. By weighing the boxes before and after wetting (wetting was completed when the surface of soil became moist) the following amounts of added water were computed.

Amounts of water added after 15 days drying

1.8 psi			3 psi		
Sugar beet	Corn	unplanted soil	Sugar beet	Corn	unplanted soil
440*	660	517	602	595	551

The 2.8 psi treatment boxes were given 30 gm. water per box per day for 17 days totaling 510 gm. per box.

*Average grams water per box

The results of seedling emergence and the measured emergence forces and energies at the beginning and end of emergence are given in Tables III and IV.

Table III

Summary of Percentage Emergence of Seedlings in Experiment 2

Compaction Psi	Seed	Days after planting								
		17	18	19	20	21	22	23	24	30
		Percent emergence of seeds planted								
1.8	beet	0	24	46	56	65	71	72	73	74
	corn	0	0	0	22	50	75	77	82	85
3	beet	2	34	80	85	85				85
	corn	0	0	6	62	75	85	85	86	86
2.8	beet	0	1	2	2	2	3	4	4	5
	corn	4	11	17	18	20	24	35	35	42.5

Table IV

Summary of Energy and Force Requirements

in Experiment 2

Age	1.8 psi		3 psi		2.8 psi	
	Force	Energy	Force	Energy	Force	Energy
	lb.	in.-lb.	lb.	in.-lb.	lb.	in.-lb.
6 days	2.28	1.14	3.38	2.72	2.8*	-
15 "	3.12	1.56	4.75	2.25	4.0*	-
20 "	0.13	0.01	0.08	0.01	2.05*	-
30 "	0.75	0.30	0.80	0.55	1.05	0.70

*values taken from the curve of emergence force change with time.

Figures 6 and 7 show the emergence of the sugar beet and corn seedling respectively as a function of time. Figure 8 indicates the change in emergence force with time under the conditions described in Experiment 2. The emergence force was approximately the same at the 30th day regardless of how the water was applied. Figure 9 presents the percentage emergence as a function of the emergence force for the mechanical seedling on the 20th day (for corn) and 21st day (for sugar beet) after planting. From these curves the following can be concluded:

1. The pattern of emergence for sugar beet and corn seedlings was almost the same for the 1.8 psi and 3 psi

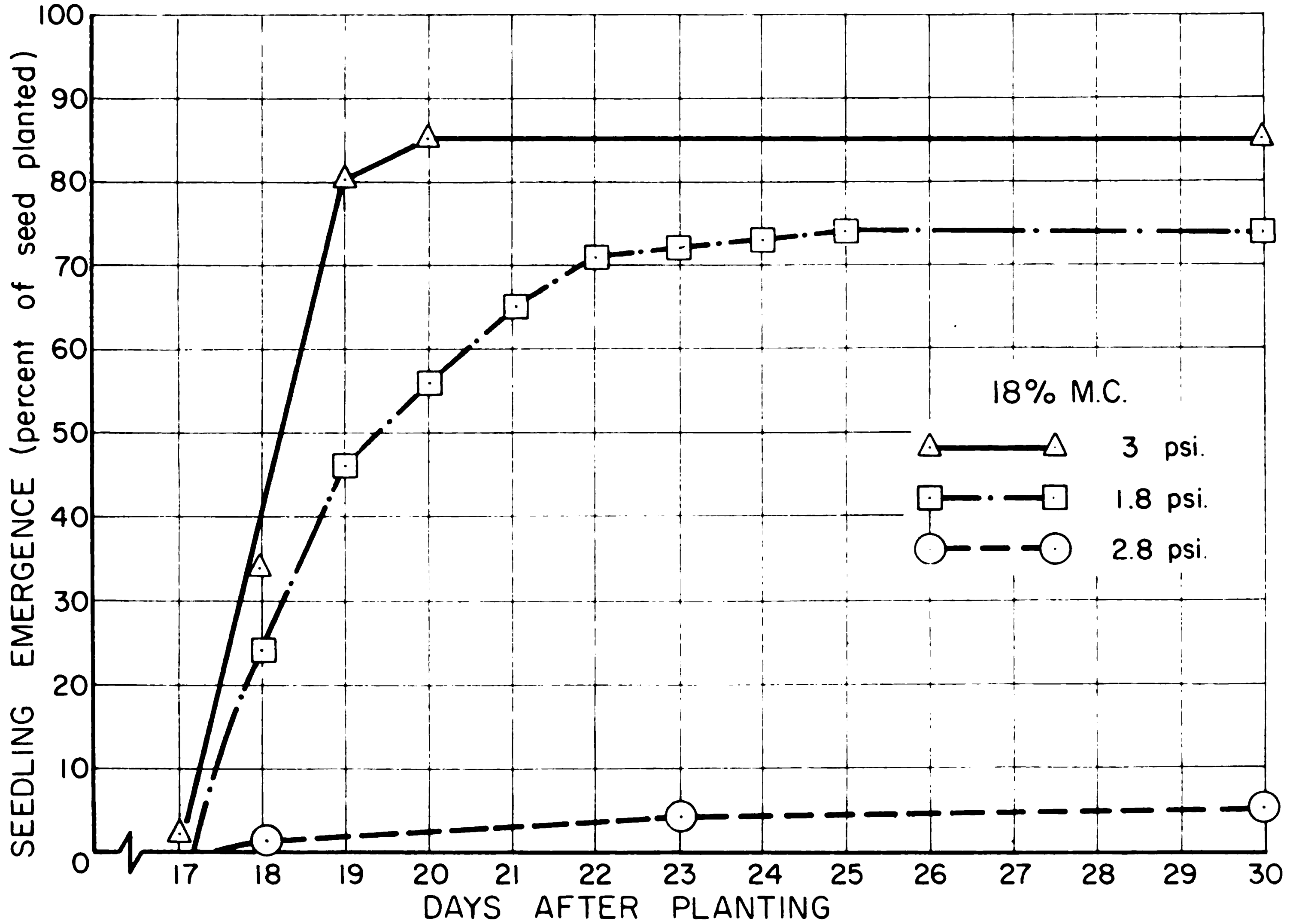


Figure 6: The Emergence of Sugar Beet Seedlings When Soil Was Dried for 15 Days Then Wetted

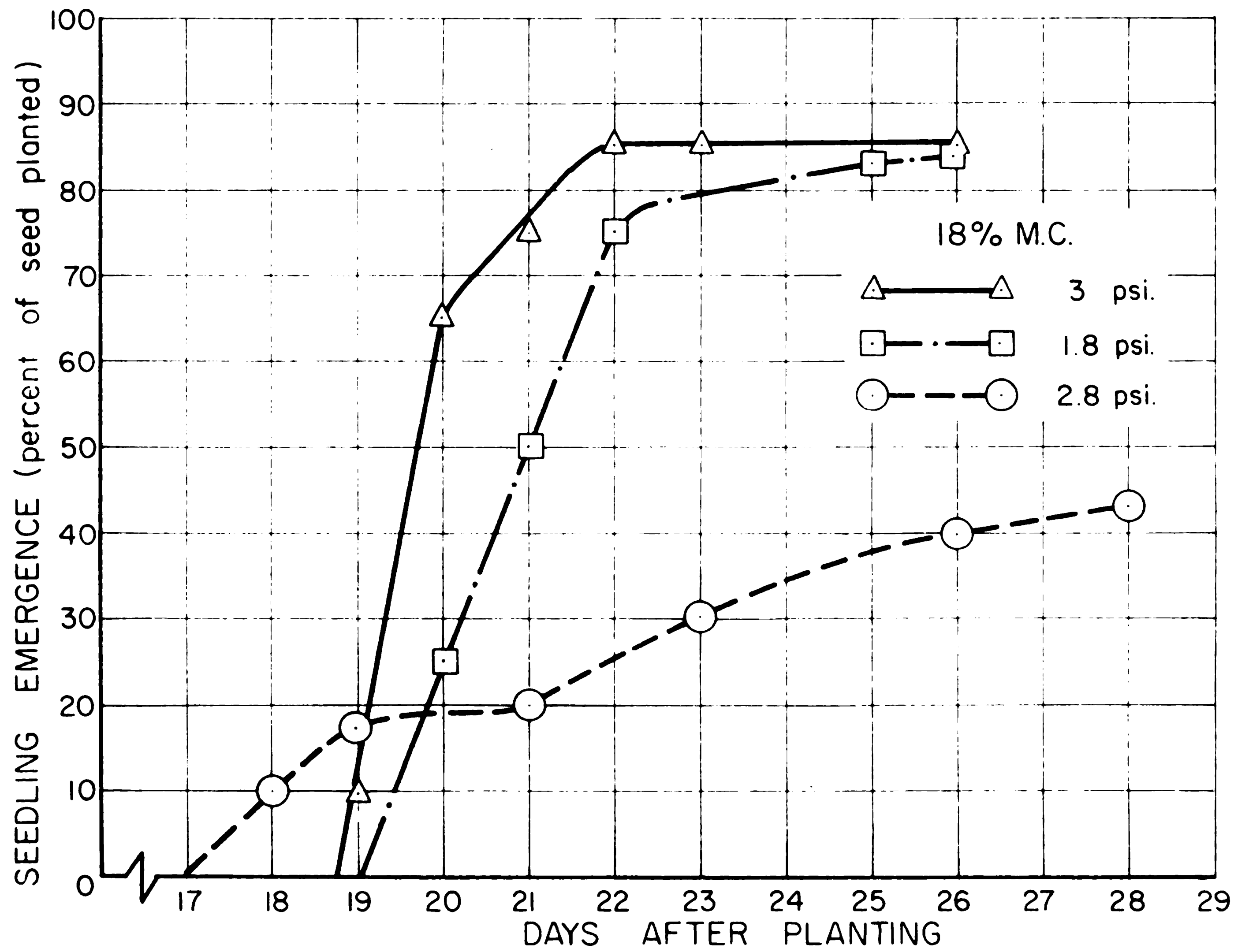


Figure 7: The Emergence of Corn Seedlings When Soil Was Dried for 15 Days Then Wetted

