

THE EFFECT OF PHYSICAL FACTORS ON
SUGAR BEET SEEDLING EMERGENCE

by
B. A. STOUT

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies
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ABSTRACT

The shortage and high cost of hand labor have made complete mechanization of spring work in the production of sugar beets desirable. At present, a major portion of this labor involves thinning and weeding. Because of the difficulties in obtaining an adequate and uniformly spaced stand, growers have had to plant an excessive number of seeds. The labor for thinning could be eliminated by planting the seeds at the proper spacing. In order to space the plants at this desired interval more data concerning the environmental conditions for optimum germination and emergence are needed. After these environmental conditions have been determined, improved planters and cultural practices can be developed.

Soil compaction is one of the important factors affecting seedling emergence. Therefore, experiments were conducted to study the effect of soil compaction in relation to soil moisture content, planting depth, aggregate size, soil temperature and soil type. Most of the work was done in the laboratory under controlled conditions, but a number of field experiments were conducted.

Brookston sandy loam was screened and then moistened to the desired moisture content. The sugar beet seeds were planted at various depths and various pressures were applied to the soil surface. Emergence was highest when low pressure

(one-half to five psi) was used and was severely reduced when the pressure was excessively high (ten to twenty-five psi). Similar trends were exhibited in an experiment using various aggregate sizes up to one-fourth inch in diameter.

In further studies, undisturbed cores of Sims sandy clay loam covered with an eight inch layer of tilled soil were used. Moisture was supplied at the bottom of the soil core. Thus, the effect of capillary movement of water was introduced. Emergence of sugar beets, corn and beans was studied. Surface pressures, in general, had a detrimental effect on emergence. Pressures applied at the seed level, however, resulted in better stands, especially when the soil moisture content was low.

Field tests were conducted using conventional planting equipment in addition to hand planted plots. The hand plantings again demonstrated that a low pressure (one-half psi) applied to the soil surface resulted in better stands than higher pressures (five or ten psi). Little difference was found between the performance of two commercial planters. The John Deere Flexi-Planter produced the best stands when the spring tension on the presswheels was a minimum (approximately six psi at seed level).

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INTRODUCTION

To design a machine suitable for precision planting of sugar beets, corn, beans or other field crops it is necessary to have accurate information concerning the functional requirements of the machine. At the present time many of the requirements of planters are vague and somewhat controversial. Proper packing of the soil both above and below the seed, depth of planting, and seed-bed preparation for optimum seedling emergence are not well enough defined to permit proper design of planting machinery. Planters currently in use are the outgrowth of many years of trial and error type development. While it is true that much progress in planter design has been made, many of the basic requirements remain unknown or are not described in terms that can be used by the engineer. The unknown aspects may be eliminated by gathering basic data describing the environmental conditions necessary for a seedling to emerge and produce a healthy plant.

In recent years, considerable emphasis has been placed on research leading to the complete mechanization of spring work in the production of sugar beets. Inability to obtain a uniform stand is a major problem. Field emergence of sugar beet seedlings is commonly as low as thirty to fifty percent. In many cases it is considerably less. Therefore, much of the work reported in this thesis deals with sugar beet seed-

lings, although emergence of corn and bean seedlings was studied in one series of experiments.

The objective of this study was to gather basic data to establish the requirements for the design and development of improved planting machinery and cultural practices.

REVIEW OF LITERATURE

Yoder (1937) stated the problem when he wrote:

"Both tillage practices and tillage implement designs have developed and progressed through the use of trial and error methods. While an enormous amount of energy is repeatedly expended in seed-bed preparation, the basic fact remains that no one can describe in definite, clean-cut terms what soil conditions one should attempt to produce in a given soil in order to obtain a desirable state of tilth."

This thought was true twenty years ago and it is still true today. A great deal of research has been done to evaluate and improve present planters. Rasmussen (1943) and Bainer (1943) were among the many researchers studying the problem of planter development with the use of sheared or segmented sugar beet seed. McBirney (1946) investigated the effect on emergence of various types of furrow openers, press wheels, planting depths, press wheel weights, furrow shape, the use of soaked seed and soil crust eliminators. Hentschel (1946) studied the effect on emergence of degree of soil fineness, soil compactness prior to planting, degree of seed-soil contact, soil compactness over the seed, type of furrow opener, and method of covering the seed. Barmington (1950a) conducted a large number of tests to determine the effect of various planter components on sugar beet seedling emergence. The ideal condition, as indicated by his tests, was good cultural practices in crops preceding beets followed by a uniform, firm

seedbed, free of trash and weed seed with sufficient moisture to produce germination. Barmington stated that planting equipment should place the seed uniformly in the bottom of a furrow which has been packed below the seed by the furrow opener. The furrow should be closed over the seed by presswheels which pack the soil tightly in the seed zone, leaving the surface mulched to prevent crusting. A single rubber presswheel operated directly over the row gave better results than two wheels set on either side of the row. Barmington (1950b) recognized the need for information describing the environment in the area near the seed. He developed a soil probe and soil sampler to study the soil conditions before and after planting. A correlation was found between the type of equipment used, the firmness of the soil, the soil moisture content in the seed zone and emergence of seedlings. French (1952) conducted an extensive study of the effect of various combinations of presswheels, furrow openers, and downward forces on the presswheels on sugar beet seedling emergence. He reported that a rolling wheel furrow opener showed promise of producing better emergence than the commercial double disc furrow opener in 1949, but no significant results could be attributed to the furrow openers in 1950. No consistent effects from downward forces on the presswheels ranging from 55 to 155 pounds were recorded. Fischer (1952) reported the results of tests with various shapes of presswheels and various packing forces on the wheels. He concluded

that improved field germination was obtainable through compaction of the soil immediately around and below the seed zone to improve capillary movement of the subsoil moisture. Under high moisture conditions, however, Fischer theorized that it is necessary to compact the soil around the seed only to the extent that the soil physically contacts the seed, and presswheels are of less consequence than in areas of marginal rainfall. Frakes (undated) described planter tests dealing with fertilizer placement and soil compaction. He recommended that the fertilizer be placed directly below the seed, and that the soil be packed before and after the seed is planted.

All of the above research has been done with limited knowledge of the environment required for the germination of seeds and the emergence of seedlings. Bowen (1956) and his co-workers recognized the nature of the problem and stated that the scope of future experiments should be broadened to include evaluations of planting methods and machines in terms of a more basic environmental history (cause) as well as percent germination, percent emergence, growth rate and yield (effect).

Factors Affecting Germination and Emergence

Many researchers have listed the basic requirements for a seed to germinate and produce a seedling. The factors listed below are compiled from the work of Crocker (1906), Shull (1911, 1912, 1914), Morinaga (1926a, 1926b) and others.

Factors affecting germination:

- a. Moisture
- b. Oxygen supply (aeration)
- c. Temperature
- d. Chemical nature of soil
- e. Characteristics of the seed
- f. Light
- g. Time

Factors affecting emergence:

All of the above plus

- a. Depth of planting
- b. Mechanical impedance of the soil
- c. Emergence force exerted by the seedling
- d. Disease

In order to present a comprehensive review of the research describing the factors affecting emergence of seedlings, the above factors are considered separately.

Moisture

The importance of soil moisture in germination and emergence has long been recognized. Peters (1920) found that peas, soybeans, corn and wheat germinated at or below the wilting coefficient in a 0.1 mm quartz sand. Doneen and MacGillivray (1943) reported that most vegetable seeds germinated well over the entire range of available water in Yolo fine sandy loam. However, seeds of all crops germinated

faster at high soil moistures than in soil near the lower limit of available moisture. Hunter and Erickson (1952) found that each species had to attain a specific moisture content before germination would occur. The minimum seed moisture content was approximately 30 percent* for corn, 26 percent for rice, 50 percent for soybeans and 31 percent for sugar beets. The soil moisture necessary to supply the above requirements for sugar beets was between 4.4 and 5.4 percent* in Miami silt loam, 8.8 and 9.5 percent in Nappanee clay loam, 10.2 and 12.0 percent in Brookston sandy clay loam, and 16.8 and 17.7 percent in Clyde clay. The soil moisture percentages required for germination, when plotted on the soil moisture tension curve for each soil, formed a line of constant moisture tension for each species. The maximum moisture tension for germination was 3.5 atmospheres for sugar beets, 12.5 atmospheres for corn, 7.9 atmospheres for rice and 6.6 atmospheres for soybeans. These results indicate a considerable difference in the ability of various species to absorb the water required from the soil.

The work of Stout (1955) indicated that there is an optimum soil moisture range for emergence of sugar beets. For a Brookston sandy loam this optimum range was from 12 to 20 percent (3 to 1/10 atmospheres). Soil either wetter or drier than the optimum resulted in reduced emergence.

*Seed moisture contents are given as percent, wet basis; soil moisture as percent, dry basis.

Hanks and Thorp (1956, 1957) reported that the ultimate seedling emergence of wheat, grain sorghum, and soybeans was approximately the same when the soil moisture content was maintained between field capacity and wilting percentage, if other factors were optimum for seedling emergence.* The rate of emergence, however, was related directly to the soil moisture content.

Most of the references discussed above are based on controlled laboratory or greenhouse experiments. In addition, many field studies of the effect of soil moisture on emergence have been made. Wofford (1953) studied the effect of various seedbed preparation techniques, soil conditioners, green manure and seed treatments on emergence and uniformity of stand of sugar beets. The various seedbed preparation techniques were not significant, nor was any improvement in stand observed by using Krilium as a soil conditioner. Field tests were made using loose-wet, loose-dry, firm-wet and firm-dry seedbeds. The best stands were obtained on the loose-wet and firm-wet plots. Water applied in the seed furrow immediately after the seed was dropped and before it was covered by the presswheels had no significant effect on emergence.

Many researchers have advocated the use of minimum seedbed preparation as a measure to conserve moisture and to ob-

* Soils used: Munjor silty clay loam, Keith silt loam, Albion fine sandy loam, Sarpy fine sandy loam, Wabash silt loam, and Ladysmith silty clay loam.

tain better stands. Cook and Rood (1953) presented data from nine Michigan farmers which showed increased beet yields during seasons in which minimum seedbed preparation was practiced. The increased yield may be due to better stands as well as better growing conditions throughout the season. Frakes (1954) points out that minimum seedbed preparation may prove valuable during periods of excessive rainfall following planting. Drainage is enhanced thus reducing the possibility of poor stands due to lack of aeration.

Cook, et al. (1958) stated that seeds should be planted in a firm, well-packed seedbed because, in firm soil, water moves quickly into the seed. They stated that water will move up to the seedling until the roots move down into moist soil, although capillary movement is effective only for short distances. Jamison (1956) pointed out, however, that a very compact soil may impede moisture movement and reduce the moisture supply available to a plant.

Baver (1956) surveyed the literature dealing with capillary flow of moisture through soil in his book and a portion is summarized as follows:

Wollny studied the capillary movement of water in a loam soil and found that the rate of capillary rise increased with temperature, looseness of packing, and original moisture content of the soil. King showed that capillary movement through a wet soil was faster than through a dry one. He advocated a thin layer of dry soil on the surface to act as a mulch for preventing evaporation. Harris and Turpin showed that capillary movement was slightly faster downward than upward or laterally. Johnson reported that capillary properties of soil

must be evaluated in terms of rate as well as distance of movement. This is a fact which is sometimes overlooked by researchers. Buckingham showed that capillary conductivity increased with the moisture content and decreased with the size of the soil pore.

The literature clearly indicates the importance of soil moisture on emergence of seedlings, but the availability of moisture in the soil is only part of the problem. The ability of the seed to absorb water is also a factor.

Moisture absorption by seeds. The necessity of water for germination and emergence has long been recognized, but the amount required and the rate of absorption are not known for all crops. Dungan (1924) found that the rapidity of water absorption was associated with the rate of germination in corn.

Burke (1930) studied the water uptake of several varieties of wheat when placed in water or between moist blotters. He was unable to correlate water absorption directly with germination because the lack of gaseous interchange interfered with germination. Burke found, however, that water uptake was much more rapid when wheat was immersed in water than when placed between blotters and that water absorption increased as the temperature was increased. The relation between moisture absorption and temperature was the same as that reported by Fayemi (1957) for legumes and Brown and Worley (1912) for barley.

The above work agrees with the findings of Stiles (1948, 1949) on the uptake of water by seeds of corn, cotton and

beans. Both the total amount of water absorption and the rate of absorption were different for various species and varieties.

Hunter and Dexter (1950) found that moisture absorption of segmented sugar beet seeds from loose soil (Brookston clay loam) containing 12 percent moisture or less was completed in about four hours. A soil moisture content of 14 percent was required to supply enough moisture for germination of segmented sugar beet seed. The seeds failed to germinate in air at 100 percent relative humidity because the seed moisture content reached only 29 percent. A seed moisture content of 31 percent has been established as the minimum for germination of sugar beet seed (Hunter and Erickson, 1952). Seeds immersed in water reached a moisture content of above 30 percent in one-half hour.

Another approach to the problem of getting moisture into the seed is soaking prior to planting. Hunter (1951) found that soaking segmented sugar beet seeds in water for four hours raised their moisture content above that required for germination. Alternate periods of soaking and drying indicated that this treatment in some way stimulated germination. As many as five soaking and drying cycles did not harm the germination potential of sugar beet seed. Soaking the seed in various chemical solutions did not increase the speed of emergence as much as soaking in water. The benefits derived from soaking the sugar beet seed were sufficient that Hunter

and Dexter (1951) planted soaked seeds in a field test. Only slightly better emergence was obtained by this treatment.

Considerable effort has been expended to cause sugar beet seedballs to absorb water rapidly. Dexter and Miyamoto (1959) found that surface coatings of hydrophilic colloids (gelatin, agar and "algin") accelerated water uptake from sand and accelerated emergence from soil under field conditions.

Aeration

Oxygen requirements for germination have been investigated by many researchers. Crocker (1906) and Shull (1911, 1914) found that failure of *Xanthium* seed to germinate was due to lack of oxygen. Hutchins (1926) found that germination of wheat was limited when the oxygen supplying power of the soil was below 2.3 to 4.5 milligrams per square meter per hour. Increasing the depth of planting and packing or wetting the soil decreased the oxygen supply sufficiently to reduce germination. Farnsworth (1941) found that in soils with an air capacity of less than 12 percent, decreased germination of sugar beet seedballs was due to poor aeration. Archibald (1952) found a definite relation between aeration of the soil and germination of sugar beet seeds. Hanks and Thorp (1956) found that oxygen was a limiting factor in the emergence of wheat seedlings whenever the oxygen diffusion rate was below 75 to 100×10^{-8} grams per square centimeter per minute. This corresponded to a pore space of approximately 16 percent in a silty clay loam and 25 percent in a fine sandy loam.

The above reports deal with germination and emergence of seedlings from soil. Several other investigators studied germination of seeds under water. Morinaga (1926a) found that alfalfa, beans, peas, wheat, corn and many other seeds would not germinate under water although they germinated well on moist blotters. Lettuce, celery and others germinated satisfactorily under water. Hunter (1951) found that segmented sugar beet seeds would not germinate under water unless an additional supply of oxygen was added to the water. Buchele (1954) found that the radicle of corn emerged only one-eighth inch in aerated water, but legumes germinated well. It is apparent that oxygen is necessary for germination and that the minimum requirement is not the same for all crops.

Temperature

Germination is essentially a series of chemical and physical reactions (Hunter, 1951). The effect of temperature on the rate of chemical reaction is well known; therefore, slower germination would be expected as the temperature is decreased. Hunter (1951) investigated the effect of temperature on the germination of sugar beet seed on moist blotters. His results are shown in Table I.

TABLE I.

GERMINATION OF SUGAR BEET SEEDS (US 215 x 216 SEGMENTED)
AT A VARIETY OF TEMPERATURES.

Days after planting	Temperature, °F				
	41	46	50	59	68
5	0	0	0	12	64
10	0	0	8	27	78
15	0	3	43	52	82
20	0	24	68	73	82

Within the limits of this experiment, "high" temperatures seem desirable. This variety would not germinate at temperatures below 46 degrees Fahrenheit. Wood (1952) reported that some varieties of sugar beets may germinate at lower temperatures. Leach, et al. (1946) found that lowering the temperature from 70 to 50 degrees Fahrenheit more than doubled the time required for emergence of sugar beet seedlings in Yolo fine sandy loam. Data by Baten and Eichmeier (1951) and by Crabb and Smith (1953) indicate that the soil temperature in the East Lansing area at a depth of one inch would average 50 to 60 degrees Fahrenheit at planting time. These low temperatures explain some of the difficulties encountered in obtaining uniform and rapid emergence of sugar beet seedlings.

Harrington (1923) and Morinaga (1926b) found that some seeds germinated better when subjected to fluctuating tem-

peratures. The alternating temperatures seemed to stimulate the embryo and also helped to break the seed coat.

Harper (1955) exposed maize seed to many combinations of soil moisture and temperature for varying periods of time. He found that germination was inhibited at the lower levels of soil moisture and at lower temperatures. Ludwig (1957) compared emergence of maize on various slopes. South (and west to a lesser extent) slopes produced early emergence because of radiant heat from the sun, while emergence on the north slopes was not as good. A close correlation was found between soil temperature and the time required to reach 50 percent emergence.

Temperature has a definite effect on the rate of moisture absorption by seeds. Brown and Worley (1912) reported that the rate of absorption of water by barley seeds increased with higher temperatures until a saturation point was reached. Fayemi (1957) reported that the time from exposure to initial absorption of water by seeds became shorter as the temperature increased. The rate of swelling was greatly influenced by temperature.

The literature indicates that temperature is an important factor affecting seedling emergence. Therefore, it should be held constant while observing the effects of other physical factors.

Depth of Planting

Depth of planting has long been recognized as an important factor affecting emergence of seedlings. McBirney (1948) stated, "The depth of planting is one of the most influential factors which affects the percentage of seedling emergence." In Colorado, early sugar beets planted at a depth of one inch gave optimum emergence, while later plantings at one and one-half inches were best. McBirney pointed out the necessity of using exactly the same planting depth when testing different types of equipment and procedures.

Moore (1943) reported that small seeded legumes and grasses emerged best under a variety of conditions when planted between 0.4 and 0.8 inch deep. Hentschel (1946) in a study of sugar beet seedling emergence in Michigan, found that better stands emerged from a planting depth of one inch than from depths of $\frac{1}{2}$, $1\frac{1}{2}$ or 2 inches. Warren (1950) reported that stands and yields of bush lima beans suffered when the seeds were planted four inches deep as compared with depths of one to two inches. Andrew (1953) studied emergence of sweet corn at low temperatures and found that planting depths of nearly four inches produced only 49 percent emergence as compared with 83 percent for one inch depth. Hudspeth and Jones (1954) found that planting depths between one and two inches resulted in best emergence and yields of cotton. Erratic stands resulted, if the seeds were not covered to the proper depth.

Heydecker (1956) investigated the affect of planting depth on emergence of vegetable seedlings (cabbage, lettuce, carrots, onions, etc.). He used 18 depths ranging from zero to nearly four inches. He found the optimum range of depths for all crops studied was between 0.6 and one inch. Heydecker recognized that weather conditions following planting are not predictable and that the proper planting depth is dependent upon the weather. He recommended a 0.7 inch planting depth for vegetable crops. He pointed out that a change in planting depth may result in an improvement in some factors, which may be offset or cancelled by a deterioration in others. For example, deeper planting may give better moisture conditions, and better anchorage, but may increase the mechanical obstruction or decrease aeration. While Heydecker was referring to specific vegetable crops, his remarks apply to many field crops.

As noted above, many researchers have reported an optimum planting depth for specific crops. It may be concluded that seeds should be planted as shallow as possible and yet have sufficient moisture for germination and emergence.

Mechanical Impedance of Soil

The importance of the physical condition of the soil on emergence of seedlings is commonly recognized, but little quantitative work has been reported. Carnes (1934) concluded that the soil should be packed below the seed in order to

give the seedling a firm footing for penetrating surface crusts. Painter (1948) reported that packing the soil over the seed depressed sugar beet seedling emergence, although the cause was not established.

Richards (1953) found that an increase in crust strength from 108 to 273 millibars* resulted in a decrease in emergence of bean seedlings from 100 to 0 percent. Hanks and Thorp (1956, 1957) reported that crusts apparently limited emergence of wheat, grain sorghum and soybeans, especially at the lower moisture contents. At a constant moisture content, seedling emergence decreased with increasing crust strength. Some emergence occurred even where the crust strength was as high as 1400 millibars.

Morton (1958) constructed a soil penetrometer for measuring the energy of emergence. The force required to penetrate the soil was measured by pushing a probe upward through the soil. By determining the force and the rate of movement, the energy expended in pushing the probe through the soil was determined.

A number of researchers have investigated the use of soil conditioners to reduce surface crusting. Liljedahl (1954) reported on the use of Krilium. Allison and Moore (1956) used VAMA and HPAN to reduce soil crusting and obtained increased

*A unit of pressure, 1000 dynes per square centimeter or 0.0145 psi.

yields of sweet corn. The critical modulus of rupture appeared to be between 1200 and 2500 millibars.

