THE EFFECT OF DEPTH OF PLANTING, COMPACTION AND SOIL MOISTURE TENSION ON THE SEEDLING EMERGENCE OF ALFALFA

By

Glover B. Triplett, Jr.

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
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Approved Milo B. Tesar

Field and greenhouse studies designed to evaluate critically the effect of depth of planting, compaction, and soil moisture on the seedling emergence of alfalfa were performed during 1957 and 1958. In the field studies, seeds were planted on two soil types at depths of 0, 1/4, 1/2, and 1 inch and the soil was compacted with 0, 3, 6, and 12 pounds per square inch. Three irrigation treatments, one-half inch of water applied after planting, one-half inch applied before planting, or no irrigation, were used. The plots were sheltered from natural precipitation with plastic covers until seedling emergence ceased, then exposed to natural precipitation for total emergence. Soil moisture was determined gravimetrically from the surface inch of soil one day after planting.

When the seedbed was not irrigated after planting, the percentage of seedling emergence increased with both increasing depth and compaction. The highest percentage of emergence was at the 1/2- to 1-inch depths of planting with 6- to 12-psi compaction. When the seedbed was irrigated after planting emergence was highest from the 1/2-inch depth of planting with little influence from increasing rates of compaction.

Emergence of seedlings from seeds planted on the surface was improved with increasing rates of compaction but was low when compared to seedling emergence of seeds planted 1/4 inch or deeper. In greenhouse studies, there was a high correlation between seedling emergence and coverage of surface-planted seeds caused by the action of irrigation applied after planting.

Multiple regression analysis of the data showed that seedling emergence was decreased as soil moisture tension increased. Compaction up to 12 psi increased emergence. Increasing the depth of planting from 1/4 to 1 inch resulted in decreased emergence when the seedbed received irrigation after planting, but resulted in increased emergence when not irrigated after planting.

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INTRODUCTION

Although the changing technology in agriculture during recent years has decreased the importance of small seeded legumes as a source of nitrogen in crop rotation systems, they are still used extensively for feed and forage. In Michigan, approximately 20% of the 10 millions acres of cropland is in a leguminous crop; in the United States, legumes occupy 20% of the cropland. It is estimated that about 20% of the seedings made each year in Michigan are total or partial failures. This high loss of seedings is not found in the establishment of the other crops commonly grown in this area. These seeding failures are probably tolerated because farmers do not realize the losses involved, and possibly because advancements in establishing and preserving good seedings have been slow in developing.

In recent years, the problem of seeding failures has been examined by research workers who have attempted to develop methods, techniques, and practices of seeding which will minimize seeding failures. Even though this research has resulted in improved seeding methods such as band seeding, Haynes (3) and Tesar et al. (15), there are many problems related to seeding failure which have not been thoroughly explored.

In 1937, Thatcher et al. (16), outlined some of the hazards to seedings. These were divided into hazards during establishment and those which cause loss of stands after the seeding has become established.

Early hazards to the seedings may be freezing, deep coverage, crusts on the soil, or drying out of the seedings. Later hazards to seedings are likely to be lack of inoculation, lack of lime or nutrients in the soil, insects, disease, drouth, competition of a companion crop or weeds, poorly adapted seed, or winter killing.

Probably the factor most often limiting in seedling establishment in Michigan and United States, especially for late spring and summer seedings, is moisture. This study was established to determine the effect of depth of seeding and compaction following seeding on the seedling emergence of alfalfa on two soil types in order to provide fundamental information on the effect of these factors on soil moisture relationship in the seedbed and their relationship to seedling establishment.

REVIEW OF LITERATURE

Certain environmental conditions must prevail before a seed will germinate. The seed must be exposed for a sufficient period of time to moisture, oxygen, and the correct temperature. The quantities of these factors necessary for the germination of seeds varies from species to species. The intensity of these factors also influences the germination of seeds and the rate of growth of the seedling. Lehenbauer (8) found that a 10° C rise in temperature doubled both the rate of germination and the rate of elongation of corn seeds. This relation held only between temperatures of 10 and 30° C. Above this, the rate of growth was decreased as temperature increased.

Apparently, the rate of germination and hypocotyl elongation in legumes is also influenced by moisture availability. Uhivits (17), working on the germination of alfalfa seed in different concentrations of mannitol and sodium chloride, found that the percentage and speed of germination decreased with increasing osmotic concentrations of these compounds. Seeds of various crops also vary in the minimum amount of soil moisture required for their germination. Hunter and Erickson (6) found that corn would not germinate if the soil moisture tension was higher than 12.5 atmospheres; minimum tensions for rice, soybeans, and sugar beets were 7.9, 6.6, and 3.5, respectively. This relation held regardless of the soil type. At higher soil moisture tensions, the seed would swell and fungi were able to grow and decompose the seed. Leach (7) used a slightly different technique and was able to get germination of sugar beet seed at soil moisture tensions just below 15 atmospheres. He also found that the speed of germination increased as the soil moisture tension decreased. Doneen and MacGillivray (2) studied several vegetable species and found that the seed of some species would germinate at soil moisture tensions slightly higher than the permanent wilting percentage or 15 atmospheres. Seed of some other species, including beets, required soil moisture tensions less than 15 atmospheres for germination.

Seed of some crop species retain their viability after periods of wetting and drying while others do not. Uttaman (18) conducted tests which showed that the drying of sprouted rice seed and the mutilation of the young radicle and plumule did not kill the germ of the seed. An individual seed could be placed in and removed from an environment favorable for germination and dried a number of times without loss of viability provided the seed was dried properly and stored out of contact with atmospheric moisture. Hunter (5) conducted tests of a similar nature with sugar beet seeds in which seeds were alternately soaked and dried. After soaking the seeds five times for a period of six hours each time and drying the seeds between each soaking period, the total germination was comparable to the untreated check and the speed of germination was greater than the check.

McKee (9) tested the ability of crimson clover to re-germinate after wetting the seeds for different lengths of time and then drying. If the radicle did not show as a result of soaking, there was no subsequent damage on re-germination.

Most workers agree that field seedings of small seeded crops should have some coverage but too much coverage is detrimental to emergence. Thatcher et al. (16) sums the situation up in this manner: "Most forage crop seed are small, and the seedlings cannot force their way to the surface if covered too deep. Critical experiments on depth of seeding are lacking, but there are many experiences of poor, thin stands following too deep seeding with or in front of a drill. On the other hand, as soon as the weather is warm enough that the surface soil dries quickly, failure to cover the seed is also fatal to good stands."

Moore (10) critically evaluated depth of planting in the field on the seedling emergence of several small seeded legumes. By planting seed on the surface and in trenches of various depths, he found optimum emergence at the planting depths of 1/4 and 1/2 inch. Surface plantings and deeper plantings produced lower emergence. Since weather records during the time of this experiment indicated ample rain, dry weather was not a primary limiting factor to emergence.

In the case of timothy seed, Williams (19) found a 1/2-inch depth of planting gave the highest emergence in the field, while a surface planting was best in the greenhouse. A planting depth of 1 inch resulted in consistently lower emergence in the field plantings and in the greenhouse.

Murphy and Arny (11) found that as the depth of planting increased beyond 1/2 inch, emergence was decreased. The magnitude of decrease in emergence due to the increase in depth of planting depended on the crop species and the soil type. Emergence from seeds planted on the surface and then sprinkled with soil to hold them in place during watering and natural precipitation was better than emergence from the 1/2-inch planting depth for some soils but poorer for others, depending on how fast the surface of the soil dried out.

Small-seeded horticultural species also show a similar trend. Heydecker (4) planted the seeds of carrot, onion, cabbage, and lettuce in a trench which was constructed so that it sloped gently, increasing in depth from 0 to 100 mm. Optimum emergence for all species occurred in the range from 15 to 30 mm.

The use of compaction in the establishment of field and forage crops is a common agronomic practice. Most row crop planters employ press wheels of some type and some drills equipped for band seeding employ press wheels. Cultipacking after seeding is a common practice which not only firms the soil but tends to cover the seeds as well. Parsons (12) showed definite improvement of alfalfa stands as a result of the use of compaction during seeding. He attributes this benefit to greater upward movement of moisture in the compacted zone. Thatcher et al. (16) and Stout (14) also reported improvement in stands due to compaction of the seeds after planting.

Moore (10), on the other hand, found little or no beneficial effect of compaction in a critical study on seedling emergence. Weather records for the period of this experiment show ample rainfall to maintain a moist condition in the soil. Seeds exposed to this moist environment apparently did not need the compaction for a high percentage of emergence.

PART I

LABORATORY EXPERIMENTS

The same lot of seed was used for all the experimental work described in this paper. A 100-pound bag of certified Vernal alfalfa seed grown in California in 1956 was procured during the winter of 1956 and 1957. This lot was selected because of its low hard seed content and its high percentage of germination. The seeds were screened over a 1/18- and through a 1/14-round hole screen, then fanned heavily so that all small, extremely large, or light seeds were removed, giving a lot of uniform size. The average germination of 600 seeds using standard techniques was 96% in 1957 and 93% in 1958. The hard seed content was less than 1%. The seeds were treated with the fungicide Arasan to reduce damping off.

Speed of germination and rate of radicle elongation of seeds.

In order to determine how individual seeds in a population germinated under different conditions of temperature, lots of 200 seeds were placed on moist blotters in a germinator at 20° and 30° C. The lots were examined every 12 hours, the number of germinated seeds was determined, and the lengths of radicles of germinated seeds were measured to the nearest 1 mm. A seed was considered germinated if the radicle penetrated the seed coat for 1 mm. or more.

The results of this experiment on the rate of germination are shown in table 1. The germination of the seeds held at 30° C was 96% after 48 hours, but only 43% for the seeds held at 20° C. Germination of the seeds held at 20° C. was not complete for 72 hours. Although 50% fewer seeds germinated in a given time at the lower temperature, there were seeds in the population which germinated more quickly at the lower temperature than some of the other seeds kept at the higher temperature.

Table 1. Percentage of germination of seeds in the laboratory at two temperatures after different time intervals.

Temperature,	Hours after planting				
degrees C.	24	36	48	60	72
30	40	72	96	--	--
20	20	30	43	86	93

The rate of elongation of the radicles of seeds germinated at 20 and 30° C. is shown in figures 1 and 2. The curve which resulted from plotting length of radicles against the number of seedlings had the same shape, regardless of the temperature or time, although the maximum was shifted by these factors. Regardless of the treatment, a few individuals germinated more rapidly or slowly than the majority of the population.

Seedling emergence in the laboratory under limiting moisture conditions.

In order to determine how moist the soil should be for germination, two soils of different texture, a Conover silt loam and a Fox

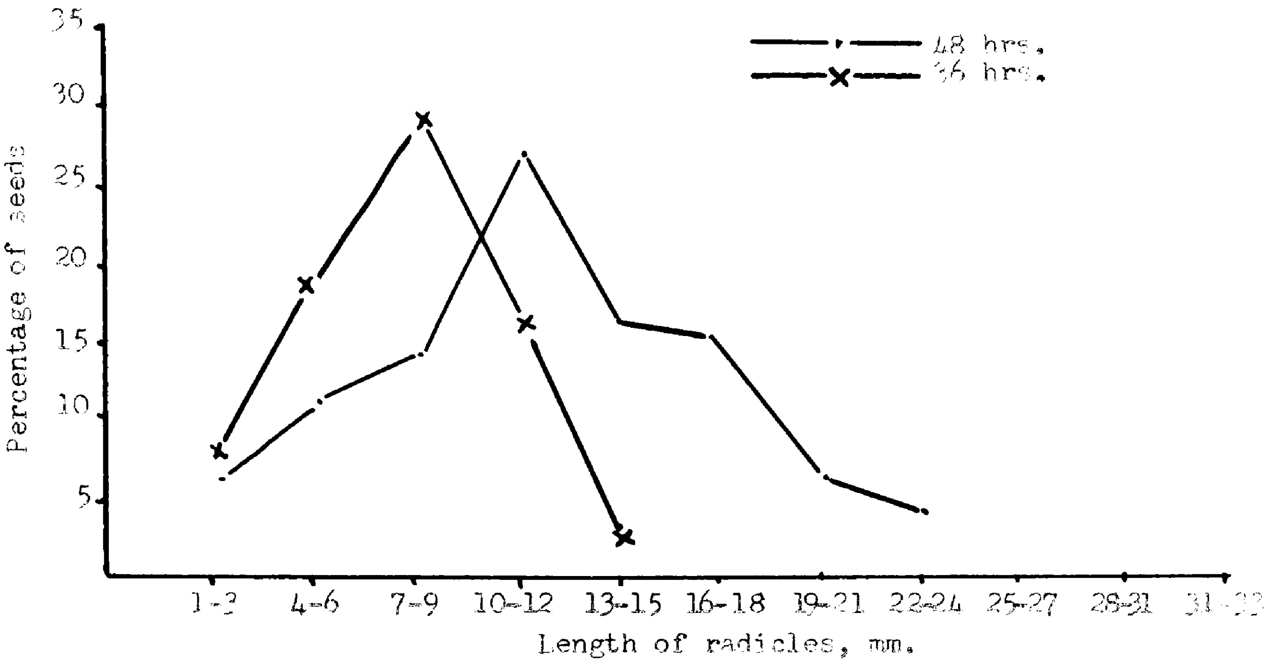

Figure 1. Lengths of radicles of alfalfa seeds after 36 and 48 hours in the germinator at 30° C.

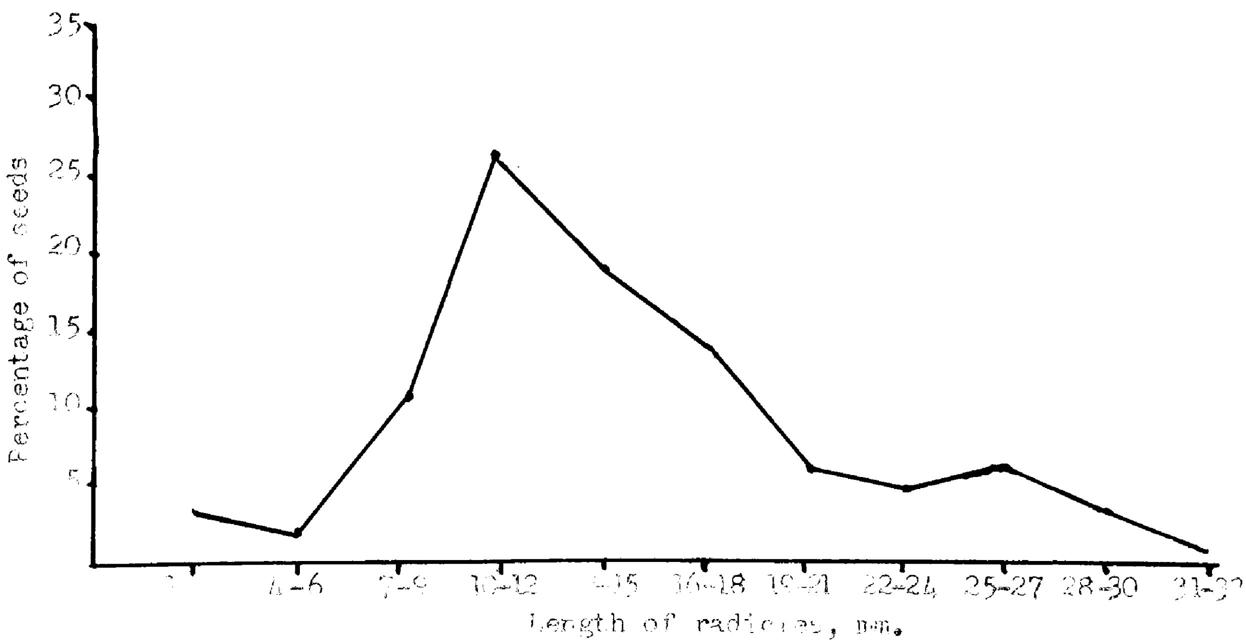

Figure 2. Lengths of radicles of alfalfa seeds after 72 hours in the germinator at 2[illegible] C.

sandy loam, were selected for the determination of germination of alfalfa seed at soil moisture tensions of 15, 13, and 11 atmospheres. Moisture tension curves for the two soils were determined by using tension tables for lower tensions and pressure membranes for tensions up to 15 atmospheres. Measured quantities of the two soils were brought to the desired moisture level and held in air tight containers. Three hundred grams of soil were placed in a plastic box 4 by 4 by 1 1/2 inches deep and 100 seeds were distributed uniformly over the surface of the soil. Enough soil was added to the box to cover the seeds 1/8 inch deep. The surface of the soil was then compacted with a pressure of 0, 2, 4 or 8 pounds per square inch (psi) and the box was covered and placed in a moist chamber at 20° C. so that moisture loss as determined by weighing was reduced to a minimum. Each treatment was replicated four times.

As shown in table 2, germination of the alfalfa seed increased with decreasing soil moisture tension. There was no germination at 15 atmospheres soil moisture tension, a few seeds germinated in both soil types at 13 atmospheres tension, while at 11 atmospheres tension the germination in both soil types averaged more than 40%. Apparently a few individual seeds were able to germinate at a soil moisture tension of 13 atmospheres which was too high for most of the seeds.

The decrease in soil volume due to compaction and the corresponding concentration of soil moisture did not increase germination consistently. At the end of this experiment, most of the ungerminated seeds in the boxes were covered with mold. This experiment indicated no consistently beneficial effect of compaction on seedling emergence in the laboratory when moisture was limiting.

Table 2. Average total germinations of alfalfa nine days after planting in the laboratory at different soil moisture tensions and with different compactions.

Soil moisture tension, atmospheres	Compaction, psi									
	0	2	4	8	Ave.	0	2	4	8	Ave.
	Fox sandy loam					Conover silt loam				
15	0	0	0	0	0	0	0	0	0	0
13	0	1	11	1	3	0	2	2	2	2
11	27	58	45	44	44	47	57	43	44	48
Ave.	9	20	18	15	16	16	20	15	15	17

Seedling emergence in the laboratory from moist soil.

Since the preceding experiment showed no consistently beneficial effect of compaction on emergence when moisture was limiting to germination, the effect of depth of planting and compaction on seedling emergence at higher moisture levels was determined. Fox sandy loam and Conover silt loam soils were used again in this experiment at 2 and 5 atmospheres soil moisture tension. Each soil was moistened to the correct moisture level and stored in a closed container. One hundred seeds were planted in plastic boxes containing 1/2 inch of soil and covered to depths of 1/4, 1/2, and 3/4 inch with loose soil of the proper moisture content. Five compactions, 0, 2, 4, 8, and 14 psi, were applied to the surface of the soil after planting and the boxes were covered and placed in a moist chamber at 20^{o} C. so there was little moisture loss. Seedlings were counted as emerged when the cotyledons rose above the surface of the soil. Each treatment was replicated three times.