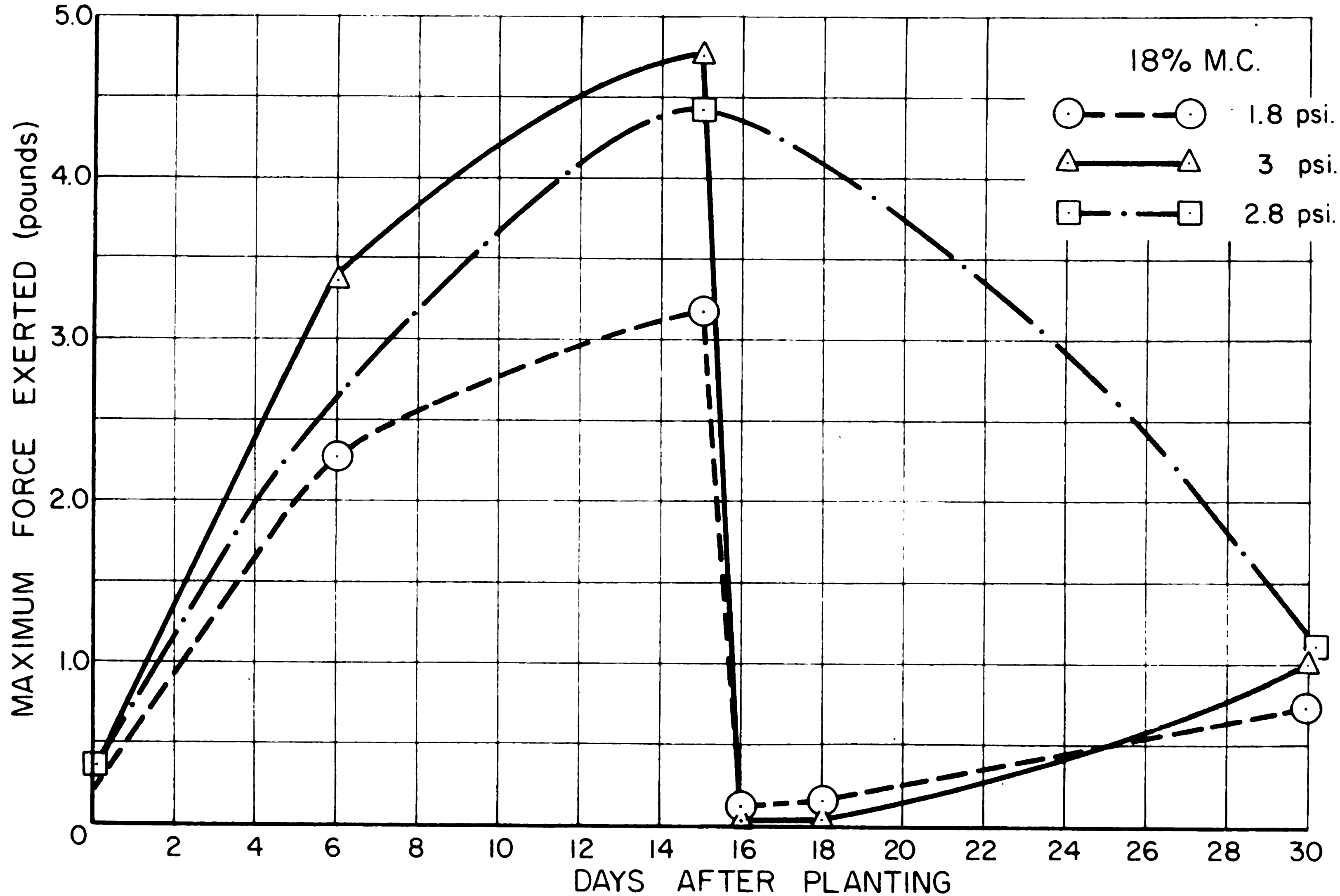


Figure 8: The Change in Maximum Emergence Force With Time as Soil Was Dried for 15 Days Then Wetted on the 16th Day for 1.8 and 3 psi Treatments, and Daily for the 2.8 psi Treatment

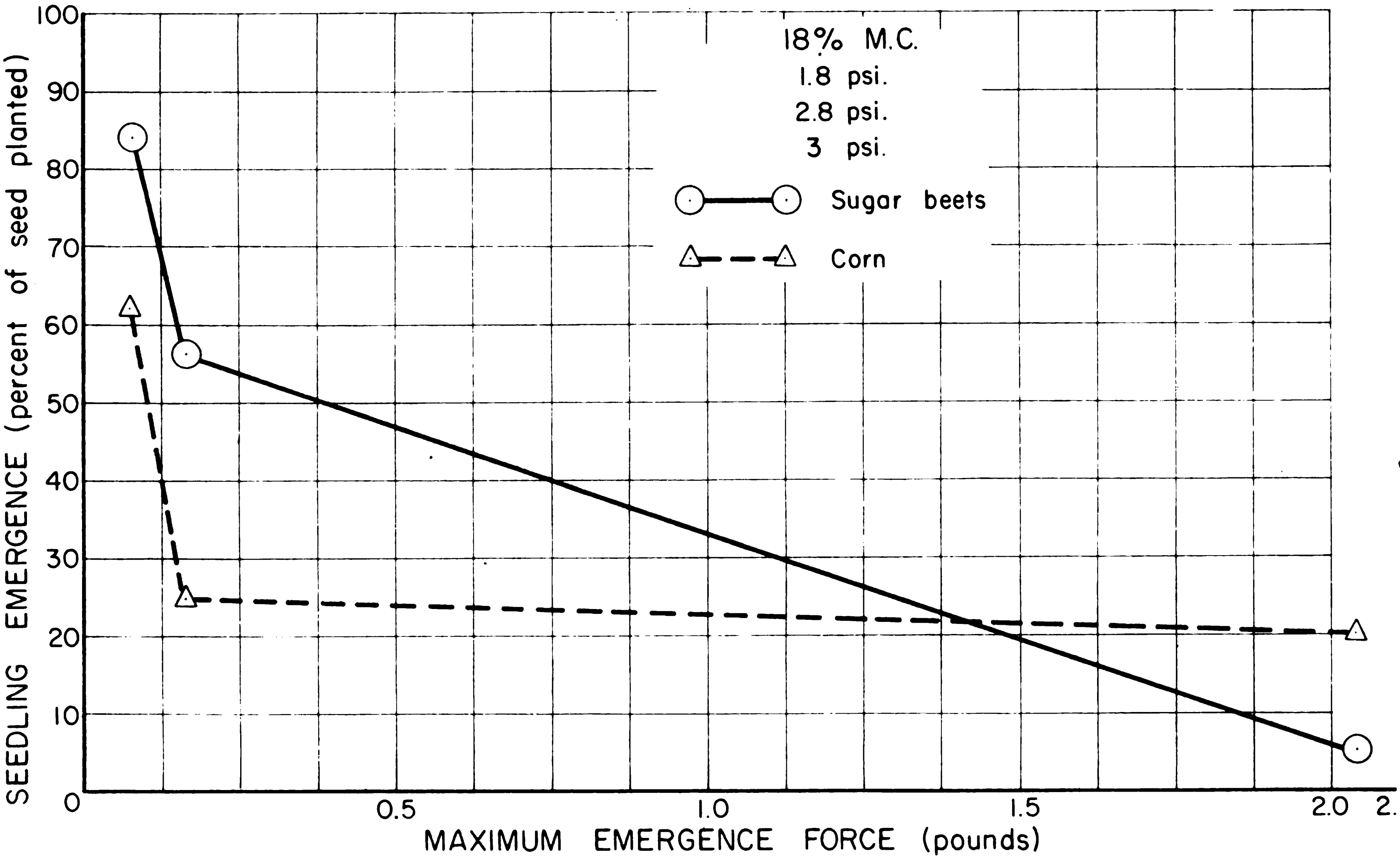


Figure 9: The Relationship Between the Maximum Emergence Force and the Emergence of Seedlings 20 Days After Planting

treatments. For the 2.8 psi treatment, corn seedlings emerged at a considerably higher rate than the sugar beet seedling. The 3.0 psi treatment had the best emergence rate followed by the 1.8 psi treatment while the 2.8 psi with small amount of water daily gave a very poor emergence.

2. The curves for the emergence energy and emergence force were approximately the same shape for all treatments. Force only was used to determine the effect of soil strength on emergence.

3. An inverse relationship was obtained between the emergence percentage and the force required for emergence.

4. The inverse relation between final emergence and emergence force was not constant within the limits of the experiment. In the range of small emergence forces, a small increase in force requirement caused a large decrease in emergence. In the larger emergence force range, the effect of force requirement was still evident but not as large as before. These two regions are shown in Figure 9.

EXPERIMENT 3

Emergence of corn seedling under drying and wetting of different soil conditions:

The boxes were packed in three treatments as follows:

Treatment	Moisture Content	Pressure
7	15 %	5.8 psi
8	15 %	8 psi
9	15 %	8.5 psi

From the graphs of Morton (1959), these compaction pressures at a single initial moisture content give three levels of emergence energies with drying periods of 6, 11, and 6 days, respectively. Thus, this experiment was conducted to show if there was a straight line inverse relation between emergence force (or energy) and the rate of emergence under the above conditions. The experience, however, had shown that under drying condition no germination takes place within the environments and settings of the experiment. Therefore the boxes had to be sprayed with water to gain any emergence. Each treatment consisted of 8 boxes as follows: Four boxes were planted at 1-inch depth with 20 evenly spaced corn seeds and 4 boxes of soil were used only for the measurement of the emergence forces. The pressure was applied at seed level and at the surface. The boxes were kept in the air-conditioned room and kept uncovered. They were sprayed with about 40 gram of water per box per day. The 8 psi treatment was left without water spraying for 5 days (to compensate for the difference in drying periods indicated by Morton), then was sprayed daily as the rest. A fine nozzle sprayer was used to avoid crust formation. Emergence was recorded daily and the results are given in Table V.

Table V

Accumulative Percentage Emergence of Corn

in Experiment 3

Days	8	10	12	14	16	18	20	22
			Percent emergence of seeds planted					
5.8 psi	4	7	11	19	24	26	29	32.5
8.0 psi	1.5	5	13	32	43	48	53	58
8.5 psi	0	1	7.5	7.5	17.5	21	25	26.2

Emergence forces and energies were measured at 6, 12, 18, and 24 days and the results are given in Table 6.

Table VI

Summary of Emergence Forces and Energies

in Experiment 3

Age	5.8 psi		8 psi		8.5 psi	
	Force lb.	Energy in.-lb.	Force lb.	Energy in.-lb.	Force lb.	Energy in.-lb.
6	2.18	1.48	3.38	2.19	3.10	2.13
12	2.15	1.28	1.75	1.14	3.40	2.12
18	3.75	2.39	2.00*	3.96	4.63	3.20
24	4.80*	-	2.62	2.11	5.60*	-

*Values estimated from graph of force versus time.

The results of Table V and VI are shown in figure 10 and 11. Figure 12 reveals the relationship between the rate of emergence and the recorded emergence forces at 12 days and 24 days after planting the seeds. From figures 10, 11, and 12 the following observations can be made:

1. The emergence started slow, and increased steadily.

2. It took 22 days for one of the three treatments to reach 58% emergence (the highest attained in this experiment), while in Experiment 1, 74 % emergence was attained in only 9 days. The reason is that the latter treatment was kept covered to prevent moisture losses during aging, in addition to ½-inch depth of planting instead of 1 inch as in Experiment 3.

3. The best emergence occurred when the boxes of the 8 psi treatment were kept without water spraying for 5 days. Drying for 5 days caused a reduction in the emergence force than the other 2 treatments. The drying and wetting cycle apparently created stress in the soil mass that weakened the strength of soil.

4. The relationship between the seedling emergence and the emergence force can be seen in Figure 12. The curve, however, does not have definite regions where this relationship changes as was the case in Experiment 2 where the curve was very steep at the small emergence force and almost horizontal at the higher forces indicating that

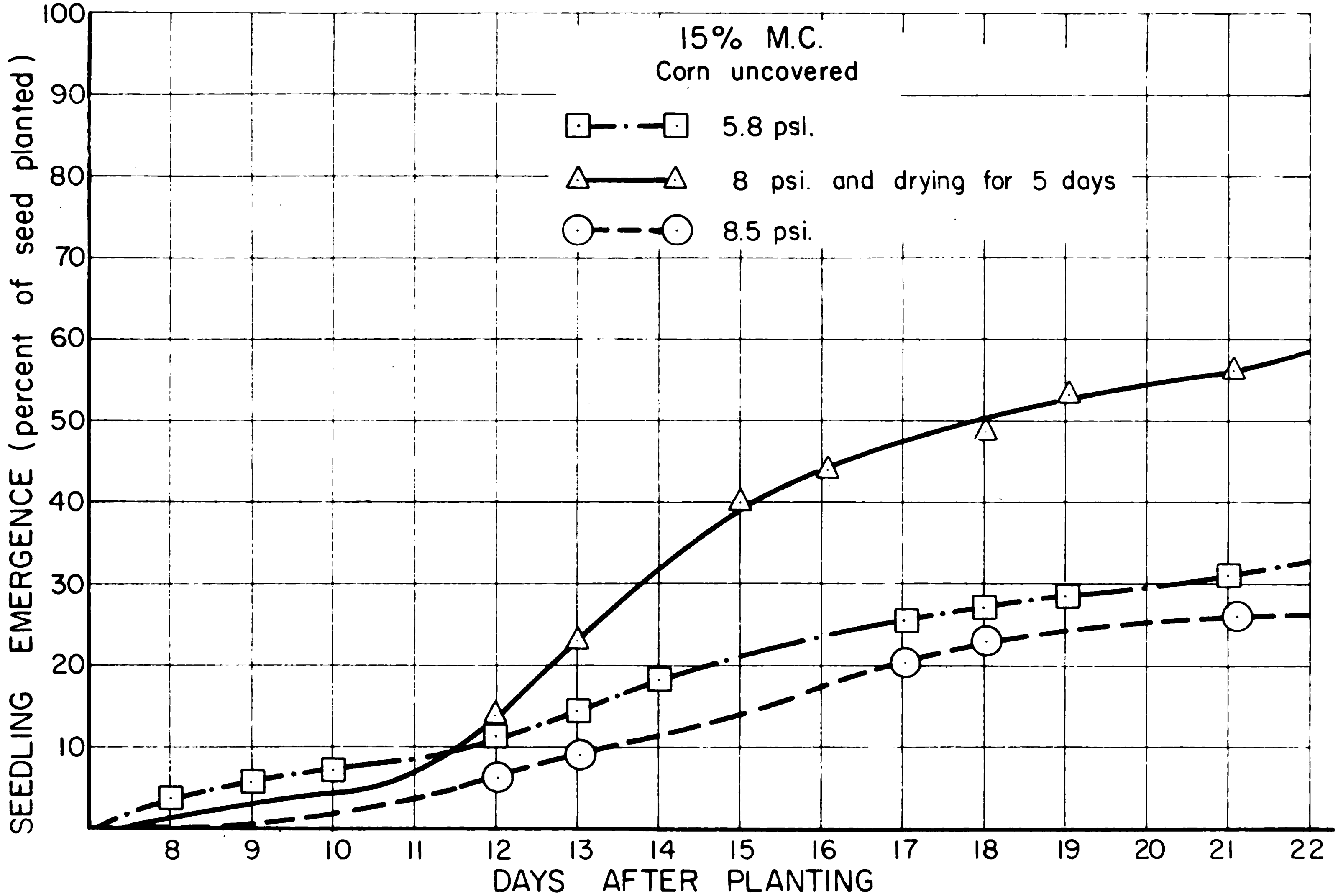


Figure 10: Emergence of Corn Seedlings Under Different Compaction Pressures and Drying and Wetting Conditions