Other Factors Affecting Germination and Emergence

A number of other factors are known to affect the germination and emergence of seedlings, but were not considered in this investigation. The placement and rate of application of fertilizer is a good example. Twenty years ago it was common practice to place fertilizer with the seed when planting sugar beets (Brown, 1940; Jensen, 1942; Jones, 1942). Later experiments have shown the harmful effects of placing fertilizer with the seed. Mellor, et al. (1950), studied the effect of placing fertilizer with the seed, and reported a 54.7 percent reduction in stand of sugar beet seedlings as compared with the unfertilized check. This severe reduction in stand was attributed to an unusual dry period after planting in which the drought was intensified by the presence of fertilizer. Recently, Cook, et al. (1957) recommended fertilizer rates of 600 to 1000 pounds per acre placed in a band two inches below the seed or one inch to the side and two inches below.

Another important factor affecting germination and emergence is the seed itself. It is obvious that a study of seedling emergence requires a high quality seed. In sugar beets, the existence of several germination inhibitors has been recognized. Stout and Tolman (1941) reported the presence of

ammonia in sugar beet seedballs in sufficient quantities to exert a toxic action on the embryo. They theorized that the ammonia was liberated from nitrogenous substances in the seed-coat. DeKock, et al. (1953) reported the presence of a yellow oil in the water extract of sugar beet seed and suggested that it was an inhibiting substance. Miyamoto (1957) found the oxalic acid contents of the seedball of beet and spinach were sufficient to inhibit germination. Thus, it is clear that inhibitors exist, although their exact nature and physiological action are not known.

"Damping off" as a result of various diseases is a problem in the growth of seedlings. This may occur before or after the seedling emerges. Coons (1953) presented an excellent summary of the diseases affecting sugar beets. Black root is especially a problem and may cause severe reductions in stands under certain climatic and soil conditions.

Statement of the Problem

The review of literature revealed a lack of precise information necessary for proper planter design. Although a great deal of research has been done to improve planter performance, the environment required by the seed to produce a healthy seedling has not been defined in terms that can be used by the engineer. Many of the factors affecting emergence of seedlings are not easily controlled by the planter. Soil compaction, however, is easily controlled by mechanical de-

vices such as presswheels on the planter; therefore, its influence on seedling emergence under various conditions is of primary interest. The range of pressures (forces on a given area) which produce optimum emergence of seedlings under various soil conditions will be determined.

The chronological order of the research is as follows:

- (a) The effect of soil compaction on sugar beet seedling emergence from soil in covered plastic boxes -- conducted in a controlled temperature room in the Horticulture Building and in the Plant Science greenhouse, December, 1955 to July, 1957.
- (b) Field investigation, summer of 1956 and 1957.
- (c) Moisture absorption by sugar beet seeds -- conducted in a controlled temperature room in the Agricultural Engineering Building, December, 1956 to April, 1957.
- (d) The effect of soil compaction on seedling emergence from soil in open boxes sixteen inches deep -- conducted in a controlled temperature room in the Agricultural Engineering Building, August to December, 1958.

The presentation that follows is not in chronological order. For clarity it is presented in the order a, d, c, b.

EFFECT OF SOIL COMPACTION ON SUGAR BEET SEEDLING EMERGENCE FROM SOIL IN COVERED PLASTIC BOXES

The review of literature revealed many examples of improvements in planting machinery by trial and error techniques. It is difficult, however, to obtain a complete understanding of the problem by this procedure. This method is often slow and inefficient for obtaining a complete solution to a problem. A better approach is to study the factors affecting germination and emergence under controlled conditions and attempt to define the environment required by a seed to produce a normal plant.

Previous investigations have indicated the importance of packing the soil in the seed zone to the proper degree. Although much research has been done using different kinds of presswheels, very few figures are available describing the amount of pressure or force that should be applied. In order to properly design a planter, the requirements of seeds at different soil moisture contents, planting depths, soil aggregate sizes, and soil types must be known. A series of laboratory experiments was planned to determine the amount of soil compaction required to give the highest rate and percentage of emergence of sugar beet seedlings. The experimental variables were carefully controlled, but no specific attempt was made to simulate field conditions. This series of

experiments was designed to establish principles which could be adapted to field conditions later.

Methods and Materials

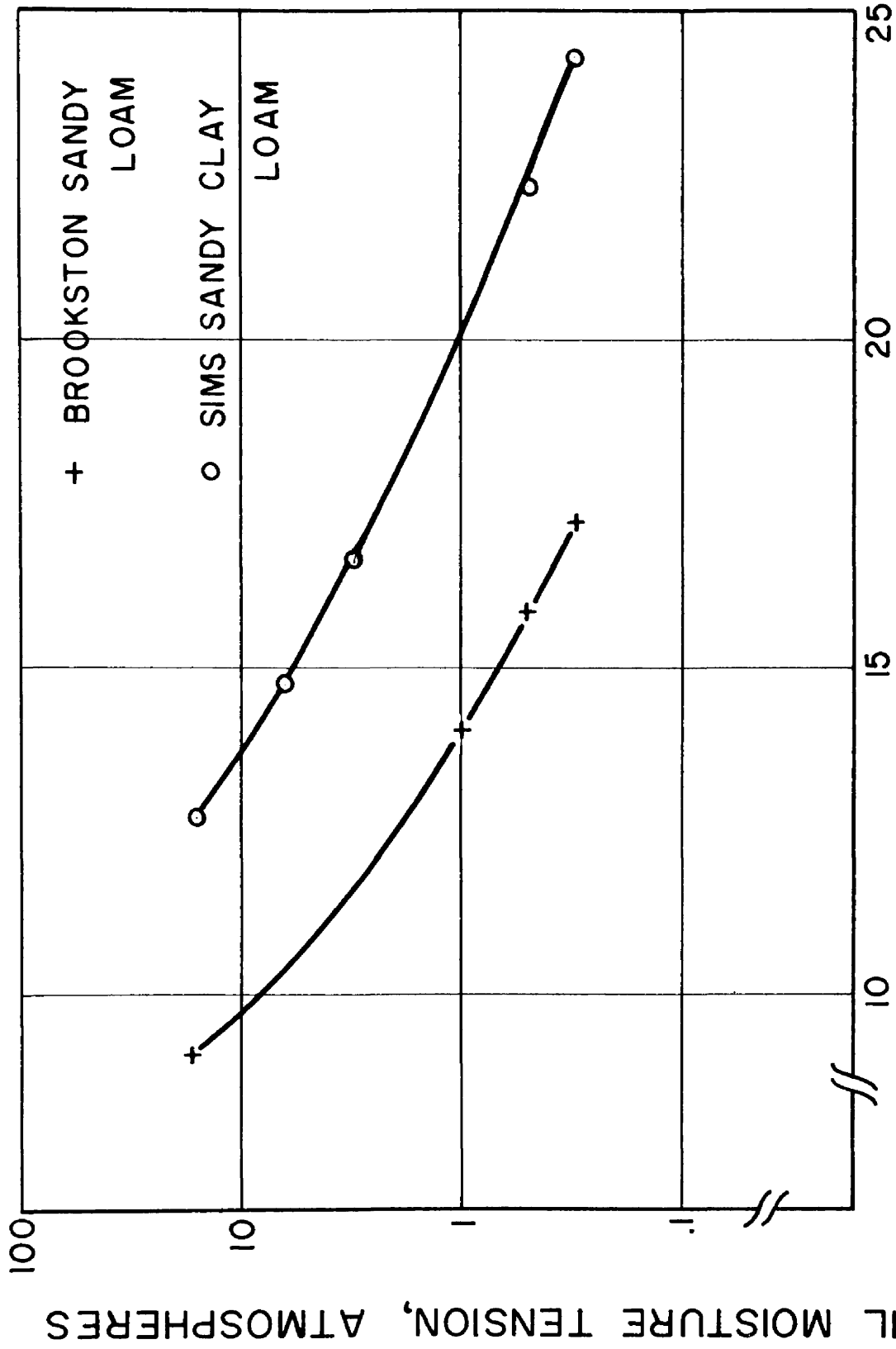
Two types of soil, Brookston sandy loam and Sims sandy clay loam, were used in the following laboratory investigations. The mechanical analyses of these soils are shown in Table II. Moisture tension curves for the two soils are shown in Figure 1.

TABLE II.

MECHANICAL ANALYSES OF SOILS USED FOR EMERGENCE STUDIES.

	Percent by weight		
	Sand	Silt	Clay
Brookston	63	23	14
Sims	47	28	25

A summary of the conditions for Experiments 1 through 4 is given in Table III. Soils used in Experiments 1, 3 and 4 were screened through a 1.19 mm sieve. The amount of water necessary to increase the soil moisture content to the desired level was added to the air dry soil. The container was sealed tightly and allowed to stand two or three days for the mixture to come to equilibrium. Each container was shaken to uniformly distribute the moisture throughout the soil. The uniformity of the moisture distribution was checked by removing twenty-



SOIL MOISTURE TENSION CURVES FOR THE TWO SOILS

Figure 1. Soil moisture tension curves for the two soils used in the laboratory experiments.

five samples from a jar and determining the oven dry moisture content. Moisture contents ranged between 15.39 to 16.58 percent.

Experiment 1 (Moisture-Depth-Pressure). The soil was placed in plastic boxes (5 inches x 7 inches x 4 inches deep) at planting time. In Experiment 1, the variables were soil moisture, depth of planting, and soil compaction. Forty whole sugar beet seedballs of variety US 400 were planted in each box. Table III gives the details of the various treatments. Pressures were applied to the soil surface momentarily by the compacting machine shown in Figure 2.* The resulting soil bulk densities are shown in Table IV. Lids were placed on the boxes to reduce evaporation to a minimum. A check showed that the soil moisture content in a covered box decreased from 13 to 12 percent in seven days. The temperature during the entire experiment was maintained at 75 degrees Fahrenheit. Daily emergence counts were made. Only the first seedling from a seedball was counted since multigerm seeds were planted and more than one seedling often emerged from a seedball.

Experiment 2 (Aggregate Size). Since Experiment 1 was carried out using finely screened soil, emergence of seedlings from soil consisting of larger aggregates could not

*This machine has been described in detail by French and Snyder (1958).

TABLE III.
SUMMARY OF CONDITIONS FOR EXPERIMENTS 1 THROUGH 4.

Expt. No. and name	No. of repli-cations	Soil type	Soil moisture		Soil moisture tension	Depth after packing	Variety of sugar beet seed	Aggregate size	
			content	percent				Pressure	mm
1 (Depth-Moisture-Pressure)	3	Brookston	12, 16, 21	2½, ½, 1/10	½, 1, 1½	US 400 whole	½, 5, 10		<1.19
2 (Aggregate size)	3	Brookston	17	3/10	¾	US 400 whole	0, 5, 10, 15, 25	<0.59 0.59-1.19 1.19-2.38 2.38-4.69 4.69-6.35	
3 (Method of packing)	4	Brookston	16	½	½	US 400 whole	0, 2, 5, 15		<1.19
4 (Soil type)	3	Sims	18	2	1	US 400 whole	0, ½, 5, 10		<1.19

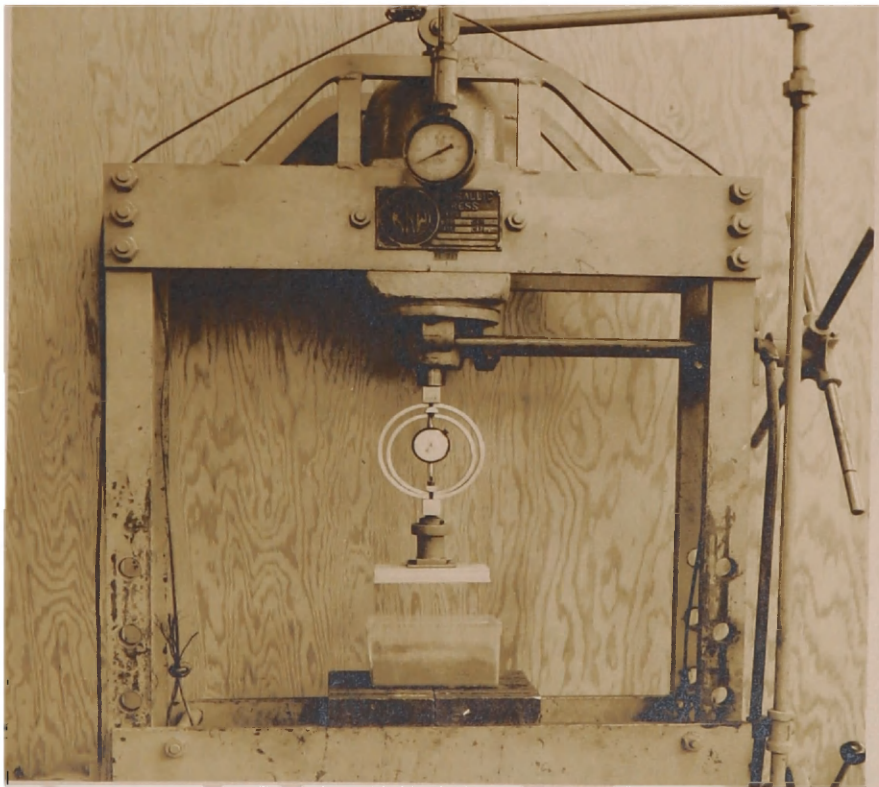
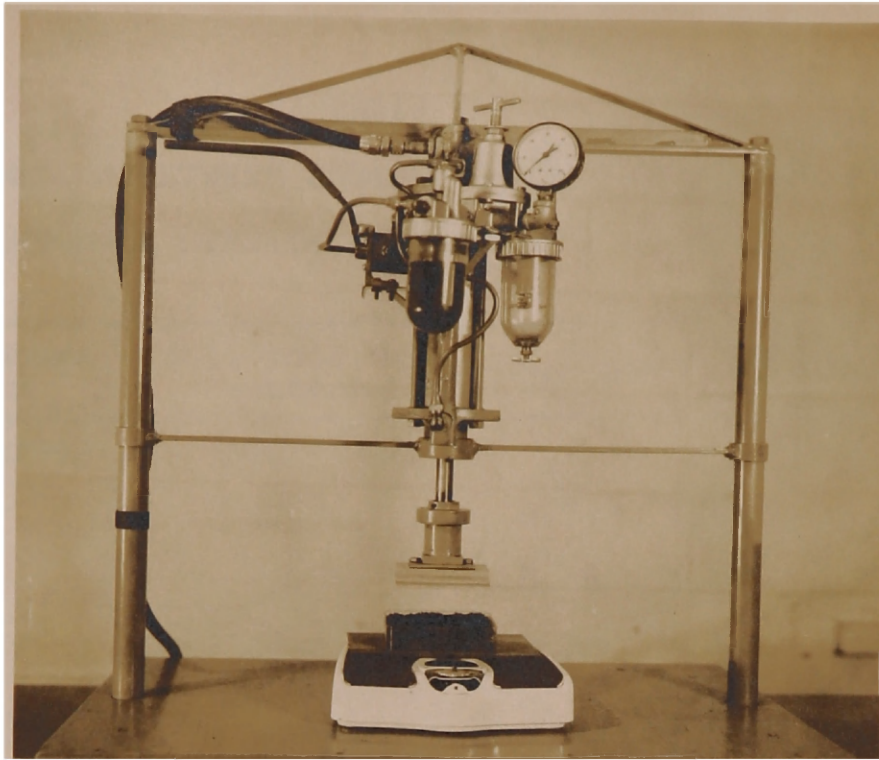


Figure 2. Machines used for compacting the soil.
a. Compressed air actuated press (above)
b. Force ring and hydraulic press (below)

TABLE IV.
RELATION BETWEEN SURFACE COMPACTION PRESSURE
AND BULK DENSITY OF BROOKSTON SANDY LOAM.

Soil moisture tension	Soil moisture content	Surface pressure, psi			
		0	2	5	15
atmospheres	percent				
$2\frac{1}{2}$	12.8	0.75*	1.04	1.13	1.29
$1/3$	16.8	0.66	1.04	1.18	1.37
$1/15$	21.7	0.72	1.13	1.29	1.48

*Bulk density, grams per cubic centimeter.

be determined. Experiment 2 was designed to answer this question. Air dried Brookston sandy loam was separated into five aggregate size classes (Table V), the largest being approximately one-quarter inch in diameter.

TABLE V.

SIZE OF SOIL AGGREGATE CLASSES USED IN EXPERIMENT 2.

Aggregate size class	Size of sieve opening mm	U.S. sieve no.
A	less than 0.59	16
B	0.59 - 1.19	16 - 30
C	1.19 - 2.38	8 - 16
D	2.38 - 4.69	4 - 8
E	4.69 - 6.35	4

Water was added to bring the soil moisture to equilibrium at approximately 17 percent. Whole seedballs of sugar beet variety US 400 were planted and covered so that after pressure was applied, the seed depth was three-fourths inch. Pressures of 0, 5, 10, 15 and 25 psi were applied to the soil surface. All plantings were replicated three times. A check on the water stability of the aggregates was made using two boxes of soil of each size class. These samples were wetted and handled in the same manner as those in which seeds were planted except that no pressure was applied to the surface. After the soil was wetted, the lids were removed, the soil

air dried, and screened again. Table VI shows the breakdown of soil aggregates during the wetting cycle.

TABLE VI.
EFFECT OF WETTING AND DRYING ON AGGREGATES IN EXPERIMENT 2.

Aggregate size before wetting	Aggregate size after wetting and drying				
	A	B	C	D	E
mm	Percent				
A (less than 0.59)	100				
B (0.59 - 1.19)	23	77			
C (1.19 - 2.38)	5	15	80		
D (2.38 - 4.69)	5	1	10	84	
E (4.69 - 6.35)	8	1	1	15	75

Experiment 3 (Method of Packing). Three methods of packing the soil were compared. The techniques were as follows:

- (a) Method 1 (used in Experiments 1 and 2). Seeds were placed on loose soil, covered with loose soil and pressure applied to the soil surface.
- (b) Method 2. Seeds were placed on loose soil, pressure applied at the seed level, more loose soil added and pressure applied a second time (on the soil surface).
- (c) Method 3. Seeds were placed on loose soil, pressure applied at the seed level, more loose soil added and allowed to remain loose.

Sixteen whole sugar beet seedballs of variety US 401 were planted in each box. The soil moisture content in the various boxes at planting time ranged from 15.5 to 16.9 percent. This variation in moisture content had little effect on emergence (Stout, 1955). Pressures of 0, 2, 5 and 15 psi were applied using each of the three methods. A single pressure was used in each box and it was applied for only an instant and then released as is the case with a presswheel. The entire experiment was replicated four times.

Experiment 4 (Soil Type). The first three experiments were conducted using Brookston sandy loam. In order to study the effect of soil type, Experiment 4 was conducted using Sims sandy clay loam. Three replications were planted so that the depth of the seed was one inch after pressures of 0, $\frac{1}{2}$, 5 and 10 psi were applied.

Experimental Results

Experiment 1 (Moisture-Depth-Pressure). The results of Experiment 1 are shown in Table VII. It is apparent that the three variables being studied had a great deal of influence on the rate and percentage of emergence. Figures 3, 4 and 5 have been prepared to show emergence as a function of compaction pressure, depth of planting, and soil moisture content, respectively. In soil at 21 percent moisture, over ninety percent of the seedballs produced at least one seedling with-

TABLE VII.
ACCUMULATIVE EMERGENCE FOR EXPERIMENT 1.