Emergence was decreased at each planting depth by increasing compaction, but the decrease in emergence was greater at deeper planting depths, causing the compaction x depth interaction to be highly significant (table 3). The average emergence was higher from the Conover silt loam than from the Fox sandy loam because emergence from the 1/2- and 3/4-inch planting depths on the Fox sandy loam was lower than from these same depths on the Conover silt loam.

When the soil was compacted, adherence of the soil particles formed a caked layer which mechanically impeded the germinating seeds. This layer varied in strength depending on the depth of planting and amount of compaction. Even though the seeds germinated readily in the boxes, only those seedlings which were near fissures or openings in this layer could emerge, especially in those treatments planted deeper than 1/4 inch. At the 1/4-inch depth of planting, individual hypocotyls of germinating seeds could penetrate this layer without too much difficulty.

These laboratory results generally agree with the results of Stout (14), who showed that increasing compaction and depth of planting were detrimental to the emergence of sugar beet seedlings from plastic boxes in the laboratory. They do not agree with the field observations of Parsons (12), Thatcher et al. (16), and Stout (14) that seedling emergence is favored by compaction.

The effect of wetting and drying on the viability of alfalfa seeds.

Several thousand alfalfa seeds were placed on the surface of an ordinary greenhouse flat filled with saturated soil. The flat was placed on a greenhouse bench and shaded from the sun for one day, then

Table 3. The effect of three depths of planting and five compaction treatments on the average percentages of emergence of alfalfa on two soils maintained at two moisture levels in the laboratory.

Planting depth, inches	Atmospheres soil moisture tension											
	Two						Five					
	Compaction, psi											
	0	2	4	8	14	Ave.	0	2	4	8	14	Ave.
	Fox sandy loam											
1/4	94	79	78	79	67	80	90	87	76	73	71	79
1/2	81	45	40	42	39	49	80	55	49	29	37	50
3/4	66	40	19	6	13	29	60	39	23	12	13	29
Ave.	80	55	45	42	40	53	76	60	49	38	40	53
	Conover silt loam											
1/4	93	96	92	68	51	80	73	74	66	68	63	61
1/2	97	78	65	44	28	62	86	68	48	41	34	55
3/4	76	84	70	46	19	59	89	61	50	33	15	49
Ave.	85	82	72	50	31	67	83	66	54	45	35	55

Partial analysis of variance for emergence between:

Source			
Moistures (M)	*	C x S	**
Soils (S)	**	C x M	NS
Depths (D)	**	D x M x S	NS
Compactions (C)	**	C x M x S	*
C x D	**	C x D x S	NS
D x S	**	C x D x M	NS
D x M	NS	C x D x M x S	NS

uncovered and allowed to dry. During this time, approximately 50% of the seeds initiated germination and produced radicles of varying lengths. The seeds were left undisturbed without watering for a period of three weeks. After this period a portion of the seeds was removed and the seeds were classified germinated if the radicle had broken the seed coat, and ungerminated if there was no visible evidence of growth. Two hundred seeds of each classification were placed on a blotter in a germinator for a six-day period in a standard germination test.

Three per cent of the seeds which had started to germinate originally before being dried produced normal seedlings in the germinator as compared to 73% of the seeds which had not started to grow originally. When the same test was performed in moist sand, the seeds with no growth evident gave an emergence of 74% as compared to 1% for those which had started to grow on the surface of the flat.

Probably the major factor which contributed to this difference in emergence was the inability of the seed to regenerate root tissue killed through the desiccation of the germinating seed. Many of the seeds which had initiated growth and then were dried were able to make more growth when placed under moist conditions. This growth consisted in the elongation of the region below the cotyledons, but few seedlings produced new roots or root hairs. When these seedlings were held under favorable conditions for a period of several days, a few would produce secondary roots. Since almost none of these seedlings emerged and produced normal plants when they were planted in sand, it can be concluded that once germinated and then desiccated, a seed has practically no value, on the average, in the establishment of a seedling.

PART II

1957 FIELD STUDIES ON THE EFFECT OF DEPTH OF PLANTING AND SOIL COMPACTION ON SEEDLING EMERGENCE

The results of the laboratory studies indicated a detrimental effect of depth and increasing compaction on emergence. This was in sharp disagreement with field observations and agronomic recommendations that some coverage of seeds and some degree of compaction are beneficial for best emergence. Consequently, studies were established during the spring and summer of 1957 to evaluate critically the effect of depth of planting and compaction on alfalfa seedling emergence and to find if any interaction existed between these two factors.

Materials and Methods

Two soil types, a Hillsdale sandy loam and a Conover silt loam, were used in these experiments. The experimental sites were located within 500 yards of each other and were part of the experimental fields at Michigan State University. Both soils are well drained and have good internal structure. Both soils are moderately high in available water holding capacity (figure 3).

The treatments on each soil type consisted of 4 depths of planting, 0, 1/4, 1/2 and 1 inch, and four compactions, 0, 3, 6, and 12 pounds per square inch (psi),applied over the planted and covered row of seeds. Thus, there was a total of 16 treatments on each soil type on each of 4 replications arranged in a randomized block.

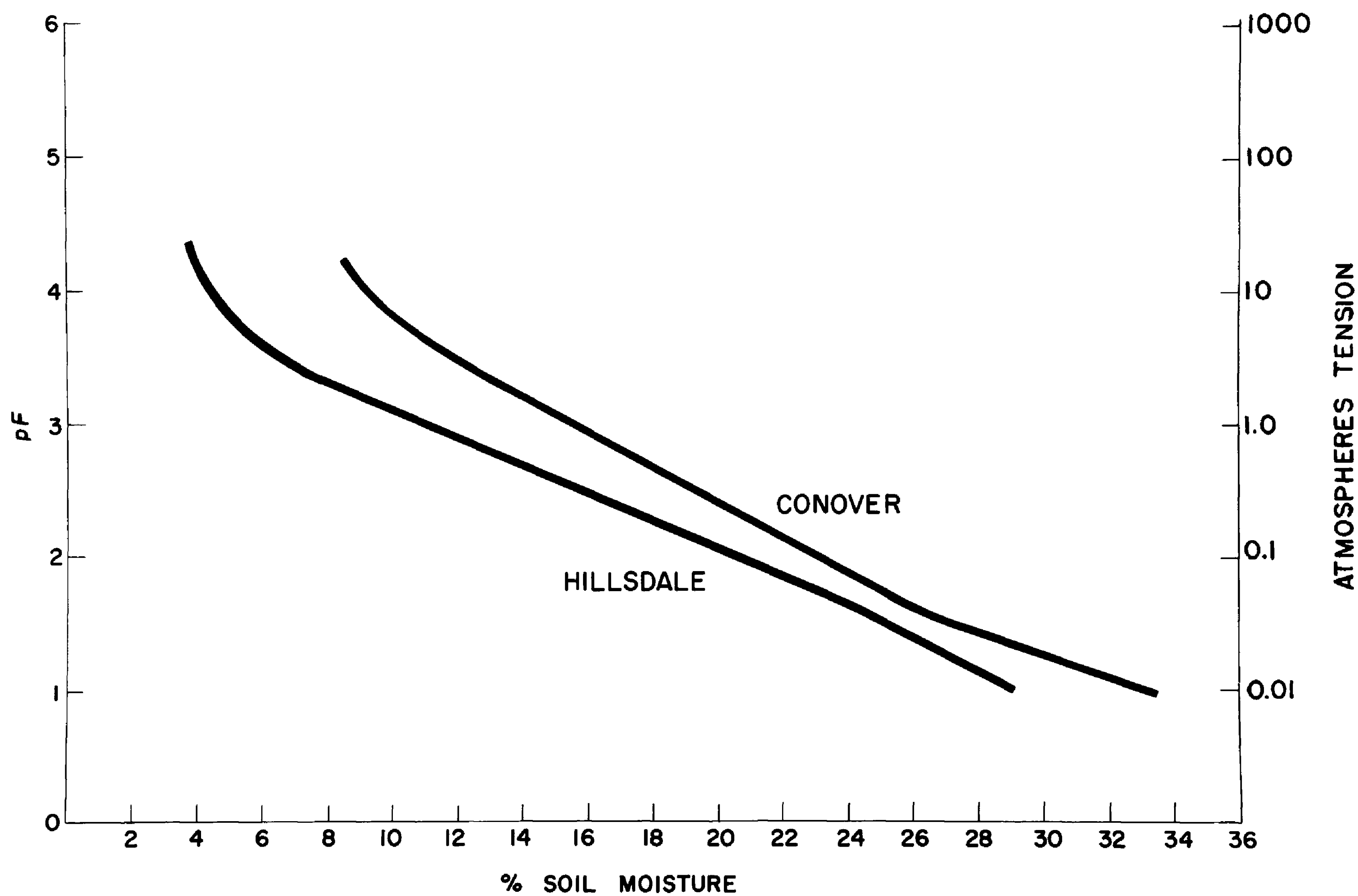

Figure 3. Relationship between the percentage of soil moisture and the pF and atmospheres tension values.

Since the extent of the environment of individual seeds is limited, the plots consisted of 100 seeds hand planted 1/4 inch apart with a vacuum planter, (figure 4), in parallel rows 2 feet long and 7 inches apart. Each replication of 16 plots was 4 feet wide and 9 feet long.

Before an experiment was planted, the soil was prepared by disking. After this, a hoe was used to throw the soil into a bed 18 inches high, 2 feet wide, and 40 feet long. During this treatment, the soil was loosened, large clods were broken up, and any stones present were removed. A garden rake was then used to level the bed. The excess soil was pulled over on each side, first with the tines of the rake pointing downward to remove smaller clods and stones, and then with the tines pointing upward and the flat back side of the rake running over the top of the bed to smooth the surface and eliminate irregularities. The bed was then leveled with a board. The final seed bed was relatively firm, free from large stones and clods, level, and very smooth. The completed bed was 4 feet wide and approximately 6 inches higher than the surrounding soil surface with a trench adjacent to each 9-foot side to facilitate drainage and prevent flooding in case of rain.

The correct seeding depth for the individual treatments was obtained by the use of a 2-foot length of board having a V-shaped piece of wood projecting downward from one side. Three boards were used to make a V-shaped trench in the soil for the 1/4-, 1/2-, and 1-inch depths, (figure 5). The board was forced gently into the soil as it was moved back and forth a few times to make the trench. After

Figure 4. Use of the vacuum seed counter in planting the seeds for the experiments.

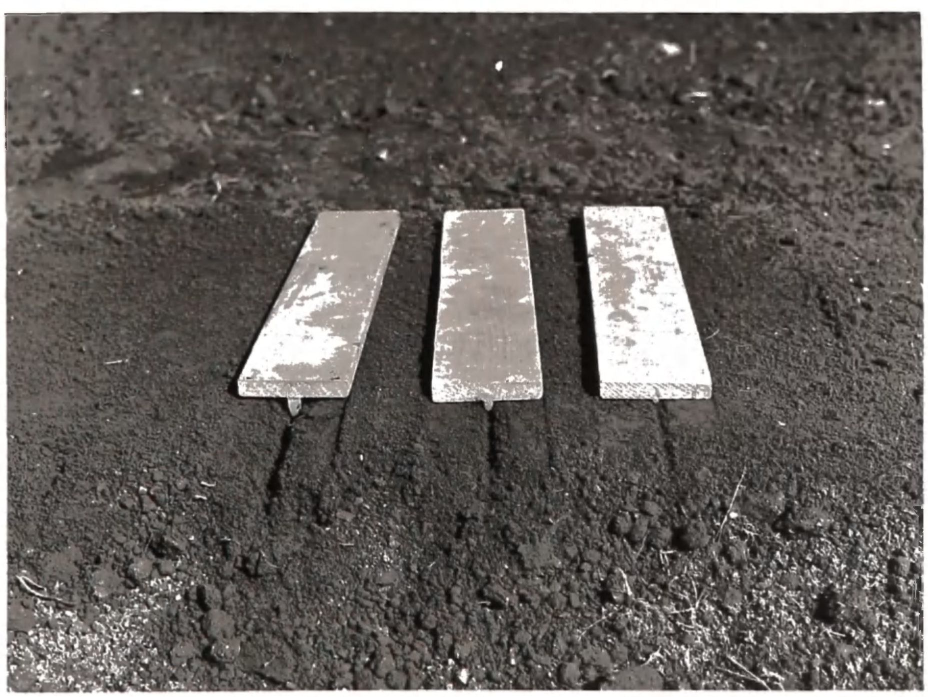

Figure 5. Construction of trenches for the planting of seeds. From left to right: 1-inch, 1/2-inch, and 1/4-inch depths.

the seeds were planted, the trench was filled with loose soil. Since considerable moisture loss may occur from the surface of the soil during a summer day, the seedbed for each replication was prepared immediately prior to planting with the result that the soil was fairly moist.

Compaction for the various treatments was applied by rolling a weighted wheel over the planted row. This instrument was calibrated by using a stress gauge developed by the Department of Agricultural Engineering at Michigan State University (1). The stress gauge consisted of a pressure-sensitive pickup which was connected to a recorder. The pickup was buried to a depth of 1 inch in loose soil, the wheel was run over the buried gauge, and the pressure recorded on a chart in pounds per square inch.

In order to determine the final depth after compaction of seeds planted in the various plots, ordinary household string was laid in the bottom of the trenches representing the three depths of planting. The trenches were filled and then compacted. The soil was carefully removed above the string and the distance from the string to the soil surface was measured in several locations. Six replications were used.

As compaction increased from 3 to 12 psi, (table 4), the depth of the string representing planted seed was decreased, even though the total mass of soil covering the seed remained the same. The 25% decrease in the depth of soil over the string at 12 psi remained constant at different depths of planting. These results, using the string to represent seeds planted at various depths, showed that compaction decreased the distance of seeds from the soil surface.

Table 4. Depth in inches of string representing seed placed at three different depths as influenced by compaction.

Compaction, psi	Depth of trench, inches		
	1	1/2	1/4
3	7/8	7/16	1/4
12	3/4	3/8	3/16

Emergence of the seedlings was counted daily. Seedlings were considered emerged as soon as the cotyledons had opened. As soon as a seedling was counted, it was removed from the plot with a pair of tweezers without disturbing the soil. Counts were made as long as seedlings continued to emerge after which the experiment was terminated. Emergence was influenced markedly by the weather conditions during and after planting. Seeds in treatments exhibited emergence with residual moisture, while others did not emerge until after a rain. The final count of total emergence, in every case, was delayed until after a rain.

Observation of early experimental results indicated that differences in soil moisture played an important role in seedling emergence. In order to determine the moisture content of the soil, a #9 cork borer was inserted into the soil adjacent to the row where the seeds were planted. A core of soil 1 inch long was removed and was cut into 3 sections, each 1/3 of an inch long. Each section (approximately 2 grams) was placed into a numbered can with a tight friction top. The cans were weighed, oven dried overnight at 105° C., re-weighed, and the moisture in the sample was calculated on an oven-dry basis.

The samples represented the moisture conditions in the area around the seed. Thus, the soil sample from the surface to the 1/3-inch depth represented the area surrounding seeds planted at a depth of 1/4 inch. The soil sample from the 1/3- to 2/3-inch depths represented the area surrounding the seeds planted 1/2 inch deep and the soil sample from the 2/3- to 1-inch depth represented the seeds planted at a depth of 1-inch. Evaluation of soil moisture at the surface was not attempted.

Experiences during this first year of planting (1957) showed that a critical evaluation of the effect of depth of planting and soil compaction on seedling emergence when soil moisture was limiting was not possible when the experimental area received rain soon after the experiment was initiated. This hazard was minimized during the latter part of this season by providing shelters for the plots. Each shelter, large enough to cover one replication, was made of a wooden frame 10 feet long and 6 feet wide covered with a clear polyethylene plastic, (figure 6). The shelters were placed over the plots only when rain was imminent and were removed as soon as the threat of rain had passed in order to minimize the effect of the shelters on the micro-climate around the plot.

During the field study in 1957, individual experiments were planted on nine separate dates on each soil type. Appropriate statistical analyses were performed on the data for each planting date and for the complete season. Since the emergence data were in percentages, they were transformed to arcsine angles for analysis by the tables found in Snedecor (13).

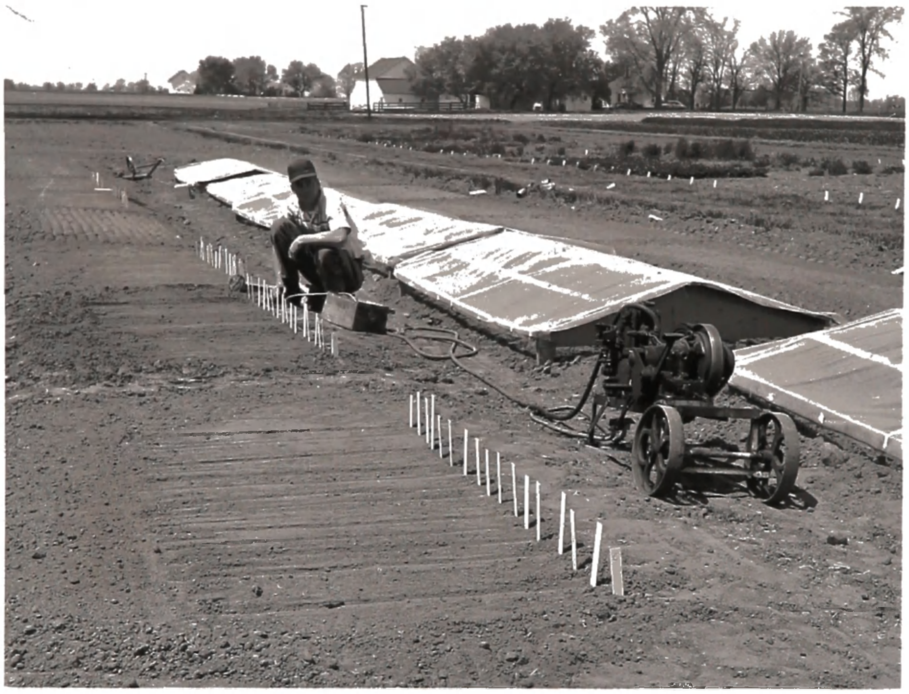

Figure 6. Shelters used to protect the plots from natural precipitation.