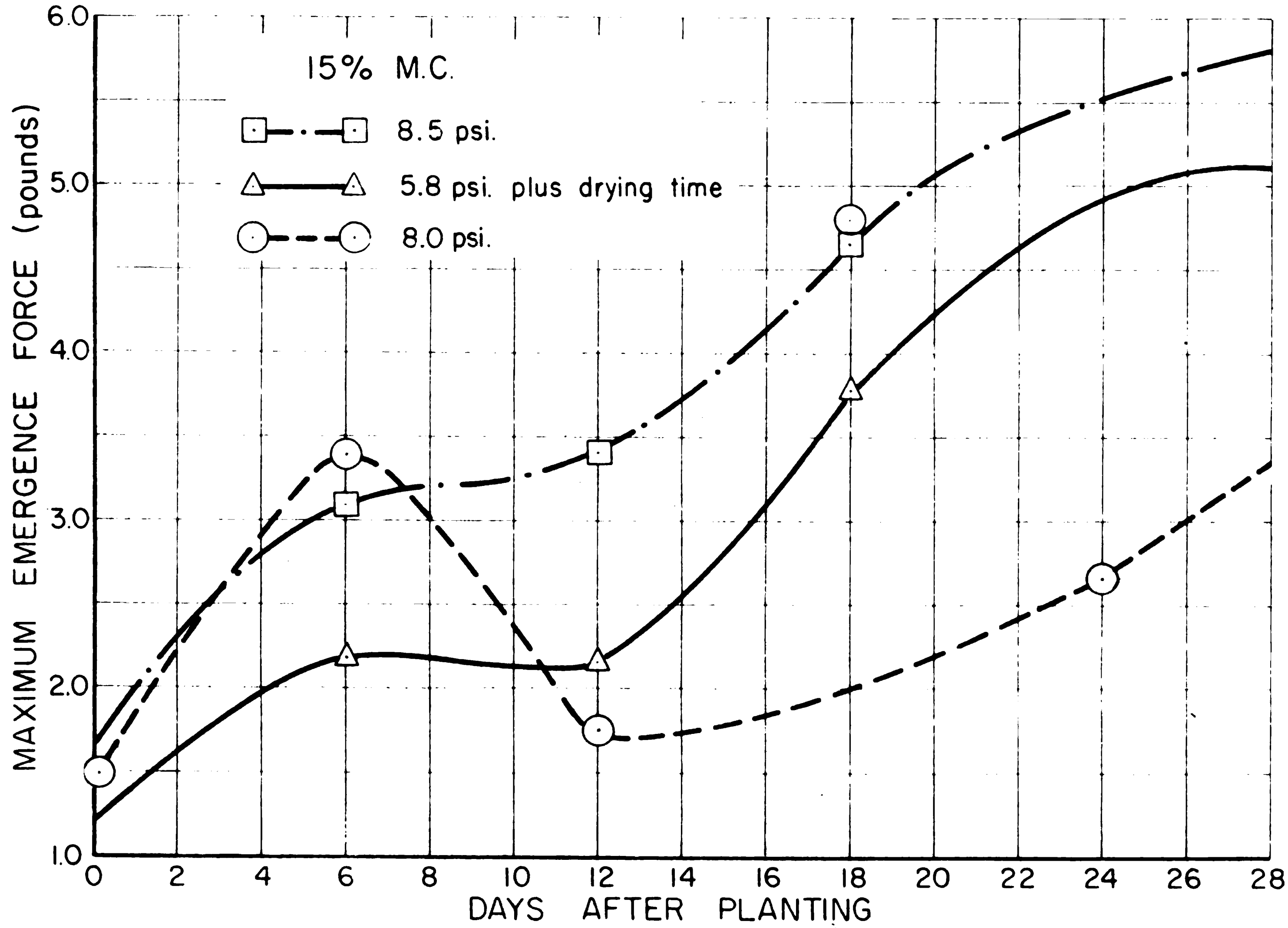


Figure 11: The Change of Emergence Force With Time Under the Drying and Wetting Conditions of Experiment 3

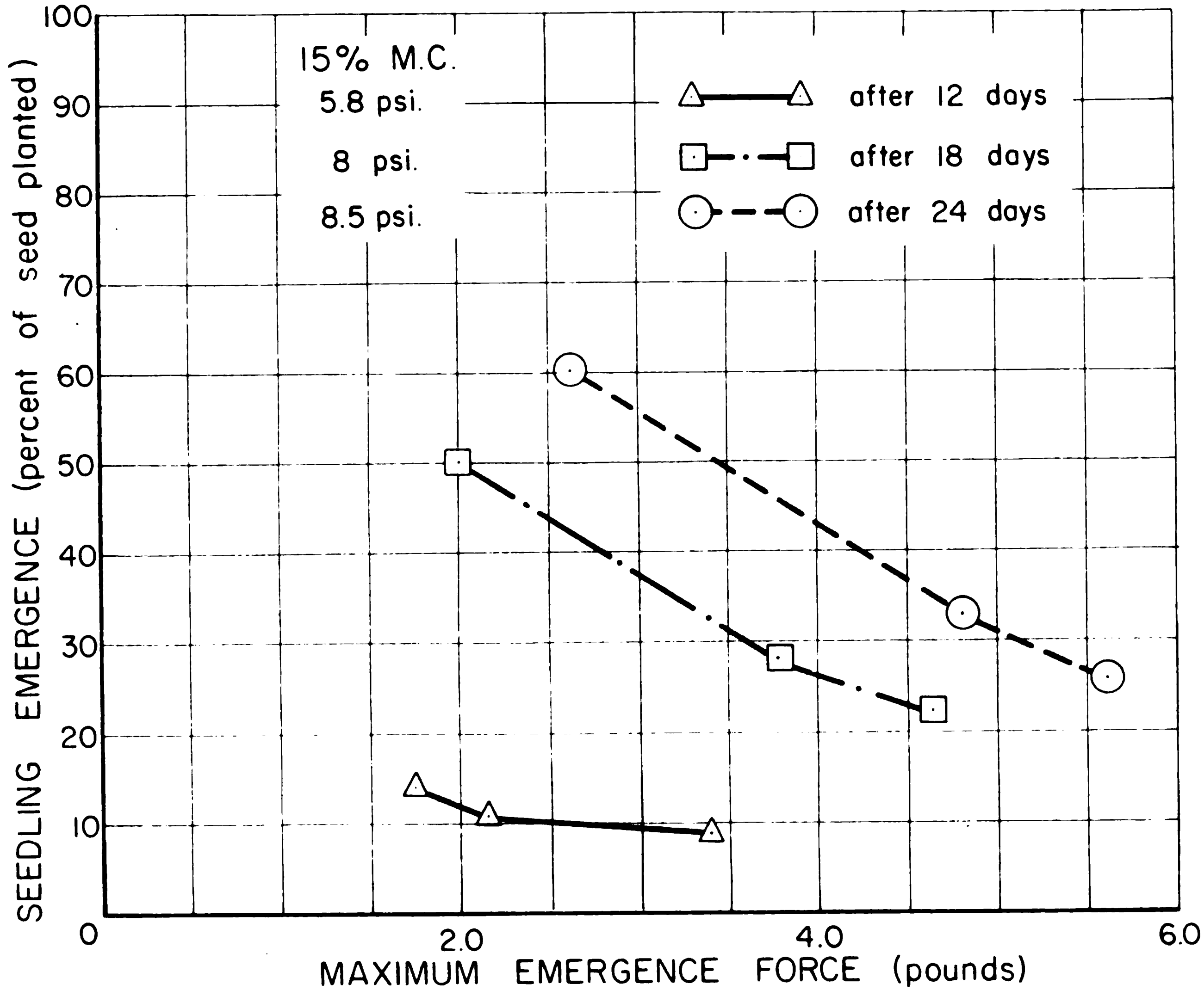


Figure 12: The Relationship Between the Emergence of Corn Seedlings and the Maximum Emergence Force Under Drying and Wetting Conditions

Figure 13: Seedlings Growing Horizontally to Emerge From Loose Soil Near the Wall of the Box. Initial Moisture Content 15%, Compaction 8 psi

Figure 14: Top View of a Sample With Initial Moisture Content 15% and Compaction Pressure 8 psi After Lifting a Block of Soil that Weighed 450 Grams. Seedlings Are Buckled Severely

$\frac{dE}{dF}$ is large at small F

$\frac{dE}{dF}$ is small at large F

where E is emergence, F is the force required for emergence.

5. Figure 12 indicates that an inverse straight line relation between emergence force and seedling emergence may exist. Figure 13 portrays the seedlings bending and growing horizontally to reach a loose spot near the wall of the box to emerge. The accumulation of plant growth at that spot caused clear separation between soil above and below seed level. The box is of treatment 8. Figure 14 is a picture of the severely twisted seedlings after removing a block of soil which weighed 450 grams. The box is of treatment 8.

EXPERIMENT 4

Emergence of corn seedlings under drying and wetting conditions for different soil conditions:

In this experiment, 3 different compaction pressures were used with one moisture content as follows:

Treatment	Moisture Content %	Compaction, psi
10	12	9.3
11	12	16
12	12	16

Treatment 12 differed from treatment 11 in that it was kept without water spraying for the first 5 days.

Each treatment had 8 boxes, 4 of which were planted at 1-inch depth with 20 evenly spaced corn seeds, the other 4 boxes were used for emergence force and energy determination. All boxes were kept uncovered in the air-conditioned room. Treatments 10 and 11 were sprayed with water, about 40 gram per box per day, for 32 days. Treatment 12 was not sprayed for the first 5 days then was treated and sprayed like the rest for the rest of the period. These compaction pressures, and the drying period of 5 days for treatment 12, were chosen from the graphs by Morton to give 3 different levels of emergence forces. The emergence percentage was recorded daily for 34 days and the results are given in Table VII.

Table VII

Accumulative Percentage Emergence of

Corn in Experiment 4

Psi	Days after planting									
	13	15	17	19	21	23	25	27	29	34
	Percent of emergence of seeds planted									
9.3	1	9	15	25	34	46	50	51	51	54
16	0	1	11	15	21	26	28	30	32	34
16, dry	0	0	5	8	22	36	40	43	43	46

Emergence force and energy requirements were measured at 0, 6, 12, 18, 24, and 32 days. The results are indicated in Table VIII.