Soil moisture content	Depth after packing	Pressure	Days after planting						
			4	5	6	7	8	9	15
percent	inches	psi	percent						
12	$\frac{1}{2}$	$\frac{1}{2}$	-	30	64	94	97	97	97
		5	1	19	48	62	67	68	68
		10	-	--	8	20	23	25	30
	1	$\frac{1}{2}$	-	--	34	89	92	94	95
		5	-	--	11	23	36	46	62
		10	-	--	--	--	--	--	7
	$1\frac{1}{2}$	$\frac{1}{2}$	-	--	7	40	57	77	90
		5	-	--	--	2	10	15	32
		10	-	--	--	--	--	--	10
16	$\frac{1}{2}$	$\frac{1}{2}$	10	68	89	91	92	92	92
		5	6	54	88	93	94	94	94
		10	1	12	43	49	53	54	54
	1	$\frac{1}{2}$	-	27	78	92	93	94	94
		5	-	12	73	88	91	91	92
		10	-	--	12	31	42	44	45
	$1\frac{1}{2}$	$\frac{1}{2}$	-	1	46	77	88	92	95
		5	-	--	3	19	45	59	68
		10	-	--	--	1	8	14	25
21	$\frac{1}{2}$	$\frac{1}{2}$	32	77	93	93	93	93	93
		5	27	87	92	92	94	94	94
		10	16	73	89	90	91	91	91
	1	$\frac{1}{2}$	10	52	92	94	94	94	94
		5	--	53	85	89	92	92	92
		10	--	21	67	81	82	82	82
	$1\frac{1}{2}$	$\frac{1}{2}$	--	28	77	83	83	83	83
		5	--	2	53	71	75	77	77
		10	--	--	3	33	57	58	60

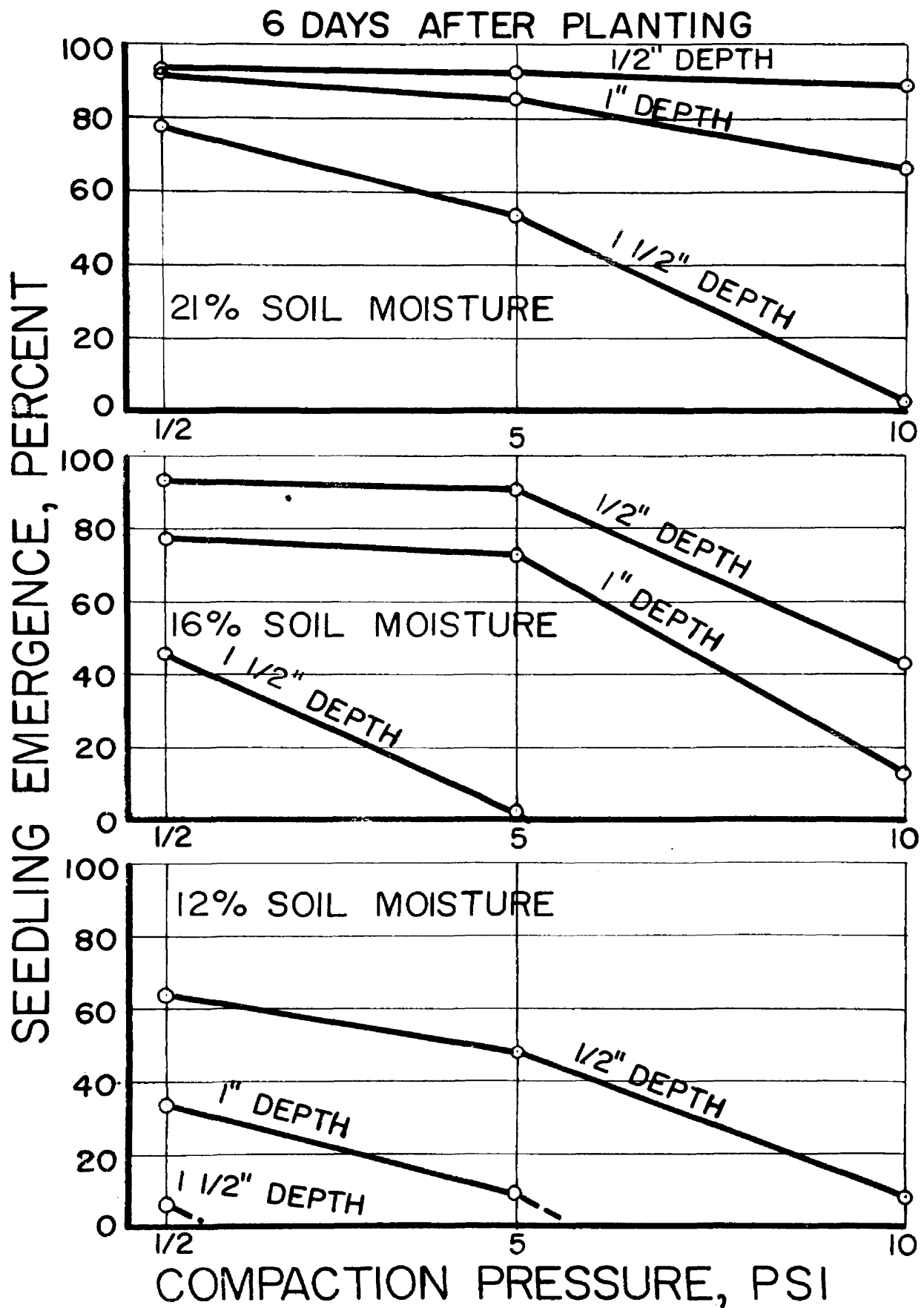


Figure 3. Effect of soil compaction on emergence of sugar beet seedlings

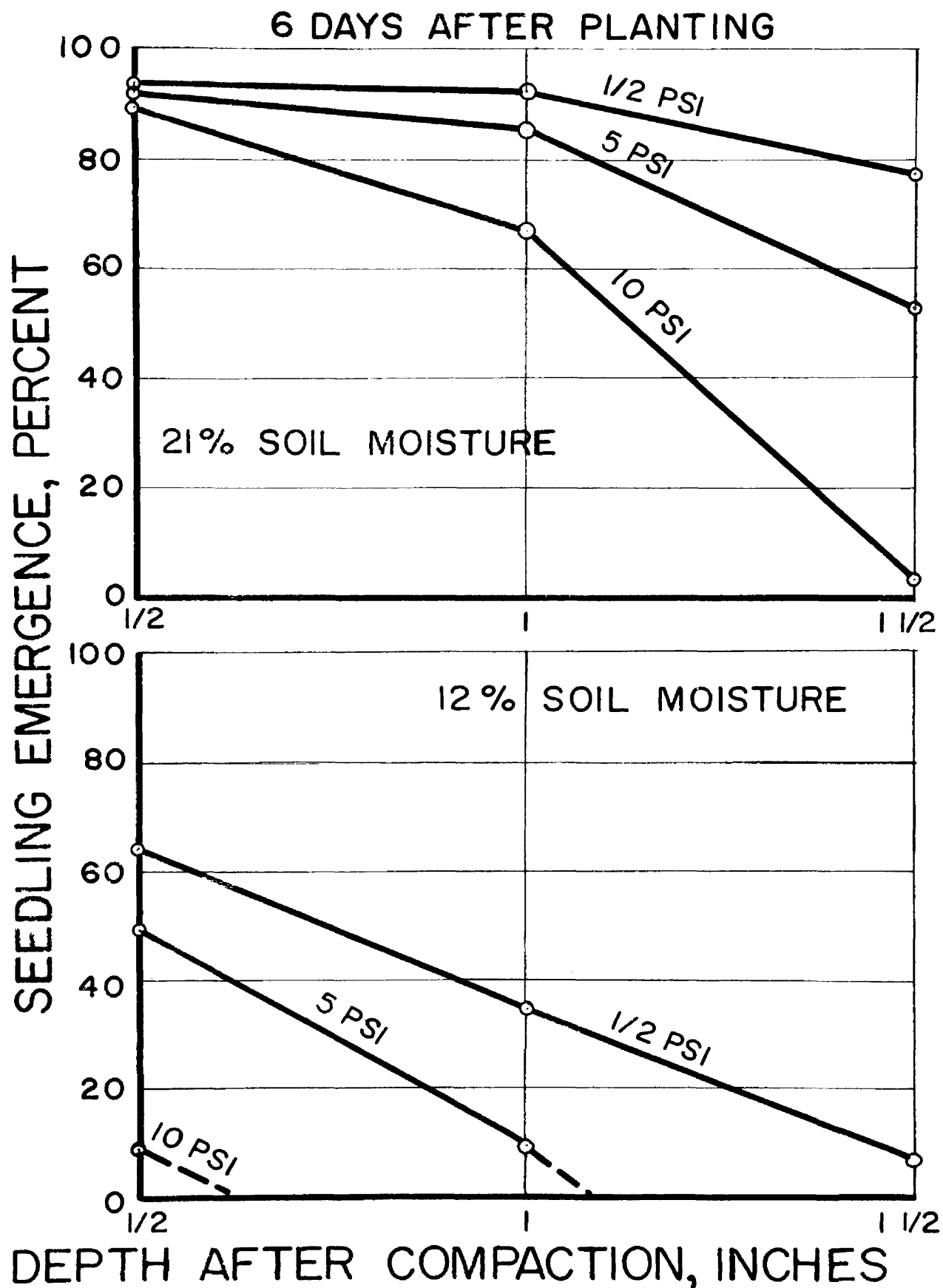


Figure 4. Effect of depth of planting on emergence of sugar beet seedlings

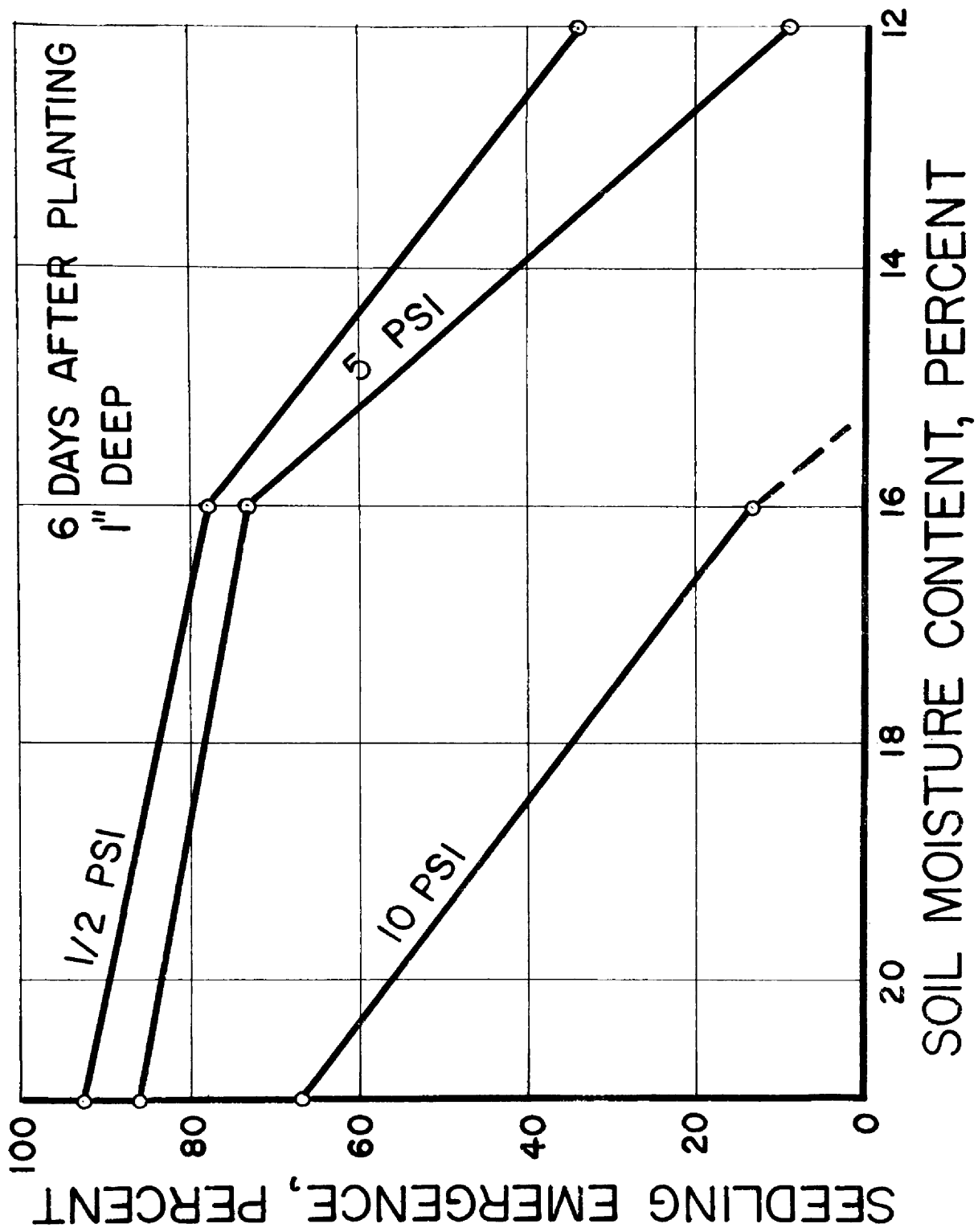


Figure 5. Effect of soil moisture content on emergence of
sugar beet seedlings

in six days after planting one-half inch deep and packing with a surface pressure of one-half psi. In contrast, no seedlings emerged from the soil at twelve percent moisture when planting $1\frac{1}{2}$ inches deep and packed with a pressure of ten psi until ten days after planting. Figure 3 shows that as the packing pressure is increased above one-half psi the emergence is decreased. The problem is more severe as the planting depth is increased and the moisture content decreased. Contrary to popular opinion, increasing the pressure after planting in dry soil did not improve the emergence. Increasing the planting depth in one-half inch increments had approximately the same effect as increasing the pressure on the soil surface in five increments. Curves of percent emergence for decreasing soil moisture have the same shape as those for increasing pressure and depth of planting.

Experiment 2 (Aggregate Size). The very fine aggregates used in Experiment 1 did not constitute a typical field soil. Experiment 2 was conducted to determine the effect of soil compaction on emergence in larger soil aggregates. The results are shown in Figure 6. Although a wide variation in emergence was obtained from the different size classes, in every case pressures above five psi reduced emergence.

Because of the great variation between replications and the peculiar effect of aggregate size on emergence, few conclusions can be drawn from this experiment. It is important to stress, however, that for all aggregate size classes the

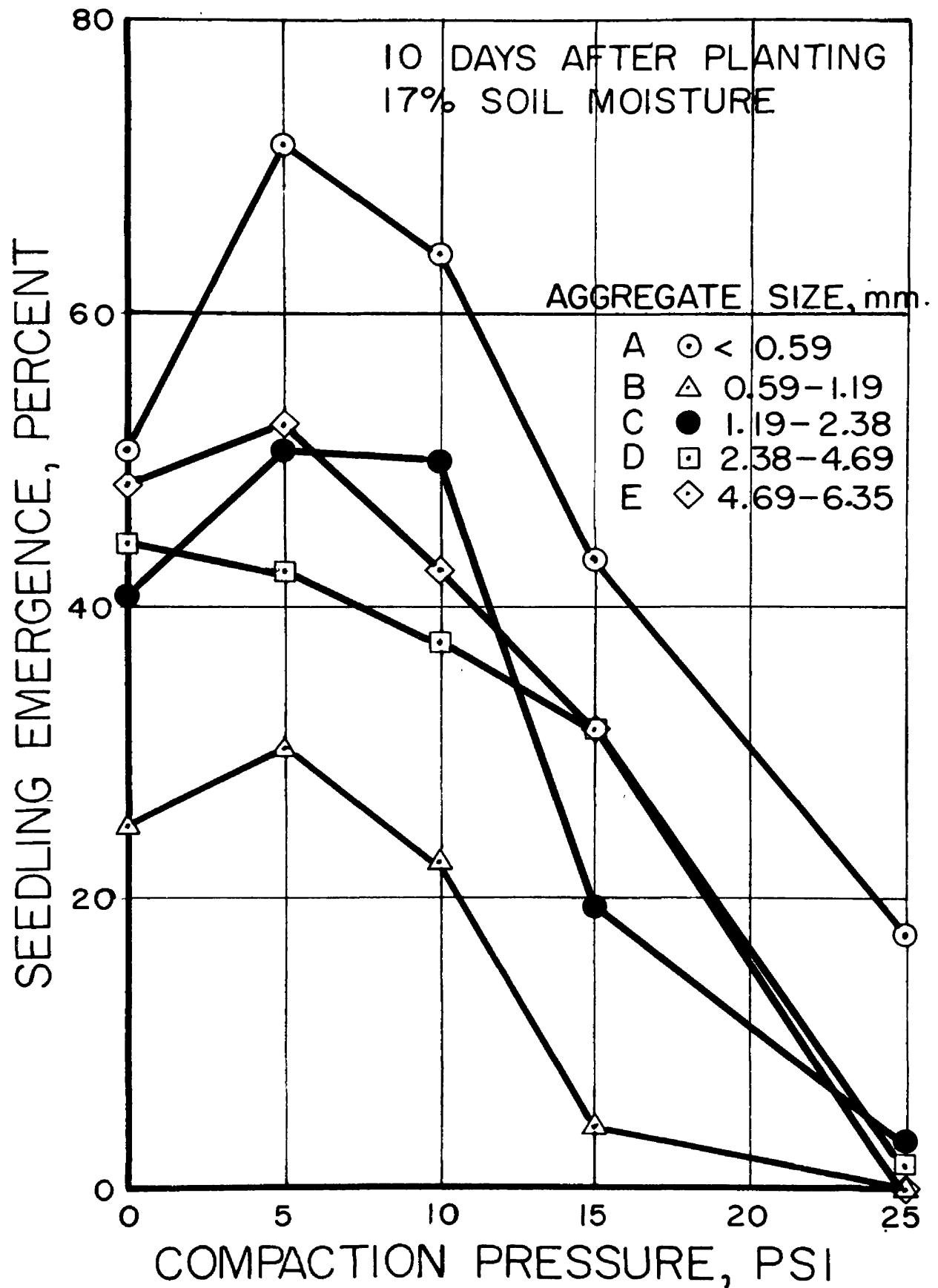


Figure 6. Effect of soil compaction on emergence of sugar beet seedlings in several soil aggregate classes

application of pressures above five psi to the soil surface decreased the emergence of sugar beet seedlings. The general effect of compaction pressure indicated in Experiment 1 for fine aggregates held true for aggregates up to approximately one-fourth inch (6.35 mm) in diameter.

Figure 7 shows typical sugar beet seedling emergence from soils compacted with surface pressures of 0, 5 and 25 psi. The soil contained all aggregate sizes up to approximately one-fourth inch in diameter. Seeds were planted in a rectangular pattern three-fourths inch apart at a depth of one inch. Large numbers of seedlings emerged from the soil receiving no pressure and five psi, but not a single seedling emerged from the soil that was packed with a pressure of twenty-five psi.

Experiment 3 (Method of Packing). In the first two experiments pressure was applied to the soil surface. Experiment 3 was conducted to determine if there was a better method of packing the soil after planting seeds. The accumulative emergence of sugar beet seedlings for the three methods of packing the soil is shown in Figure 8. The effect of packing pressure applied by each of the three methods is shown in Figure 9. Under the conditions of this test, packing the soil at the surface (Method 1) resulted in the best emergence. Regardless of the method used, pressures higher than five psi resulted in decreased emergence.