Results of 1957 Field Plantings

First planting date, 1957

The first field plantings for the 1957 season were made on May 2 on the Conover silt loam and on May 3 on the Hillsdale sandy loam soil. Data were collected from three replications on the Hillsdale soil since the fourth replication was destroyed by a mole.

The initial emergence after eight days for this experiment represented the number of seedlings which were able to grow with residual soil moisture since there was no measured rainfall during this period, (table 5). Both depth and compaction and their interaction had a highly significant effect on emergence. Emergence was increased by greater compaction at the 1/2-inch depth of planting for both soil types, but not at the 1-inch depth. Emergence from the 1-inch seeding depth on the Conover soil was almost twice as great as emergence from this depth on the Hillsdale soil, even though emergence was increased greatly on both soil types with increased depth of planting. Since the initial emergence from the 1/2-inch depth of planting for both soil types was similar, this poor emergence from a 1-inch depth of planting on the Hillsdale soil indicated that moisture relations may not have been the primary factor limiting emergence in this case.

At the final count of emergence 23 to 24 days after planting, there was a significant difference in depth of planting, the lowest emergence being at the 0-inch planting depth. The initial beneficial effect of increased compaction on emergence from the 1/2-inch planting depth was eliminated by the emergence following the rains.

Table 5. Average percentages of seedling emergence of the May 2 and 3 planting of alfalfa from initial soil moisture and total emergence following natural precipitation. (1)

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (2)					Total emergence				
	May 2 planting on Conover silt loam									
0	0	0	0	0	0	14	11	17	22	16
1/4	0	1	0	3	1	50	54	46	49	50
1/2	2	11	20	38	18	74	74	78	74	75
1	60	56	61	59	59	69	61	72	64	67
Ave.	16	17	20	25	20	52	50	53	52	52
	May 3 planting on Hillsdale sandy loam									
0	0	0	0	0	0	18	10	20	26	18
1/4	0	0	0	16	4	39	45	36	52	43
1/2	1	12	17	43	18	59	59	56	55	57
1	31	33	42	33	34	40	44	45	36	41
Ave.	8	11	15	24	14	39	39	39	42	40

(1)

Soil type	Precipitation in inches							
	Days after planting							
Conover	8	9	10	11	12	16	18	22
Hillsdale	7	8	9	10	11	15	17	21
	1.48	0.47	0.35	0.11	0.94	0.35	2.05	0.17

(2) Conover--initial emergence after 8 days, total emergence after 24 days. Hillsdale--initial emergence after 8 days, total emergence after 23 days.

Partial analysis of variance for emergence between:

Source	Conover		Hillsdale	
	8 days	24 days	8 days	24 days
Compactions	**	NS	**	NS
Depths	**	**	**	**
Interaction, C x D	**	NS	**	NS

Second planting date, 1957

Emergence after four days from plots planted on the Conover soil on May 28 was similar to the pattern exhibited from the May 2 and 3 planting dates. There was little emergence from a planting depth of 1/4 inch. Emergence from the 1/2-inch depth was greatly improved by increasing compaction; emergence from the 1-inch planting depth showed a gradual increase as compaction increased from 0 to 6 psi.

Depth, compaction, and their interaction had a significant effect on total emergence determined 11 days after planting. Emergence was increased by compaction at planting depths of 0 and 1/4 inch but was not affected by compaction at the 1/2- and 1-inch depths.

The plots planted on Hillsdale soil on May 24 received a rain two days after planting so no data was collected for emergence due to residual soil moisture, (table 6). Depth of planting and the interaction between depth and compaction had a significant effect on total emergence determined after 13 days. Emergence was not influenced by compaction at a planting depth of 1/4 and 1/2 inch, but increasing compaction increased emergence of surface-planted seed and generally decreased emergence at a planting depth of 1 inch. The net effect of these trends cancelled any effect of compaction over all planting depths.

Surface plantings were poor on both soil types and the emergence from the 1-inch depth of planting was lower on the Hillsdale than on the Conover soil.

Table 6. Average percentages of alfalfa seedling emergence from initial soil moisture and total emergence following natural precipitation. (1)

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (2)					Total emergence				
	May 28 planting on Conover silt loam									
0	0	0	0	0	0	5	7	9	26	17
1/4	0	0	0	1	0	58	67	80	78	71
1/2	0	3	8	26	9	77	84	80	79	80
1	22	30	37	36	31	66	70	64	69	68
Ave.	5	8	11	16	10	52	57	58	63	58
	May 24 planting on Hillsdale sandy loam									
	(2)									
0	--	--	--	--	--	10	10	29	35	21
1/4	--	--	--	--	--	68	72	69	71	70
1/2	--	--	--	--	--	80	80	78	71	77
1	--	--	--	--	--	63	56	46	46	53
Ave.	--	--	--	--	--	55	54	55	55	55

(1)

Soil type	Precipitation in inches Days after planting			
Conover			4	5
Hillsdale	2	3	8	9
	0.20	T	0.19	0.27

(2) Conover--initial emergence after 4 days, total emergence after 11 days. Hillsdale--no data collected on initial emergence, total emergence after 13 days.

Partial analysis of variance for emergence between:

Source	Conover 11 days	Hillsdale 13 days
Compactions	**	NS
Depths	**	**
Interaction, C x D	*	**

Table 7. Average percentages of total alfalfa seedling emergence following natural precipitation. (1) Planted June 21.

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Conover silt loam					Hillsdale sandy loam				
0	12	11	23	45	23	20	7	19	38	21
1/4	63	74	69	73	70	64	62	67	72	66
1/2	74	78	79	61	73	71	71	67	66	69
1	58	55	59	50	55	59	67	69	59	63
Ave.	52	54	58	57	55	53	52	56	59	55

(1) Soil type	Precipitation in inches				
	Days after planting				
Conover	2	4	5	7	8
Hillsdale	2	4	5	7	8
	0.51	T	T	0.18	0.50

(2) Total emergence on Conover after 12 days, on Hillsdale after 10 days.

Partial analysis of variance for emergence between:

Source	Conover 12 days	Hillsdale 10 days
Compactions	*	NS
Depths	**	**
Interaction, C x D	**	*

Third planting date, 1957

On June 21, plots were planted on both Conover and Hillsdale soil types. The plots received 0.51 inches rain two days after planting so no data could be collected for emergence due to residual soil moisture. Total emergence was completed after 10 days on the Hillsdale soil and after 12 days on the Conover soil, (table 7).

Emergence for surface-planted seeds tended to increase with increased compaction for both soil types, but there was no beneficial effect of compaction on emergence at the other planting depths in this experiment conducted under favorable conditions of precipitation. The significance of the interaction, C x D, for both soil types was due to this difference. Depth had a highly significant effect on emergence for both soil types. Emergence from surface-planted seed was poor, but was good for all other depths on both soil types. The results from this planting date were similar to those for the total emergence on the preceding experiments.

Fourth planting date, 1957

The experiment seeded on Conover soil on July 20 received 1.34 inches of rain within three days after planting. This precipitation was sufficient to cause a high percentage of emergence from plots planted at the 1/4-, 1/2-, and 1-inch depths. Depth, compaction, and their interaction had a highly significant effect on emergence for this experiment, (table 8). Emergence from depths of 1/4, 1/2, and 1 inch was relatively uniform both in respect to the effect of compaction and depth. The emergence from the seed planted on the surface was increased threefold as compaction increased from 0 to 12 psi.

Table 8. Average percentages of total seedling emergence of alfalfa seven days after planting on July 20 on Conover silt loam soil. Emergence determined following natural precipitation occurring 2 and 3 days after planting. (1)

Planting depth, inches	Compaction, psi				
	0	3	6	12	Ave.
0	16	14	27	60	29
1/4	65	66	76	71	70
1/2	72	77	79	71	75
1	74	82	82	76	79
Ave.	57	60	66	70	63

(1)

Precipitation in inches	
Days after planting	
2	3
0.23	1.11

Partial analysis of variance for emergence between:

Compactions	**
Depths	**
Interaction, C x D	**

Table 9. Average soil moisture tensions two days after planting and average percentages of seedling emergence of the July 25 planting on Hillsdale sandy loam soil. Initial emergence was from residual soil moisture and total emergence was obtained following natural precipitation. (1)

Sampling depth, inches	Atmospheres soil moisture tension, two days after planting				
	Compaction, psi				
	0	3	6	12	Ave.
0-1/3	5.7	3.1	3.4	2.1	3.6
1/3-2/3	1.8	1.3	1.7	1.4	1.5
2/3-1	1.5	1.0	1.4	1.1	1.3
Ave.	3.0	1.8	2.2	1.5	

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (2)					Total emergence				
0	0	0	0	0	0	6	5	8	13	8
1/4	1	4	12	14	8	40	28	24	23	29
1/2	16	51	55	59	45	39	56	60	60	54
1	41	55	56	51	52	43	58	59	51	53
Ave.	15	28	31	31	26	32	37	38	37	36

(1)

Precipitation in inches							
Days after planting							
16	30	31	33	35	36	37	38
T	0.47	0.31	T	0.35	0.19	0.04	0.20

(2) Initial emergence after 7 days, total emergence after 38 days.

Partial analysis of variance for initial and total emergence and soil moisture tension and analysis of covariance betweenititial emergence and soil moisture tension.

Source	Emergence after 7 days	Soil moisture tension	Covariance	Total emergence
Compactions	**	**	NS	NS
Depths	**	**	*	**
Interaction, C x D	**	*	NS	**
Individual plots			**	

The results of the planting of July 25 on Hillsdale soil are shown in table 9. This experiment was planted following 1.75 inches of rain on July 23; the initial soil moisture was high. This experiment marked the initiation of soil moisture sampling for the season and the soil moisture tension was found to be relatively low for all treatments two days after planting. The initial emergence for this experiment was improved by increasing depth and compaction, but the magnitude of increase in emergence with increasing compaction became less as the depth of planting was increased.

The analysis of covariance between soil moisture tension two days after planting and initial emergence showed that the negative correlation between soil moisture tension and emergence was highly significant. Thus, as the soil moisture tension increased, emergence decreased.

The total emergence of this experiment at the 1/4-inch depth of planting showed the effect of increasingly better initial moisture relations on subsequent emergence. As compaction increased, initial emergence increased, being 1% at 0 psi to 14% at 12 psi. This trend was completely reversed in the final emergence, indicating that the seeds in the drier plots suffered less injury than those in plots with greater initial emergence. Seeds planted 1/2 and 1 inch deep and subjected to compactions of 3, 6, and 12 psi did not increase greatly in the total emergence, but emergence was high enough initially to be considered good.

Fifth planting date, 1957

This experiment was irrigated with 1/2 inch of water immediately after planting and the results illustrated some of the differences between the two soil types. Lack of moisture limited initial emergence in this experiment even though the area was irrigated since total emergence from both soil types was improved by subsequent rain, (table 10).

Initial emergence was highest from a 1-inch depth on the Conover soil, but was the lowest from this depth on the Hillsdale soil; it was even lower than emergence from surface planting. The factor most limiting to emergence on the Conover soil was moisture as shown by the increasing emergence as depth of planting and compaction were increased. On the Hillsdale soil, however, moisture relations were favorable enough for an average of 66% emergence from the 1/4-inch depth of planting. The low emergence from the 1-inch depth was caused by some factor other than limited moisture, probably mechanical impedence or the restriction of the emergence of the seedlings due to a hardened or crusted layer since the moisture relations in the soil improved with depth.

The effect of depth on emergence was highly significant for both soils as was compaction for the Conover soil, another indication of limiting moisture. The total emergence from the Conover soil reflected the same trend as the initial emergence in respect to compaction, indicating injury to some of the seeds which did not emerge initially.

Table 10. Average percentage of initial seedling emergence of alfalfa planted on August 6 and 7 and irrigated with 1/2 inch of water immediately after planting and total emergence determined following natural precipitation. (1)

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (2)					Total emergence				
	August 6 planting on Conover silt loam									
0	6	2	4	39	13	21	22	28	69	35
1/4	17	34	33	42	32	57	59	59	62	59
1/2	33	41	61	64	50	56	57	71	77	66
1	41	52	53	62	52	48	56	57	65	57
Ave.	24	32	38	52	37	46	49	54	68	54
	August 7 planting on Hillsdale sandy loam									
0	29	29	43	66	42	41	43	53	68	51
1/4	61	67	72	62	66	71	74	76	71	73
1/2	69	71	69	66	69	71	72	71	68	71
1	38	54	34	27	38	44	60	36	29	43
Ave.	49	56	55	55	54	57	63	59	59	60

(1)

Soil type	Precipitation in inches							
	Days after planting							
Conover	4	18	19	21	23	24	25	26
Hillsdale	3	17	18	20	22	23	24	25
	T	0.47	0.30	T	0.35	0.19	0.04	0.20

(2) Conover--initial emergence after 10 days, total emergence after 27 days. Hillsdale--initial emergence after 8 days, total emergence after 26 days.

Partial analysis of variance for emergence between:

Source	Conover 10 days	Conover 27 days	Hillsdale 8 days	Hillsdale 26 days
Compactions	**	**	NS	NS
Depths	**	**	**	**
Interaction, C x D	*	*	**	**

Sixth planting date, 1957

Initial emergence was greater for this planting on the Hillsdale soil than on the Conover soil, indicating more favorable soil moisture relations in the Hillsdale soil, (table 11). The trend of emergence was similar to that found on previous plantings which had limited moisture.

Total emergence from both soils was high because of favorable intervening rainfall. The effects of depth, compaction and their interaction on total emergence are highly significant for both soils. Emergence from the surface depth of planting was increased threefold by increasing compaction on both soils, but the total emergence of the other depths of planting showed little effect from compaction. The surface planting had the lowest emergence for both soil types.

Seventh planting date, 1957

Seedings were made on August 19 and 20 on a moist seedbed after 1/2 inch of water was applied. The plots were sheltered from rain until all emergence ceased, then uncovered, and total emergence was determined after natural precipitation. This experiment was the only one sheltered from rain during 1957.

The initial emergence on the Conover soil as shown in table 12 was less than when plantings were made on the Hillsdale soil at the same time, (table 13). The initial emergence from both soil types was increased by both greater depths of planting and increased compaction. Total emergence at the 1/4-inch depth of planting on both soil types showed the effect of limited initial moisture on subsequent emergence. Seed planted 1/4 inch deep with no compaction exhibited no initial

Table 11. Average percentages of initial alfalfa seedling emergence from initial soil moisture and total emergence following natural precipitation. (1)

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (2)					Total emergence				
	August 14 planting on Conover silt loam									
0	0	0	0	0	0	20	35	34	63	38
1/4	0	0	0	0	0	77	81	81	85	81
1/2	0	0	0	0	0	79	84	82	76	80
1	3	2	14	21	10	79	80	82	79	80
Ave.	1	1	4	5	2	64	70	70	76	70
	August 13 planting on Hillsdale sandy loam									
0	0	0	0	0	0	26	31	56	74	47
1/4	0	0	0	4	1	69	75	71	75	73
1/2	0	2	2	12	4	84	76	78	75	78
1	7	12	24	30	18	51	63	76	64	63
Ave.	2	3	6	12	6	57	61	70	72	65

(1)

Soil type	Precipitation in inches — Days after planting						
Conover	10	11	13	15	16	17	18
Hillsdale	11	12	14	16	17	18	19
	0.47	0.30	T	0.35	0.19	0.04	0.20

(2) Conover--initial emergence after 9 days, total emergence after 19 days. Hillsdale--initial emergence after 10 days, total emergence after 22 days.

Partial analysis of variance for emergence between:

Source	Conover 19 days	Hillsdale 10 days	Hillsdale 22 days
Compactions	**	**	**
Depths	**	**	**
Interaction, C x D	**	NS	**

Table 12. Average percentages of initial and total seedling emergence of the August 20 planting of alfalfa on Conover silt loam soil. Initial emergence determined after a 1/2 inch irrigation before planting and total emergence determined after a period of natural precipitation. (1)

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (2)					Total emergence				
0	0	0	0	6	2	14	19	31	36	25
1/4	0	1	3	9	3	63	49	48	40	50
1/2	7	21	56	62	37	53	59	69	70	63
1	45	63	63	64	59	61	71	65	68	66
Ave.	13	22	31	36	25	48	50	53	54	51

(1)

Precipitation in inches				
Days after planting				
14	15	21	22	24
0.13	0.17	0.21	0.02	0.21

(2) Initial emergence after 13 days, total emergence after 27 days.

Partial analysis of variance for emergence between:

	13 days	27 days
Compactions	**	NS
Depths	**	**
Interaction, C x D	**	**

Table 13. Average soil moisture tension one day after planting and average percentages of seedling emergence of the August 19 planting of alfalfa on Hillsdale sandy loam soil. Initial emergence from a 1/2-inch irrigation before planting, total emergence determined after natural precipitation. (1)

Sampling depth, inches	Atmospheres soil moisture tension one day after planting				
	Compaction, psi				
	0	3	6	12	Ave.
0-1/3	12.1	5.2	2.0	1.8	5.2
1/3-2/3	2.4	1.5	1.2	.9	1.5
2/3-1	1.5	1.0	1.1	.9	1.1
Ave.	5.3	2.6	1.4	1.2	

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (2)					Total emergence				
0	0	0	0	13	3	12	29	39	19	25
1/4	0	3	23	46	18	73	42	28	46	47
1/2	4	56	67	70	49	43	64	68	70	61
1	64	75	70	73	70	64	75	70	73	70
Ave.	17	33	40	51	35	48	52	51	52	51

(1)

Precipitation in inches		
Days after planting		
22	23	24
0.21	0.02	0.21

(2) Initial emergence after 19 days, total emergence after 26 days.

Partial analysis of variance for initial and total emergence and soil moisture tension and analysis of covariance between initial emergence and soil moisture tension.

	Emergence after 19 days	Total emergence	Soil moisture tension	Covariance
Compactions	**	NS	**	*
Depths	**	**	**	NS
Interaction, C x D	**	**	**	NS
Individual plots				**

emergence, but after the experimental area received several rains, a high percentage (63 to 73%) emerged on the two soil types. Total emergence for the higher levels of compaction at the 1/4-inch depth was lower than when no compaction was used.

Analysis of covariance for soil moisture tension of Hillsdale sandy loam one day after planting and initial emergence showed a highly significant negative correlation between soil moisture tension and emergence.