Table VIII

Summary of Energy and Force Requirements in Experiment 4

Day	9.3 psi		16 psi		16 psi, dry	
	Force lb.	Energy in.-lb.	Force lb.	Energy in.-lb.	Force lb.	Energy in.-lb.
2	2.40	1.44	3.03	2.32	4.22	2.72
12	3.00	2.08	4.00	3.00	3.80	2.70
18	2.78	2.06	3.92*	2.20	3.00*	1.94
24	2.80	2.01	2.80	2.46	3.65	2.84
32	3.40	2.54	4.40	3.05	5.35	3.54

*Obtained from the graph after it was drawn.

Figure 15 represents the emergence curves for the three treatments drawn versus time. Figure 16 shows the change in emergence force with time under the conditions of the experiment. Figure 17 describes the relation between the seedling emergence and the emergence force given on the 24th day and the 32nd day after planting. These two days were selected because they gave a better picture of the emergence than any day earlier than the 24th.

From Figure 17, one can see that:

1. The emergence was inversely proportional to the emergence force, with the exception of one point where the measured emergence force at the end of the period was larger for a higher percentage emergence. This point may be of little significance if we account for the fact that the emergence actually takes place prior to the time when the measurement was taken.

2. The emergence was generally low and the forces were high. The emergence forces increased steadily while the rate of emergence (the slope of the emergence versus time curve) decreased.

Figure 18 presents a comparison between the way the seedling emerges through the soil surface and the way the probe emerges. The two small soil cones (produced in samples of 12% M.C. and 16 psi) are almost identical. The one to the left is that produced by the mechanical seedling (probe).

Figure 19 shows a comparison between the emergence of seedlings. The left box (12% M.C. and 16 psi) has been sprayed from the first day after planting. The right hand box was left to dry for 5 days then sprayed daily like the first. The latter box is more crowded and the emergence was better, but most plants were twisted several times. This may be due to the fact that the drying and spraying cycle causes more stress in the soil and weakens it and causes more cracks.

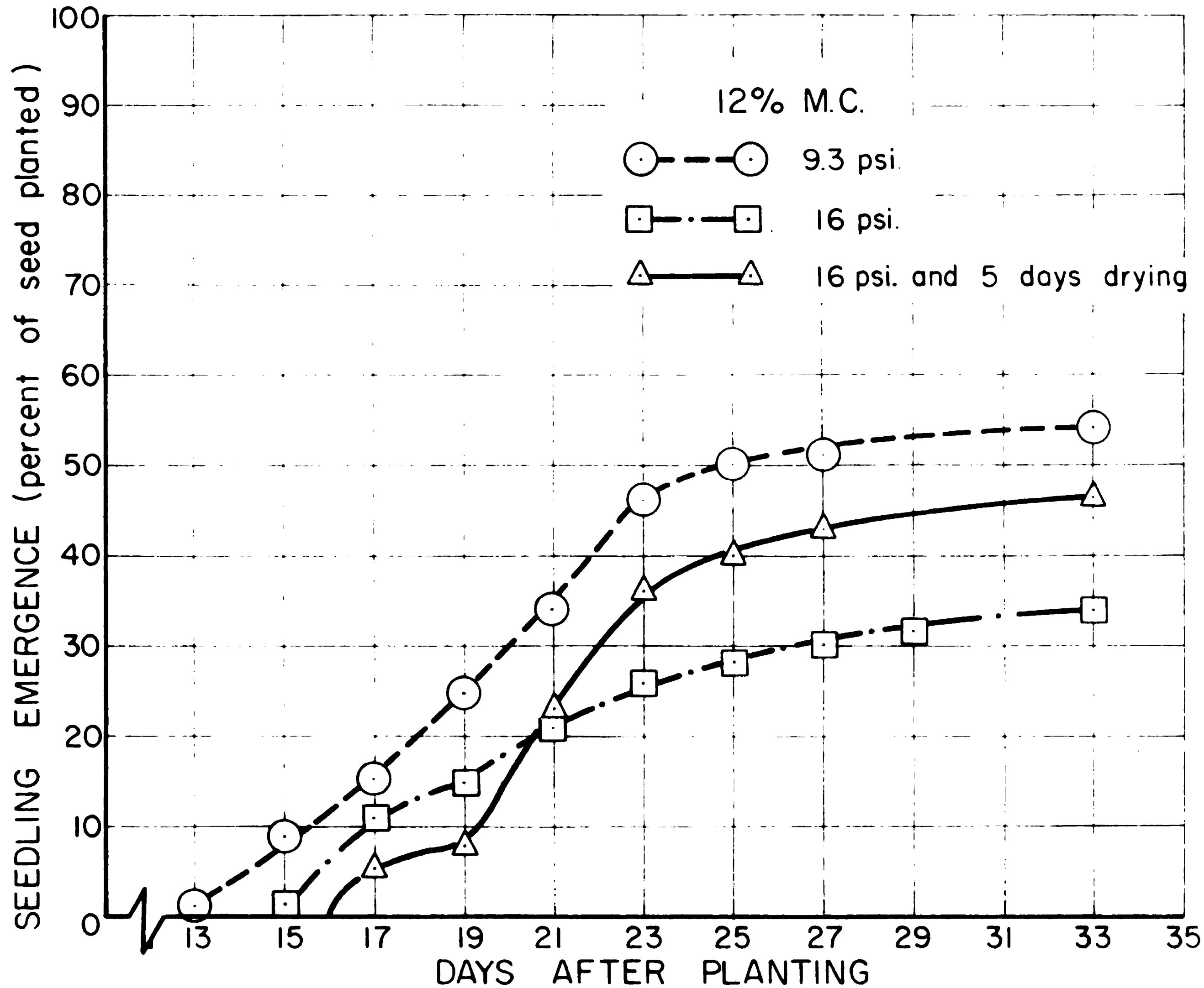


Figure 15: Emergence of Corn Seedlings Under Drying and Wetting Conditions for Soils of Different Compactions

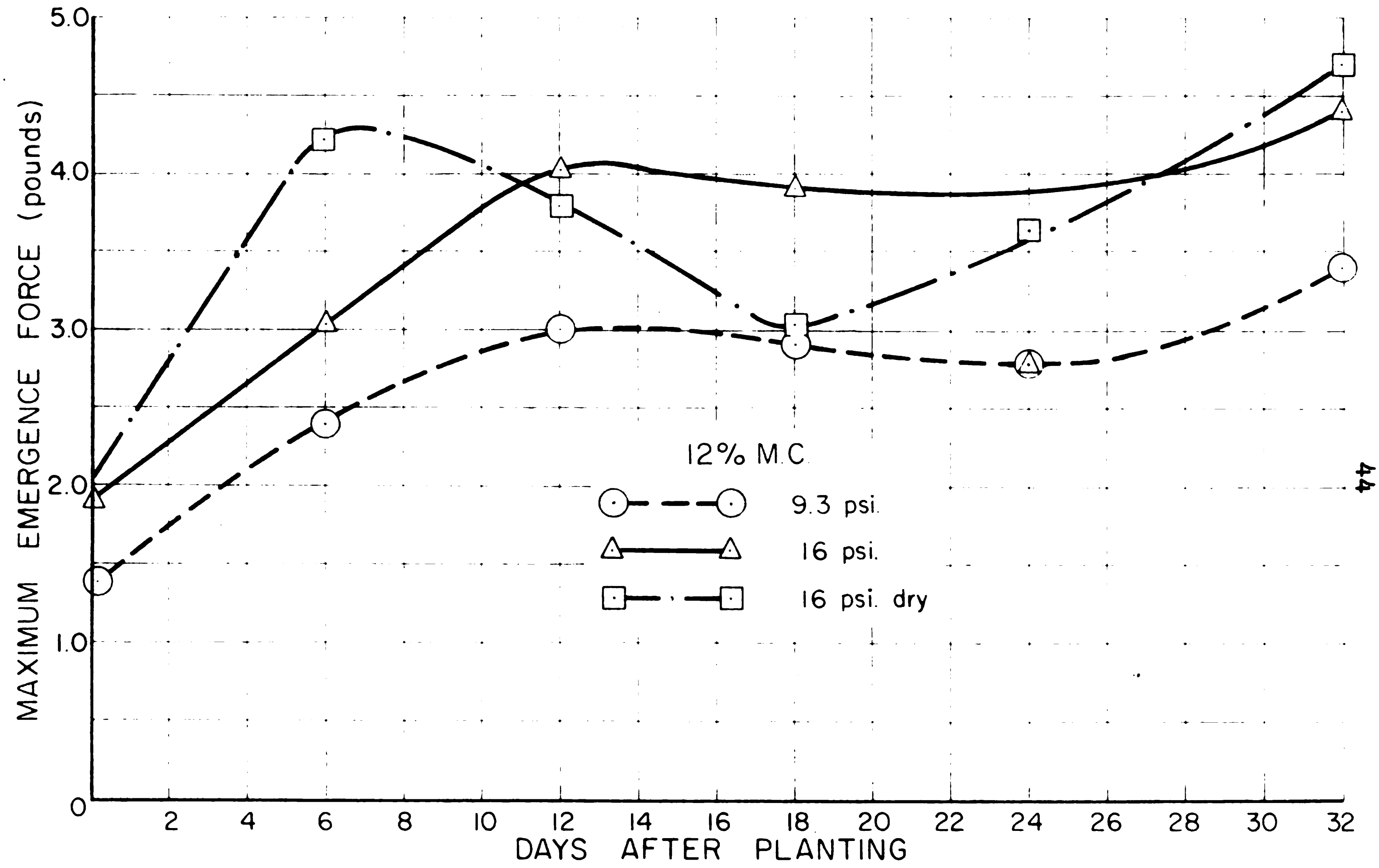


Figure 16: The Change of Maximum Emergence Force With Time Under the Conditions of Drying and Spraying Given in Experiment 4

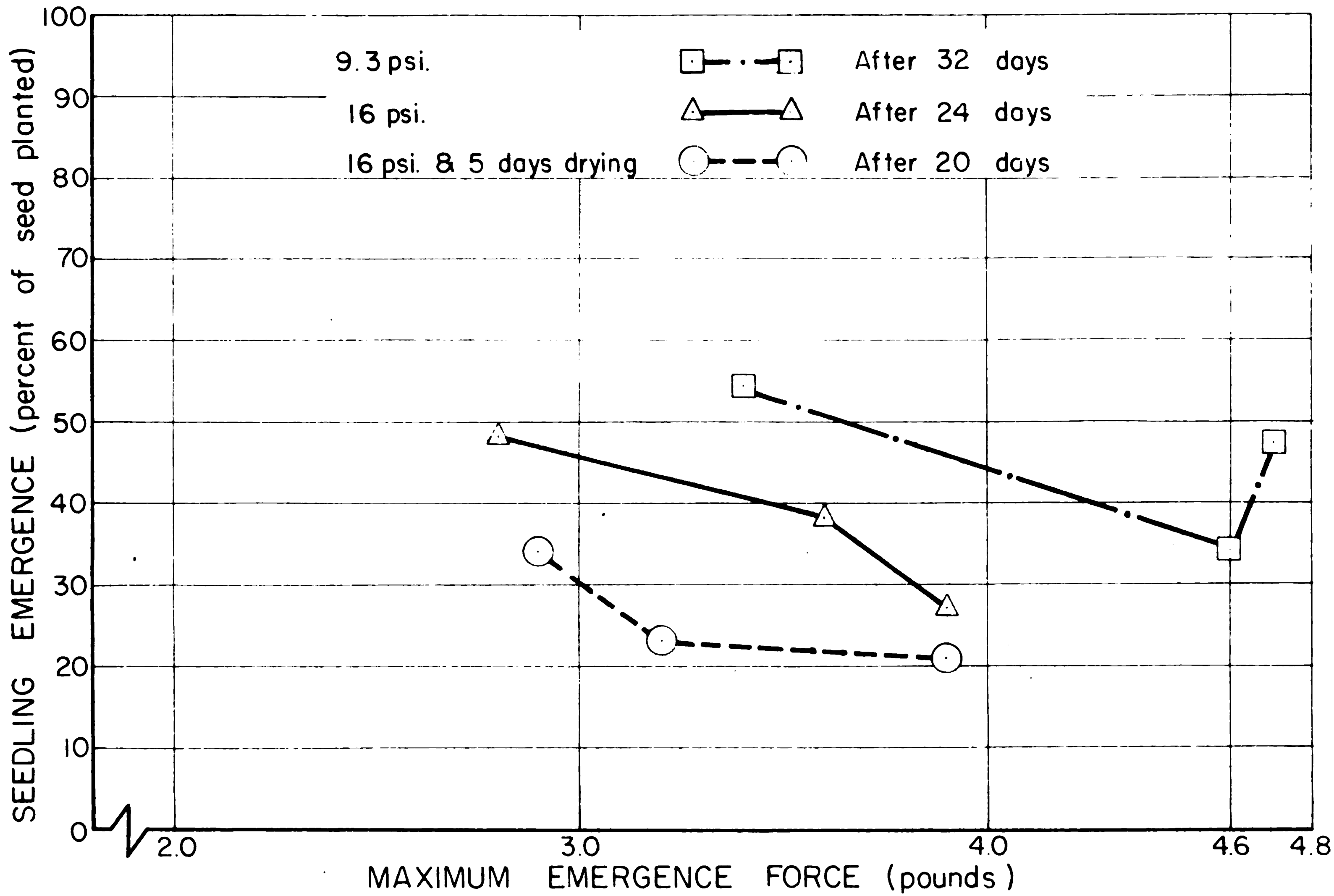


Figure 17: Relationship Between Emergence of Corn Seedlings and Maximum Emergence Force Under Drying and Spraying Conditions