Figure 7. Effect of soil compaction on emergence of sugar beet seedlings

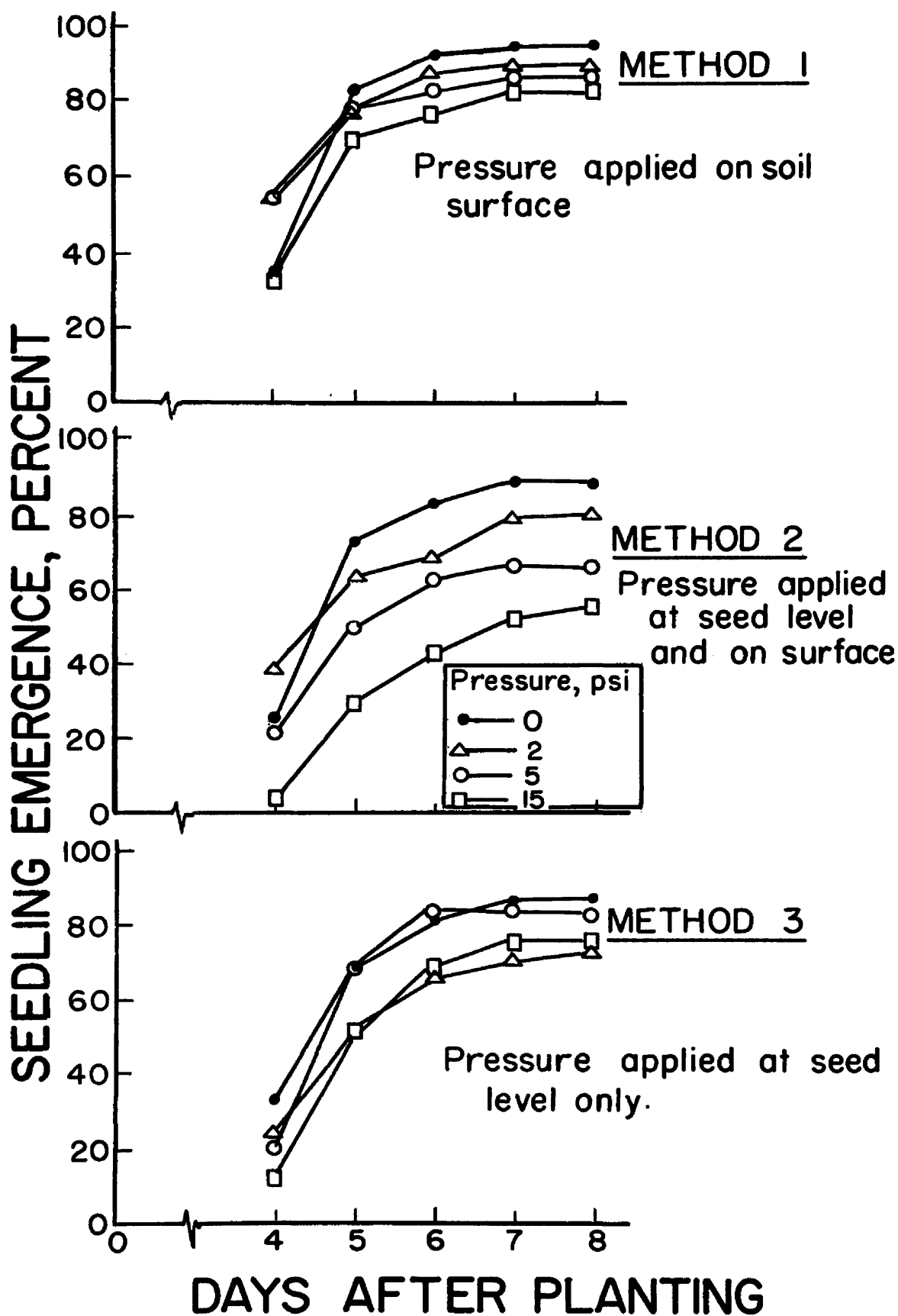


Figure 8. Accumulative emergence for three method of packing the soil

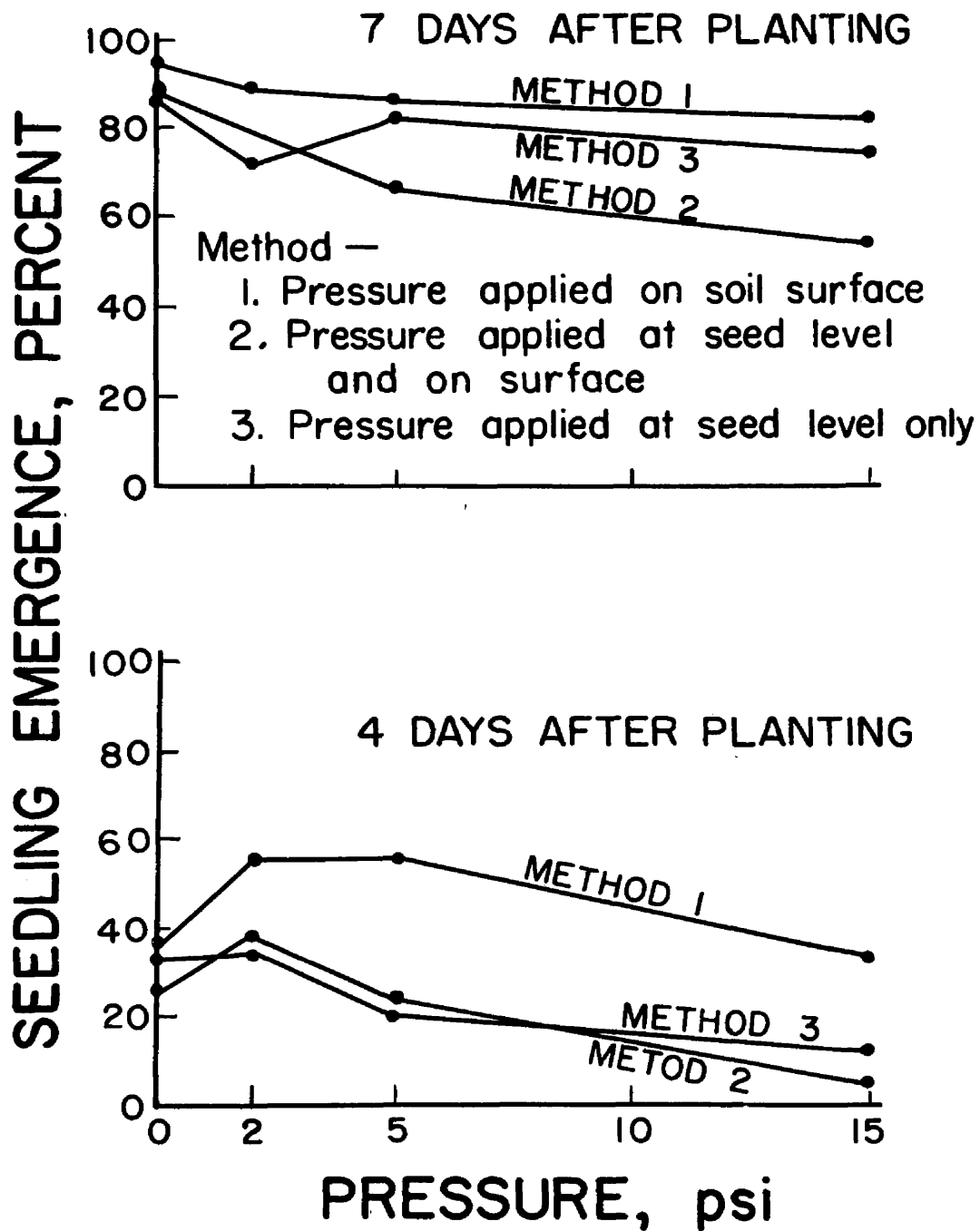


Figure 9. Effect of three methods of packing the soil on emergence of sugar beet seedlings

Experiment 4 (Soil Type). An attempt was made to apply the results of the previous work to a more typical sugar beet soil. The effect of soil compaction on emergence of sugar beet seedlings in Sims sandy clay loam is shown in Figure 10 along with typical results for Brookston sandy loam. As was expected, pressures of $\frac{1}{2}$, 5 and 10 psi resulted in nearly the same emergence for both soils. The difference in emergence in the two soils was not significant (Table XVIII, Appendix), although the difference in emergence due to the various pressures was highly significant.

Discussion of Results

Specific information showing the effect of soil compaction on sugar beet seedling emergence with various soil moisture contents, depths of planting, aggregate sizes, and methods of packing was obtained in the first three experiments. The above work was conducted using Brookston sandy loam; however, a limited amount of data indicated a similar effect of compaction in Sims sandy clay loam.

The results obtained should be interpreted cautiously considering the experimental conditions and recognizing the limitations. All data were collected in the laboratory and no attempt was made to simulate field conditions. Moisture was thoroughly mixed with the soil and prevented from escaping by placing a lid on each soil container after plant-

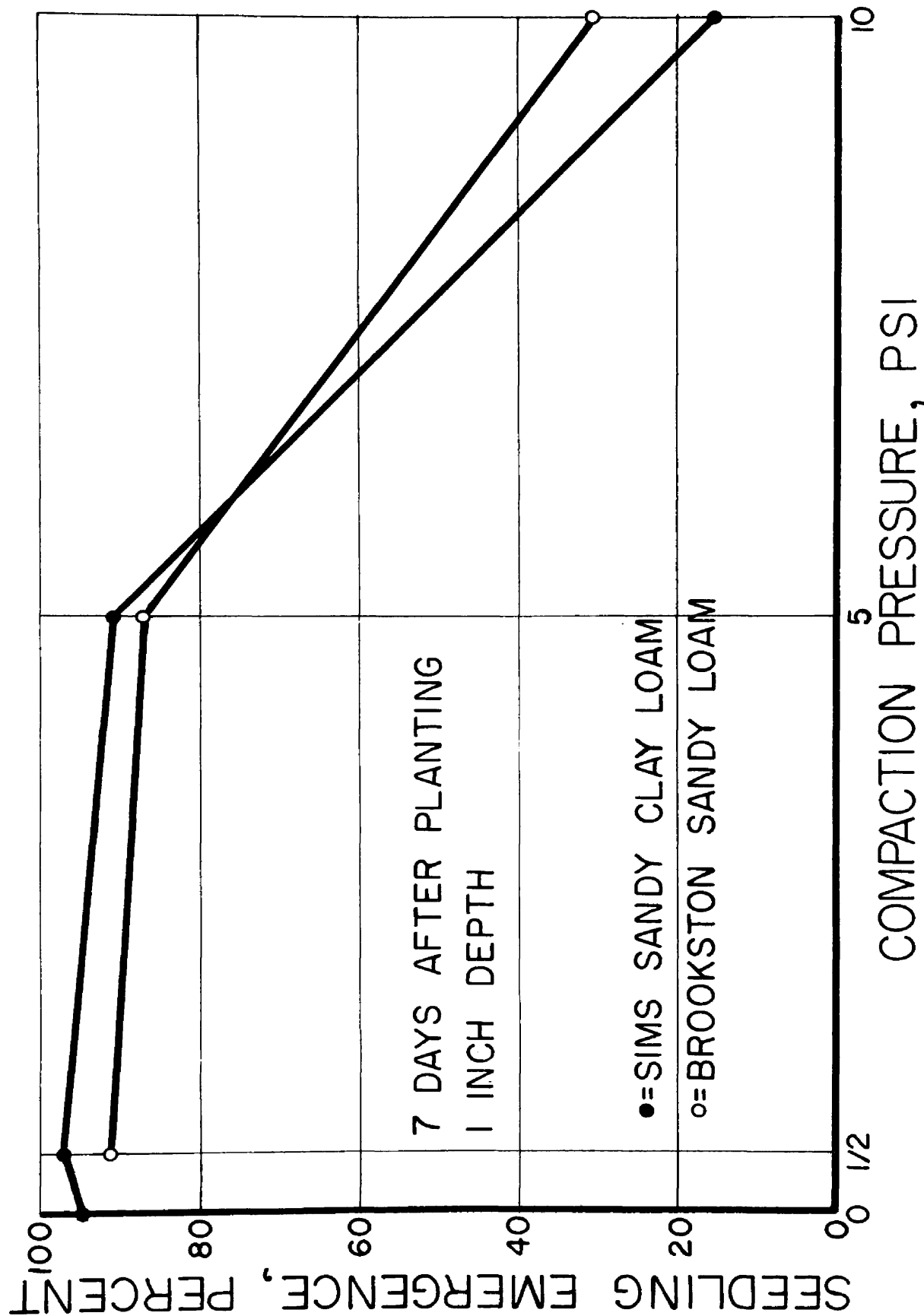


Figure 10. Effect of soil compaction on emergence of sugar beet seedlings in Sims and Brookston soil

ing. Thus, there was little surface drying and little if any crust formation. Moisture movement through the soil, as affected by soil compaction, was not studied because of the absence of any appreciable moisture gradient.

Seeds were covered with sufficient soil so that the planting depths were constant after the various pressures were applied. This means that seeds receiving high pressure treatments were covered with more loose soil than those receiving low pressures. This technique was used because the primary object of this study was to determine the effect of soil compaction on seedling emergence and every effort was made to hold other factors constant. Because planting depths before packing the soil were not constant, these laboratory results cannot be compared directly with field results. Commercial planters commonly use depth bands or gage wheels to control the depth before the presswheels pass over the planted seed.

The small size of the containers used should also be considered when interpreting the results of the first series of experiments. Vandenberg (1959) found that actual pressures within the soil were somewhat higher near the sides or bottom of a container than the pressure applied to the surface. Thus, to get an accurate indication of the effect of soil compaction on emergence of seedlings a larger soil container should be used.

Experiments 5 through 9 were conducted under conditions more nearly approximating those expected in the field and may be used as a partial check on the validity of Experiments 1 through 4.

EFFECT OF SOIL COMPACTION ON SEEDLING EMERGENCE FROM SOIL IN BOXES SIXTEEN INCHES DEEP

The previous experiments were conducted in plastic boxes containing soil which was sufficiently moist for seeds to germinate and seedlings to emerge. Under field conditions, moisture may be supplied to the germinating seed by capillarity from the surrounding soil or by rains. This series of laboratory experiments was conducted under simulated field conditions.

Methods and Materials

Three boxes of the type shown in Figures 11 and 12 were constructed. Each was divided into three compartments by removable partitions. Cores of undisturbed Sims subsoil were placed on a layer of gravel in the bottom of the boxes and sealed along the edges with agar. A layer of Sims sandy clay loam topsoil was placed above the cores. Provisions were made for adding water to the soil at the bottom permitting upward capillary flow through the soil. The experiments were conducted in a constant temperature chamber equipped with a special fan and duct system to move air across the top of the boxes to simulate a wind blowing across a field. Heat lamps were placed above the soil surface to provide radiant heat. An electric timer operated the lamps approximately four hours

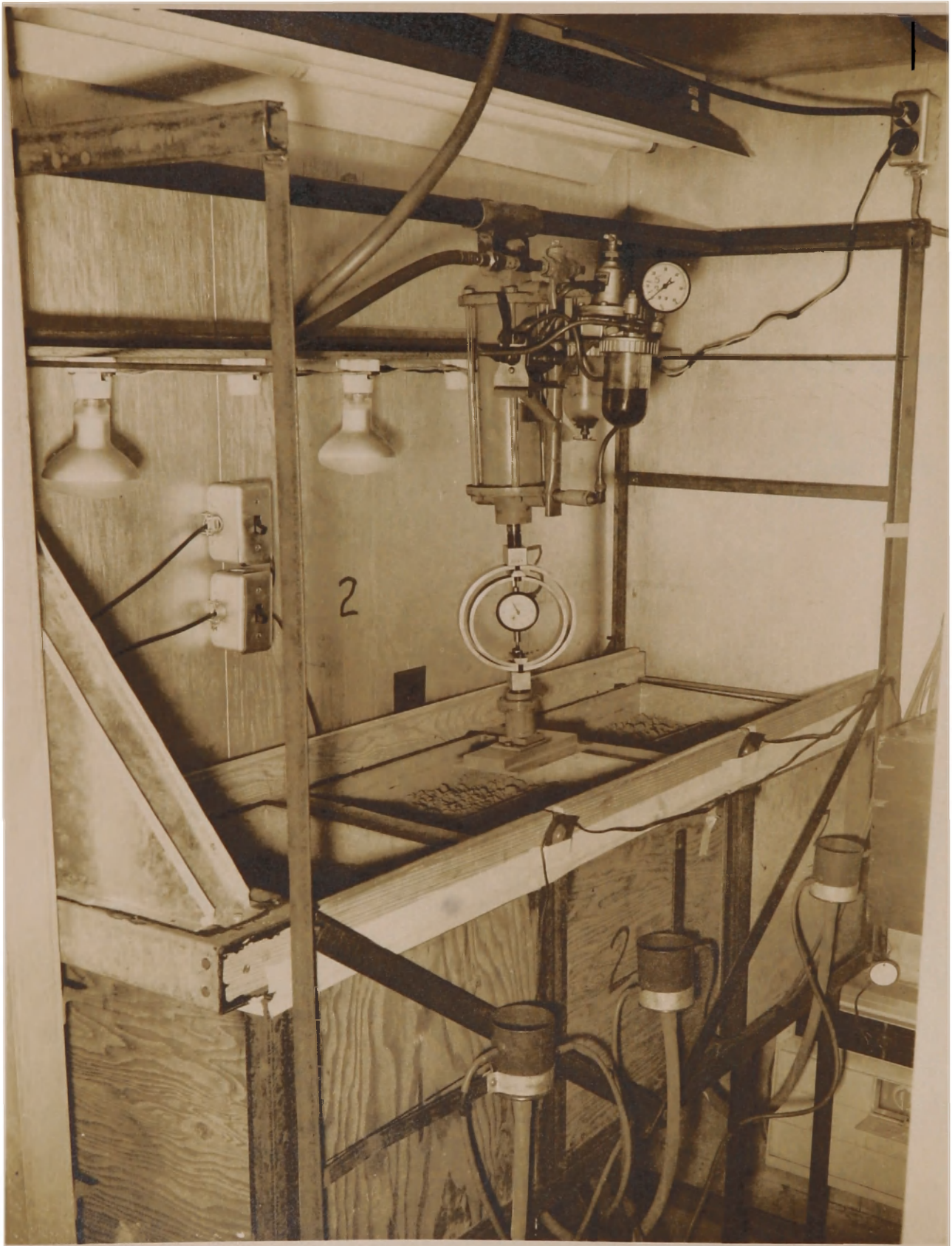


Figure 11. Apparatus used for studying the effect of soil compaction on emergence of seedlings in soil boxes 16 inches deep

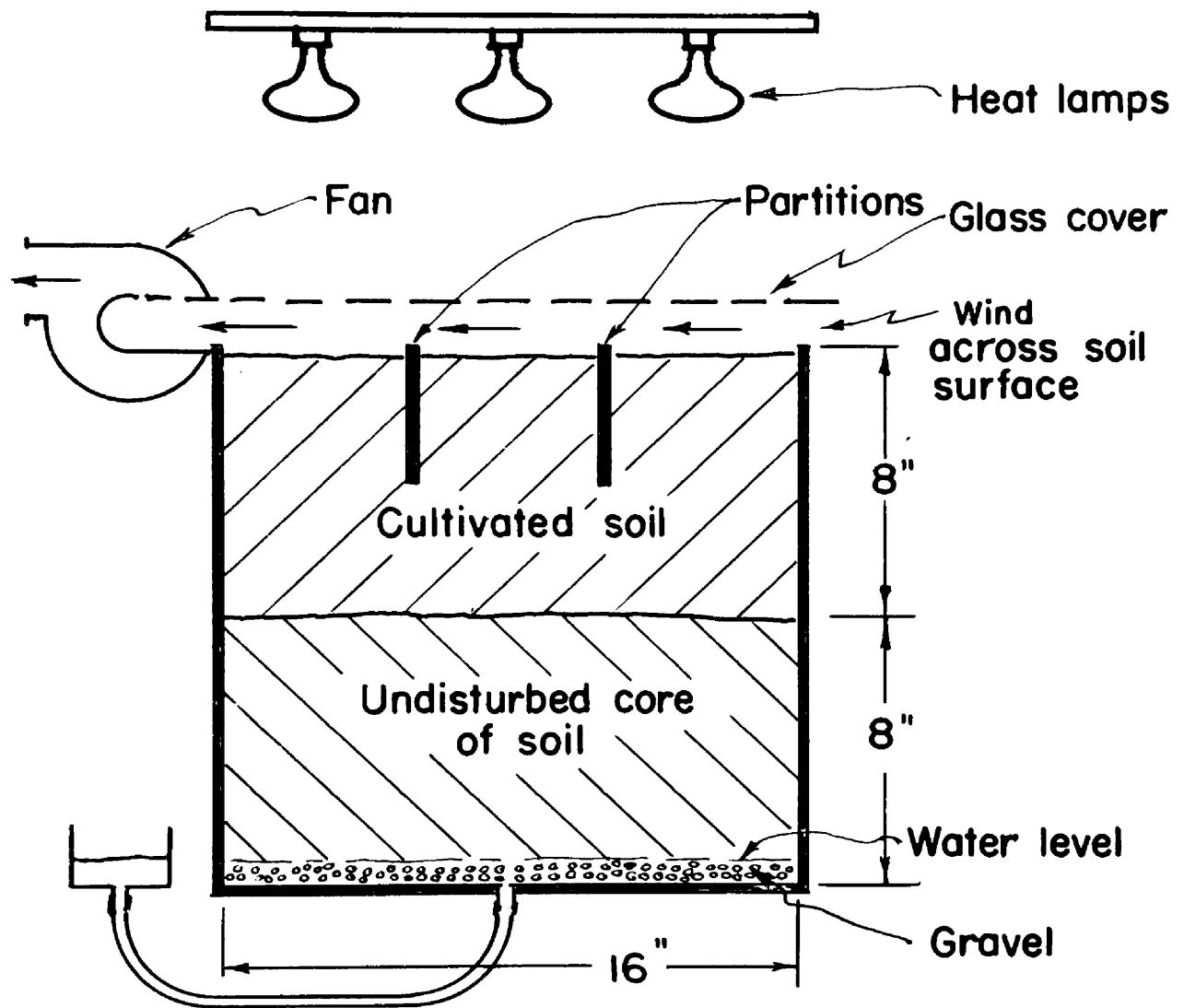


Figure 12. Schematic drawing of soil box and apparatus

each day. Weather bureau records were consulted to establish typical weather conditions in the field at planting time. Baten and Eichmeier (1951) in a summary of weather conditions for East Lansing, Michigan give the following data for the middle of May:

Average mean air temperature	56°F
Soil temperature one inch below surface	55°F
Average wind velocity	6.5 to 8.5 mph
Percent of possible sunshine	63%

Using these weather data as a guide, the test chamber was maintained at an air temperature of 60 degrees Fahrenheit and a wind velocity of five mph was simulated.

At the beginning of each experiment the soil moisture content was adjusted to the desired level by raising the water head on each soil box. An attempt was made to use standard plaster of paris -- nylon Bouyoucos Moisture Blocks to measure the soil moisture content several inches below the surface and at the seed level; however, sampling and oven drying provided a practical and more accurate method of determining the soil moisture content. Within the experimental design, each box constituted a replication and each compartment represented a different pressure treatment. Three crops were used: corn, beans and sugar beets.* All seeds were treated with Arasan fungicide before planting.

*See Table VIII for varieties.

Either 12 or 16 seeds of each crop were planted in each compartment in a rectangular pattern at least three-fourths inch apart and covered with one inch of loose soil. Compaction pressures were applied to the soil surface using the compressed-air actuated hydraulic cylinder and force ring shown in Figure 11. A frame was constructed so that the compactor could be quickly moved to any position above the boxes. A 28.4 square inch plate was attached to the force ring. Forces of 14.2, 142 and 284 pounds, resulting in average compaction pressures of $\frac{1}{2}$, 5 and 10 psi were used in this series of experiments.

Emergence counts were made daily. Special data sheets were prepared having a space representing each seed. Whenever a seedling emerged, the date and crop were recorded in the appropriate space. The original data were transferred to summary sheets showing accumulative emergence for each pressure and crop.