Eighth planting date, 1957

Seedings made on the Conover soil on September 5, (table 14), received 0.21 inch of rain five days after planting, and this was time enough to count the initial emergence. Probably a few more seedlings would have emerged, but the data for the initial emergence were similar to those of previous planting dates. Analysis of covariance for the initial emergence and soil moisture tension two days after planting showed a highly significant negative correlation between emergence and soil moisture tension.

Total emergence was high for seed planted 1/4 inch or deeper. Emergence from the surface seeding was greatly increased by increasing compaction. Only 6 and 8% emergence was obtained at the compaction levels of 0 and 3 psi, respectively, whereas emergence at the compaction levels of 6 and 12 psi was 22 and 70%, respectively.

Seedings made on the Hillsdale soil on September 7, (table 15), received rain three days after planting, so initial emergence data from residual soil moisture was not recorded. The data for total

Table 14. Average soil moisture tension two days after planting and average percentages of seedling emergence of the September 5 planting of alfalfa on Conover silt loam soil. Initial emergence from residual soil moisture, total emergence following natural precipitation. (1)

Sampling depth, inches	Atmospheres soil moisture tension two days after planting				
	Compaction, psi				
	0	3	6	12	Ave.
0-1/3	16	14.7	10.1	4.8	12.3
1/3-2/3	5.8	2.9	2.1	1.4	3.0
2/3-1	1.9	1.9	1.4	1.3	1.6
Ave.	9.1	6.5	4.5	2.5	

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (2)					Total emergence				
0	0	0	0	1	0	6	8	22	70	27
1/4	0	0	2	22	6	83	82	81	76	81
1/2	3	22	52	76	40	81	75	84	84	81
1	72	69	72	61	69	81	73	74	63	73
Ave.	19	23	32	39	29	63	60	65	73	65

(1)

Precipitation in inches			
Days after planting			
5	6	8	11
0.21	0.02	0.21	0.16

(2) Initial emergence after 6 days, total emergence after 14 days.

Partial analysis of variance for initial and final emergence and soil moisture tension and analysis of covariance between initial emergence and soil moisture tension.

Source	Emergence after 6 days	Total emergence	Soil moisture tension	Covariance
Compactions	**	**	**	*
Depths	**	**	**	NS
Interaction, C x D	**	**	**	
Individual plots				**

Table 15. Average percentages of total seedling emergence due to natural precipitation (1) and determined 10 days after planting alfalfa on September 7 on a Hillsdale sandy loam soil.

Planting depth, inches	Compaction, psi				
	0	3	6	12	Ave.
0	1	6	17	78	25
1/4	83	82	80	69	78
1/2	81	72	70	60	71
1	58	51	58	48	54
Ave.	56	53	56	64	57

(1)

Precipitation in inches			
Days after planting			
3	4	6	9
0.21	0.02	0.21	0.16

Partial analysis of variance for emergence between:

Compactions	**
Depths	**
Interaction, C x D	**

emergence of this experiment were similar to the experiment planted on Conover silt loam except that the emergence from the 1-inch depth of planting was 24% lower than from the 1/4-inch depth of planting on the Hillsdale soil and only 8% lower on the Conover soil.

<u>Ninth planting date, 1957</u>

These experiments were irrigated with 1/2 inch of water after planting. A total of 0.60 inch of rain which was well distributed resulted in favorable emergence. The total emergence for both soil types was similar (table 16). The emergence on the Hillsdale soil was highest from a planting depth of 1/4 inch and decreased as the depth increased, indicating a detrimental effect of deep coverage when moisture was adequate for emergence. Emergence from the surface depth of planting was high for this experiment because of the very favorable soil moisture relations resulting from irrigation before planting and subsequent rainfall.

On the Conover soil, the same general trend prevailed except that the emergence from the surface seeding was not as good as on the Hillsdale soil, nor was the effect of deep planting as detrimental to emergence.

Table 16. Average percentages of seedling emergence (1) of alfalfa irrigated with 1/2 inch of water immediately after planting on September 17 on the Hillsdale sandy loam soil and September 18 on the Conover silt loam soil. Natural precipitation occurred after planting. (2)

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Hillsdale sandy loam					Conover silt loam				
0	15	56	73	60	51	15	21	40	58	34
1/4	63	61	55	50	57	68	65	63	66	66
1/2	54	51	52	38	49	63	67	58	67	64
1	35	25	37	39	34	52	46	50	51	50
Ave.	42	48	54	47	48	50	49	53	61	53

(1) Total emergence on Hillsdale after 11 days (planted Sept. 17), on Conover after 10 days (planted Sept. 18).

(2)

Soil type	Precipitation in inches Days after planting			
Conover	3	4	5	6
Hillsdale	4	5	6	7
	0.01	0.34	T	0.03

Partial analysis of variance for emergence between:

	Conover	Hillsdale
Compactions	**	*
Depths	**	**
Interaction, C x D	**	**

Average emergence for 1957 plantings

Emergence results for the experiments planted in the 1957 season followed two distinct patterns which depended on the moisture relations prevailing after the seeding was made. When the experimental area received a rain soon after planting, emergence was high from all treatments planted 1/4 inch or deeper. As moisture became more limiting to emergence, the effect of compaction and depth of planting became increasingly important on both soil types during this season.

Table 17 shows the average percentage of initial emergence on the two soil types for the planting dates when initial emergence depended on residual soil moisture, i.e., no rain after planting. A critical comparison of the absolute values for both soil types was not permissible since some of the planting dates on the two soil types were different. Nevertheless, definite trends were evident for both soil types. There was no emergence of surface-planted seeds except when the compaction was 12 psi at which level it ranged from 1 to 3%. Emergence was increased at the 1/4- and 1/2-inch planting depths by increased compaction, but was not increased appreciably by compaction at the 1-inch depth of planting for either soil type. The overall increase in emergence with increasing depth and compaction was highly significant for both soil types. The compaction x times of planting interaction was not significant for either soil type indicating the increase in emergence due to compaction was similar over all dates of planting. The depth x time of planting interaction was significant for both soil

Table 17. Average percentages of initial emergence of alfalfa due to residual soil moisture with no rain after planting.

Planting depth, inches	Compaction, psi														
	0	3	6	12	Ave.	0	3	6	12	Ave.	0	3	6	12	Ave.
	Hillsdale sandy loam (1)					Conover silt loam					Average initial emergence				
0	0	0	0	3	1	0	0	0	1	0	0	0	0	2	0
1/4	0	2	9	20	8	0	0	1	7	2	0	1	5	13	5
1/2	5	30	35	46	29	2	11	27	41	20	3	21	31	44	25
1	36	44	48	47	44	40	44	49	48	45	38	44	48	48	45
Ave.	10	19	23	29	20	10	14	19	24	17	10	17	21	27	19

(1) Hillsdale--planted on May 3, July 25, August 13 and 19; Conover--planted on May 2 and 28, August 14 and 20, and September 5.

Partial analysis of variance for emergence between:

Source	Conover	Hillsdale
Dates of planting (T)	**	**
Compactions (C)	**	**
Depths (D)	**	**
C x D	**	NS
C x T	NS	NS
D x T	*	**
C x D x T	*	**

types because emergence from the 1/4- and 1/2-inch depths of planting varied from date to date, depending on the amount of moisture present at the time of planting.

A more critical comparison of the initial emergence during similar conditions from both soil types is shown in table 18. All three of the treatments were planted during a dry period in August of 1957. The experiments were planted one day apart on each soil type and received no rain until initial emergence ceased.

Treatment A, table 18, was irrigated with 1/2 inch of water the evening before planting so that the seedbed was moist at the time of planting. Emergence was increased by compaction and depth for both soil types, but the emergence from the Hillsdale soil was higher at every depth than from the Conover soil. The greatest difference in emergence between the two soil types was found at the 1/4-inch depth of planting with an average of 3% for the Conover silt loam and 18% for the Hillsdale soil, a six-fold difference. In light of the negative correlation between emergence and soil moisture tension, this indicates that moisture was more favorable for emergence on the Hillsdale soil than on the Conover soil.

Treatment B, table 18, was irrigated with 1/2 inch of water after planting. Emergence increased with increasing depth of planting for the Conover soil and was highest from the 1 inch depth. On the Hillsdale soil, emergence was highest from the 1/4- and 1/2-inch depths of planting and lowest from the 1-inch depth, even lower than from the surface-planting depth. Emergence was increased for the surface-planting depth by compaction on the Hillsdale soil, but the increase in

Table 18. Average percentages of initial emergence from Hillsdale sandy loam and Conover silt loam soils under different moisture conditions with no rain after planting.

Planting depth, inches	Compaction, psi														
	Hillsdale					Conover					Average				
	0	3	6	12	Ave.	0	3	6	12	Ave.	0	3	6	12	Ave.
Treatment A--1/2 inch irrigation before planting on August 19 and 20															
0	0	0	0	13	3	0	0	0	6	2	0	0	0	10	2
1/4	0	3	23	46	18	0	1	3	9	3	0	2	13	27	10
1/2	4	56	67	70	49	7	21	56	62	37	5	39	61	66	43
1	64	75	70	73	70	45	63	63	64	59	55	69	66	69	65
Ave.	17	33	40	51	35	13	22	31	36	25	15	27	35	44	30
Treatment B--1/2 inch irrigation after planting on August 6 and 7															
0	29	29	43	66	42	6	2	4	39	13	18	16	23	53	28
1/4	61	67	72	62	66	17	34	33	42	32	39	50	53	52	49
1/2	69	71	69	66	69	33	41	61	64	50	51	56	65	65	60
1	38	54	34	27	38	41	52	53	62	52	40	53	44	44	45
Ave.	49	56	55	55	54	24	32	38	52	37	36	44	47	53	45
Treatment C--dry seedbed (no irrigation) August 13 and 14															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/4	0	0	0	4	1	0	0	0	0	0	0	0	0	2	0
1/2	0	2	2	12	4	0	0	0	0	0	0	1	1	6	2
1	7	12	24	30	18	3	2	14	21	10	5	7	19	25	14
Ave.	2	3	6	12	6	1	1	3	5	2	1	2	5	9	4

Partial analysis of variance for emergence between:

Source	Hillsdale sandy loam Treatment			Conover silt loam Treatment		
	A	B	C	A	B	C
Compactions	**	NS	**	**	**	**
Depths	**	**	**	**	**	**
Interaction, C x D	**	**	NS	**	*	NS

emergence over all depths was not significant. For the Conover soil, the increase in emergence with increasing rates of compaction was highly significant. Average emergence for the Hillsdale soil was 54% as compared to 37% for the Conover soil. The behavior of the emergence from the Hillsdale soil indicates that enough moisture was present for a high percentage of emergence on this soil type, but that emergence was limited by the moisture supply on the Conover soil. Since the same amount of irrigation was applied in each case, it can be concluded that the Hillsdale soil maintained sufficient moisture for germination near the surface better than did the Conover soil.

Treatment C, table 18, was planted during the same period on a seedbed which contained only moisture from a rain two weeks before. The initial emergence from this treatment was increased by increasing depth and compaction for both soil types. Emergence occurred on the Conover soil only at the 1-inch depth of planting while it occurred at the 1/4- and 1/2-inch depths of planting on the Hillsdale soil. Total emergence was higher on the Hillsdale than on the Conover soil.

An explanation of the beneficial effect of increasing the compaction and planting depths on emergence when moisture was limiting was found in the behavior of soil moisture in the area around the seed. Increasing compaction decreased the soil moisture tension at a given depth; likewise, increasing the depth of planting decreased soil moisture tension around the seed. The decrease in soil moisture tension due to the influence of increasing depth and compaction was highly significant whenever soil moisture samples were obtained. The analysis of covariance showed a highly significant negative correlation between initial emergence and soil moisture tension on both soil types after each planting date whenever the soil was sampled for moisture.

The total emergence for individual experiments during this season varied greatly, (table 19). Thus, one treatment may have produced good emergence for one planting date and very poor emergence on another date. The treatment averages for the nine planting dates on each soil type reflect certain overall trends. The treatments which consistently produced good emergence had a higher average than those with a greater number of failures.

Since analysis of variance of this data showed a large number of highly significant interactions, several definite statements may be made about these data. The four main factors, soils, dates of planting, compaction, and depth of planting all had a highly significant effect on total emergence.

The net effect of depth of planting over the nine dates and both soil types indicated that a seeding depth of 1/2 inch was the most reliable; it gave an average emergence of 69% as compared to 63, 60, and 28% emergence for the 1/4-, 1-, and 0-inch depth of planting, respectively. In addition, this same treatment gave the best emergence on each of the two soil types.

Increasing compaction increased total emergence of surface-planted seeds for both soil types, but did not greatly affect the net emergence of any seeds covered 1/4 inch or more. The highest total emergence on each of the soil types and for the average of both soil types (72%) was obtained when the seeds were planted 1/2 inch deep and

Table 19. Effect of compaction and depth of planting on average percentages of total emergence of alfalfa planted on nine dates on two soil types between early May and mid-September, 1957.

Planting depth, inches	Compaction, psi														
	0	3	6	12	Ave.	0	3	6	12	Ave.	0	3	6	12	Ave.
	Conover silt loam					Hillsdale sandy loam					Average				
0	14	16	26	50	27	17	22	35	46	30	16	19	30	48	28
1/4	65	66	67	67	66	63	60	56	59	60	64	63	62	63	63
1/2	70	73	76	73	73	65	67	67	63	65	68	70	72	68	69
1	65	66	67	65	66	51	55	55	49	53	58	60	61	57	60
Ave.	54	55	59	64	58	49	51	53	54	52	52	53	56	59	55

Partial analysis of variance for the total emergence of nine planting dates on two soils, 1957 between:

Soils (S)	**	C x T	NS
Dates (T)	**	D x T	**
Compactions (C)	**	S x T	**
Depths (D)	**	C x D x S	NS
C x D	**	C x D x T	**
C x S	NS	D x S x T	**
D x S	**	C x S x T	NS
		C x D x S x T (1)	**

(1) The fourth order interaction, C x D x S x T was found to be significant and was used as the error term in testing for significance of the other factors.

compacted with 6 psi. The next best treatment was at the same depth of planting with 3 psi compaction (70%). The lack of significance in the interaction of compaction x soils, compaction x times, and compaction x soils x times indicated that the effect of compaction on emergence was similar for both soils even under widely varying weather conditions.

PART III

1958 FIELD STUDIES ON THE EFFECT OF DEPTH OF PLANTING, SOIL COMPACTION, AND SOIL MOISTURE TENSION ON SEEDLING EMERGENCE

Materials and Methods

The field work performed during the spring and summer of 1958 was a continuation and expansion of the field experiments carried out in 1957. The same two soil types used the previous year were again utilized during this season. In order to evaluate critically the effect of moisture relations on seedling emergence, three different moisture levels were added as whole plots. Within each whole plot there were 16 subplots consisting of 100 seeds per plot planted at the same depths and with the same compaction treatments used the previous season.

This experiment was repeated on 3 dates for the Hillsdale sandy loam soil and 4 dates on the Conover silt loam soil. On the last planting date for each soil type, an additional moisture treatment was added. This treatment consisted of keeping the soil moist on the surface for several days after planting in an effort to provide an optimum moisture level for maximum emergence. The whole plots, then, consisted of the following moisture treatments:

All planting dates:

A. Irrigation with 1/2 inch of water the evening prior to planting with final seedbed preparation immediately before planting.
B. Irrigation with 1/2 inch of water immediately after planting
C. No additional moisture.

Last planting date:

D. Irrigation with 1/2 inch of water immediately after planting as in B followed by daily watering to keep the seedbed moist continually.

Whole plots were sheltered from rain by plastic-covered wooden frames for a period of 10 days and then left uncovered. Plots were not covered unless it was raining or rain was imminent. Sun shades covered with black plastic were used to protect treatment D from the direct rays of the sun in order to reduce evaporation and insure a moist seedbed. These covers were constructed with a wooden frame on 4 legs 3 feet high. The plots were shaded but the air movement over the plots was not restricted.

The seedbed was prepared in a manner similar to that used the preceding year. A large bed was first made the day before seeding by throwing 2 furrows together with a 3-bottom plow. This bed was about 6 feet wide and had a channel on each side where the left moldboard ran. The plowed strip was disked lengthwise several times to level it and break up the clods and finally the bed was cultipacked. The tractor used in the final preparation had wheels set wide enough to straddle the bed so the bed received uniform compaction across its entire width.

After the machine preparation of the seedbed was completed, the area to be occupied by each of the whole plots was marked off. The plots which received irrigation prior to planting were irrigated with 1/2 inch of water. Twelve 1-quart oil cans were arranged over the whole plot so that there were 4 rows of 3 cans spaced equally across the plot. A garden hose with an adjustable nozzle was used to spray the plot from one end to the other and the water was applied as fast as it would infiltrate into the soil. The water in the cans was measured in a 100 ml graduated cylinder and the entire area was irrigated so that all the cans would contain the same amount of water. The diameter of the cans was such that 1 ml of water in the can equalled 0.005 inch of water. Thus, 1/2 inch of water had been applied when the cans contained 100 ml of water.

The final preparation of the seedbed was made in the same manner as in the preceding year. The top of the bed was loosened with a hoe, raked to remove clods, and leveled with a board. The subplots were planted according to a randomized plan and were compacted after planting. The whole plots which received irrigation after planting were watered in the manner previously described when the complete experiment had been seeded.

The soil moisture sampling technique used the preceding year was modified slightly for this season. Instead of taking only one sample of the 3 depths at each compaction level, a total of 4 samples was taken from each compaction treatment within each whole plot. Each sample was segmented into 1/3-inch lengths and each length was placed into a separate can. The four samples were composited within the same depth and compaction. These larger samples tended to reduce the disadvantages of very small samples and to buffer the effect of any atypical samples. Soil samples were taken during the afternoon for several days after planting and the moisture content was determined gravimetrically as described in part II.

Results of 1958 field plantings

May 14 planting on Conover silt loam soil

At the time this experiment was planted, the weather was very dry and windy, causing the surface of the soil to dry very quickly. The soil was dry initially and no seedlings emerged without irrigation, treatment C. Analysis of variance for the initial emergence of both treatments which were irrigated, A and B, (table 20), showed that emergence increased significantly with greater depth when the depth of planting was 1/4 inch or more or when compaction was increased at the 1/2-and 1-inch depth of planting.