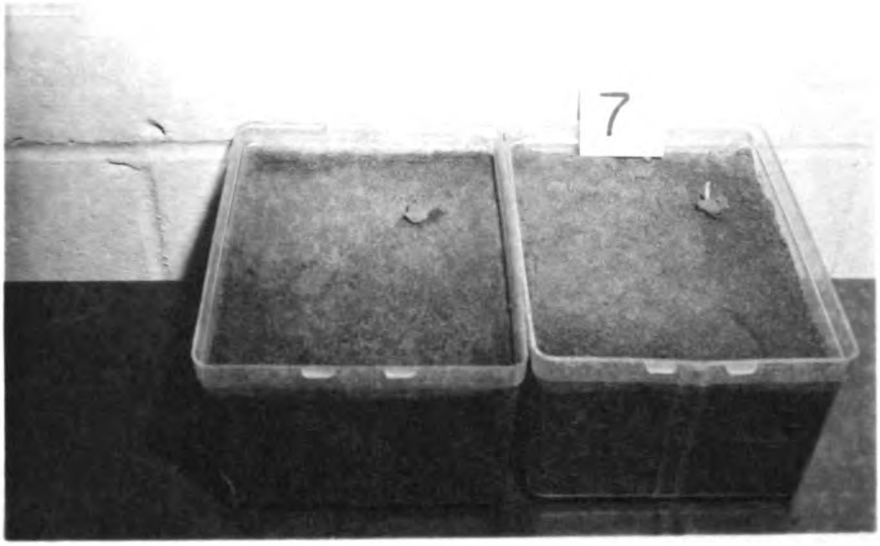


Figure 18: The Similarity Between the Soil Cone Produced by the Mechanical Seedling (at left) and the Cone Produced by Plant Seedling (at right)

Figure 19: Top View of Seedlings in Soil of 12% Initial Moisture Content and 16 psi Compaction Pressure. Spraying Was Daily From the First Day for Sample at Left and After 5 Days for Sample at Right

EXPERIMENT 5

Emergence of corn seedlings under variable moisture and compaction without drying:

Six different treatments were applied to prepared soils. They were intended to provide 2 different levels of emergence force or energy under non-drying conditions. They were as follows:

Treatment	Moisture Content %	Psi
13	12	1.0
14	12	4.0
15	16	0.75
16	16	3.5
17	20	0.50
18	20	3.0

Each treatment consisted of 8 boxes, 4 boxes were planted with 20 evenly spaced corn seeds at 1-inch depth, the other 4 boxes were used for force measurements. Pressure was applied at both the seed level and the surface. All boxes were kept covered in the air-conditioned room. The percentage emergence was recorded daily, and the accumulation is recorded in Table IX for the six treatments. Emergence forces and energies were measured after 0 and 8 days from planting, and the accumulation of these measurements is given in Table X. Figures 20 and 21 show seedling emergence in percent versus time. Figure 22 is a curve of the relationship between seedling emergence and emergence force 7 and 8 days after planting.

Table IX

Accumulated Percentage Emergence

in Experiment 5

Moisture Content	Compaction	Days after planting							
Percent	psi	5	6	7	8	9	10	11	12
				Percent Emergence					
12	1.0	0	0	16	51	70	80	87	91
12	4.0	0	0	10	44	60	68	75	82
16	0.75	0	15	77	94	94		96	96
16	3.5	0	9	69	95	95	95	96	96
20	0.50	18	88	100					100
20	3.0	8	80	97	100				100

Table X

The Emergence Forces Measured

in Experiment 5

A - Experiments with relatively low emergence force.

Age	12% M.C.		16% M.C.		20% M.C.	
	1 psi		0.75 psi		0.5 psi	
	Force lb.	Energy in.-lb.	Force lb.	Energy in.-lb.	Force lb.	Energy in.-lb.
0 day	0.11	0.08	0.11	0.12	0.10	0.10
8 days	0.15	0.12	0.11	0.10	0.10	0.11

Table X (Cont.)

B - Experiments with relatively high emergence force.

Age	12% M.C.		16% M.C.		20% M.C.	
	4 psi		3.5 psi		3 psi	
	Force lb.	Energy in.-lb	Force lb.	Energy in.-lb.	Force lb.	Energy in.-lb
0 day	0.59	0.39	0.54	0.46	0.44	0.44
8 days	0.65	0.50	0.60	0.51	0.52	0.49

Figure 20 shows the emergence for moisture contents 12, 16, 20% at pressures 1.0, 0.75, 0.50 psi respectively in which the 20% M.C. 1/2 psi treatment gives the highest emergence rate and final stand, followed by the 16% M.C.-0.75 psi treatment, while the slowest emergence was that of 12% M.C.-1.0 psi treatment. This result seems to be in accordance with the expected from the measured forces for the three treatments (0.10, 0.11, 0.15 lb. respectively). Figure 21 shows the same relation between the three treatments of 12, 16, 20% M.C. and 4.0, 3.5, 3.0 psi respectively as the emergence was best for the 20% M.C. 3.0 psi treatment, lowest for the 12% M.C. 4.0 psi treatment. This again was inversely following the forces required for emergence (0.65, 0.60, 0.52).

When the relationship between seedling emergence and emergence force, however, was studied it was obvious that a much better curve would be obtained if moisture content would be plotted as the third variable. The curves in Figure 21 were selected as follows:

When plotting the points representing the seedling emergence at a certain emergence force on the 8th day the result was the points connected by solid lines in Figure 21. It was clear that each two points may be connected to give the emergence at a certain moisture level as shown in the graph. The three resulting lines are almost parallel and they show that seedling emergence is higher for the higher moisture. To draw 2 lines each connecting 3 points would give another way of visualizing the emergence as a function of force, but this would mean that a very small increase in force (from 0.6 pound to 0.65 pound) has resulted in reduction of emergence from 95% to 45%. While the left hand curve would include a point of 50% seedling emergence at 0.15 pound emergence force the right hand curve will include a point of 100% emergence at 0.50 pound emergence force. For this reason the first method was used to indicate the definite effect of moisture on emergence, and to show some effect of the emergence force in reducing the seedling emergence. The same method was used for emergence at the 7th day. It can be seen that the seedling emergence was dependent on the moisture content and was higher for the higher moisture contents. Compaction pressure has little effect, particularly at the higher moisture content.

Figures 23 and 24 indicate the effect of moisture content at both emergence force levels.

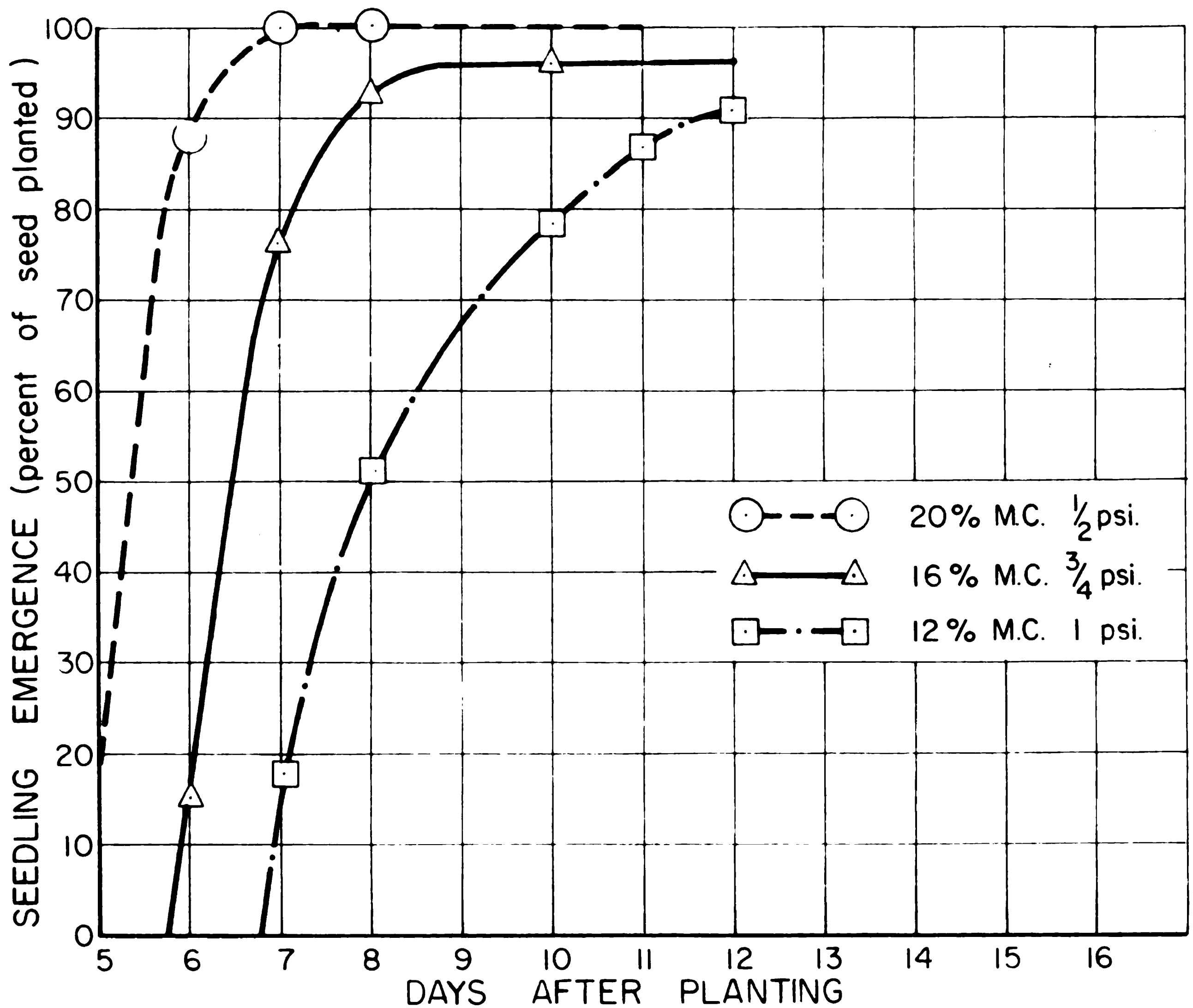


Figure 20: Emergence of Corn Seedlings Under Different Soil Moisture and Relatively Low Compaction Pressures (0.50, 0.75 and 1.0 psi)