After emergence was nearly complete, soil moisture samples were taken from each compartment. In some cases, bulk density cores were removed also. The partitions were removed from between the compartments at the completion of each experiment and the soil was thoroughly mixed to a depth of four or five inches. Several days elapsed between tests for the moisture content to approach equilibrium. A summary of the conditions for the five experiments in this series is given in Table VIII.

TABLE VIII.

SUMMARY OF CONDITIONS FOR EXPERIMENTS 5 THROUGH 9.

Soil type - Sims sandy clay loam (see Table II and Figure 1
for physical properties)

Number of replications - 3

Variety of seed: Corn - Michigan 480 hybrid

Beans - Michelite

Sugar beets - US 400 whole seedballs

Pressure, psi - $\frac{1}{2}$, 5, 10

Aggregate size - Natural field soil through a one-fourth inch
screen

Depth of planting - One inch before packing; approximately
 $\frac{15}{16}$, $\frac{3}{4}$, $\frac{1}{2}$ inch after packing.

Wind velocity - Five mph

Expt. No.	Soil moisture content at seed level		Water added to soil after planting	Method of applying pressure
	Initial	Final		
	percent			
5	19	18.0	None	At the soil surface
6	17	16.3	Water level eight inches below surface	At the soil surface
7	18	17.0	None	At the seed level, covered with one inch of loose soil.
8	15	20.2	Water level 15 inches below surface	Five psi at seed level in all com- partments; $\frac{1}{2}$, 5, 10 psi on the surface.
9	--	17.2	Simulated rain - $1\frac{1}{8}$ inch water added to surface after packing	At the soil surface

Experiment 5 (Deep Box - Surface Pressure). The seeds were planted at a soil moisture content of approximately 19 percent. Pressures were applied to the soil surface after the seeds were covered with one inch of loose soil. Air was drawn across the soil surface continuously at five mph. At the end of this experiment, 23 days after planting, the average of the moisture samples taken at seed level from the nine compartments was 18.0 percent.

Experiment 6 (Deep Box - Surface Pressure - Water Added). The soil moisture content at planting time was approximately 17 percent. Pressures were applied on the surface as in Experiment 5. Air was drawn across the soil surface at five mph for nine hours each day. After seven days the soil surface was very dry. A visual inspection of the soil at seed level indicated that moisture would have to be added before any emergence could be expected. Therefore, the water level was raised to the top of the soil cores, eight inches below the soil surface. (Approximately one gallon of water was added to each box.) The average soil moisture content at the seed level at the end of the experiment, twenty days after planting, was 16.3 percent.

Experiment 7 (Deep Box - Pressure at Seed Level). The initial soil moisture content was approximately 18 percent. No water was added after planting. A one-inch layer of soil was removed and the seeds placed on the moist soil. Pressures

of $\frac{1}{2}$, 5 and 10 psi were applied directly to the soil on which the seeds were laid, pressing them firmly into the soil. The one-inch layer of soil was replaced and allowed to remain loose. Air was forced across the soil surface continuously at five mph. The average soil moisture content at the seed level was 17.0 percent at the end of the experiment, 21 days after planting.

Experiment 8 (Deep Box - Pressure at Seed Level and Surface). The initial soil moisture content was approximately fifteen percent. A one-inch layer of soil was removed, the seeds placed on the moist soil and a pressure of five psi applied to the soil in all nine compartments. Then the seeds were covered with one inch of soil and pressures of $\frac{1}{2}$, 5 and 10 psi were applied to the soil surface. After planting, water (approximately $\frac{3}{4}$ gallon) was added to each box of soil through the inlet at the bottom. Air was forced across the soil surface continuously at five mph. The final average soil moisture content at the seed level, 29 days after planting, was 20.2 percent.

Experiment 9 (Deep Box - Surface Pressure - Rain). Seeds were planted one inch deep and pressures of $\frac{1}{2}$, 5 and 10 psi were applied to the surface. To simulate a rain, one-half inch of water was applied to the soil surface as a fine spray. Severe crusting (Figure 13) developed as a result of the moisture applied. Another one-half inch of water was applied on



Figure 13. Severe crusting caused by simulated one-half inch rain on soil surface after planting
(Experiment 9)

the fifth day, one-eighth inch on the seventh day, and a trace on the ninth day in an effort to keep the soil surface moist and permit the seedlings to penetrate the crust. Air was forced across the soil surface at five mph until the seventh day when the fans were shut off to reduce surface drying. On the tenth day after planting, no seedlings had emerged and it became apparent that the crust would have to be broken so that the seedlings could emerge. This was done and the upper one-fourth to one-half inch of soil loosened. The first seedling emerged on the twelfth day and emergence continued normally. At the end of Experiment 9, bulk density cores were removed. The average bulk densities were 0.96, 1.01 and 1.08 grams per cubic centimeter in the compartments receiving $\frac{1}{2}$, 5 and 10 psi, respectively. The final average moisture content at the seed level was 17.2 percent, 35 days after planting.

Experimental Results

A summary of the effect of soil compaction on seedling emergence for all experiments in this series is given in Table IX. The percentages of emergence are for the tenth, twelfth and eighteenth days after planting.

Experiment 5 (Deep Box - Surface Pressure). When the soil contained ample moisture for emergence, packing the soil with a surface pressure in excess of one-half psi reduced emergence (Figure 14). An exception to this general statement occurred with beans after the twelfth day when a pressure of

TABLE IX.

EFFECT OF SOIL COMPACTION ON EMERGENCE OF SEEDLINGS
(EXPERIMENTS 5 THROUGH 9)

		Experiment Number																			
		5				6				7				8				9			

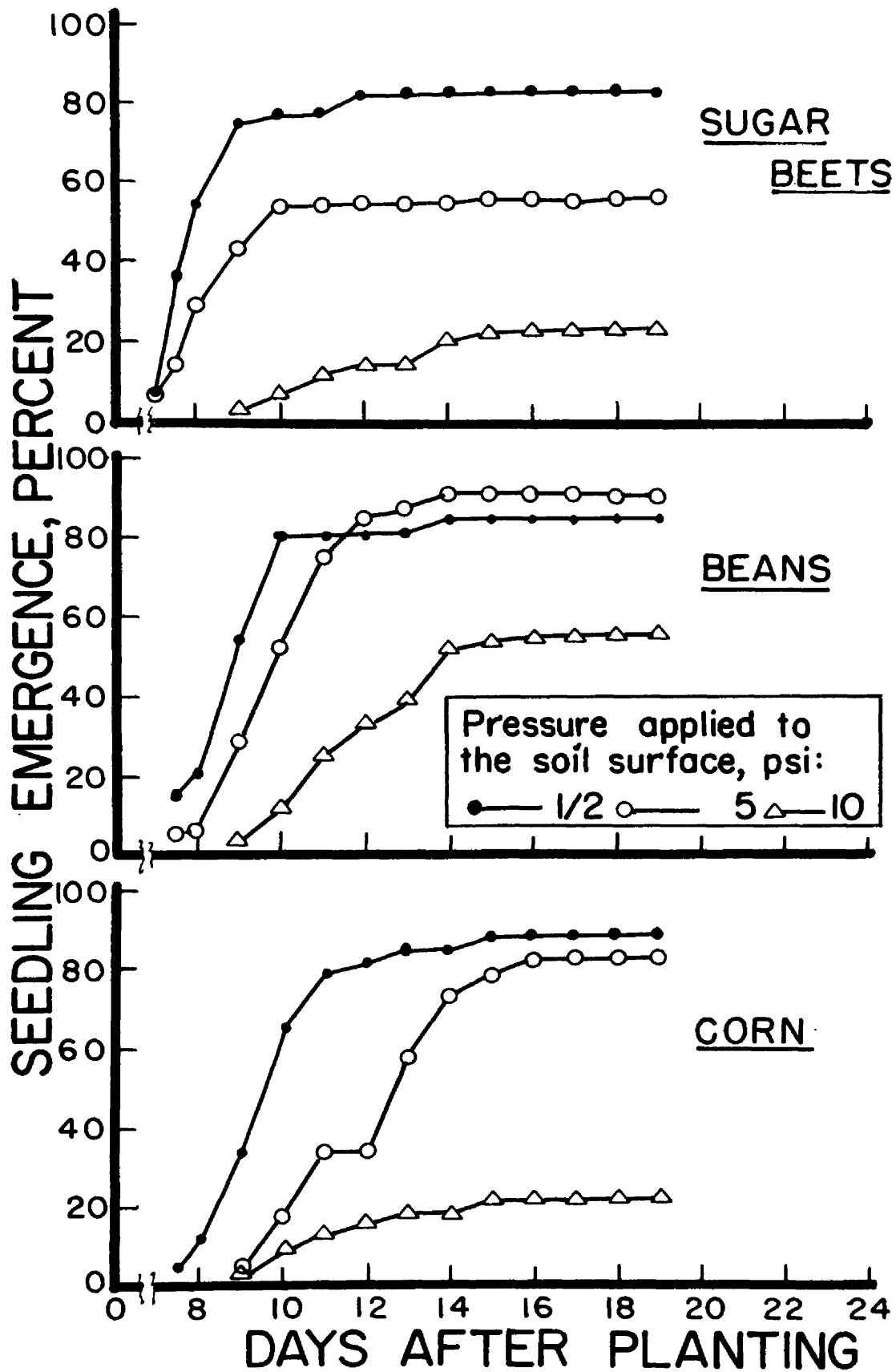


Figure 14. Accumulative emergence for Experiment 5, soil moisture ample

five psi resulted in slightly higher emergence than that produced by one-half psi. Under the conditions of this experiment, many seedlings failed to emerge in the compartments receiving a pressure of ten psi even after 19 days; however, nearly every seed germinated. The reason for poor emergence was not established but apparently was due to inability of the seedlings to penetrate the compacted soil. Figure 15 shows several seedlings taken from soil that was packed with a surface pressure of ten psi after planting. Many were unable to penetrate the packed soil and those that emerged lacked vigor.

Experiment 6 (Deep Box - Surface Pressure - Water Added).

The emergence patterns in this experiment (Figure 16) where the soil was somewhat drier, were entirely different from those of Experiment 5. Since the soil appeared too dry for good germination and emergence, the water table was raised to eight inches below the surface on the seventh day after planting. Within a few days the soil in the compartments which received pressures of five and ten psi appeared moist on the surface while that which was packed with one-half psi remained dry. When these test conditions are considered, the results are logical. The higher pressures resulted in faster emergence than in the one-half psi compartment, but after twenty days there was little difference in the number of seedlings. Soil moisture is apparently a major factor in these results. Soil in the compartments receiving one-half psi was moist enough



Figure 15. Corn, sugar beet and bean seedlings taken from soil that was packed with a surface pressure of ten psi after planting

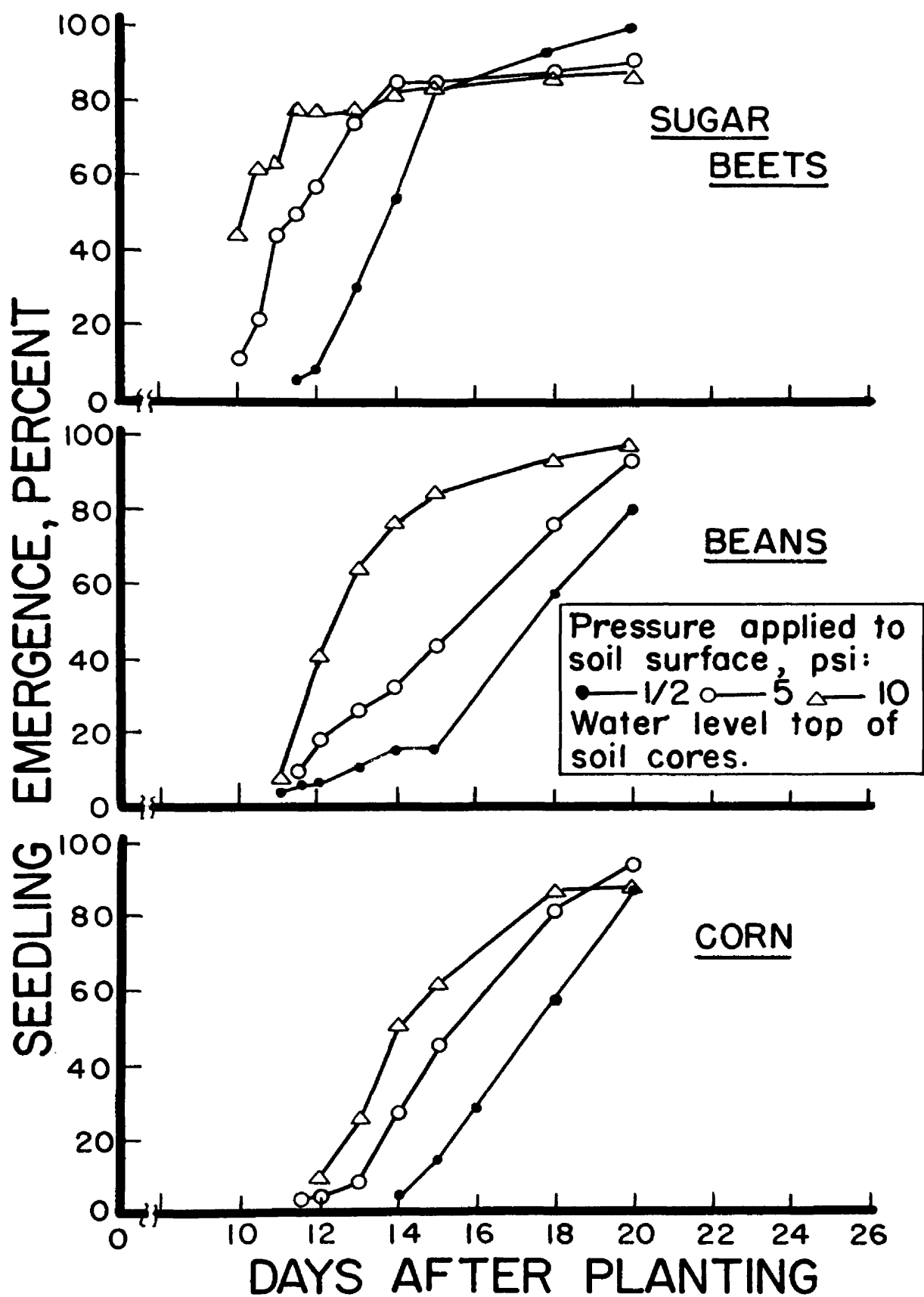


Figure 16. Accumulative emergence for Experiment 6, soil moisture at planting time deficient

at planting time for germination and emergence to occur, although at a slow rate. Because the soil was loose, there was apparently little upward movement of water by capillarity. In the compartments receiving five and ten psi, the soil was wetted appreciably by upward capillary flow from the water table eight inches below the surface. This moisture not only caused accelerated germination and emergence but also reduced the mechanical strength of the packed soil. This combination of desirable factors permitted rapid emergence of the seedlings.

The results of Experiment 5 indicate that excessive pressure on the soil surface is undesirable because the seedlings were unable to penetrate the packed soil. Under dry conditions (Experiment 6), however, a certain amount of soil compaction is desirable when there is a supply of moisture below the seed to provide more favorable moisture relations at the seed level. In order to take advantage of any beneficial effects of packing the soil and yet not impede the emerging seedling it seemed logical to apply pressure to the soil at the seed level and cover the seeds with loose soil.

Experiment 7 (Deep Box - Pressure at Seed Level). Pressures of $\frac{1}{2}$, 5 and 10 psi were applied directly to the soil in which the seeds were laid, pressing them firmly into the soil. Then all seeds were covered with one inch of loose soil. The results are shown in Figure 17. The most rapid and the highest percent of emergence occurred in the compartments receiv-

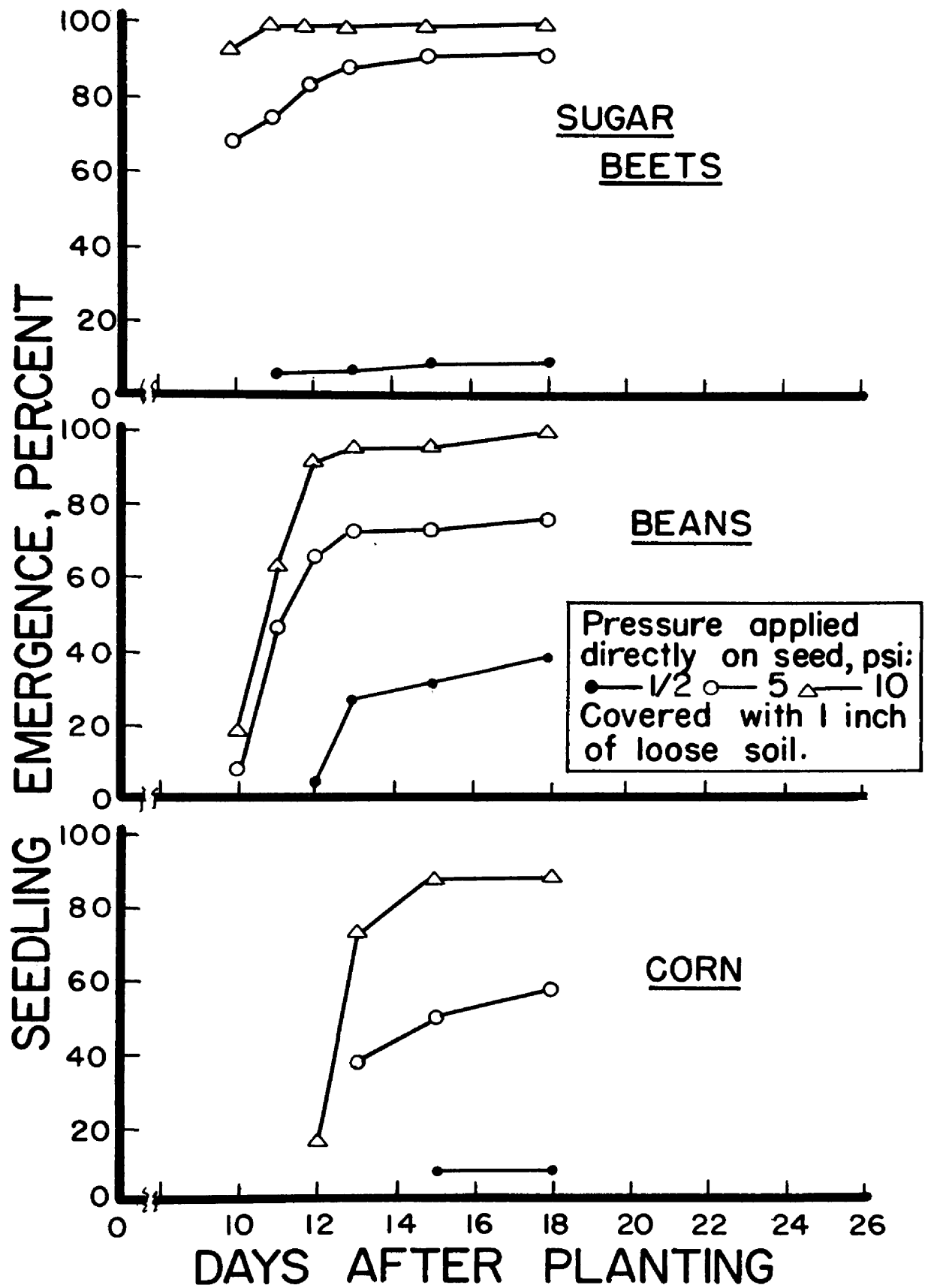


Figure 17. Accumulative emergence for Experiment 7, pressure applied only at seed level

ing the highest pressure. Emergence was poor in the compartments receiving only one-half psi. These results have a great deal of practical significance. They show that better stands can be obtained by pressing the seed firmly into the soil, but leaving the soil over the seed loose so that it will offer a minimum of resistance to the emerging seedling. Nearly every commercial planter now being used employs press-wheels which compact the soil at the surface.