Evaporation from a wet pan about 500 yards from the experimental site was 0.29 inch on May 15. This high moisture loss was reflected in the soil moisture tension of samples taken in the afternoon of May 15. The influence of compaction on the soil moisture tension one day after planting was evident when the soil was irrigated before planting but was not evident when the soil was irrigated after planting.

Water loss from the surface 1/3 inch of soil was very rapid during this period, (table 21). The low emergence of seed planted on the surface and at a depth of 1/4 inch reflected this loss of moisture. Since the soil moisture was in a dynamic state, the moisture content of the plots irrigated after planting probably rose during the night to more favorable levels. At any rate, the plots which were irrigated after planting did not have any great evaporation for a period of

Table 20. Initial emergence after planting and total emergence after natural precipitation for the May 14 planting date on Conover silt loam soil.

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (1)					Total emergence				
	Treatment A -- 1/2 inch irrigation before planting									
0	0	0	0	0	0	5	10	15	24	13
1/4	0	0	0	0	0	56	68	75	64	66
1/2	0	1	1	10	3	78	78	79	71	77
1	21	40	32	47	35	61	74	73	69	69
Ave.	5	10	8	14	9	50	57	61	57	56
	Treatment B -- 1/2 inch irrigation after planting									
0	0	0	0	0	0	19	19	30	37	26
1/4	0	0	1	14	4	55	51	58	69	58
1/2	9	19	22	29	20	56	66	63	68	64
1	34	28	39	43	36	38	37	49	46	43
Ave.	11	12	16	22	15	42	43	50	55	47
	Treatment C -- No supplemental irrigation									
0	0	0	0	0	0	15	13	23	45	24
1/4	0	0	0	0	0	68	74	69	70	70
1/2	0	0	0	0	0	63	71	68	66	67
1	0	0	0	0	0	68	64	70	59	65
Ave.	0	0	0	0	0	54	55	58	60	56
						Average total emergence				
0						13	14	23	35	21
1/4						60	64	67	68	65
1/2						66	72	70	68	69
1						56	58	64	58	59
Ave.						49	52	56	57	53

(1) Initial emergence 12 days after planting, total emergence 22 days after planting.

Partial analysis of variance for emergence between:

Source	Treatment A Initial	Treatment A Total	Treatment B Initial	Treatment B Total	Treatment C Total	Total
Moistures (M)						**
Compactions (C)	*	**	*	*	NS	**
Depths (D)	**	**	**	**	**	**
Interaction,						
C x D	NS	NS	NS	NS	**	**
C x M						**
D x M						**
C x D x M						NS

Precipitation in inches, days after planting

	Sheltered			Not sheltered		
Days	3	4	8	11	14	18
Inches	0.01	0.06	0.14	0.01	0.02	1.70

approximately 14 hours after planting. This was long enough for some of the seeds planted at a depth of 1/4 inch to start germination and a few were able to grow roots long enough to escape the moisture deficit in their immediate vicinity.

Table 21. Atmospheres soil moisture tension one day after planting for the May 14 planting on Conover silt loam soil.

Sampling depth, inches	Soil moisture tension							
	Compaction, psi							
	0	3	6	12	0	3	6	12
	Irrigation before planting				Irrigation after planting			
0-1/3	+15	+15	+15	+15	+15	+15	+15	+15
1/3-2/3	13.1	8.0	5.1	3.9	3.2	3.3	3.7	3.1
2/3-1	4.4	3.0	2.8	2.2	2.2	1.8	2.5	2.1

The analysis of variance for the total emergence 22 days after planting (1.70 inch of rain on the 18th day) showed that the main treatments and all the second order interactions were highly significant. Seedling emergence of surface-planted seed was increased by compaction for all moisture treatments. Seeds planted 1/4 inch or deeper varied in their response to compactions. Emergence was generally improved by increased compaction at any depth when irrigation followed planting, treatment B. As compaction increased from 0 to 3 psi, emergence was improved in most instances at the 1/4- and 1/2-inch depths of planting in treatment A, irrigated before planting and treatment C, not irrigated. A planting depth of 1/2 inch gave the best emergence in the 2 irrigation treatments, the 2 best treatments being at the 6 and 12 psi compaction levels. Seeds with no supplemental moisture germinated and seedlings emerged favorably after the 1.70 inches of rainfall 18 days after planting. The high emergence resulting when seeds were planted 1/4 inch or deeper was not affected by compaction; emergence from surface-planted seed was lower and was improved with increasing compaction. All these seeds had been in the soil for a period of over two weeks without apparent injury before germinating.

May 29 planting on Conover silt loam soil

Two factors detracted from the value of the experiment planted on this date. First, one of the whole plots which was to receive irrigation only before planting, treatment A, was also irrigated with 0.1 inch water after planting and had to be discarded, leaving 3 replications for this treatment instead of 4. Secondly, a heavy rain accompanied by high winds during the night of May 31 blew some water underneath the shelters and wetted some of the plots. This required that some of the data be discarded and missing plots calculated for statistical analysis of the results.

Increasing compaction increased initial emergence at all three water levels, (table 22). The effect of compaction for the treatment irrigated after planting was evident mostly at shallow planting depths where moisture was limiting. Thus, there was very little increase in emergence due to compaction of seed planted 1 inch deep when irrigation followed planting. There was a slight effect of compaction at a depth of 1 inch where irrigation preceded planting and a marked increase in emergence due to compaction where no extra water was applied. This

Table 22. Initial emergence after planting and total emergence after natural precipitation for the May 29 planting date on Conover silt loam soil.

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (1)					Total emergence				
	Treatment A -- 1/2 inch irrigation before planting									
0	0	0	0	0	0	2	6	10	28	12
1/4	0	1	4	23	7	65	47	38	43	48
1/2	6	24	34	54	29	55	56	59	62	58
1	52	55	58	61	56	55	56	59	62	58
Ave.	15	20	24	34	23	42	39	38	47	42
	Treatment B -- 1/2 inch irrigation after planting									
0	1	5	5	26	9	12	25	38	49	31
1/4	22	42	40	47	38	56	58	56	51	55
1/2	45	51	59	61	54	52	57	60	62	58
1	53	54	56	57	55	54	54	56	58	55
	Treatment C -- No supplemental irrigation									
0	0	0	0	0	0	5	8	15	33	15
1/4	0	0	0	0	0	68	65	67	63	66
1/2	0	3	4	17	6	60	68	65	65	64
1	33	41	52	52	45	65	61	73	62	65
Ave.	8	11	14	17	13	49	50	55	56	52
						Average total emergence				
0						6	13	21	37	19
1/4						63	57	54	52	56
1/2						53	58	57	61	57
1						58	57	63	61	59
Ave.						45	46	48	53	47

(1) Initial emergence after 11 days, total emergence after 14 days.

Partial analysis of variance between:

	Treatment A		Treatment B		Treatment C		Total
	Initial	Total	Initial	Total	Initial	Total	
Moistures (M)							*
Compactions (C)	**	NS	**	**	*	NS	**
Depths	**	**	**	**	**	**	**
Interaction,							
C x D	**	NS	NS	**	NS	**	**
C x M							NS
D x M							**
C x D x M							NS

Precipitation in inches, days after planting

	Sheltered			Not sheltered	
Days	3	4	10	11	12
Inches	1.70	0.01	0.08	0.43	0.21

trend was more evident at the 1/2-inch depth of planting where increasing compaction from 0 to 12 psi improved emergence from 6 to 54% when irrigation preceded planting, (table 22).

Over all levels of compaction, initial emergence from a depth of 1 inch was best. The emergence from the 1/2-inch depth of planting with 6 and 12 psi compaction on those plots receiving irrigation was equal to the emergence from the 1-inch depth.

Analysis of covariance, (table 23), for the initial emergence of plots receiving irrigation before planting showed a highly significant negative correlation between emergence, (table 22), and soil moisture tension, (table 24), one day after planting. The correlation between emergence and soil moisture tension at different compactions was also significant.

Table 23. Analysis of variance and covariance between soil moisture tension one day after planting and initial emergence. One-half inch irrigation applied before planting.

Source	Initial emergence	Soil moisture tension	Covariance
Compactions	**	**	*
Depths	**	**	NS
Interaction, C x D	**	**	
Individual plots			**

The analysis of variance for the soil moisture tension showed that compaction, depth, and their interaction had a highly significant effect on soil moisture tension. Thus, the 0- to 1/3-inch layer of soil showed a high decrease in soil moisture tension with increasing compaction under irrigation treatments. This trend was evident at all

Table 24. Soil moisture tension of plots planted May 29 on Conover silt loam soil.

Sampling depth, inches	Compaction, psi	Days after planting 1	2	4	7
	Treatment A -- 1/2 inch irrigation before planting				
0-1/3	0	+15	+15	+15	+15
	3	12.5	11.3	+15	+15
	6	8.6	7.9	+15	+15
	12	4.9	5.3	9.0	+15
1/3-2/3	0	2.6	5.2	8.1	+15
	3	2.4	2.7	4.1	+15
	6	2.5	2.0	3.0	8.7
	12	1.7	1.8	2.5	6.9
2/3-1	0	1.8	2.1	3.5	9.3
	3	1.7	2.0	2.7	4.5
	6	1.7	1.8	2.3	4.4
	12	1.2	1.2	1.9	3.2
	Treatment B -- 1/2 inch irrigation after planting				
0-1/3	0	13	+15	+15	+15
	3	11.2	14	+15	+15
	6	9.8	13.6	+15	+15
	12	7.0	10.9	+15	+15
1/3-2/3	0	2.0	3.1	4.8	+15
	3	2.0	2.3	3.1	+15
	6	1.5	2.7	3.8	13.3
	12	1.6	2.2	2.6	13.6
2/3-1	0	1.3	2.1	2.1	8.4
	3	1.2	1.5	2.2	4.3
	6	1.1	1.9	2.1	4.5
	12	1.1	1.7	2.0	4.3
	Treatment C -- No supplemental irrigation				
0-1/3	0	+15	+15	+15	+15
	3	+15	+15	+15	+15
	6	+15	+15	+15	+15
	12	+15	+15	+15	+15
1/3-2/3	0	+15	+15	+15	+15
	3	+15	+15	+15	+15
	6	14.6	13.1	+15	+15
	12	11.2	12.3	7.2	+15
2/3-1	0	10.2	9.2	4.8	+15
	3	5.9	9.5	4.0	12.5
	6	4.8	4.5	5.1	8.2
	12	6.4	6.1	3.2	11.3

depths of sampling but the magnitude of difference at the greater sampling depths was less, (table 24). This behavior paralleled that exhibited by the emergence of plots where moisture was limiting. Thus, when soil moisture tension was high, emergence was low.

Analysis of variance for the total emergence determined after 14 days with 0.64 inch of rain following removal of shelters of this experiment, (table 22), showed the main treatments and all the second order interactions except compactions x moistures were significant. When seeds were planted on the surface there was a marked increase in emergence as compaction increased, but when planted 1/4 inch or deeper, there was relatively little increase in emergence from increased compaction. The only plots with a marked deviation from the general trend were those in which the seeds were planted 1/4 inch deep and irrigation preceded planting. In this case, emergence decreased with increased compaction. The moisture content of these plots at the time of planting was enough to promote some emergence from the plots which received compaction. There was no emergence in the treatment which received no compaction. As a result, total emergence in this treatment decreased as compaction increased, since fewer seeds apparently germinated and died at the low level of compaction than at the higher levels of compaction. Emergence of seeds planted at a depth of 1 inch with irrigation was over 50%, but emergence was essentially completed at this depth from initial soil moisture.

June 17 planting on Conover silt loam soil

Analysis of variance for the initial emergence after 13 days for

Table 25. Initial emergence after planting and total emergence after natural precipitation for the June 17 planting date on Conover silt loam soil.

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (1)					Total emergence				
	Treatment A -- 1/2 inch irrigation before planting									
0	0	0	0	0	0	7	6	6	14	8
1/4	0	1	2	5	2	72	63	45	39	55
1/2	9	26	35	42	28	60	51	48	49	52
1	52	41	48	55	49	59	45	50	56	52
Ave.	15	17	22	25	20	50	41	37	50	42
	Treatment B -- 1/2 inch irrigation after planting									
0	0	1	3	9	3	17	26	22	36	25
1/4	16	40	53	65	43	67	62	69	70	67
1/2	50	55	59	62	56	58	60	62	65	61
1	37	50	54	48	47	38	51	55	48	48
Ave.	26	36	42	46	37	45	50	52	55	50
	Treatment C -- No supplemental irrigation									
0	0	0	0	0	0	7	6	10	26	12
1/4	0	0	0	1	0	68	71	73	56	67
1/2	0	2	11	28	10	74	62	64	59	65
1	31	41	43	63	45	58	54	54	66	58
Ave.	8	11	13	23	13	52	48	50	52	50
						Average total emergence				
0						10	13	13	25	15
1/4						69	65	62	55	63
1/2						64	58	58	58	60
1						52	50	53	57	53
Ave.						49	46	46	49	47

(1) Initial emergence after 13 days, total emergence after 20 days.

Partial analysis of variance for emergence between:

Source	Treatment A		Treatment B		Treatment C		Total
	Initial	Total	Initial	Total	Initial	Total	
Moistures (M)							*
Compactions (C)	**	**	**	*	**	NS	NS
Depths (D)	**	**	**	**	**	**	**
Interaction,							
C x D	**	**	**	NS	**	**	**
C x M							**
D x M							**
C x D x M							**

Precipitation in inches, days after planting

	Sheltered		Not sheltered		
Days	7	8	16	17	18
Inches	0.05	0.39	1.56	1.06	0.06

all three moisture levels, (table 25), indicated that depth, compaction, and their interaction had a highly significant effect on emergence. Moisture tension decreased as sampling depth increased and as compaction increased within each depth. That emergence was influenced by the soil moisture tension is indicated by the highly significant negative correlation, (table 26), between soil moisture tension, (table 27), one day after planting and initial emergence when irrigation preceded planting. Emergence was not increased by compaction in all cases at the 1-inch planting depth for the moisture treatments irrigated before or after planting but it was increased in some comparisons. It was improved with increasing compaction at the 1/4- and 1/2-inch depths. Soil moisture tension in these plots was uniformly low following planting and stayed low long enough for most of the seedlings to emerge.

Table 26. Analysis of variance and covariance between soil moisture tension one day after planting and initial emergence. One-half inch irrigation applied before planting for the June 17 planting date on Conover silt loam soil.

Source	Initial emergence	Soil moisture tension	Covariance
Compactions	**	**	*
Depths	**	**	NS
Interaction, C x D	**	**	
Individual plots			**

The greatest total emergence from seed planted 1/4 inch or deeper occurred when moisture was initially too low for any seedlings to emerge. When seeds planted 1/4 inch deep were irrigated before planting, there was no initial emergence without compaction, but the

Table 27. Soil moisture tension for the June 17 planting date on Conover silt loam soil.

Sampling depth, inches	Compaction, psi	Days after planting				
		1	2	3	4	9
	Treatment A -- 1/2 inch irrigation before planting					
0-1/3	0	+15	+15	+15	+15	+15
	3	10.8	+15	+15	+15	+15
	6	8.1	13	9.7	+15	+15
	12	5.6	7.9	6.2	9.1	+15
1/3-2/3	0	5.1	8.2	7.7	+15	+15
	3	2.3	2.8	2.9	4.7	11.4
	6	1.8	2.5	2.2	3.3	7.3
	12	1.4	1.7	1.7	2.1	2.7
2/3-1	0	1.7	2.3	2.5	3.9	5.7
	3	1.4	2.0	2.0	2.2	3.2
	6	1.5	1.5	1.8	2.1	3.0
	12	1.0	1.2	1.2	1.5	1.9
	Treatment B -- 1/2 inch irrigation after planting					
0-1/3	0	10.8	+15	+15	+15	+15
	3	9.2	+15	+15	+15	+15
	6	8.1	11.0	14.0	+15	+15
	12	5.6	8.2	8.0	15	+15
1/3-2/3	0	1.5	2.5	2.6	12	+15
	3	1.2	2.5	2.9	4.5	12
	6	1.2	2.3	2.3	3.3	7.1
	12	1.1	1.7	1.9	2.2	4.0
2/3-1	0	1.0	1.6	1.7	2.6	6.2
	3	.7	1.4	1.7	2.2	4.0
	6	.8	1.5	1.7	2.0	3.0
	12	.7	1.2	1.3	1.5	2.4
	Treatment C -- No supplemental irrigation					
0-1/3	0	+15	+15	+15	+15	+15
	3	+15	+15	+15	+15	+15
	6	+15	+15	+15	+15	+15
	12	+15	+15	+15	+15	+15
1/3-2/3	0	+15	+15	+15	+15	+15
	3	+15	+15	+15	+15	+15
	6	8.0	8.2	8.7	+15	+15
	12	4.6	4.1	5.6	6.6	12.0
2/3-1	0	6.7	12.0	9.0	+15	+15
	3	4.3	4.3	4.5	9.2	8.9
	6	2.9	2.7	2.8	5.6	5.2
	12	1.8	2.4	2.5	2.7	3.2

total emergence after 2.6 inches of rain was over 70%, (table 25). Increasing compaction increased initial emergence and decreased total emergence. This trend was also evident at a 1/2-inch planting depth when no supplemental irrigation was applied.

The analysis of variance of the total emergence of all three moisture levels, (table 25), showed that the net effect of compaction was not significant. The decrease in total emergence as compaction increased in the treatment receiving irrigation prior to planting offset the increase in total emergence as compaction increased when irrigation was applied after planting. When irrigation was applied after planting, soil moisture was sufficient for a high percentage of emergence from most of the seeds planted 1/4 inch or deeper. Total emergence from these seeds was not increased greatly by natural precipitation, especially at the 1/2- and 1-inch depths of planting. Thus, the original trend of increasing emergence with increasing compaction was preserved.

The initial emergence was low at the 1/4- and 1/2-inch planting depths when irrigation preceded planting, but it was increased by increasing compaction. The total emergence for these plots showed a reversal of this original trend with high emergence from the non-compacted seeds planted 1/4 and 1/2 inch deep and lower emergence with increasing compaction. Plots having seeds exposed to enough moisture for a small amount of emergence apparently had many seeds which started to germinate and then died before seedling emerged.

July 11 planting on Conover silt loam soil

An additional moisture treatment was added to this experiment. In this treatment, (D), the plots were irrigated after planting as in treatment B and were then shaded from the sun and irrigated daily until emergence was completed. Since moisture was not a limiting factor in this treatment, the initial emergence of these plots was the same as the total emergence. No soil samples were taken from this treatment for moisture determinations, since enough water was applied to keep the surface of the plots moist at all times.