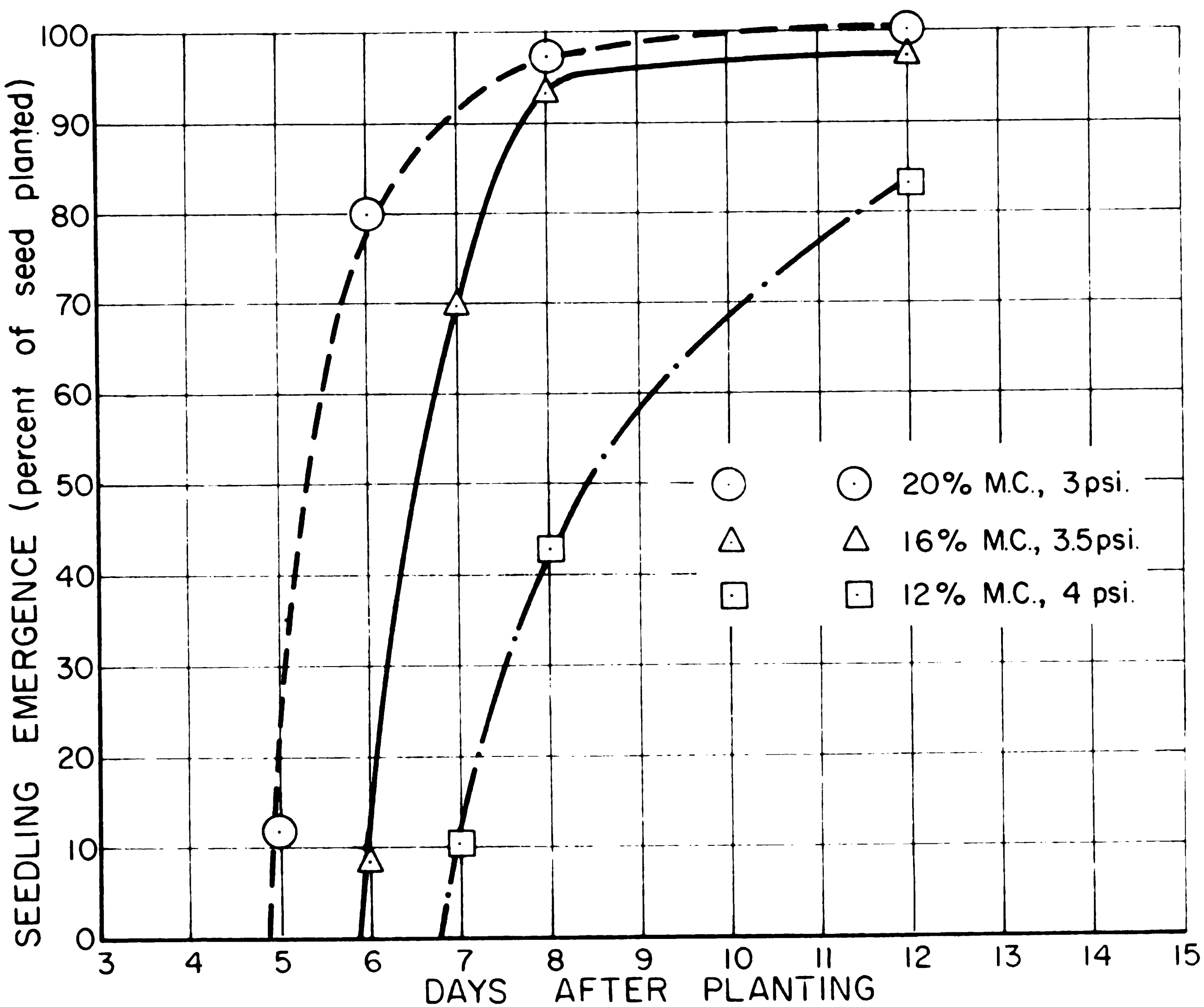


Figure 21: Emergence of Corn Seedlings Under Different Soil Moistures and Relatively High Compaction Pressures (3.0, 3.5 and 4.0 psi)

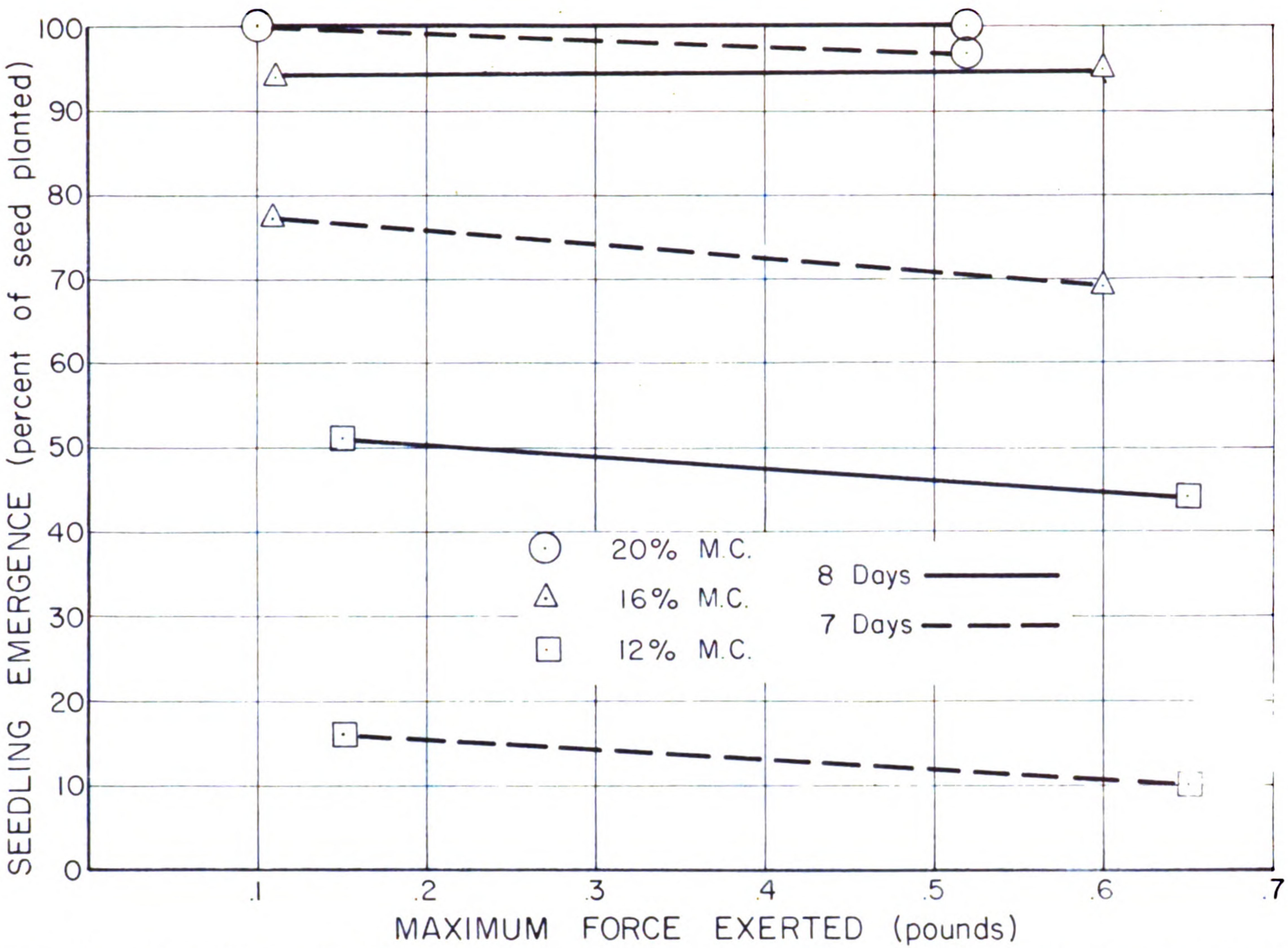
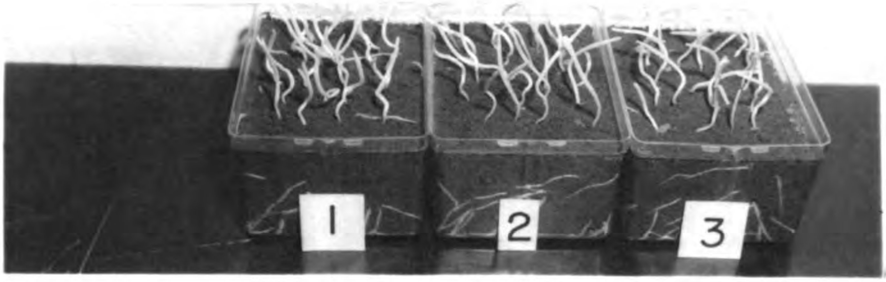
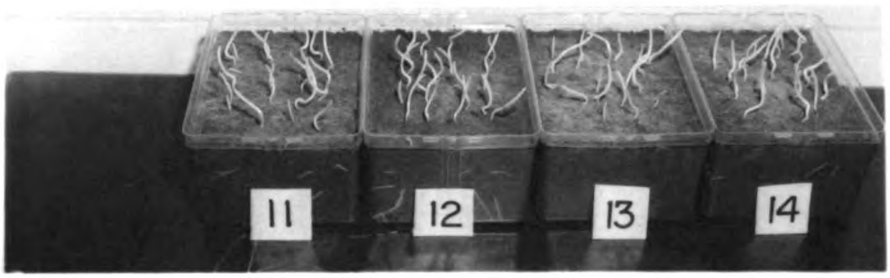


Figure 22: The Relationship Between Seedling Emergence and Emergence Force for Experiment 5 Showing 3 Different Levels of Emergence Depending on the Moisture Content



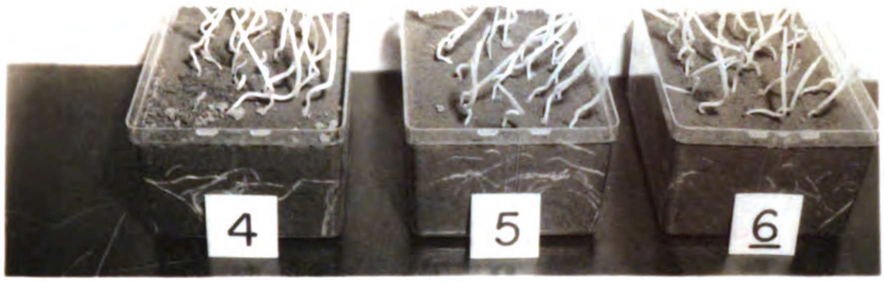
M.C. 20%



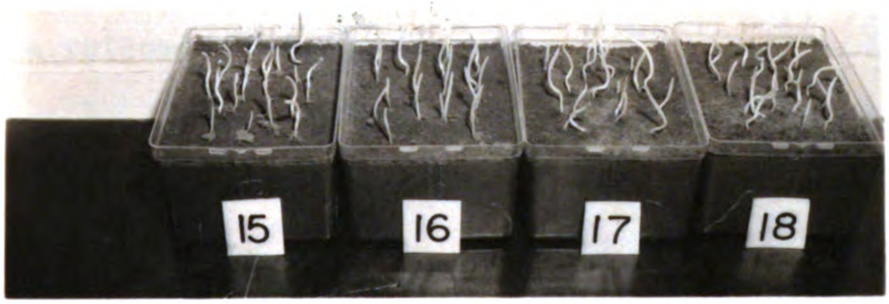
M.C. 16%

M.C. 12%

Figure 23: The Effect of Soil Moisture Content On Emergence. The Three Treatments Had Almost Identical Emergence Force (about 0.11 pounds)



M.C. 20%



M.C. 16%

M.C. 12%

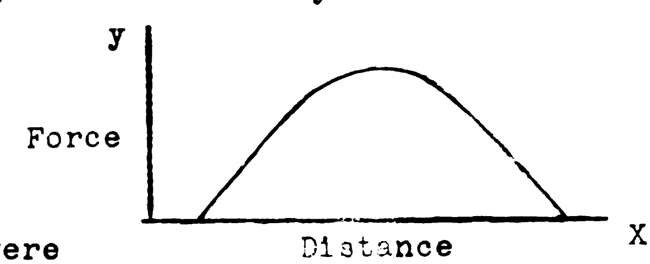
Figure 24: The Effect of Soil Moisture Content on Emergence. The Three Treatments Had Almost Identical Emergence Force (about 0.60 pounds)

DISCUSSION OF THE RESULTS

This series of experiments was designed to test the relationship between the emergence of the seedlings of sugar beet and corn to the emergence force required to push a probe of 0.078 inch diameter through the same distance that the seedling tip had to penetrate. We must, however, make the following reservations:

1. The procedure originally intended had to be modified because of the absence of any emergence in some cases (experiments 2 and 3). Water had to be added to secure emergence of the seedlings and to provide a basis for comparison.