Experiment 8 (Deep Box - Pressure at Seed Level and Surface). The benefits of compacting the soil at the seed level and placing loose soil over the seed were clearly shown in Experiment 7. In addition to packing the soil below the seed, a certain amount of packing of the soil over the seed may be desirable. Therefore, in Experiment 8, a pressure of five psi was applied directly to the soil on which the seeds were laid; then the seeds were covered with one inch of loose soil and pressures of $\frac{1}{2}$, 5 and 10 psi were applied to the surface. The results are shown in Figure 18. Emergence was somewhat slow in this experiment, perhaps because the soil moisture content was lower than for previous experiments. Until the sixteenth day after planting, there was no appreciable benefit from surface pressures above one-half psi. Sugar beet emergence was two to three days earlier when only one-half psi was applied to the surface as compared to pressures of five or ten psi. The total emergence of sugar beets and corn was somewhat higher as a result of the one-half psi treatment,

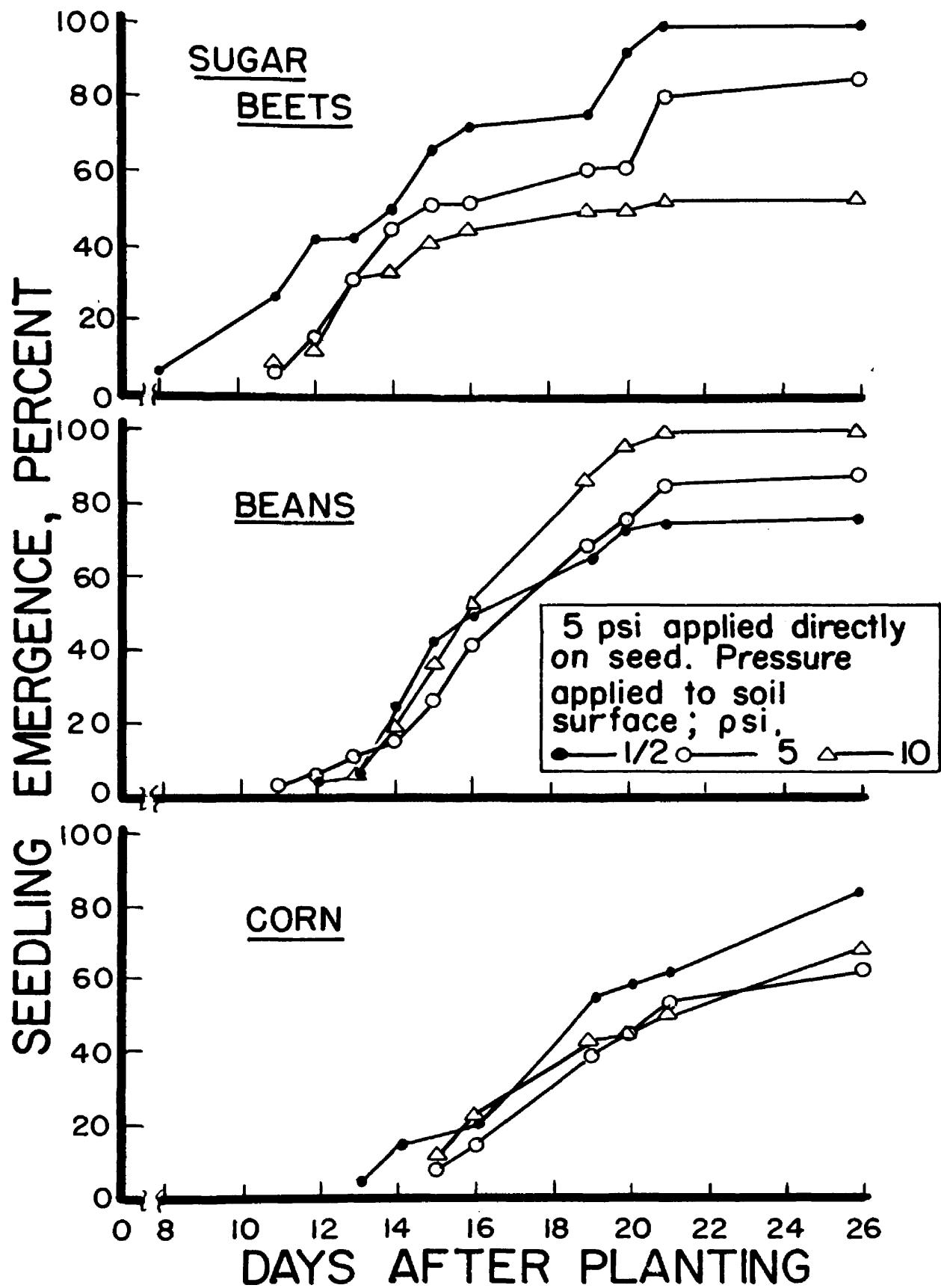


Figure 18. Accumulative emergence for Experiment 8, pressure applied at seed level and at the soil surface

while emergence of beans was higher as a result of the ten psi treatment. Only limited practical significance is attached to the total emergence because it was not reached until approximately three weeks after planting. The effects of surface pressures were less than for experiments in which no pressure was applied at the seed level.

Experiment 9 (Deep Box - Surface Pressure - Rain). In the final experiment of this series, pressures of $\frac{1}{2}$, 5 and 10 psi were applied to the soil surface, and then simulated rains totaling 1 $\frac{1}{8}$ inches were applied. The heavy crust was broken on the tenth day after planting to aid emergence. The results obtained after breaking the crust are shown in Figure 19. A pressure of one-half psi was more favorable than heavier pressures for emergence of sugar beet seedlings but little can be concluded about the effects of soil compaction on bean or corn seedlings because no emergence occurred until three weeks after planting.

Discussion of Results

This series of experiments was designed to simulate field conditions. The effect of soil compaction on emergence of seedlings varied with the soil moisture content and the point of application of pressure. When the soil moisture content was adequate for emergence (Experiment 5), the most rapid emergence (80 percent in 9 to 11 days) resulted from a surface pressure of one-half psi while higher pressures (5 or 10 psi)

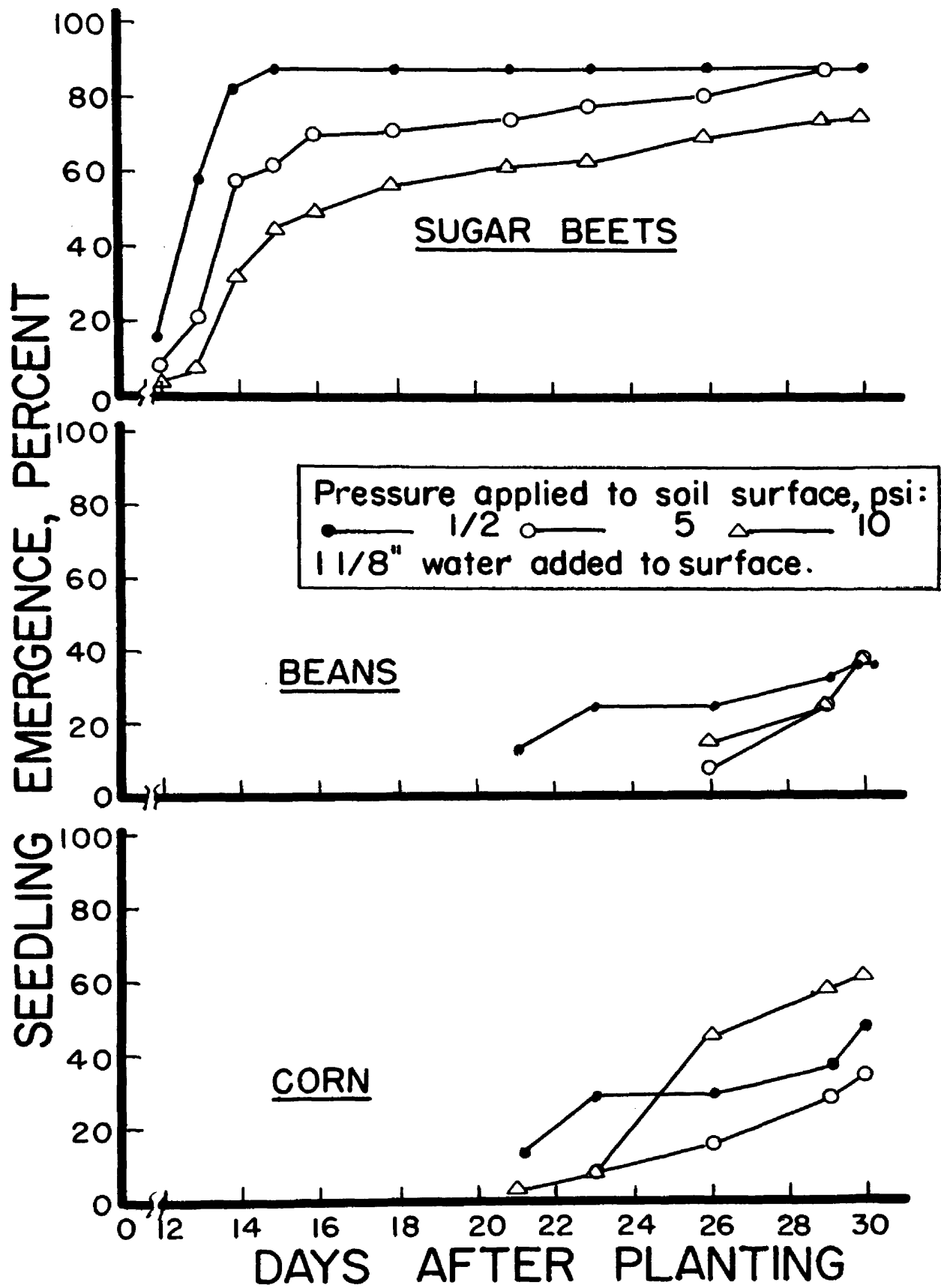


Figure 19. Accumulative emergence for Experiment 9, pressure applied at the soil surface followed by simulated rains

suppressed emergence. This may have been due to (a) poor aeration, or (b) the inability of the seedlings to penetrate the compacted soil, or (c) a combination of both.

When the soil moisture content was near the minimum required for emergence and lacked a supply of moisture from below the seed level (Experiment 1), packing the soil with surface pressures up to ten psi did not improve emergence. In Experiment 6, however, when a supply of capillary moisture was available below the seed, a surface pressure of ten psi resulted in faster emergence than a pressure of one-half psi. The emergence pattern was intermediate for a pressure of five psi. The final emergence was about the same regardless of the pressure applied. The results of Experiments 1 and 6 indicate that packing the soil will improve emergence only when adequate moisture is available below the seed.

Since packing the soil at the surface adversely affected seedling emergence under certain conditions, another method of packing the soil was needed. A possible improved method was packing the soil at the seed level (no packing on the soil surface). This would insure moisture transfer from below and minimize crusting at the soil surface. Emergence data from Experiment 7 indicate that this method of packing will enhance rapid emergence.

MOISTURE ABSORPTION BY SUGAR BEET SEEDS

While the laboratory experiments disclosed that excessive pressures applied to the soil surface decreased emergence of seedlings, the exact cause remains uncertain. Packing the soil may affect the emerging seedling by altering (a) the availability of moisture, (b) the availability of oxygen, and (c) the mechanical resistance of the soil. To help explain the results obtained, a series of experiments was designed to determine the rate of moisture absorption by sugar beet seeds. The other two factors are being studied by Morton. Preliminary reports have been written (Morton, et al., 1958, 1959).

Methods and Materials

Experiments 10, 11 and 12 (Moisture Absorption by Seeds).

Air dry Brookston sandy loam was screened through a US No. 16 screen.* The moisture content was adjusted to the desired level by placing 2000 grams of soil into a gallon container and adding the amount of water calculated to produce the desired moisture content. The sealed container was shaken for a few minutes each day for a period of three days to promote a uniform mixture.

*Physical properties are given in Table II and Figure 1.

Approximately one inch of soil was placed in a small plastic box. Forty sugar beet seeds were placed three-fourths inch apart on the soil surface and covered with approximately one inch of soil. The pressures were applied to the soil surface using the force ring shown in Figure 2. Plastic lids were placed on the boxes. They were maintained at 75 degrees Fahrenheit. Additional details are given in Table X.

At specified times after planting, the seeds were removed from one box at each pressure. The seeds were shaken to remove as much soil as possible and their moisture content* was determined by oven drying. A correction for the small amount of soil adhering to each seed was made on the first experiment. The correction was so small that it was neglected in later tests.

The rate of absorption of water by US 400 decorticated sugar beet seeds while submerged in water was determined by taking twenty samples within a six hour period.

Experimental Results

The complete results of this series of experiments are shown in Tables XI, XII and XIII. The influence of soil compaction on the rate of moisture absorption by sugar beet seeds is shown graphically in Figures 20, 21 and 22. It is apparent from these graphs that packing the soil around the

*Seed moisture contents are given as percent, wet basis, while soil moisture contents are given as percent, dry basis.

TABLE X.

SUMMARY OF CONDITIONS FOR EXPERIMENTS 10, 11 AND 12.

Soil type - Brookston sandy loam (see Table II and Figure 1 for physical properties)

Pressure, psi - 0, 5, 15

Aggregate size - Through a US No. 16 screen (1.19 mm)

Depth of planting - One inch before packing

No. of Expt. No.	Soil moisture content	Soil moisture tension	Variety of sugar beet seed	Times after planting when seeds were removed	Moisture absorption of seeds submerged in water measured
	percent	Atmos- pheres		hours	
10	5	16	$\frac{1}{2}$ US 401 whole seedballs	$\frac{1}{4}$, $\frac{3}{4}$, $1\frac{1}{2}$, 3, 6	No
11	5	12	$2\frac{1}{2}$ US 401 whole seedballs	$\frac{1}{4}$, 1, 3, 6, 24	No
12	3	12	$2\frac{1}{2}$ US 400 decor- ticated seed- balls	$\frac{1}{4}$, 1, 3, 6, 24	Yes

TABLE XI.

WATER ABSORPTION BY WHOLE SUGAR BEET SEEDBALLS (US 401)
FROM SOIL CONTAINING 16 PERCENT MOISTURE.

Time after planting	Pressure	Replication					Average
		1	2	3	4	5	
hours	psi	percent					
1/4	0	21.9	18.9	20.6	21.0	20.6	20.6
	5	26.0*	21.8	22.8*	24.3	25.1	24.0
	15	24.8	23.8	22.4	25.3	26.6	24.6
3/4	0	29.8	28.4	28.6	24.2	29.5	28.1
	5	32.6	29.4	30.8	27.5	29.8	30.0
	15	30.3	30.6	29.8	28.0	30.6	29.8
1 1/2	0	33.9	33.9	34.4	28.7	33.1	32.8
	5	35.4	35.0	32.9	37.0	37.3	35.5
	15	34.2	33.2	33.2	36.8	35.2	34.5
3	0	40.1	40.5	41.2	40.0	36.7	39.7
	5	40.5	37.4	39.7	40.2	40.0	39.6
	15	37.5	35.7	36.4	36.6	39.2	37.1
6	0	39.3	44.4	45.7	45.6	42.8	43.6
	5	42.4	41.8	43.2	44.7	42.4	42.9
	15	40.6	39.8	38.9	42.0	41.1	40.5

*Calculated missing values

TABLE XII.

WATER ABSORPTION BY WHOLE SUGAR BEET SEEDBALLS (US 401)
FROM SOIL CONTAINING 12 PERCENT MOISTURE.

Time after planting	Pressure	Replication					Average
		1	2	3	4	5	
hours	psi	percent					
1/4	0	--	19.8	17.4	17.8	18.9	18.5
	5	--	22.6	20.1	21.0	20.7*	21.1
	15	--	22.8	20.9	22.0	20.6	21.6
1	0	--	--	25.8	27.8	27.0	26.9
	5	--	--	29.7	28.6	28.6	28.9
	15	--	--	28.4	29.7	28.0	28.7
3	0	36.1	34.4	36.8	35.3	38.7	36.2
	5	37.5	35.8	38.2	35.9	37.6	37.0
	15	37.7	36.3	36.4	35.3	37.1	36.6
6	0	41.8	--	38.2	41.9	41.7	40.9
	5	43.7	--	38.9	40.3	37.6	40.1
	15	39.9	--	38.8	39.8	40.3	39.7
24	0	45.1	40.1	44.7	42.8	38.7	42.3
	5	43.2	40.9	37.9	39.2	39.7	39.1
	15	41.3	39.2	35.4	37.8	37.6	38.2

*Calculated missing value

TABLE XIII.

WATER ABSORPTION BY DECORTICATED SUGAR BEET SEEDBALLS
(US 400) FROM SOIL CONTAINING 12 PERCENT MOISTURE.

Time after planting	Pressure	Replication			Average
hours	psi	1	2	3	
1/4	0	16.3	14.8	18.4	16.5
	5	16.3	16.3	18.0	16.9
	15	15.8	16.2	17.8	16.6
1	0	23.0	21.7	24.4	23.0
	5	22.7	21.2	24.9	22.9
	15	22.3	21.6	24.6	22.8
3	0	28.7	28.8	28.9	28.8
	5	26.6	27.0	29.7	27.7
	15	26.2	27.8	29.8	27.9
6	0	31.9	32.1	33.1	32.4
	5	31.1	30.8	31.7	31.2
	15	29.3	30.0	32.2	30.5
24	0	33.9	34.7	35.8	34.8
	5	31.8	34.7	34.9	33.8
	15	33.2	33.3	32.8	33.1

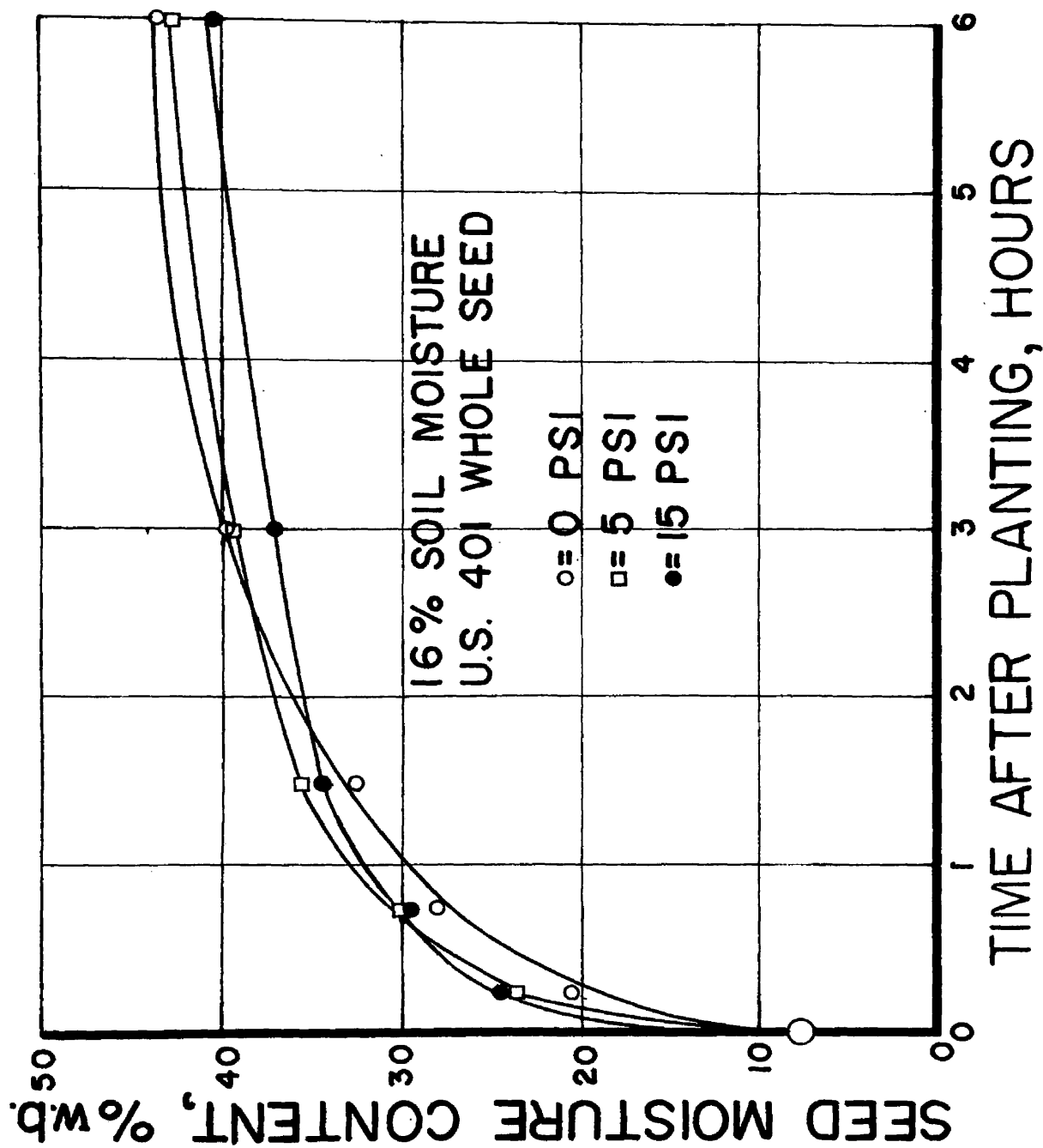


Figure 20. Moisture absorbed by whole sugar beet seedballs from soil containing 16 percent moisture