The initial moisture content of the seedbed was higher for this experiment than for any of the other experiments planted on Conover silt loam during the 1958 season. Enough moisture was present in the treatment receiving no irrigation for a 22% emergence (table 28), from seeds planted 1/4 inch deep and compacted with 12 psi.

At the time of planting for the treatment which received prior irrigation, the soil was wet enough to be sticky. When compaction was applied to these plots, the soil was pressed into a solid layer over the seed which impeded emergence at a planting depth of 1 inch. Thus, emergence was higher from a planting depth of 1/2 inch than from 1 inch even though moisture relations were more favorable at the 1-inch depth.

Analysis of covariance of the initial emergence, (table 29), and soil moisture tension, (table 30), for both the plots which received irrigation prior to planting and those which were not irrigated showed that there was a highly significant negative correlation between emergence and soil moisture tension one day after planting. Initial emergence was improved by increasing compaction at shallow planting depths

Table 28. Initial emergence after planting and total emergence after natural precipitation for the July 11 planting date on Conover silt loam soil

Planting depth, inches	Initial emergence (1): 0 psi	3	6	12	Ave.	Total emergence: 0 psi	3	6	12	Ave.
	Treatment A -- 1/2 inch irrigation before planting									
0	0	1	0	2	1	4	6	3	5	4
1/4	2	25	16	45	22	22	37	31	53	36
1/2	13	41	46	53	38	31	49	54	57	48
1	39	39	33	32	36	40	39	34	32	39
Ave.	13	26	24	33	24	24	33	31	37	32
	Treatment B -- 1/2 inch irrigation after planting									
0	2	3	2	11	5	8	7	10	15	10
1/4	29	54	59	60	51	36	58	63	65	55
1/2	58	66	72	64	65	62	68	73	65	67
1	51	55	48	53	52	51	56	48	54	52
Ave.	35	44	45	47	43	39	47	49	50	46
	Treatment C — No supplemental irrigation									
0	0	0	0	1	0	10	6	9	18	11
1/4	0	2	10	22	8	40	34	48	48	42
1/2	7	22	24	30	21	46	48	51	52	49
1	39	49	45	49	45	47	56	52	54	52
Ave.	11	18	20	25	18	36	36	40	43	39
	Treatment D -- daily irrigation					Average total emergence				
0	23	20	25	29	24	11	10	12	17	12
1/4	73	69	74	70	72	43	49	54	59	51
1/2	70	67	66	70	68	52	55	61	61	57
1	58	56	63	64	60	49	52	49	51	50
Ave.	56	53	57	58	56	39	41	44	47	43

(1) Initial emergence after 9 days, total emergence after 23 days. Initial and total emergence on treatment D are identical.

Partial analysis of variance for emergence between:

Source	Treatment A Initial	Treatment A Total	Treatment B Initial	Treatment B Total	Treatment C Initial	Treatment C Total	Treatment D Total	Total
Moistures (M)								**
Compactions (C)	**	**	**	**	**	**	NS	**
Depths	**	**	**	**	**	**	**	**
Interaction,								
C x D	**	**	**	**	NS	NS	NS	**
C x M								*
D x M								**
C x D x M								**

Precipitation in inches, days after planting

	Sheltered		Not sheltered	
Days	1	5	14	17
Inches	0.24	0.06	0.03	0.97

where soil moisture tension became limiting soon after planting. Both depth and compaction had a highly significant effect on emergence when moisture tended to become limiting. The depth x compaction interaction was not significant for the unirrigated plots since emergence was increased at all depths by increased compaction.

Table 29. Partial analysis of variance and covariance between soil moisture tension one day after planting and initial emergence for treatments irrigated before planting and not irrigated. July 11 planting date on Conover silt loam soil.

Source	Initial emergence	Soil moisture tension	Covariance
Treatment A -- 1/2 inch irrigation before planting			
Compactions	**	**	NS
Depths	**	**	NS
Interaction, C x D	**	**	
Individual plots			**
Treatment C -- no irrigation			
Compactions	**	**	*
Depths	**	**	NS
Interaction, C x D	NS	NS	
Individual plots			**

Emergence was highest for the treatment which was watered daily. Depth of planting had a highly significant effect on emergence for this treatment, but compaction and the depth x compaction interaction did not. The highest emergence was found at the 1/4-inch planting depth; emergence decreased as the planting depth increased beyond 1/4 inch. Surface-planted seed gave the poorest emergence.

The total emergence of the other treatments was not much greater than the initial emergence. Seeds planted at the 1/4-inch depth and not irrigated after planting probably had enough moisture present to initiate

Table 30. Soil moisture tension of plots planted July 11 on Conover silt loam soil.

Sampling depth, inches	Compaction, psi	Days after planting: 1	2	3	4	7
	Treatment A -- 1/2 inch irrigation before planting					
0-1/3	0	6.0	+15	+15	+15	+15
	3	4.4	10.7	13.1	12.3	+15
	6	2.8	10.0	12.3	9.6	+15
	12	1.8	4.5	4.1	7.0	10.2
1/3-2/3	0	1.4	3.1	2.9	2.6	8.3
	3	1.3	2.6	2.6	2.1	6.0
	6	1.1	2.2	2.6	2.2	3.8
	12	1.0	1.7	1.7	2.3	2.6
2/3-1	0	.8	1.8	1.5	1.4	2.2
	3	.9	1.4	1.5	1.4	2.5
	6	1.0	1.5	1.5	1.6	2.1
	12	.8	1.2	1.2	1.3	1.8
	Treatment B -- 1/2 inch irrigation after planting					
0-1/3	0	11.2	+15	+15	+15	+15
	3	6.8	+15	+15	+15	+15
	6	5.5	+15	+15	+15	+15
	12	3.9	9.7	8.7	9.3	+15
1/3-2/3	0	1.5	4.7	6.8	7.4	14
	3	1.3	2.6	3.1	3.2	8.5
	6	1.2	2.3	2.9	2.8	6.5
	12	1.0	2.1	1.9	2.1	3.6
2/3-1	0	.8	1.6	2.2	2.1	2.7
	3	.7	1.4	1.6	1.4	2.5
	6	.8	1.5	1.6	1.5	2.3
	12	.7	1.5	1.4	1.4	2.0
	Treatment C -- No supplemental irrigation					
0-1/3	0	+15	+15	+15	+15	+15
	3	+15	+15	+15	+15	+15
	6	+15	+15	+15	+15	+15
	12	13	14	+15	+15	+15
1/3-2/3	0	5.2	8.3	9.0	11	10.5
	3	3.0	6.2	7.2	4.5	7.2
	6	2.3	4.7	4.4	3.5	7.3
	12	1.7	2.5	3.8	1.9	4.7
2/3-1	0	1.9	4.5	2.2	2.3	2.6
	3	1.5	2.6	1.8	1.5	2.2
	6	1.1	1.2	1.5	1.3	1.8
	12	.9	1.2	1.7	1.2	1.7

germination but not enough to emerge. When these plots received rainfall, the subsequent emergence was greater from those which were not compacted. This increase, however, was not enough to make total emergence higher from the non-compacted plots.

All four moisture levels and their interactions had a significant effect on emergence for this experiment, (table 28). The average total emergence for this experiment followed the trend exhibited by the treatments A, B, and C in which the overall emergence was increased by compaction, and emergence was highest from the 1/2-inch planting depth.

<u>May 17 planting on Hillsdale sandy loam soil</u>

Soil moisture tension where no irrigation was applied either before or after planting was high at all sampling depths. Emergence from these plots, (table 31), indicated that only a few seeds were in contact with sufficient moisture for germination. Lack of moisture limited emergence whenever irrigation preceded planting or where there was no irrigation. Under these two moisture levels, there was no emergence from seed planted on the surface. At all depths of planting where emergence occurred, emergence was improved with increasing compaction; it increased 2 to 8 times as compaction increased from 0 to 12 psi. Emergence also increased as the planting depth increased. Soil moisture tension, (table 32), for the treatment irrigated before planting was higher at shallow depths and at lower rates of compaction within each depth. Analysis of covariance between soil moisture tension one day after planting and initial emergence, (table 33), indicated a highly significant negative correlation between these two factors. Thus, as soil moisture tension decreased, emergence increased.

Initial emergence from the treatment irrigated after planting followed quite a different pattern. The weather one day after planting was cloudy and humid so that the soil moisture tension was uniformly low for all plots the first day after sampling. Since the samples were taken in the afternoon, the seeds in all plots were exposed to favorable moisture relations for at least a 36-hour period. Even though the soil moisture tension around seeds planted 1/4 inch deep with 0 psi compaction was 10.8 atmospheres two days after planting, it was 0.9 atmospheres one day after planting; the emergence was 64%. In this case, many of the

Table 31. Initial emergence after planting and total emergence after natural precipitation for the May 17 planting date on Hillsdale sandy loam soil.

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (1)					Total emergence				
	Treatment A -- 1/2 inch irrigation before planting									
0	0	0	0	0	0	2	3	6	23	8
1/4	0	1	9	16	6	64	52	46	48	52
1/2	4	12	29	31	19	43	36	47	38	41
1	11	28	29	28	24	15	32	32	31	27
Ave.	4	10	17	19	12	31	31	33	35	32
	Treatment B -- 1/2 inch irrigation after planting									
0	2	13	21	51	19	4	16	25	53	25
1/4	64	62	70	65	65	67	66	72	68	68
1/2	62	57	60	50	57	66	59	63	51	60
1	26	30	17	17	22	27	31	22	20	25
Ave.	38	40	42	46	41	41	43	46	48	44
	Treatment C -- No supplemental irrigation									
0	0	0	0	0	0	2	8	29	48	22
1/4	0	0	0	0	0	64	71	67	61	66
1/2	0	0	0	1	0	60	68	60	57	61
1	6	17	16	31	17	52	49	37	44	45
Ave.	1	4	4	8	4	45	49	48	52	48
						Average total emergence				
0						3	9	20	41	18
1/4						65	63	62	59	62
1/2						56	54	57	49	54
1						31	37	30	32	32
Ave.						39	41	42	45	41

(1) Initial emergence after 9 days, total emergence after 20 days.

Partial analysis of variance for emergence between:

Source	Treatment A Initial	Treatment A Total	Treatment B Initial	Treatment B Total	Treatment C Initial	Treatment C Total	Total
Moistures (M)							*
Compactions (C)	**	NS	*	*	**	*	**
Depths (D)	**	**	**	**	**	**	**
Interaction,							
C x D	NS	**	**	**	**	**	**
C x M							NS
D x M							**
C x D x M							**

Precipitation in inches, days after planting

Days	Sheltered 1	Sheltered 5	Sheltered 8	Not sheltered 11	Not sheltered 15
Inches	0.06	0.14	0.01	0.02	1.70

Table 32. Soil moisture tension for the May 17 planting date on Hillsdale sandy loam soil.

Sampling depth, inches	Compaction, psi	Days after planting			
		1	2	3	7
	Treatment A -- 1/2 inch irrigation before planting				
0-1/3	0	12.3	+15	+15	+15
	3	6.5	+15	+15	+15
	6	5.2	14	+15	+15
	12	3.7	10.7	+15	+15
1/3-2/3	0	3.4	6.9	12.8	+15
	3	2.8	6.1	9.4	+15
	6	2.5	4.6	6.7	10.9
	12	2.1	3.7	4.9	8.8
2/3-1	0	2.6	3.5	5.8	12
	3	2.4	3.8	5.1	7.9
	6	2.3	3.6	4.6	5.7
	12	1.7	3.1	3.8	4.8
	Treatment B -- 1/2 inch irrigation after planting				
0-1/3	0	.9	10.8	+15	+15
	3	1.3	9.6	+15	+15
	6	1.2	8.7	+15	+15
	12	1.3	7.9	+15	+15
1/3-2/3	0	1.1	4.0	6.5	+15
	3	1.5	3.7	6.2	12.1
	6	1.2	3.0	6.2	8.1
	12	1.3	3.1	4.5	6.7
2/3-1	0	1.0	2.6	4.1	6.5
	3	1.2	2.6	4.1	5.6
	6	1.1	2.2	3.9	4.7
	12	1.3	2.1	3.2	4.0

Table 33. Partial analysis of variance and covariance between soil moisture tension one day after planting and initial emergence. One-half inch irrigation applied before planting for the May 17 planting date on Hillsdale sandy loam soil.

Source	Initial emergence	Soil Moisture tension	Covariance
Compactions	**	**	*
Depths	**	**	
Interaction, C x D	NS	**	
Individual plots			**

seeds must have had favorable moisture relations for a period long enough for the radicle to grow into a zone of more favorable moisture relations. After this, the moisture relations prevalent in the original vicinity of the seeds assumed a role of lesser importance.

When irrigation followed planting, emergence was not increased by compaction except for the surface-planting depth. Emergence decreased as planting depth increased beyond 1/4 inch, even though moisture relations were more favorable at the greater depths. This indicated that the emergence of seeds from the 1-inch depth of planting could have been impeded by the layer of soil above the seed.

Increase in total emergence due to the effect of compaction in the entire experiment was highly significant, (table 31). This increase was found in the emergence of seeds planted on the surface, with a slight decrease in emergence with increasing compaction at other planting depths. The greatest total emergence for all plots was found at the 1/4-inch planting depth with a lower emergence at greater depths. Emergence from a depth of 1-inch was poor after irrigation.

Total emergence from the seeds planted 1/4 inch deep was similar in both the cases where irrigation was applied after planting and where there was no irrigation. Emergence averaged 66% in one case and 68% in the other with no evident effect of compaction. These treatments had one thing in common—they both were subjected to a period of favorable moisture relations. For one treatment, this was after irrigation and for the other it was a 1.70-inch rain 15 days after planting. There was enough moisture present for a small amount of initial emergence when seed was planted 1/4 inch deep, irrigated before planting and where compaction was applied; no seedlings emerged without compaction. After 1.70 inches of rain, the emergence from the plots with 0 psi compaction was 64%. This compared favorably with the total emergence from this depth and compaction in the other two moisture levels. Emergence decreased with increasing compaction for this depth with an emergence of 48% at 12 psi. The higher initial moisture at higher compactions was enough to cause some emergence and to cause some of the non-emerged seeds to loose their viability.

June 6 planting date on Hillsdale sandy loam soil

Two factors which exerted influence over initial emergence of seedlings from all three moisture levels of this experiment were limited moisture and deep planting. The increase in emergence due to compaction was highly significant for all three moisture treatments, (table 34); the soil moisture tension one day after planting was decreased at a given depth by increasing compaction, (table 35). Thus, at a given depth, as compaction increased soil moisture tension decreased and emergence increased. The negative correlation between these two factors, (table 36), was highly significant. Emergence was highest following irrigation after planting and lowest with no irrigation.

Regardless of the moisture level, initial emergence was highest from a planting depth of 1/2 inch. The greatest initial and total emergence for individual moisture levels and as an average of all moisture levels was obtained at a planting depth of 1/2 inch and a compaction of 12 psi. Soil moisture tension, however, was lowest at the 2/3- to 1-inch sampling depth. Seeds planted 1 inch deep probably initiated germination but failed to emerge.

Table 34. Initial emergence after planting and total emergence after natural precipitation for the June 6 planting date on Hillsdale sandy loam soil.

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (1)					Total emergence				
	Treatment A -- 1/2 inch irrigation before planting									
0	0	0	0	0	0	3	4	9	15	8
1/4	1	12	25	24	16	31	20	30	28	27
1/2	16	31	28	33	27	18	32	29	34	28
1	19	27	24	24	24	20	27	24	24	24
Ave.	9	17	19	20	17	18	21	23	25	22
	Treatment B -- 1/2 inch irrigation after planting									
0	6	6	12	22	12	8	8	15	22	13
1/4	17	54	56	55	45	44	56	56	55	53
1/2	47	48	54	62	53	47	48	55	62	53
1	31	31	31	37	32	32	32	32	38	34
Ave.	25	35	38	44	35	33	36	40	44	38
	Treatment C -- No supplemental irrigation									
0	0	0	0	0	0	1	6	15	34	14
1/4	0	3	11	16	7	48	27	27	30	33
1/2	11	25	31	46	28	29	29	33	47	34
1	18	31	28	24	25	19	31	28	24	25
Ave.	7	15	17	22	15	24	33	27	34	26
						Average total emergence				
0						4	6	13	24	12
1/4						41	34	38	38	38
1/2						31	36	39	48	39
1						24	30	28	29	28
Ave.						25	26	30	35	29

(1) Initial emergence after 10 days, total emergence after 25 days.

Partial analysis of variance for emergence between:

Source	Treatment A		Treatment B		Treatment C		Total
	Initial	Total	Initial	Total	Initial	Total	
Moistures (M)							**
Compactions (C)	**	**	**	**	**	**	**
Depths (D)	**	**	**	**	**	**	**
Interaction,							
C x D	**	*	NS	NS	**	**	**
C x M							NS
D x M							**
C x D x M							**

Precipitation in inches, days after planting

Days	Sheltered				Not sheltered		
	2	3	4	7	9	18	19
Inches	0.08	0.43	0.21	0.59	0.01	0.05	0.39

Table 35. Soil moisture tension for the June 6 planting date on Hillsdate sandy loam soil.

Sampling depth, inches	Compaction, psi	Days after planting 1	2	4	7
	Treatment A -- 1/2 inch irrigation before planting				
0-1/3	0	11	5.1	4.9	10.0
	3	5.5	2.0	1.8	3.5
	6	4.4	1.8	1.7	2.6
	12	2.7	1.5	1.6	2.4
1/3-2/3	0	2.1	1.6	1.6	2.6
	3	1.9	1.3	1.3	1.6
	6	1.8	1.2	1.1	1.5
	12	1.6	1.1	1.2	1.4
2/3-1	0	1.6	1.2	1.1	1.5
	3	1.5	1.1	1.2	1.4
	6	1.5	1.1	1.0	1.3
	12	1.4	1.0	1.0	1.2
	Treatment B -- 1/2 inch irrigation after planting				
0-1/3	0	3.7	1.4	1.4	4.2
	3	2.4	1.4	1.4	3.2
	6	2.2	1.3	1.2	3.0
	12	2.4	1.2	1.2	2.9
1/3-2/3	0	1.8	1.2	1.2	2.4
	3	1.6	1.1	1.2	1.9
	6	1.3	1.0	1.0	2.0
	12	1.4	1.0	1.1	1.9
2/3-1	0	1.2	1.0	1.1	1.8
	3	1.2	1.0	1.0	1.7
	6	1.0	.9	1.0	1.8
	12	1.1	.8	1.0	1.7
	Treatment C -- No supplemental irrigation				
0-1/3	0	16	11.8	10.5	1.7
	3	11.0	4.1	3.2	4.9
	6	8.7	2.9	3.3	4.1
	12	5.5	2.1	2.7	3.8
1/3-2/3	0	6.3	3.7	2.8	7.2
	3	3.5	1.8	1.6	2.2
	6	2.3	1.7	1.6	1.8
	12	2.0	1.4	1.4	1.5
2/3-1	0	2.0	1.6	1.4	2.0
	3	2.3	1.4	1.4	1.5
	6	1.8	1.5	1.4	1.4
	12	1.6	1.3	1.3	1.3

The behavior of soil moisture tension during the sampling period was different from the general trend observed for other sampling periods. Even though plots were sheltered from rain, frequent showers and high humidity resulted in low evaporation from the soil with resulting favorable moisture conditions for emergence. The evaporation from the soil surface during this time must have been less than the upward movement of moisture, resulting in an increase in the available moisture at or near the surface as shown in table 35.