2. In measuring the emergence energy and force, a curve was obtained on the chart of the oscillograph. The area under curve was assumed to represent the energy required to push the probe through the soil a distance of 3 inches from the bottom of the box up through the surface. The y axis representing the force at any distance S from the bottom of the box, where S is the co-ordinate of the point on the x axis. There were two alternatives in interpreting this curve as follows:



To take the whole curve for each treatment and use it as a basis for comparison of the energy expended. This would assume a constant relation between the energy and maximum force in the top section above the seed level and below the seed level down to the bottom of the box. The second alternative was to locate the point on the X axis which represents the seed level (which varied in different experiments), and draw a perpendicular from the X axis to intersect the curve. The resulting curve (from the seed level to the top of the soil was taken as basis for comparison). The second method was chosen for the following reasons:

1. There was no consistency in the shape of the curves to permit the use of the whole curve as a basis for energy comparison.

2. Because of the change in the depth of planting, it would be more representative to the actual forces and energies to take only the part of the curve from seed level to the point where the mechanical seedling tip ceased to meet any resistance. We must keep in mind that this part of the curve furnishes a means of comparison between treatments only, and does not give the actual forces encountered by the seedling tip or the energy expended during emergence.

With these reservations in mind, the following observations can be made:

1. Figures 5, 9, 12, 17, and 22 represent the relation between the seedling emergence and emergence force. These curves show a definite trend of low seedling emergence at high emergence forces, and a higher emergence rate at lower emergence forces. Thus, one can conclude that soil impedance, represented by the force required to push a probe through it, is a limiting factor to the emergence of corn and sugar beet seedlings. This statement can be put in general form because of the different combinations of conditions under which this research was performed.

2. In Experiment 1 the effect of soaking the seeds for 3 hours, to help germination, was tested. Figure 5 shows that soaking the seed for 3 hours did not improve emergence. This result, however, may be changed if the seeds were soaked for a longer period.

3. Corn seedlings appeared to have relatively better capability of penetrating the soil than sugar beet seedlings (Figure 9) under the same conditions. This was particularly true at the low strength soils.

4. When a relationship between emergence and emergence force or energy is sought, the investigation must be restricted with respect to time. If soil requiring an emergence energy (X) and emergence force (F) was planted with seeds, at the 6th day there would be E_1% emergence, when the emergence energy may be $X_1 > X$ and force $F_1 > F$ due to drying. At the 10th day there would be emergence

$E_2\% > E_1\%$, but the emergence energy would be $X_2 > X_1$ and force $F_2 > F_1$ due to drying. There are two present explanations for this phenomena:

a. The emergence is dependent on the rate at which the seedling expends energy. The seedling at the 6th day had not produced enough energy to overcome X_1 but by the 10th day has expended enough energy to overcome X_2 which is larger than X_1 and thus was capable of emerging. But the rate of emergence energy expended is the power expended, and in this case, one can state that emergence is dependent on emergence power in the seedling.

b. If emergence is effected by force, the above case would mean that the seedling at the 6th day was not capable of exerting enough force to overcome F_1 but by the 10th day the seedling had larger turgor pressure in the tip cells to produce force to overcome not only F_1 but F_2 which is larger.

5. When plotting the emergence percentage versus the emergence force for seedlings in soils of 20 % moisture content, 16% moisture content and 12% moisture content under different compaction pressures and with no drying taking place, the curves in Figures 25, 26, and 27 respectively were obtained. These curves show that under a condition of identical moisture contents the emergence of the seedling is a function of the emergence force or the strength of the soil. This was true at 6, 8 and 12 days

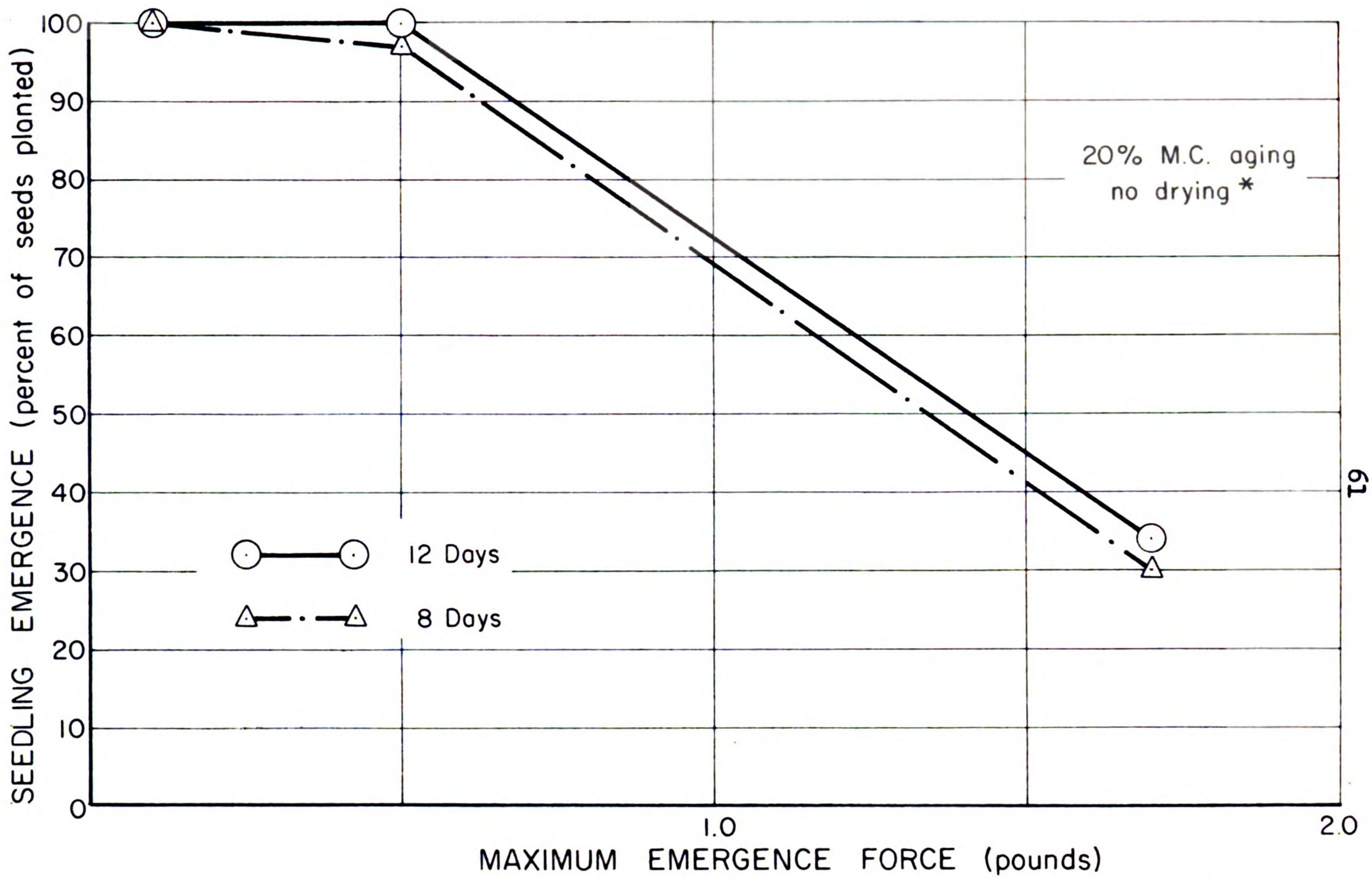


Figure 25: Seedling Emergence as a Function of Emergence Force for Soils Under Different Conditions. Plotted From Results of Experiments 1 and 5 at 20% Soil Moisture Content

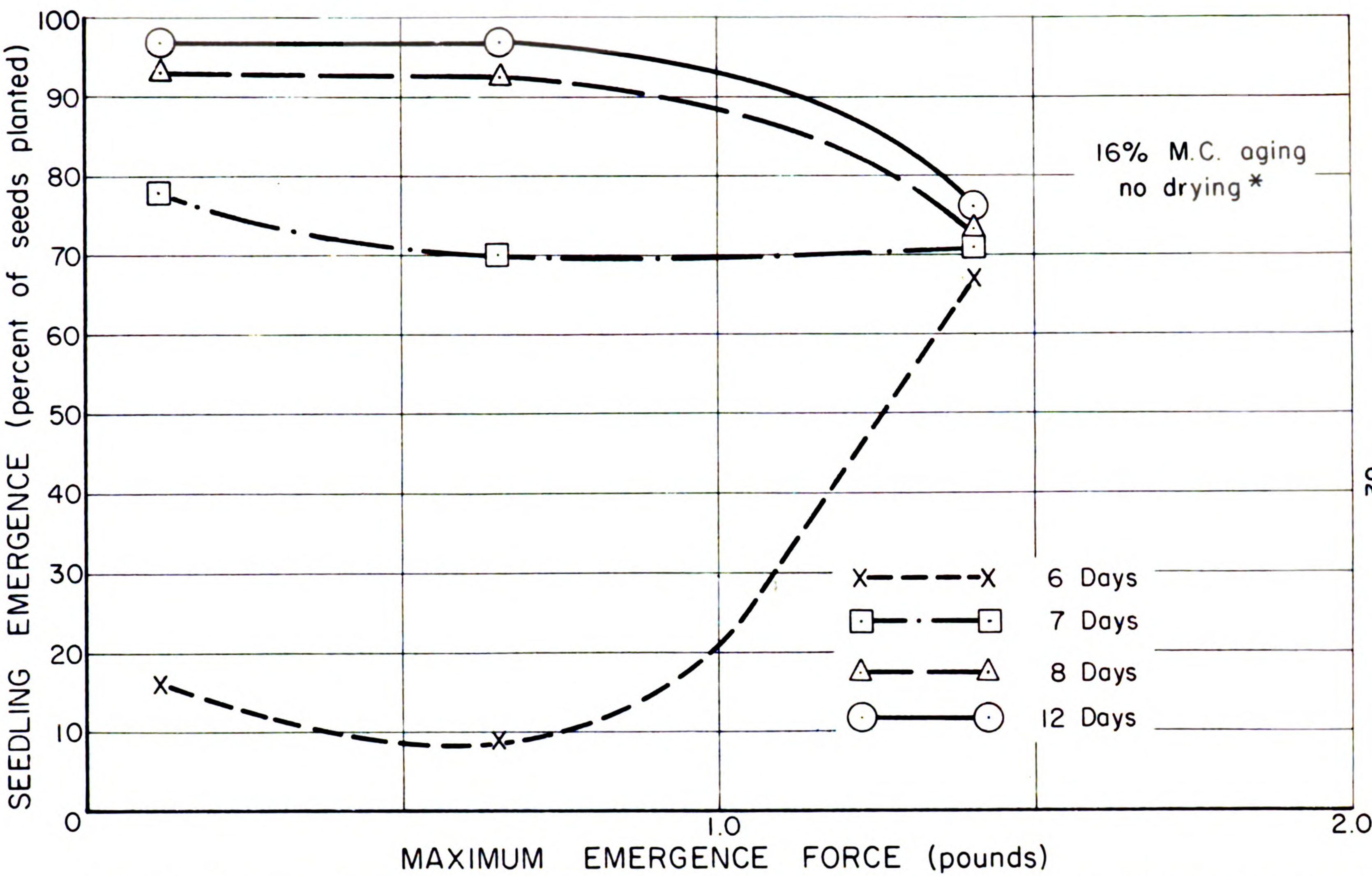


Figure 26: Seedling Emergence as a Function of Emergence Force for Soils Under Different Conditions. Plotted From Results of Experiments 1 and 5 at 16% Soil Moisture Content