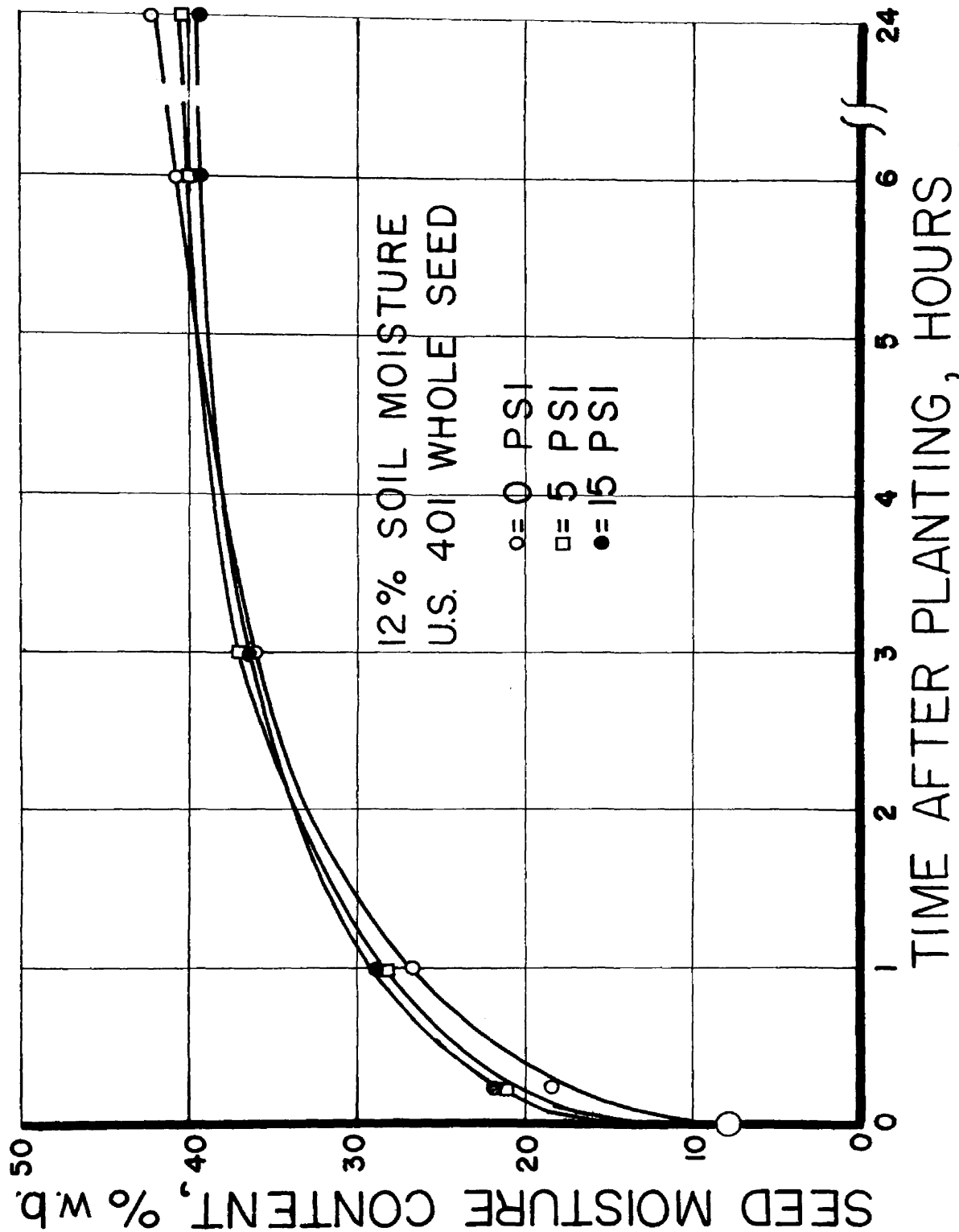


Figure 21. Moisture absorbed by whole sugar beet seedballs from soil containing 12 percent moisture

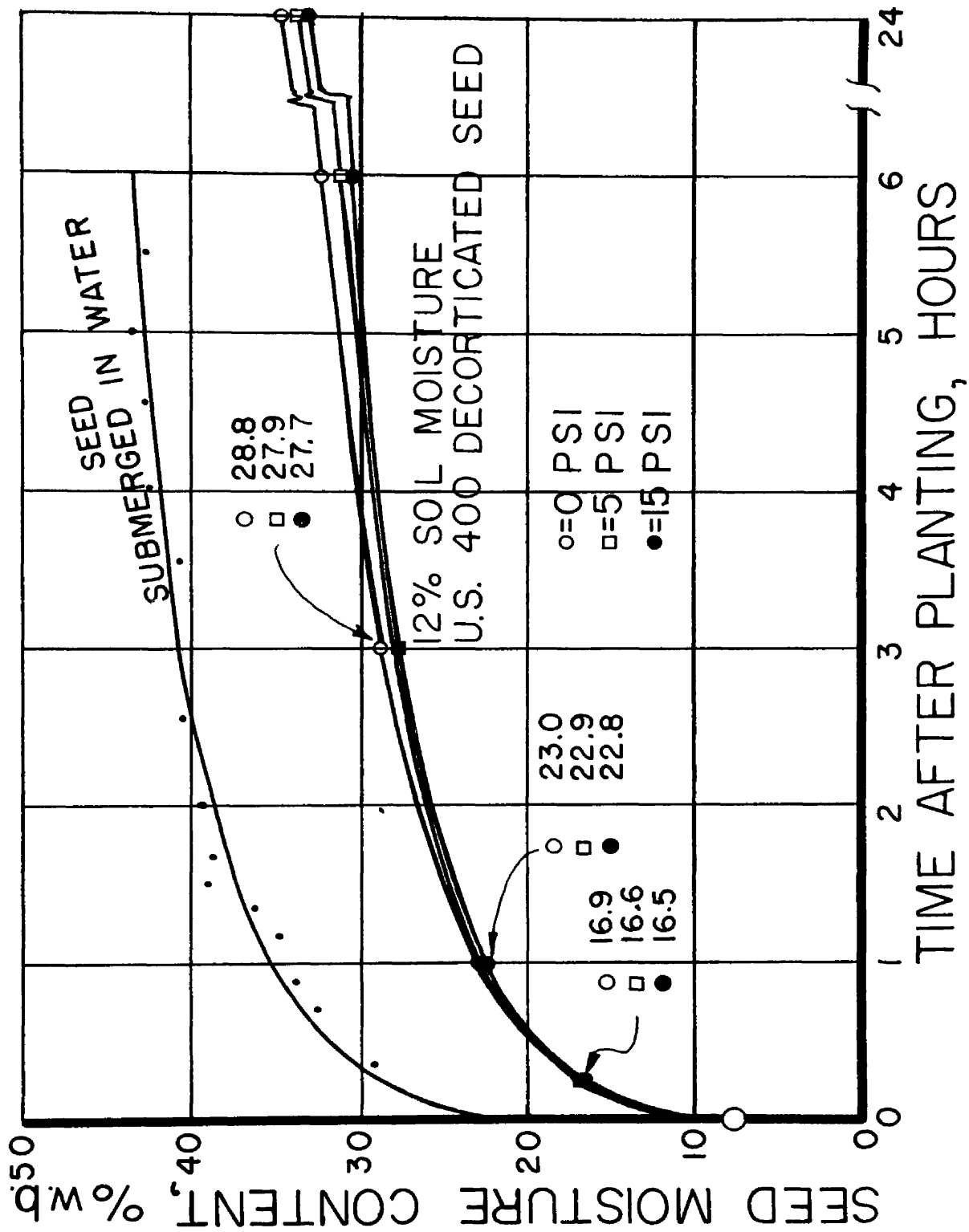


Figure 22. Moisture absorbed by decorticated sugar beet seedballs from soil containing 12 percent moisture

seed aided the seed in absorbing moisture during the first few hours. Within two to five hours after planting, however, the seeds planted in relatively loose soil reached the highest moisture content. This unexpected trend was observed consistently. The analyses of variance revealed that some of the differences in seed moisture content were statistically significant after six to twenty-four hours. A summary of the results of the statistical analyses is given in Table XIV. The complete analyses are given in the Appendix, Tables XIX through XXI. Although the differences in seed moisture content are statistically significant, they may have little practical significance. These laboratory results show, however, that compacting the soil does not necessarily result in a higher final seed moisture content. When interpreting the results of this series of experiments, it should be remembered that Hunter and Erickson (1952) reported that decorticated sugar beet seeds must reach a moisture content of 31 percent before germination will occur. The curves of Figure 22 show that the seeds had acquired sufficient moisture for germination after five to six hours.

Experiment 12 included a study of the uptake of moisture by sugar beet seeds while submerged in water. The results are shown in Figure 22 along with those for moisture absorption from soil. A comparison of the curves for soil with the curve for water shows that the seeds absorb moisture faster when placed in water than when planted in moist soil.

TABLE XIV.

SUMMARY OF ANALYSES OF VARIANCE FOR MOISTURE ABSORPTION FROM SOIL.

Expt. No.	Soil moisture content	Type of seed	Effect of packing pressure on moisture content of sugar beet seedballs		
			$\frac{1}{4}$ hr. after planting	6 hr. after planting	24 hr after planting
percent					
10	16	US 401 whole seedballs	N.S.	0 psi higher than 15 psi*	- - - - -
11	12	US 401 whole seedballs	15 psi higher than 0 psi**	- - - - -	0 psi higher than 15 psi*
12	12	US 400 decor- ticated seedballs	N.S.	- - - - -	N.S.

N.S. - not significant

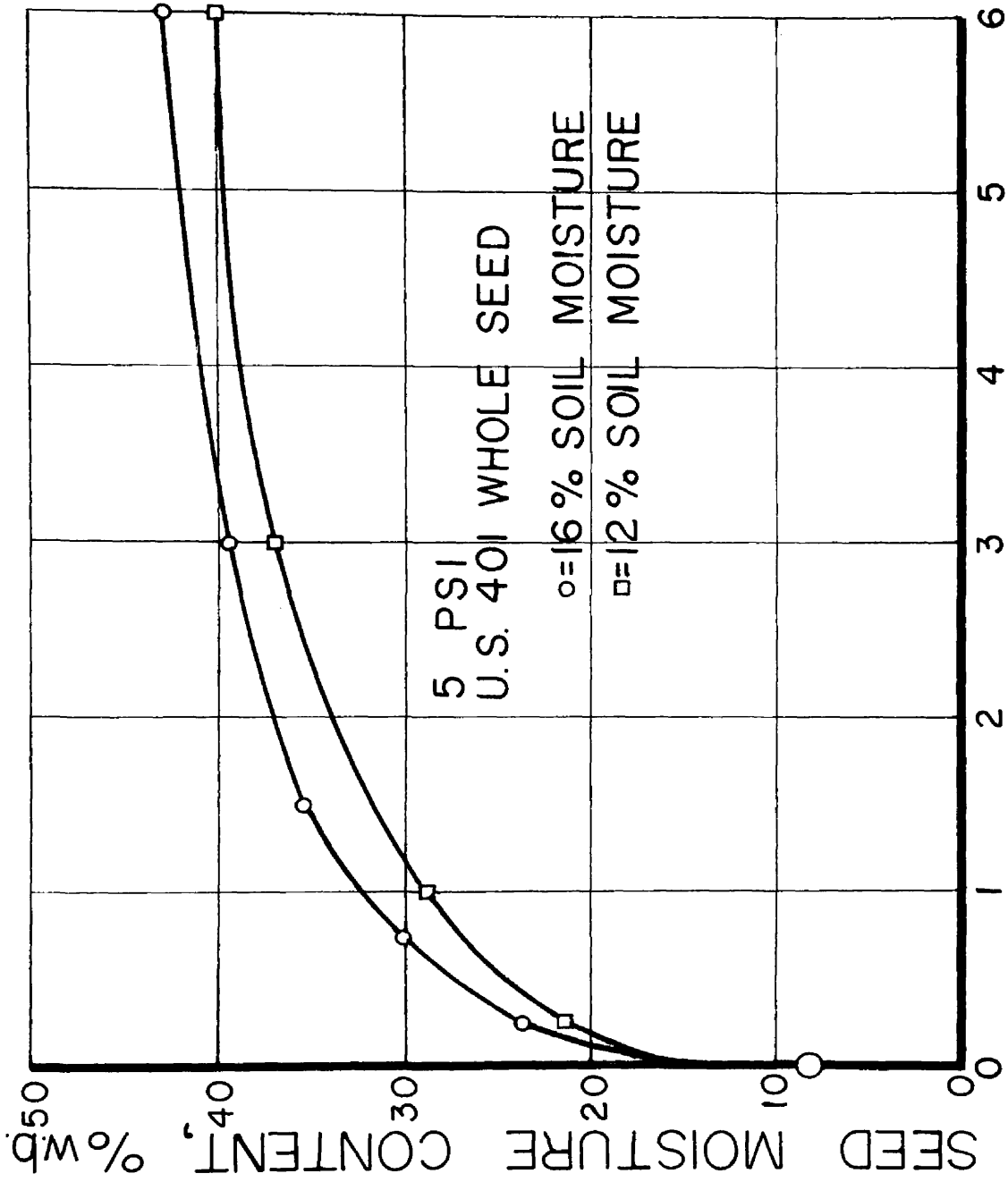
* - significant at 5% level

** - significant at 1% level

From these curves, one might deduce that absorption of water from moist soil by decorticated sugar beet seedballs is limited by external factors such as the rate of flow of water through the soil rather than the flow of water into the seedball. This hypothesis is further supported by Figure 23 where the effect of two soil moisture contents on the rate of moisture absorption by whole sugar beet seeds is shown. Seeds absorbed moisture faster from the soil containing 16 percent moisture than from soil at 12 percent.

Discussion of Results

The reason that seeds absorbed more water from loose soil than from compacted soil is not known. It is commonly accepted, however, that a good seed-soil contact is needed in order to obtain rapid flow of moisture to the seed from the soil immediately surrounding it. Pressure applied to the soil surface insures good seed-soil contact and thereby causes the initial flow to be high. As the moisture immediately surrounding the seed is absorbed by the seed, a moisture gradient is formed. Moisture then flows from the wet region to the dryer one surrounding the seed. As the soil is compacted, the size of the soil pores is decreased. Poiseuille's equation (Taylor, 1948) as modified by Swartzendruber (1952) for moisture transfer in soil shows that the rate of transfer decreases as a function of the radius of the pores. The reduction in size of the pores in soil when the soil is compressed could account for



TIME AFTER PLANTING, HOURS

Figure 23. Comparison of moisture absorbed by whole sugar beet seedballs from soil containing 12 and 16 percent moisture

the decreased rate of moisture uptake by the seeds in a given time as compared with the uptake when no pressure was applied.

A theoretical analysis of the wetting curves can be made by considering wetting as the reverse of drying. Newton's law of cooling is commonly used as an analogy for drying (Hall, 1957). Newton's law states:

$$\frac{dt}{d\theta} \approx t - t_e \text{ - - - - - (1)}$$

where t is the temperature at any time, t_e is the equilibrium temperature, θ is the time. For drying this becomes:

$$\frac{dM}{d\theta} \approx M - M_e \text{ - - - - - (2)}$$

where M is the moisture content and M_e is the equilibrium moisture content. Separating variables, supplying limits, and integrating, the solution is:

$$\frac{M - M_e}{M_0 - M_e} = e^{-k\theta} \text{ - - - - - (3)}$$

where M_0 is the original moisture and k is a constant. The expression $\frac{M - M_e}{M_0 - M_e}$ is called the moisture ratio. Equation 3 is proposed to represent the moisture absorption of grain or seeds when placed in moist soil. If Equation 3 is a valid representation of the moisture absorption data, a semi-logarithmic plot of the moisture ratio versus time after planting will be linear and have a slope, k . Figure 24 reveals that Equation 3 does not represent the moisture absorption of sugar beet seedballs, unless k is considered a variable.

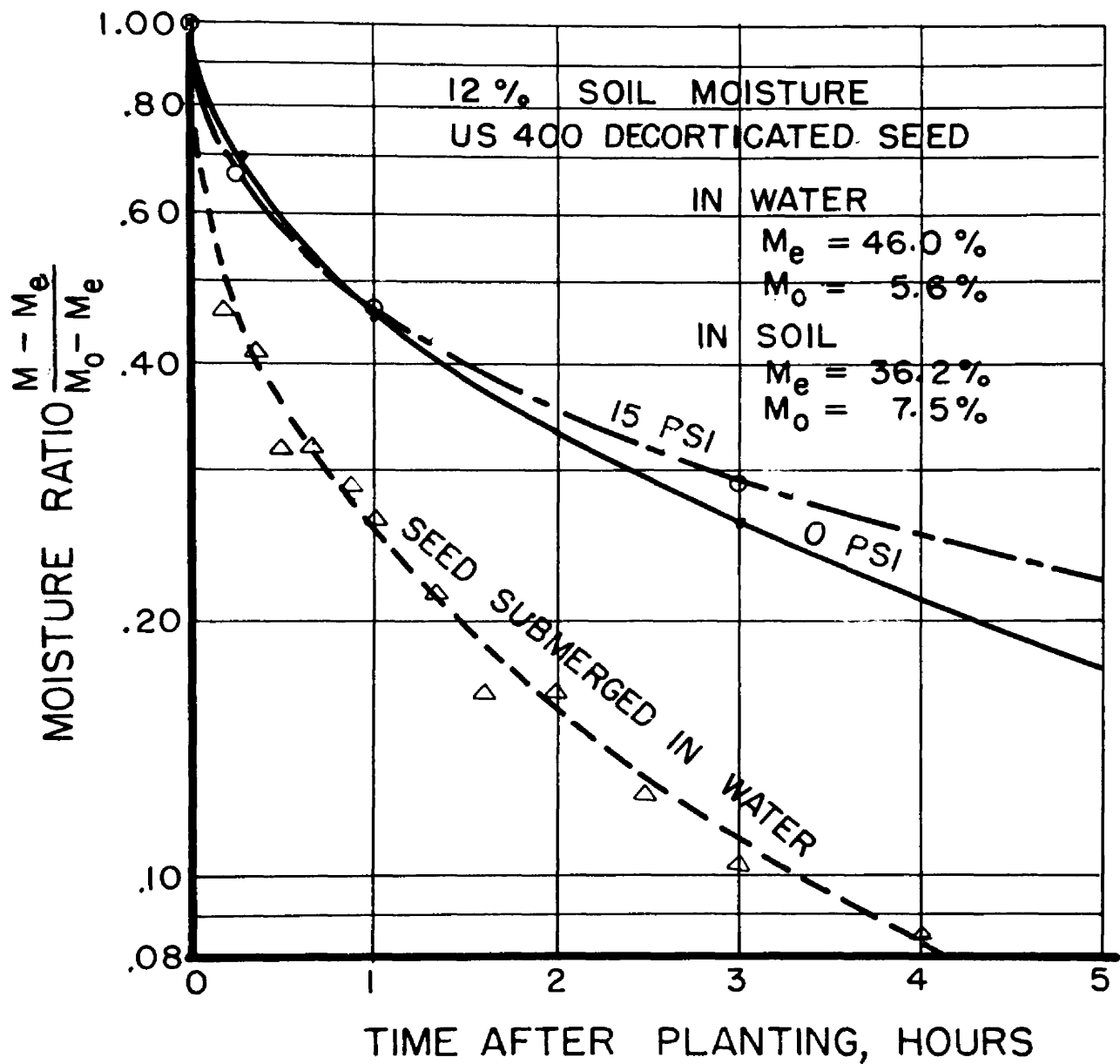


Figure 24. Moisture ratio versus time after planting for decorticated sugar beet seedballs from soil containing 12 percent moisture

Hall (1957), in a discussion of grain drying theory, suggests a better method of representing the data. By adding an exponent to θ , Equation 3 becomes:

$$\frac{M - M_e}{M_o - M_e} = e^{-k\theta^u} \quad \text{--- (4)}$$

where u is an experimental constant. The curves of Figure 24 are approximately linear when a u -value of one-half is substituted in Equation 4. Swartzendruber, et al. (1954) reported that the capillary absorption of water by soil (Marshall silt loam, Clarion loam, and Keomah silt loam) varied linearly with the square root of time. This suggests a definite relation between the rate of capillary flow through soil and the rate of moisture absorption by sugar beet seeds.

The slopes of the moisture absorption curves (k) are 0.715 for a packing pressure of fifteen psi, 0.771 for zero psi, and 1.145 for seeds submerged in water. The vertical intercept of the curves for soil was unity, but for water it was 0.81. A small quantity of moisture on the outside of the seed may have caused the intercept to be less than expected.

FIELD INVESTIGATION

Although an effort was made to simulate field conditions during a part of the previous tests, the final evaluation of laboratory results must be made in the field. Three field experiments were conducted to determine the effect of soil compaction on emergence of sugar beet seedlings.

Methods and Materials

Experiment 13 (Field - Hand-planted). The first field experiment was planted by hand. Conover loam was prepared for planting by plowing and later disking to secure a fine seedbed. US 400 whole sugar beet seeds were carefully planted by hand to insure a uniform depth of one inch after pressures of $\frac{1}{2}$, 5 and 10 psi were applied to the soil surface. The specified pressures were applied by using a weight and a wooden foot of the necessary dimensions. The weight was attached to a tractor drawbar as shown in Figure 25 and could be raised or lowered easily as the tractor moved along the row. All plantings were repeated four times during the season. The planting dates and average soil moisture content at the seed level at planting are given in Table XV.