The total emergence of this experiment after natural precipitation was not increased greatly over the initial emergence except in a few cases. When irrigated after planting, only those seeds planted 1/4 inch deep with 0 psi had better emergence after natural precipitation than before the precipitation. The moisture treatments which were irrigated before planting or not irrigated both had some emergence from seeds planted on the surface. Many of the seeds which did not emerge initially were probably destroyed by the high moisture present soon after planting.

Increasing both the depth of planting and compaction improved total emergence strikingly for the individual moisture levels in this experiment, (table 34). The depth x compaction interaction was significant when irrigation preceded planting or when not irrigated, but it was not significant when irrigation followed planting. Although the initial emergence for all three moisture levels exhibited an increase due to compaction, the total emergence for the 1/4-inch depth with no supplemental irrigation reversed this trend, causing the interaction to be significant in this case. Analysis of the complete experiment, (table 34), showed that the only factor which behaved similarily over all three moisture levels was compaction. All the rest of the main factors and their interactions were significant.

Table 36. Partial analysis of variance and covariance between soil moisture tension one day after planting and initial emergence. June 6 planting date on Hillsdale sandy loam soil.

Source	Initial emergence	Soil moisture tension	Covariance
	Treatment A -- 1/2 inch irrigation before planting		
Compactions	**	**	
Depths	**	**	
Interaction, C x D	**	**	
Individual plots			**
	Treatment C -- No irrigation		
Compactions	**	**	*
Depths	**	**	
Interaction, C x D	**	**	
Individual plots			**

July 2 planting date on Hillsdale sandy loam soil

This experiment included the three moisture treatments described in the preceding section plus another, treatment D, which was shaded with black plastic covers and irrigated daily until all emergence was completed.

The soil moisture data for this experiment, (table 38), was not complete due to a rainy period for several days following the seeding of this experiment. Although the plots were sheltered, showers during the afternoon prevented sampling for soil moisture. Consequently, covariance analysis of soil moisture tension and emergence was not performed.

Depth, compaction, and their interaction had a significant effect on emergence for all three moisture treatments. Emergence was increased by compaction at the 1/4- and 1/2-inch depth when plots were either irrigated before planting or not irrigated, indicating that moisture was limiting to emergence at lower rates of compaction. Emergence from the plots which received irrigation after planting showed no increase due to compaction except for seeds planted on the surface. Initial emergence, (table 37), was 70% from the 1/4-inch depth of planting; it decreased to 63 and 48% at the 1/2- and 1-inch depths, respectively.

Total emergence was the same as initial emergence when irrigation followed planting. The humid conditions after planting were favorable for a high percent of emergence, even when only 1/2 inch of water was applied after planting. With no irrigation or irrigation before planting, emergence was increased by the 0.30 inch of natural rainfall on the 13th and 14th day after planting, (table 37); emergence was highest from the 1/2-inch depth of planting for these treatments. The moisture conditions initially were favorable for a low amount of emergence at the 1/4-inch planting depth and many of the seeds which did not germinate and then emerge initially did not emerge after natural precipitation.

Some individual compaction treatments gave over 50% total emergence, but the average was lower. With irrigation before planting, seeds planted 1/4 inch deep with 12 psi compaction gave an initial emergence of 54%. Subsequent rainfall did not increase emergence. Some of the other treatments with less compaction gave 25, 15, and 3% better emergence than determined before the natural precipitation but this was not enough to reach the total originally attained by the seeds compacted with 12 psi. Without irrigation, the initial emergence from the 1/2-inch depth was much lower than when irrigated but still exhibited a great

Table 37. Initial emergence after planting and total emergence after natural precipitation for the July 2 planting date on Hillsdale sandy loam soil.

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence (1)					Total emergence				
	Treatment A -- 1/2 inch irrigation before planting									
0	0	0	4	15	5	4	13	13	24	13
1/4	6	18	38	54	29	31	33	41	55	40
1/2	31	49	50	55	47	33	53	51	55	48
1	31	48	52	45	44	31	48	52	45	44
Ave.	17	29	36	42	31	25	37	39	45	36
	Treatment B -- 1/2 inch irrigation after planting									
0	9	15	33	68	31	9	16	33	68	31
1/4	72	71	67	68	70	72	71	68	68	70
1/2	70	61	62	59	63	71	61	62	59	63
1	53	51	50	40	48	53	52	50	41	49
Ave.	51	50	53	59	53	51	50	53	59	53
	Treatment C -- No supplemental irrigation									
0	0	0	0	0	0	8	27	30	31	24
1/4	0	1	7	34	10	53	42	41	42	45
1/2	18	18	36	41	28	50	47	50	50	49
1	36	33	37	37	37	39	40	44	39	40
Ave.	13	13	20	28	18	38	39	41	40	40
	Treatment D -- daily irrigation (2)					Average total emergence				
0	15	27	34	61	34	9	21	27	46	26
1/4	64	72	75	55	62	55	52	54	55	54
1/2	56	56	57	58	57	53	54	55	55	54
1	58	53	60	54	56	45	48	51	45	47
Ave.	48	50	54	57	52	40	44	47	50	45

(1) Initial emergence after 10 days, total emergence after 22 days.
(2) As in treatment B and subsequent daily watering to keep the soil moist.

Partial analysis of variance for emergence between:

Source	Treatment A Initial	Treatment A Total	Treatment B Initial	Treatment B Total	Treatment C Initial	Treatment C Total	Treatment D Total	Total
Moistures (M)								**
Compactions (C)	**	**	*	*	**	NS	*	**
Depths (D)	**	**	**	**	**	**	**	**
Interaction, C x D	**	NS	**	**	**	**	**	**
C x M								*
D x M								**
C x D x M								**

Precipitation in inches, days after planting

Days	Sheltered 1	2	3	5	8	9	Not sheltered 13	14
Inches	1.56	1.06	0.06	0.55	0.02	0.02	0.24	0.06

Table 38. Soil moisture tension for the July 2 planting date on Hillsdale sandy loam soil.

Sampling depth, inches	Compaction, psi							
	0	3	6	12	0	3	6	12
	4 days after planting				7 days after planting			
	Treatment A -- 1/2 inch irrigation before planting							
0-1/3	16	5.6	3.5	2.8	+15	11.8	8.8	6.5
1/3-2/3	4.3	2.7	2.1	1.3	10.1	4.9	2.9	2.5
2/3-1	2.2	1.9	1.9	1.2	3.5	2.9	2.7	1.9
	Treatment B -- 1/2 inch irrigation after planting							
0-1/3	3.6	2.5	2.6	2.2	+15	9.4	9.1	6.6
1/3-2/3	2.1	2.1	1.9	1.6	4.9	3.5	3.5	2.9
2/3-1	1.6	1.6	1.6	1.4	3.4	2.6	2.8	2.4
	Treatment C -- No supplemental irrigation							
0-1/3	+15	+15	+15	12.7	+15	+15	+15	+15
1/3-2/3	14	9.1	8.3	3.9	+15	+15	14	9.7
2/3-1	6.2	4.3	4.4	2.2	12	6.7	5.2	3.9

increase with increasing compaction. Seeds planted 1/4 inch deep with no compaction gave no initial emergence, but gave an emergence of 53% after the natural precipitation. After 0.30 inch of natural precipitation, emergence from treatments compacted at 3, 6, and 12 psi was increased 41, 34, and 8% respectively. Thus, seeds not compacted did not germinate initially but germinated after a rain.

All the main treatments and interactions had a significant effect on the total emergence, (table 37), for this experiment. Emergence from surface-planted seed improved by increasing compaction regardless of the moisture treatment. Emergence was highest from a planting depth of 1/2 inch when a lack of moisture limited emergence initially, but was highest from a 1/4-inch depth of planting when moisture was adequate after planting.

Average emergence for 1958 plantings

The average percentages of initial and total emergence for four planting dates on Conover silt loam and three planting dates on Hillsdale sandy loam soils are found in tables 39 and 40, respectively. Since the results are similar to the 1957 results and the data from 1957 did not include all the moisture treatments found in 1958, these results will be used for a discussion of the two-years' results. A critical comparison of the results between the two soil types is difficult since each planting was subjected to different weather conditions, even though each planting was sheltered from rain. The variability of the data was reflected in the statistical significance of dates of planting on emergence for moisture treatment and the significance of interactions containing dates of planting.

The moisture treatments used for these experiments provided two general types of conditions that might be encountered in a seeding in the field. Treatments A and C represented seedings in soil which was moist but dry enough for the use of tillage implements. Initial emergence under these conditions depended on the moisture in the soil at the time of planting. Treatments B and D received irrigation after planting and the initial emergence in these cases depended on the length of time the seeds were in a zone of favorable moisture. Total emergence in all cases was determined after the experimental area had received natural precipitation and the live seeds which did not emerge initially had a chance to grow. The initial moisture conditions

Table 39. Average percentage emergence of seeds planted in different moisture treatments on Conover silt loam soil for four planting dates (1) in 1958.

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence					Total emergence				
	Treatment A -- 1/2 inch irrigation before planting									
0	0	0	0	0	0	4	6	9	18	9
1/4	1	7	6	18	8	54	54	47	50	51
1/2	7	23	29	40	25	56	58	60	60	58
1	41	44	43	49	44	54	54	54	55	54
Ave.	12	18	19	27	19	42	43	43	48	44
	Treatment B -- 1/2 inch irrigation after planting									
0	1	2	2	12	4	14	19	25	34	23
1/4	17	34	38	46	34	53	57	61	64	59
1/2	40	48	53	54	49	57	63	64	65	62
1	44	47	49	50	48	45	50	52	52	50
Ave.	25	33	35	40	33	42	47	50	54	48
	Treatment C -- no supplemental irrigation									
0	0	0	0	0	0	9	8	14	30	15
1/4	0	1	2	6	2	61	61	64	59	61
1/2	2	7	10	19	9	61	62	66	65	63
1	26	33	35	41	34	62	59	62	60	61
Ave.	7	10	12	17	11	48	48	51	53	50
Treatment D -- planted July 11 (1) Irrigated daily						Average total emergence Treatments A, B, C.				
0	23	20	25	59	24	9	11	16	27	16
1/4	73	69	74	70	72	56	57	57	58	57
1/2	70	67	66	70	68	58	61	63	63	61
1	58	56	63	64	60	54	54	56	56	55
Ave.	56	53	57	58	56	44	46	48	51	47

(1) A, B, and C planted on 4 dates, D planted on July 11 only.
Partial analysis of variance for four dates of planting in 1958 between:

Source	Treatment A		Treatment B		Treatment C		Total
	Initial	Total	Initial	Total	Initial	Total	Average
Dates (T)	**	**	**	*	**	**	**
Compactions	**	NS	**	**	**	NS	**
Depths	**	**	**	**	**	**	**
C x D	NS	NS	*	NS	NS	*	**
C x T	NS	NS	NS	NS	NS	NS	**
D x T	**	NS	**	**	NS	*	**
C x D x T	**	**	NS	NS	**	*	**
Moistures							**
T x M							**
C x M							**
D x M							**
C x D x M							NS
C x T x M							NS
D x T x M							**
C x D x T x M							NS

Table 40. Average percentage of emergence of individual moisture treatments on Hillsdale sandy loam soil for three planting dates in 1958 (1).

Planting depth, inches	Compaction, psi									
	0	3	6	12	Ave.	0	3	6	12	Ave.
	Initial emergence					Total emergence				
	Treatment A -- 1/2 inch irrigation before planting									
0	0	0	1	5	2	3	7	9	21	10
1/4	2	10	24	31	16	42	38	39	44	41
1/2	17	31	36	40	31	31	40	42	42	39
1	20	34	35	32	30	22	36	36	33	32
Ave.	10	19	24	27	20	25	30	32	35	30
	Treatment B -- 1/2 inch irrigation after planting									
0	6	11	22	47	21	7	13	24	48	23
1/4	51	62	64	63	60	61	64	65	64	64
1/2	60	55	59	57	58	61	56	60	57	58
1	37	37	35	31	35	37	38	35	33	36
Ave.	39	41	45	49	43	41	43	46	50	45
	Treatment C -- No supplemental irrigation									
0	0	0	0	0	0	4	14	25	38	20
1/4	0	1	6	17	6	55	47	45	44	48
1/2	10	14	22	29	19	46	48	48	51	48
1	20	27	27	31	26	37	40	36	36	37
Ave.	7	10	14	19	12	35	37	38	42	38
	Treatment -- D planted July 2 Irrigated daily					Average total emergence Treatments A, B, C.				
0	15	27	34	61	34	5	11	19	36	18
1/4	64	62	65	55	62	53	50	50	51	51
1/2	56	56	57	58	57	46	48	50	52	49
1	58	53	60	54	56	32	38	36	34	35
Ave.	48	50	54	57	52	34	37	39	43	38

(1) A, B, and C planted on 3 dates; D on July 2 only.

Partial analysis of variance for four dates of planting in 1958 between:

Source	Treatment A Initial	Treatment A Total	Treatment B Initial	Treatment B Total	Treatment C Initial	Treatment C Total	Average Total
3 dates (T)	**	**	**	**	**	**	**
Compactions	**	**	*	*	**	*	**
Depths	**	**	**	**	**	**	**
C x D	**	*	**	**	NS	**	**
C x T	NS	NS	NS	NS	NS	NS	NS
D x T	NS	**	*	*	**	NS	**
C x D x T	*	*	**	**	**	**	**
Moistures							**
T x M							*
C x M							NS
D x M							**
C x D x M							**
C x T x M							*
D x T x M							**
C x D x T x M							**

surrounding the seeds often influenced total emergence.

Initial emergence from treatments A and C (moist soil and no irrigation after planting) on both soil types was increased by increasing depth of planting and compaction. Emergence from the 1/4-inch depth of planting exhibited an increase in emergence from six to ten-fold as compaction was increased from 0 to 12 psi while at the 1-inch level, the increase was only 10 to 20%. Treatment A received irrigation before planting and had a higher emergence at all depths of planting than did treatment C (no irrigation) indicating that the emergence depended on the amount of moisture available to the seeds.

Analysis of covariance between soil moisture tension one day after planting and initial emergence was highly significant for all dates of planting. The coefficient of determination for these negative correlations ranged from 33 to 68% indicating that this amount of the total variation in emergence was accounted for by the association of these two variables. Soil moisture tension was decreased both by increasing compaction and depth, but again the magnitude of decrease in soil moisture as compaction increased from 0 to 12 psi was greatest at the shallow depths.

The Hillsdale sandy loam soil had more moisture near the surface than did the Conover silt loam soil. This resulted in higher initial emergence from planting depths of 1/4 and 1/2 inch on treatments A and C on the Hillsdale sandy loam soil. Initial emergence of seeds planted on the surface was negligible, occurring only in one treatment at compactions of 6 and 12 psi for treatment A and C on both soil types.

Total emergence of seeds in treatments A and C exhibited a radical departure from the trends exhibited in the initial emergence in that compaction had very little effect on the emergence of seeds planted 1/4 inch or deeper. In some cases, total emergence increased slightly with increasing compaction at a given depth, and decreased slightly in other cases. When the seeds at a given depth were in contact with enough moisture for a limited amount of emergence from those plots with the higher rates of compaction, many of those which did not emerge were killed by either germinating and not emerging or by their decomposition by micro-organisms. Seeds at the same depth in very dry soil were stored without injury until natural precipitation brought them up. This condition on several individual planting dates resulted in higher total emergence from seeds planted without any compaction than when compacted. In other cases, there was enough moisture present for a high percentage of emergence from seeds compacted with 12 psi and low emergence from those with no compaction. Under these conditions, the total emergence from seeds with no compaction was lower than from the seeds with high compaction at the same depth.

The total emergence for treatments A and C was highest from the 1/2-inch depth of planting on the Conover silt loam soil and from the 1/4-inch depth on the Hillsdale sandy loam soil. The difference between the 1/4- and 1/2-inch depths of planting was minor on both soil types, but emergence from a depth of 1 inch was significantly lower for both soil types. Seeds planted on the surface gave a two to three-fold increase in total emergence as the rate of compaction increased from 0 to 12 psi, but seeding on the surface was inferior to all other depths of seeding.

Treatments B and D both received a 1/2 inch irrigation after planting; in addition, treatment D received daily irrigations until all emergence ceased. Under these very favorable conditions in treatment D, compaction had essentially no effect on emergence of seeds planted 1/4 inch or deeper, and emergence was the highest from seeds planted 1/2 inch deep. This treatment was optimum as far as moisture was concerned, and the decrease in emergence with increased depth of planting was due to the difficulty of weak seedlings pushing up from greater depths. Emergence of seeds planted on the surface of the soil was increased by increasing compaction from 0 to 12 psi on both soil types.

Treatment B was irrigated with 1/2 inch of water immediately after planting and received no more water until initial emergence was completed. Again, the emergence from a 1/4-inch depth on the Conover silt loam soil was lower than from the same depth on the Hillsdale sandy loam soil. This indicated, again, that even with 1/2 inch of irrigation, the surface 1/4 inch on the Conover silt loam soil dried out more quickly than did the Hillsdale sandy loam soil which had the highest percentage of initial emergence from the 1/4-inch depth.