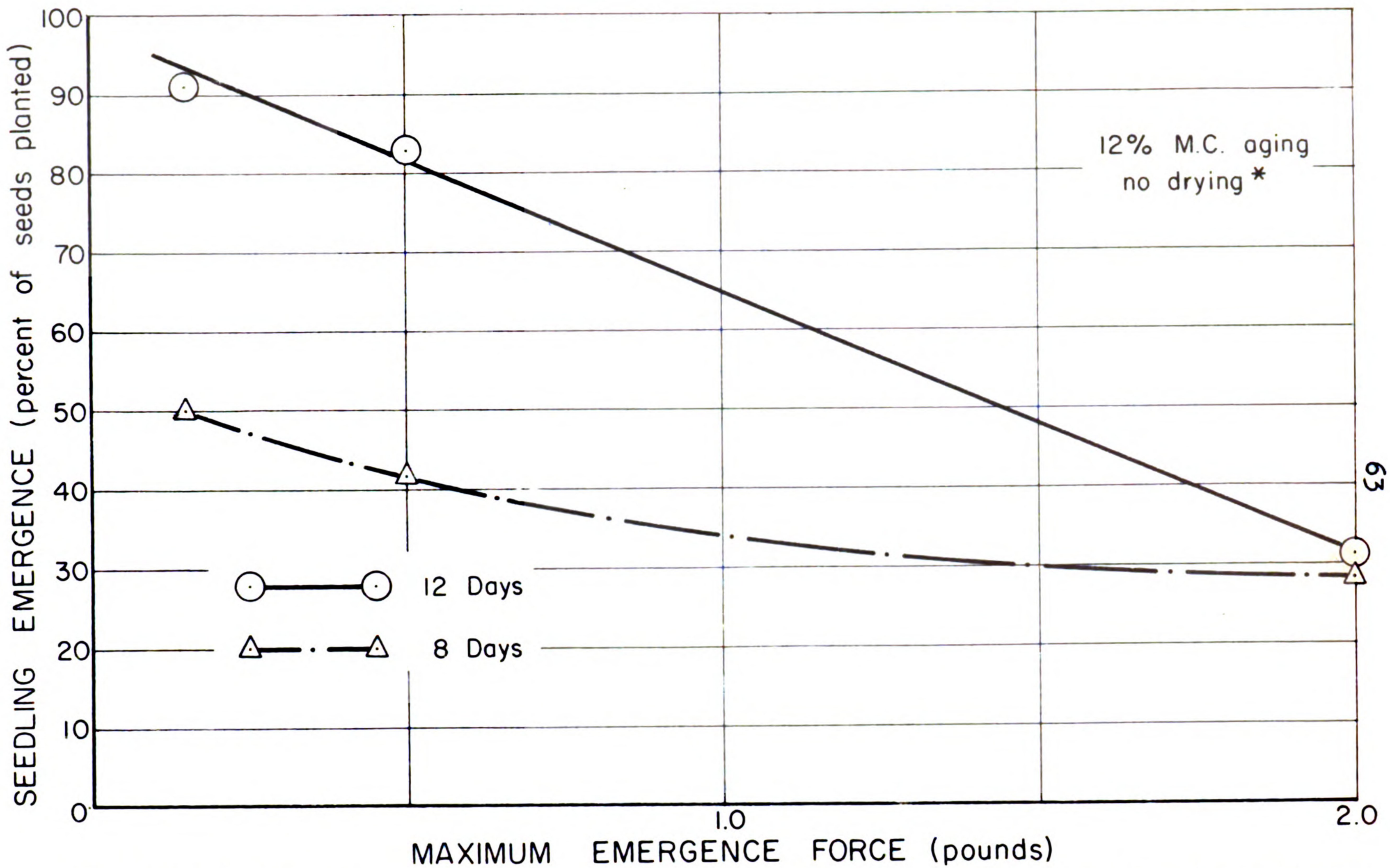


Figure 27: Seedling Emergence as a Function of Emergence Force for Soils Under Different Conditions. Plotted From Results of Experiments 1 and 5 at 12% Soil Moisture Content

after planting.

6. At the lowest emergence force encountered during the experiment, the dominant factor for the rate and final stand of emergence was the moisture content rather than the soil strength represented by the emergence force or energy. This is shown in Figure 22, where the third variable differentiating the curves was the moisture content. The 20% moisture content treatments (both 0.5 and 3.0 psi) reached 100% emergence within 7 days. The 16% moisture content treatments (0.75 and 3.5 psi) final stand was almost complete (96.2%) but after 12 days. The 12% moisture content treatments had limited emergence of 91% for the treatment compacted to 1.0 psi and 82.5% for the treatment compacted to 4.0 psi. This again shows that at low emergence energy and force levels, increasing compaction pressure retards emergence more at low moisture content than it does at the higher moisture contents.

7. By making a comparison between Experiment 1 (treatment 16% M.C., compaction 8 psi) and seeds planted at ½-inch depth and Experiment 3 (treatment 15% M.C., compaction 8 psi), and seeds planted at 1 inch depth, these two cases had the same compaction pressure and almost the same moisture content (a deviation in moisture content of 0.3% was expected). The first one was kept covered and very little or no drying took place. The emergence reached 74% by the 9th day from planting. The second case was kept

uncovered all the period and was sprayed with 40 grams water per box per day starting from the 6th day. The emergence reached only 4% at the 9th day and 58.3% at the 22nd day. In spite of the difference of the depth of planting*, this still indicates that the drying of soil, even when moisture was raised by adding water, caused an increase in soil strength and emergence force requirements and decreased the rate of emergence and total seedling emergence.

8. Comparing Experiment 1 (treatment of 12% M.C. and compaction of 16 psi) and seeds planted at ½-inch depth with Experiment 4 (treatment 12% M.C. and 16 psi and seeds planted at 1 inch depth). There are two identical initial soil conditions, but different treatment in the following period: In the first case, the box of soil was covered and little or no drying took place. The emrgence was small due to the very high pressures used. Stout (1959) indicated that pressured more than 5 psi retard emergence markedly, the emergence reached 30% by the 9th day and 33% by the 15th day. In the second case, boxes were kept uncovered and were sprayed with 40 grams of water per box per day. The emergence was small, but was also much slower than the first case. Emergence was 0% at 9th day and 33% by the 33rd day. This again shows that with the increase in soil strength due to drying (even with moisture compensation) there was a

*Stout (1959) found that at 16% M.C. and 10 psi, planting at ½-inch depth gave only 16% increase in emergence than planting at 1 inch depth.

retardation in the emergence. By referring to Tables 16, 17, and 18 in Morton's data (1959), it is indicated that the moisture lost from soil at initial moisture content at 12% and compaction pressure 16 psi was 40.7 grams for the first day, 22.3 grams for the second day and 14 grams for the third day. Thus, the 40 grams of water added to the boxes in Experiment 4 was enough to compensate for moisture loss from the surface. The increase in soil strength is probably due to the act of drying itself which, in this case, caused the soil to act like concrete or to form a crust at the surface, thus impeding the emergence.

9. By examining Figures 12 and 17 for the seedling emergence and the emergence force on the 24th day we get the following points:

Point	Force (pounds)	Emergence (percentage)
1	2.6	58
2	2.8	48
3	3.6	38
4	3.9*	28
5	4.8	32
6	5.6	26

*This point was evaluated from the curve, the actual reading was 2.8 pounds and was far off the curve.

The above table was taken from results of Experiments 3 and 4, and with the exception of point 4 (which was uncertain) we found that there is a definite inverse relation between the emergence force and seedling emergence. These two experiments were conducted under soil moisture contents 15% and 12% and pressures of 5.8, 8, 8.5, 9.3 and 16 psi.

PRACTICAL APPLICATIONS

I. Any process that will reduce soil strength will hasten emergence and produce better stands.

a) Decreasing compaction at the surface will help decrease the soil strength.

b) If the seedbed were covered, less soil strength will be developed, particularly under dry weather. Mulch may be used for covering.

c) Shallow planting depths, within limits, will help emergence. However, too shallow planting may cause the seed to lose moisture and fail to germinate.

d) Modification of soil strength by chemical means, such as calcium acrylate, may increase the stability of individual aggregates and by improved aggregation decrease the total soil strength. Gypsum may effectively decrease the strength of crusts and clods.

II. Emergence is dependent on the amount of energy - as well as force - expended during emergence. A reduction in the period of emergence would help in two ways as follows:

a) Avoid an excessive increase in soil strength due to drying.

b) Save the energy expended in performing functions other than emergence, such as energy of respiration, and supply more energy for seedling emergence.

To reduce the period of emergence the following suggestions may be studied:

1. Soaking the seed for a sufficient period to reduce time of germination.

2. Using additives to speed the emergence. These may be chemicals or hormones.

SUMMARY

Experiments were conducted to test the hypothesis that the rate of emergence and final emergence is inversely related to the emergence force or emergence energy. Different combinations of moisture contents, compaction pressures and drying periods were used. In some cases water had to be sprayed on the soil to secure emergence of seedlings when otherwise no emergence would have occurred. This last treatment, though far from the actual case in the field, gives an idea of what happens when the planting is followed by rain either directly or after 5 days of drying.

Under the conditions of the different experiments it was clear that the above hypothesis is true at least within the limits of moisture content and compaction pressure of each experiment alone. It was possible to plot the seedling emergence versus the emergence force for some of the combinations tested in different experiments on one graph. The results still indicate that the above hypothesis was, under particular conditions, true.

A more general conclusion of the truthfulness of this hypothesis did not seem feasible, due to the inconsistency of the seedling emergence-emergence force relationship over

all the experiments at one time.

Soil moisture content proved to be a major factor in rate of emergence and final stand of seedlings, particularly when the test was under similar emergence forces. The effect of pressure in causing the seedlings to buckle was clear for compaction pressures of 8 and 16 psi, in comparison to slight or no buckling that occurred at pressures of 0.5 and 1.0 psi.

CONCLUSIONS

1. There was a definite increase in emergence with the increase of moisture content from 12% to 16%. A smaller increase in final emergence resulted when the moisture content was raised to 20% as this probably helped speed the emergence of the seedlings.

2. Drying (within the experimental conditions which is certainly not identical with the field conditions) increased the strength of the soil and the emergence force and thus decreased the rate of emergence and final stand of seedlings even though water was sprayed to simulate rain.

3. The effect of drying decreased emergence as the drying period increased.

4. Within the moisture contents of 12-20%, pressures of 3 psi were better than 1.8 psi for emergence of sugar beet seedlings while there was no difference for corn seedlings.

5. There was a definite relation between the emergence rate and final stand of seedlings and the emergence force required to penetrate the soil with the penetrometer used by Morton (1959).

6. The hypothesis that the rate of emergence and the final stand of seedlings is inversely related to the emergence force was not proved conclusively. The effect of moisture on the seedling emergence was found to be more than simply the influence of water on emergence force of a mechanical seedling.

PROPOSED INVESTIGATION

This thesis has shown that there is a relation between emergence force, emergence energy and the emergence of seedlings. However, there was a lack of information on the physiological activities of the seed and seedling and the quantitative analysis of the energy requirements once the seed initiates the germination process until the seedling emerges and receives energy for photosynthesis from the sun. Investigations should be conducted to determine precisely how and when the seed and the seedling use the energy furnished in the seed's stored food.

The tests in this research should be repeated under more practical conditions concerning the pressures applied. To avoid excessive drying and to resemble the field conditions, deeper boxes should be used and preferably capillary water should be available to keep the soil near the surface moist enough for germination and emergence.

The growth pressure capabilities of plants should be thoroughly investigated, as this pressure determines the seedling's ability to grow against soil impedance. The factors which influence the metabolic aspects of the growth pressure must be determined.

The evaluation of mechanical impedance should be made in more than mechanical terms alone.

APPENDIX

The relationship between soil moisture tension and soil moisture content for Brookston sandy loam is:

Moisture Content percent dry basis	Moisture Tension atmosphere
12*	2.37
15	0.70
16	0.52
18	0.22
20	0.11

*Figures taken from graph by Stout (1959).

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