Experiment 14 (Field - John Deere Planter). A second field experiment was planted with one of the newest commercial seeding units, the John Deere Flexi-Planter. The unit

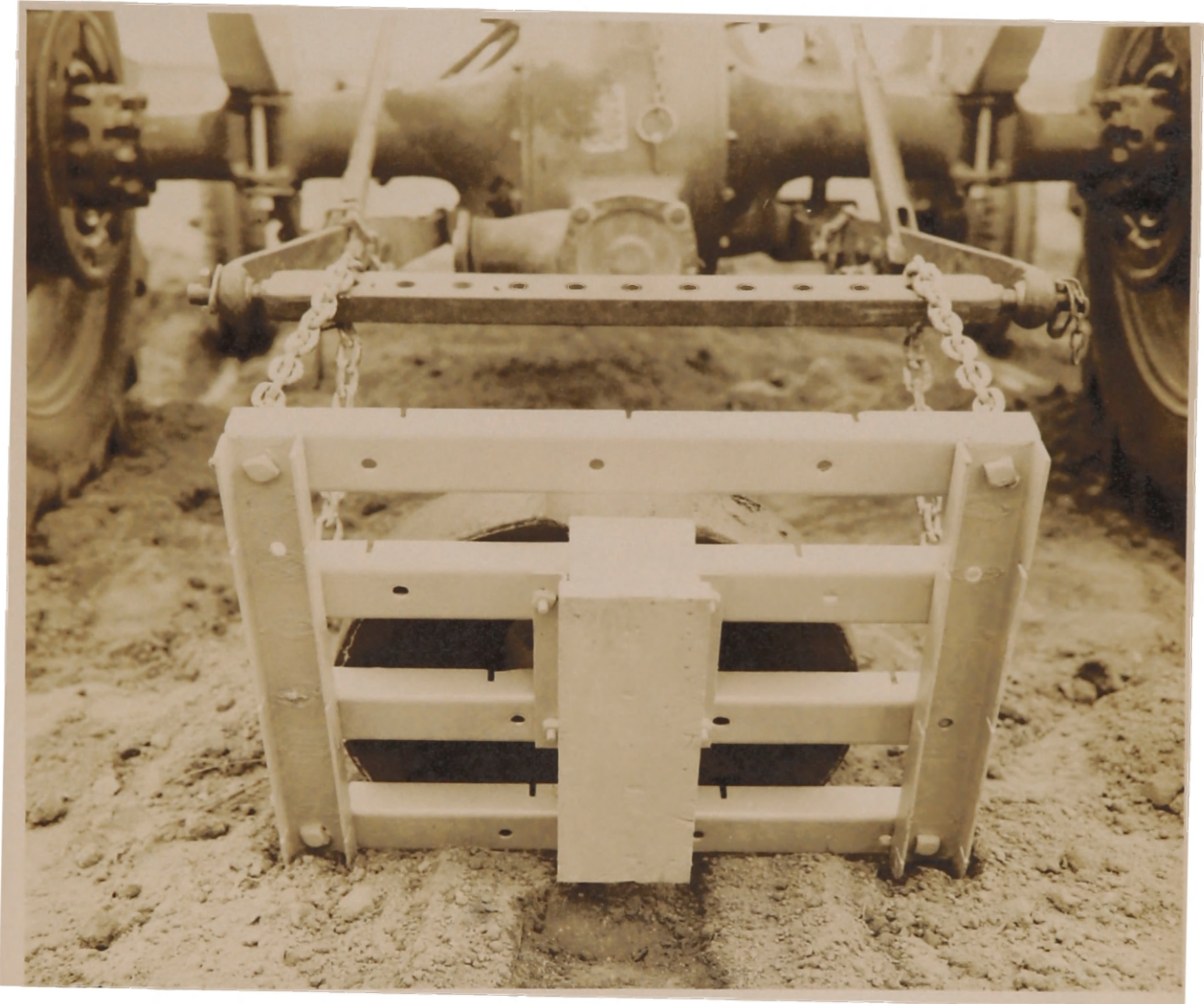


Figure 25. Device used for packing the soil in a hand-planted field experiment (looking toward the bottom of the 4 by 12 inch plate)

was modified by offsetting the presswheel approximately ten inches so that seedling emergence could be observed when the soil was left completely loose after planting. This planting unit was designed so that various compacting forces could be exerted on the presswheel simply by adjusting the tension on a spring. The treatments included no pressure (presswheel offset), low (minimum spring tension), medium, and high (maximum spring tension) pressures on the presswheel. A chain was dragged behind the furrow opener in order to cover the seed for the no pressure treatment. To permit a comparison of the field treatments with the laboratory work, the pressure exerted by the presswheel was measured using the strain gage cell described by Cooper, et al. (1957). A pressure at the seed level of over fourteen psi was measured with maximum spring tension and about six psi with minimum spring tension (Stout, 1956). The relation between spring tension and measured pressure was linear. In addition, bulk density cores were removed from the center of each of the 24 rows. The average bulk density was 0.77 grams per cubic centimeter with only a small variation observed as a result of the various treatments.

The seedbed was tilled on May 3 in a once-over operation using a plow and clodbuster. Planting was completed within four hours after plowing. The average soil moisture content at planting time was 18 percent. The experimental design was a randomized block with six replications. Each replication consisted of four rows approximately eighty feet long. Emer-

gence counts were made on five 100-inch portions of the row, randomly located along each row. Counts were made on the seventh, tenth and twenty-fourth days after planting. The same 100-inch sections were counted each time.

Experiment 15 (Field - John Deere and Milton Seeding Units). A final field experiment was conducted to compare the performance of the John Deere Flexi-Planter and the Milton seeding units.* The seedbed preparation and experimental design was the same as for Experiment 14. The four treatments were as follows:

- (1) John Deere with medium spring tension.
- (2) Milton with no added weight on presswheel
- (3) Milton with ten pound weight directly above the presswheel
- (4) Milton with thirty pound weight on presswheel

Seedling counts were made seven and twelve days after planting.

Experimental Results

Experiment 13 (Field - Hand-planted). Table XV gives the complete results. Figure 26 shows average emergence from four planting dates. It is apparent that under the conditions of this experiment, pressures above one-half psi applied to soil surface were undesirable and markedly decreased emergence

*Milton seeding units are used on Palsgrove planters.

TABLE XV.

EFFECT OF SOIL COMPACTION ON EMERGENCE OF SUGAR BEET (US 400)

SEEDLINGS IN A HAND PLANTED FIELD EXPERIMENT.

Planting date	Average soil moisture percent	Pressure psi	Days after planting																
			5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	percent emergence	
May 28	16.7	$\frac{1}{2}$ 5 10	--	--	80	80	72	72	--	--	64	60	58	56	56	--	--		
			--	--	14	20	24	32	--	--	34	32	32	32	32	--	--		
			--	--	12	16	16	16	--	--	16	16	18	18	18	--	--		
Aug. 30	17.2	$\frac{1}{2}$ 5 10	12	56	58	58	60	62	54	54	--	48	--	--	--	40	--		
			0	4	14	16	18	18	26	30	--	30	--	--	--	30	--		
			0	0	0	0	2	2	2	2	--	2	--	--	--	2	--		
Aug. 31	14.3	$\frac{1}{2}$ 5 10	10	38	46	54	62	62	56	--	54	--	--	--	50	--	--		
			0	8	10	14	18	22	24	--	24	--	--	--	24	--	--		
			0	2	2	2	2	4	4	--	4	--	--	--	4	--	--		
Sept. 7	12.2	$\frac{1}{2}$ 5 10	--	6	42	70	80	84	82	82	82	--	--	--	--	--	80		
			--	0	0	24	38	50	44	48	48	--	--	--	--	--	46		
			--	0	0	0	2	2	2	6	8	--	--	--	--	--	12		

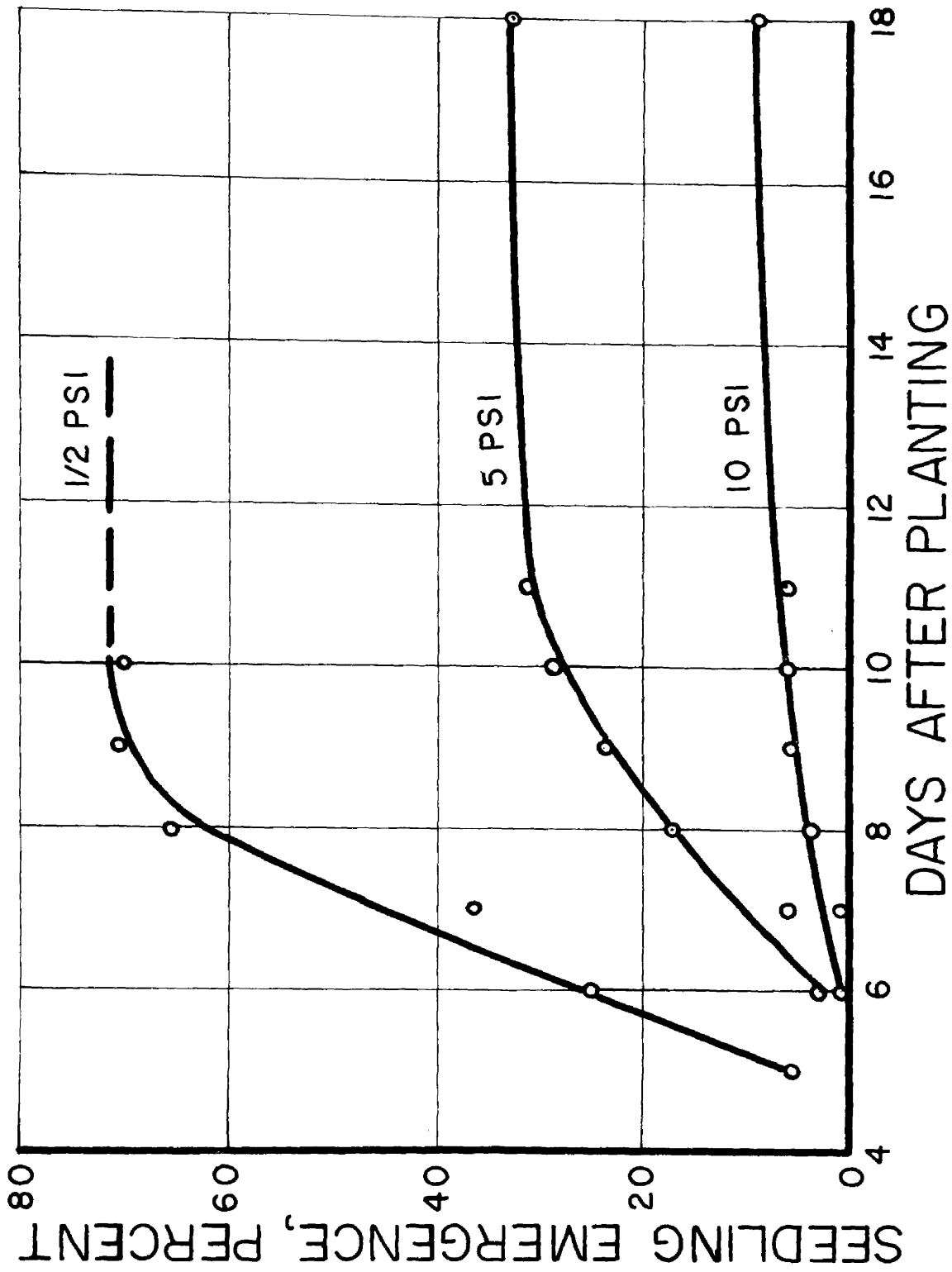


Figure 26. Effect of soil compaction on emergence of sugar beet seedlings in a hand-planted field experiment

of sugar beet seedlings. Considerable "damping off" occurred on the rows receiving a pressure of one-half psi; therefore the curve is shown as a dashed line after the tenth day. The five and ten psi treatments packed the soil to such a degree that the seedlings were unable to emerge, although observations at the end of the experiment indicated that most of the seeds had germinated.

Experiment 14 (Field - John Deere Planter). The results using the John Deere planting unit with four pressure settings are shown in Table XVI. Considerably more seedlings emerged in the plots receiving low or medium presswheel pressures.

A similar experiment was conducted in the Saginaw, Michigan area by representatives of the sugar beet industry under the author's direction.* Low, medium and high spring tensions were used on the John Deere planter. Based on the average of fourteen fields, the best stands resulted when the minimum force was applied to the presswheels. Approximately six and twenty-two percent fewer seedlings emerged from the plots receiving the medium and maximum pressure treatments, respectively. Because of poor depth control on the planter, pressure may be confounded with depth of planting. The results indicate, however, that under a variety of soils and field conditions excessive surface pressure applied by the presswheels may reduce the number of seedlings which emerge.

*Mr. Grant Nichol, Monitor Sugar Company and Mr. Mark Berrett, Farmers and Manufacturers Beet Sugar Association observed and recorded these data.

TABLE XVI.
EFFECT OF VARIOUS FORCES ON THE PRESSWHEEL OF
THE JOHN DEERE FLEXI-PLANTER.

Force on presswheel	Replication	Days after planting		
		7	10	24
		number of seedlings		
0	1	27*	128	209
	2	17	124	144
	3	2	45	118
	4	8	71	220
	5	24	91	212
	6	7	63	131
	Average	<u>14</u>	<u>87</u>	<u>178</u>
Low	1	47	192	262
	2	35	114	145
	3	17	101	167
	4	38	235	256
	5	28	178	216
	6	<u>20</u>	<u>92</u>	<u>168</u>
	Average	<u>31</u>	<u>152</u>	<u>202</u>
Medium	1	10	179	186
	2	37	251	266
	3	23	172	169
	4	17	242	274
	5	21	192	195
	6	<u>29</u>	<u>218</u>	<u>255</u>
	Average	<u>23</u>	<u>209</u>	<u>224</u>
High	1	0	43	66
	2	4	162	160
	3	1	100	157
	4	5	156	185
	5	10	132	148
	6	<u>1</u>	<u>72</u>	<u>134</u>
	Average	<u>4</u>	<u>111</u>	<u>142</u>

*Total number of seedlings in five 100-inch sections of row.

Experiment 15 (Field - John Deere and Milton Seeding Units). The results are given in Table XVII. They show no appreciable difference in stands from plantings with the John Deere and Milton seeding units.

TABLE XVII.
COMPARISON OF JOHN DEERE AND MILTON SEEDING UNITS.

Make of planter	Force on presswheel	Replications	Days after planting	
			7	12
			number of seedlings	
John Deere	Medium	1	181*	219
		2	115	145
		3	141	167
		4	227	252
		5	218	230
		6	<u>198</u>	<u>288</u>
		Average	180	217
Milton	Low	1	108	200
		2	146	192
		3	155	215
		4	29	172
		5	23	195
		6	<u>57</u>	<u>209</u>
		Average	86	197
	Medium	1	98	197
		2	100	210
		3	215	227
		4	121	227
		5	86	224
		6	<u>103</u>	<u>218</u>
		Average	120	217
	High	1	201	235
		2	195	249
		3	133	177
		4	147	216
		5	90	189
		6	<u>31</u>	<u>189</u>
		Average	133	209

*Total number of seedlings in five 100-inch sections of row.

SUMMARY

Basic information needed for proper design of planting machinery was collected in a series of laboratory and field experiments.

In the first series of laboratory experiments, the effect of soil compaction on sugar beet seedling emergence was studied in relation to soil moisture content, planting depth, aggregate size and method of packing the soil. These experiments were conducted in covered plastic boxes where the environment could be controlled.

In a second series of laboratory experiments, field conditions were simulated. Water was added to the soil at the bottom of a box sixteen inches deep; heat lamps were placed above the soil surface; air was forced across the soil surface; and the temperature was controlled at 60 degrees Fahrenheit. The soil was packed at the surface or at the seed level and the resulting emergence of sugar beet, bean and corn seedlings was observed. In one experiment water was added to the soil surface to study the effect of surface crusting on seedling emergence.

In a third series of laboratory experiments the rate of moisture absorption by sugar beet seedballs from moist soil was studied to aid in explaining the effect of compacting the soil on seedling emergence. Whole and decorticated

sugar beet seeds were planted in moist soil and various pressures were applied to the soil surface. At specified times after planting, seeds were removed from the soil to determine their moisture content. The rate of moisture absorption from moist soil and from water was compared in graphical form.

Under most conditions encountered in the laboratory studies, surface pressures in excess of five psi suppressed emergence of seedlings. However, similar pressures applied at the seed level improved emergence. Moisture absorption by sugar beet seedballs in moist soil was not improved by packing the soil at the surface.

The effect of soil compaction on the emergence of sugar beet seedlings in the field was studied. One experiment was hand-planted in order to control seed placement. Other plantings were made using commercial planters. The emergence data indicate little difference in the performance of two commercial seeding units. Sugar beet seedling emergence was highest when the planter presswheel applied a pressure of approximately six psi at seed level. Greater packing of the soil over the seed reduced emergence.

CONCLUSIONS

1. Evidence obtained in the laboratory indicates that planters for sugar beets, corn and beans should be designed to (a) pack the soil below the seed level, (b) press the seeds into the compacted soil, and (c) then cover the seed with loose soil.
2. For each set of soil conditions there is a range of packing pressures which induces maximum seedling emergence. In contrast, insufficient or excessive pressures may reduce emergence.
3. Improper soil compaction, planting depth or soil moisture may lead to poor stands. Carefully controlled conditions must be maintained while studying the effects of these factors on seedling emergence.
4. Packing the soil in the seed zone caused sugar beet seeds to absorb water at a greater rate for a period of two to five hours; however, after that period, seeds absorbed more water from uncompacted soil. Intimate seed-soil contact does not necessarily insure maximum uptake of water by the seeds.
5. Decorticated sugar beet seeds absorbed water faster when immersed in water than when placed in moist soil. Apparently the rate of moisture absorption is limited by external factors such as the movement of water through the soil.

6. In a hand-planted field experiment, surface pressures of five and ten psi seriously suppressed emergence of sugar beet seedlings as compared to a pressure of one-half psi.
7. Better stands of sugar beets resulted from the minimum or medium spring tension on the presswheels of the John Deere Flexi-planter than from the zero or maximum setting.
8. The moisture content of the soil greatly influences the effect of soil compaction on seedling emergence. Packing the soil may improve seedling emergence if adequate moisture is available below the seed. If not, packing the soil is of no benefit and may suppress emergence.

FUTURE INVESTIGATION

The present investigation revealed advantages of packing the soil below the seed and leaving the soil above the seed relatively loose. A planter should be designed to test this principle in the field. This planter should prepare a furrow, drop the seeds uniformly and then press the seeds into the soil while packing the soil below the seed. A presswheel capable of exerting pressures on the soil ranging from 0 to 15 psi is needed. The presswheel should be followed by a seed covering device which will insure a uniform planting depth at the various pressure settings. A second presswheel might be attached behind the seed covering device to apply low pressures to the soil surface. The present study, however, indicated that little or no pressure need be applied to the soil surface.

Field tests should be conducted with this machine to determine the proper settings for various soil conditions.

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APPENDIX

TABLE XVIII
ANALYSIS OF VARIANCE
EXPERIMENT 3 - EMERGENCE OF SUGAR BEET SEEDLINGS
IN SIMS AND BROOKSTON SOIL.

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F"
Total	17	3109		
Pressure	2	2953	1476	184.5**
Soil	1	4	4	0.5
P x S	2	53	26	3.2
Error	12	99	8	

**Highly significant difference (1% level) between pressures.

TABLE XIX.

ANALYSIS OF VARIANCE

EXPERIMENT 10 - MOISTURE ABSORPTION BY WHOLE SUGAR BEET
SEEDBALLS FROM SOIL CONTAINING 16 PERCENT MOISTURE.

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F"
$\frac{1}{2}$ hour after planting				
Total	13 [†]	178.8		
Replication	4	27.0	6.8	0.7
Pressure	2	86.9	43.4	4.7
R x P	7 [†]	64.9	9.3	

6 hours after planting				
Total	14	65.8		
Replication	4	17.6	4.4	1.6
Pressure	2	26.6	13.3	4.9*
R x P	8	21.7	2.7	

*Significant difference (5% level) between pressures.

[†]Reduced D.F. because of missing value.

TABLE XX.

ANALYSIS OF VARIANCE

EXPERIMENT 11 - MOISTURE ABSORPTION BY WHOLE SUGAR BEET
SEEDBALLS FROM SOIL CONTAINING 12 PERCENT MOISTURE.

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F"
$\frac{1}{4}$ hour after planting				
Total	10 [†]	32.3		
Replication	3	8.5	2.8	7.0*
Pressure	2	22.1	11.0	27.5**
R x P	5 [†]	1.8	0.4	

24 hours after planting				
Total	14	108.0		
Replication	4	39.5	9.9	2.9
Pressure	2	41.2	20.6	6.1*
R x P	8	27.3	3.4	

* Significant difference (5% level)

** Significant difference (1% level)

† Reduced D.F. because of missing value.

TABLE XXI.

ANALYSIS OF VARIANCE

EXPERIMENT 12 - MOISTURE ABSORPTION BY DECORTICATED SUGAR
BEET SEEDS FROM SOIL CONTAINING 12 PERCENT MOISTURE.

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F"
$\frac{1}{2}$ hour after planting				
Total	8	10.9		
Replication	2	9.2	4.6	11.5*
Pressure	2	0.2	0.1	0.2
R x P	4	1.5	0.4	

24 hours after planting				
Total	8	12.4		
Replication	2	4.0	2.0	2.0
Pressure	2	4.4	2.2	1.1
R x P	4	4.0	1.0	

*Significant difference (5% level)