Total emergence of treatment B on the Conover silt loam soil was highest from the 1/2-inch depth of planting; it was highest from the 1/4-inch depth on either soil. The emergence from a depth of 1 inch was lower on both soil types and emergence from seeds planted on the surface was inferior to any of the seeds which were covered 1/4 inch or deeper. For total emergence, compaction was important only for seeds planted on the surface.

The best average total emergence (63%) of treatments A, B, and C on the Conover soil was obtained at a depth of 1/2 inch with compactions of 6 and 12 psi; the best emergence on the Hillsdale soil was obtained at the 1/4 and 1/2 inch planting depths with minor differences due to compaction.

FIELD RESULTS FOR 1957-1958

Multiple regression analysis of initial emergence for 1957-1958.

Simple analysis of variance and covariance of initial emergence of data collected during the 1957-58 seasons showed that depth, compaction, and soil moisture tension had a significant effect on initial emergence. Multiple regression analysis of the data was necessary for a critical evaluation of each factor independently of the others, since soil moisture tension varied from date to date, even though depth and compaction were held constant. Another factor, evaporation one day after planting, was introduced at this point since this influenced the rate of drying of the surface of the soil. Evaporation data were taken from weather bureau records of a station located 1/2 mile from the experimental area.

The multiple regression equation, $Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$ where

Y = predicted yield
a = constant
b = regression coefficient
x = an independent variable

assumes that the effect of each variable on emergence or yield is linear. A plot of the soil moisture tension and emergence showed that this relation was logarithmic so the soil moisture tension data was converted to the log of the soil moisture tension in atmospheres. Data from individual plots was calculated for all the experiments in 1957 and 1958 having soil moisture tension determinations so that as broad a base as possible could be used. Data from the surface depth of planting was not included in this analysis. Over 700 observations for the two soil types were available for this analysis. The methods for multiple regression analysis are found in Snedecor (13).

The data were grouped for analysis according to soil type and irrigation. First, all the data from each soil type were analyzed, then the data from each soil type were broken down according to whether the experimental area received 1/2 inch irrigation after planting or received no irrigation after planting. The results of this analysis are shown in table 41.

The partial regression coefficients may not be compared directly as to their relative value in predicting emergence. For this purpose, standard partial regression coefficients (b^1) were calculated. Thus, if b^1_1 had a value of 0.75 and b^1_2 a value of 0.25, then b^1_1 would be three times as valuable as b^1_2 in predicting emergence. b^1 values were not calculated for the total emergence of either soil type since depth of planting had a highly significant negative or positive value depending on whether irrigation was applied after planting or no irrigation was applied.

The partial regression coefficient for the log of soil moisture tension had a highly significant negative value in all cases. This was the most important factor influencing emergence when irrigation was not applied after planting. When irrigation was applied after planting, this factor was as important as any other on the Conover soil but it was only 1/4 as important as depth of planting on the Hillsdale soil.

Table 41. Partial regression coefficients for multiple regression analysis of 1957-58 initial emergence for experiments with soil moisture tension data.

Partial regression coefficients	Average		No irrigation after planting		Irrigation after planting	
	Hillsdale	Conover	Hillsdale	Conover	Hillsdale	Conover
b_1	-56.71**	-25.94**	-43.19**	-17.24**	-25.28**	-19.35**
b_2	+ 0.23NS	+ 0.89**	+ 0.68**	+ 1.18**	+ 0.17NS	+ 1.98**
b_3	-20.65**	+ 5.51NS	+ 4.46NS	+32.99**	-49.09**	-14.44**
b_4	+20.13NS	+23.32NS	-16.04NS	+ 4.95NS	* 8.13NS	-31.43**
Number of Observations	336	388	240	244	96	144
R	.73**	.64**	.82**	.81**	.80**	.84**
R^2	.52**	.42**	.67**	.66**	.65**	.71**
Standard Partial Regression Coefficients						
$b^1{}_1$	---	---	.74	.37	.24	.58
$b^1{}_2$	---	---	.16	.24	NS	.60
$b^1{}_3$	---	---	NS	.07	.89	.54
$b^1{}_4$	---	---	NS	NS	NS	.14

b_1 (x_1)	Log of soil moisture tension	0 - 15 atmospheres
b_2 (x_2)	Compaction	0 - 12 psi
b_3 (x_3)	Depth of planting	1/4 - 1 inch
b_4 (x_4)	Evaporation one day after planting	
R	Correlation coefficient	
R^2	Coefficient of determination	

Thus, as soil moisture tension increased, holding all other factors constant, emergence decreased.

The partial regression coefficient for compaction was positive in all cases and was significant except for the average emergence on the Hillsdale soil and, on the Hillsdale soil irrigated after planting. This factor was as important as any other on the Conover soil, but was not as important on the Hillsdale soil.

Depth of planting had a highly significant positive value for the emergence from Conover silt when there was no irrigation after planting. When the seeds were irrigated after planting, the value became negative on both soil types. Thus, increasing depth to 1 inch improved emergence when there was no irrigation after planting for Conover silt loam, emergence was increased by increasing the depth of planting from 1/4 to 1/2 inch but decreased as planting depth increased from 1/2 to 1 inch when irrigation was applied after planting.

The amount of evaporation one day after planting was significant in its effect on emergence only for the experiments irrigated after planting on Conover soil. Even so, a comparison of the b^1 values for this and the other factors showed that evaporation had only about 1/4 the value of compaction, depth, or soil moisture tension in predicting emergence.

The coefficient of determination (R^2) for these data showed that where the experiments were grouped according to irrigation and soil type, between 65 to 71% of the total variation in emergence could be accounted for by the association of soil moisture tension, depth of planting, compaction, and evaporation.

Discussion of 1957 and 1958 field results

The most important factor having an influence on emergence of seeds planted from the surface to a depth of 1 inch is the amount of moisture in the vicinity of the seed and the availability of this moisture to the seed. Alfalfa seeds require from 24 to 48 hours of exposure to an optimum amount of moisture for germination depending on the temperature and the characteristics of the individual seeds. If this amount of moisture is limited, this time necessary for germination is increased. As the soil becomes drier the seeds may be injured by exposure to moisture levels inadequate for germination. If the soil is dry enough, the seeds may lie in the soil without any activity until a rain brings favorable moisture conditions for germination.

Emergence was negatively correlated with the soil moisture tension in the vicinity of the seed one day after planting. This correlation was highly significant for all experiments in which soil moisture samples were taken.

The influence of depth and compaction on seedling emergence depended on the amount of moisture in the soil. If the seeds were planted in moist soil and received no water after planting, emergence was increased by increasing depth of planting and compaction. Under these conditions, the highest percentage of emergence occurred at a depth of 1 inch with 12 psi compaction. Emergence from all depths was increased by compaction, but the magnitude of increase was much greater at the shallow depths of planting.

When the seeds received rain after planting, the soil usually stayed moist for a period long enough for the seeds to germinate and for the elongating radicle to grow down into a zone where the soil moisture was more favorable than near the surface. Under these conditions, compaction had very little effect on emergence of seeds planted deeper than 1/4 inch on the Hillsdale or 1/2 inch on the Conover soil. Under optimum moisture conditions where the surface of the soil remained moist for several days, the highest percentage of emergence was found at the 1/4-inch depth. Increasing compaction from 0 to 12 psi increased emergence of seeds planted on the surface from two to three-fold, regardless of the amount of moisture.

The Hillsdale sandy loam soil apparently had more favorable moisture relations for seed germination near the surface than did the Conover silt loam soil. This was reflected in the higher emergence due to initial soil moisture in the case of the Hillsdale soil. When moisture was initially sufficient to cause a small amount of emergence in a given treatment, those seeds which did not give emergence were often injured (germination and then death due to lack of moisture). The Conover soil, on the other hand, lost moisture more quickly so the seeds were not injured as often. When the plots received rain, the weather usually stayed cloudy and damp long enough for emergence from either soil type before the soil dried out. At this time, injury to the seeds in plots which had sufficient moisture for a small percentage of initial emergence was reflected in low total emergence.

Although this phenomonen is interesting, its importance is probably not too great under natural conditions. In many cases this behavior was associated with rainy weather after planting. The experiments were sheltered but the rate of evaporation was slowed so the seeds could at least be subjected to a saturated atmosphere for a short period. If the plots had not been sheltered, the rain would have been sufficient in most cases to facilitate a high percentage of emergence from these same seeds.

The Hillsdale soil also had poor structural stability as determined by wet-sieve aggregate analysis, (table 42). After a hard rain, the emergence of seeds planted at a depth of 1 inch was decreased due to the formation of a hard layer over the seed which the arched elongating hypocotyls could not penetrate readily. Since the Conover soil had a higher percentage of water-stable aggregates, the condition of cementing was not encountered as often on this soil type as on the Hillsdale soil.

Table 42. Percentage of water stable aggregates (Yoder Method) in Conover silt loam and Hillsdale sandy loam soils.

Soil type	Size of aggregates					
	>4 mm	>2 mm	>1 mm	>0.50 mm	>0.25 mm	>0.10 mm
Conover silt loam	1.1	6.0	12.0	27.4	58.7	84.4
Hillsdale sandy loam	0	2.2	5.2	13.2	44.8	65.5

When planted in a moist seedbed without subsequent rainfall, all seeds covered 1/2 inch or more gave high emergence. When there was a rain after planting, seeds planted at a 1/4-inch depth with no compaction gave as good an emergence as those planted deeper and with more compaction. On the other hand, if moisture became limiting, the shallow depths of planting were affected first at the low rates of compaction. This was shown by both emergence and soil moisture tension data.

The soil moisture at a given depth was improved by compaction, especially at the 1/4- and 1/2-inch depths. This often determined whether or not there would be any emergence from plots planted at 1/4- and 1/2-inch depths. The negative correlation between soil moisture tension and emergence at different rates of compaction was often significant and the value approached significance in other cases. This relation served to point out the close association between emergence and soil moisture tension in their response to compaction.

Application of data obtained to the planting of alfalfa seed on a farm scale indicated that the primary importance of both compaction and depth of planting is to place the seeds in an area of favorable moisture relations so they can germinate. The value of deep planting and the improved moisture relations that result from deep planting are limited by the ability of the seedlings to penetrate the layer of soil which covers them. Obviously a high percentage of germination would be of no value if the seeds were planted so deep that no emergence was possible.

With the objective of interpreting the data obtained to make practical recommendations for seeding, several conclusions can be drawn. If seedings are made in a period of weather when evaporation is low and the soil is generally moist, shallow depths of planting with little or no compaction should result in satisfactory emergence. Under conditions of this type in these experiments, compaction showed no influence on emergence except for surface seedings. Emergence from the 1-inch depth was lower than from 1/4- or 1/2-inch depth but was still high enough to consider the seeding as a success. Such seeding, on a practical scale, would be satisfactory if heavy rains did not cause excessively deep coverage and silting over the seed usually placed in a depression. Such action would likely result in poor emergence and possible seeding failures. Planting at the 1/4- or 1/2-inch depths would appear to be a sounder practice since emergence was normally better from the shallower depths of planting and less danger of excessive coverage or silting is likely to occur than at the 1-inch depth of planting. Conditions like this may be found any time of the year but generally prevail in the early spring. Furthermore, because of the danger of dry weather in most parts of the United States following seeding at any time of the year, compaction would be advisable to reduce the danger that soil moisture around the seed would become limiting to germination.

When seeds are planted under dry conditions, such as prevail in the summer, different techniques might be advisable to obtain a satisfactory stand. Seeds could be planted about 1/2 inch deep with compaction. Under these conditions, the soil surrounding the seed becomes very dry and the seeds are stored in the soil with little or no damage until a period of rainy weather occurs. Under conditions such as prevail in arid sections of the United States, planting at depths of 1-inch would probably be preferable to a planting depth of 1/2-inch because of the great danger of rapid drying of the surface of the soil before seeds could germinate and seedlings emerge.

If the soil contained a sufficient amount of moisture, the seeds could be planted in such a way that many could emerge without subsequent moisture. This would require that the seeds be planted relatively deep--1/2- to 1-inch-- and compacted. Moisture relations near the surface would be improved by this method and emergence would probably be sufficient to secure an early stand. This could be important for summer seedings in arid areas where delayed germination could result in small seedlings subject to winter injury if no further precipitation occurred for several weeks.

PART IV

GREENHOUSE STUDIES

The Effect of Different Planting Techniques on Emergence of Seeds Planted on the Surface and Irrigated After Planting.

The percentage of emergence of seeds planted on the surface in the field was consistently lower than when the seeds were planted 1/4 inch or deeper. Following an observation that seeds on the surface would often germinate but not become established, this experiment was established in the greenhouse to determine the effect of different surface-planting techniques on the percentage of seeds covered by soil and the subsequent percentage of emergence when irrigated after planting.

Four hundred seeds (8 replications of 50 seeds each) were planted in flats filled with screened Hillsdale sandy loam soil in each of the following 3 treatments:

1. Seeds planted on the surface and compacted with 4 psi,
2. Seeds planted in a trench 1/4 inch deep and not covered,
3. Seeds planted on the surface with no compaction (0 psi).

After planting, the flats were watered thoroughly and carefully with a hose so there was no washing of the seeds. After watering, the number of seeds remaining on the surface in each row was counted.

Table 43. Average percentage of seeds on the surface after watering and subsequent emergence of seeds planted in the greenhouse.

Determination	Method of planting		
	Compacted with 4 psi.	1/4-inch deep trench	Surface
Seeds covered by soil	56	70	38
Emergence	30	34	16

Partial analysis of variance for the number of seeds covered after watering and emergence and for covariance for individual treatments and individual rows.

Source	Coverage	Emergence	Covariance
Treatments	**	**	NS
Individual plots			**

The results in table 43 show that 38% of the seeds were covered when planted on the surface, 56% were covered when surface planted and compacted with 4 psi, and 70% were covered when planted in a trench 1/4 inch deep. When the seeds were in a depression caused by a compaction (4 psi) or in a 1/4-inch trench, the silting action of irrigation covered a higher number than when they were not in a depression. Analysis of covariance for this data showed a highly significant positive correlation between emergence and the number of seeds covered.

These data indicated that many small legume seeds sown on the soil surface may be covered as a result of a rain and this coverage may be beneficial to emergence. The plantings in the field were always made on a very fine, smooth seedbed. Seeds planted on the surface had little opportunity to fall into crevices or other depressions in the soil surface and to be covered by the action of rain. When compaction was applied to the seeds planted on the surface, the seeds were not only pressed into the soil and the soil firmed around them, but they were in a depression resulting from the action of the compaction wheel. The depth of the depression containing the seeds increased as compaction increased. It is probable that increased seedling emergence which resulted with increased compaction in the field was partly due to the favorable location of the seeds in a slight depression when it rained or when the plots were irrigated after planting.

Determination of the status of unemerged seeds

The field experiments provided little information on the status of seeds which were planted but did not emerge. This greenhouse experiment was designed to determine what happened to unemerged seeds.

Fifty seeds were planted in each of 6 replications (a total of 300 seeds) at depths of 1/2 and 1 inch in flats of screened Conover silt loam and Hillsdale sandy loam soils. The seeds were covered with soil after planting and the soil was soaked thoroughly so that the surface showed a moist color after four days. The emergence was counted after four days and the unemerged seeds were dug up and the status of each seed was determined.

Emergence ranged from 59.4 to 71.0% on the Hillsdale and Conover soils, respectively, (table 44). This was similar to the percentages of emergence in the field even though the germination of the seed lot was 93% on blotters. Emergence from a depth of 1/2 inch was greater than from 1 inch on the Hillsdale sandy loam soil but there was no difference in emergence from the Conover silt loam soil at the 1/2- and 1-inch depths of planting.

Table 44. Percentage seedling emergence and status of unemerged seeds in the greenhouse from seeds planted in two soils at two depths.

Planting depth, inches	Emergence	Unemerged seeds		
		Alive, unemerged	Germinated and dead	Dead--no activity
		Conover silt loam		
1/2	70.6	0.0	18.0	11.4
1	71.4	2.0	14.6	12.0
Ave.	71.0	1.0	16.3	11.7
		Hillsdale sandy loam		
1/2	65.4	0.6	20.0	14.0
1	53.4	1.4	29.2	16.0
Ave.	59.4	1.0	24.6	15.0

Partial analysis of variance for emergence between:

Soils	**
Depths	**
Interaction, S x D	NS

Correlation between emergence and the number of seeds germinated and dead.

$r = -.8185^{**}$

An examination of the seeds removed from the soil showed that 1.0% of the germinated seeds were alive and not emerged. This indicated that, under the conditions of this experiment where the surface of the soil showed a moist color after four days, moisture was not limiting to emergence.

The percentage of dead seeds averaged from 11.7 to 15.0% for all treatments. These seeds were mostly decomposed after four days in the soil and probably represented the fraction of dead and weak seeds in the population. This percentage of dead seeds (average 13.3%) was 5% more than the percentage of dead seeds on blotters. This indicates that some of the seeds which germinated on blotters were too weak to initiate germination in the soil. Some of those seeds may have become diseased before they were able to germinate.

The other category of seeds included those which germinated and died before the seedlings emerged. In these seeds, growth was initiated and the radicle started to grow downward. At some stage of growth before the cotyledons penetrated the surface, the seedlings became brown and soft, probably due to disease and growth stopped. Various parts of the seedlings were attacked. In some cases, part of the hypocotyl became brown and soft and the cotyledons and radicle were still healthy in appearance. In other cases, the end of the radicle was affected by the disease probably "damping off". The diseased condition occurred even though the seeds were treated with the fungicide Arasan.

The negative correlation between emergence and the number of seedlings which initiated germination and became diseased was significant at the 1% level of probability.

The coefficient of determination for this experiment (r^2) shows that over 66% of the differences in total emergence in this experiment can be accounted for by the diseased seedlings. Under the conditions of this experiment, disease was the most important factor limiting emergence.

The conditions of this planting in the greenhouse could be compared to a seeding which received a soaking rain after planting and stayed moist for several days. Moisture was adequate for germination of the seeds and almost all of the healthy seedlings had emerged four days after planting.

SUMMARY OF RESULTS

Field and laboratory experiments were conducted in 1957 and 1958 to determine the influence of depth of planting, compaction and soil moisture on the seedling emergence of alfalfa.

Laboratory experiments were conducted in which seeds were planted in soil at specified depths and compacted with varying pressures. The soil was held in a moist chamber so that evaporation was reduced to a minimum. Under these conditions, both increasing compaction and depth of planting were detrimental to emergence if the moisture tension of the soil was between 2 and 5 atmospheres. When the soil moisture tension was higher (in the range of 11 - 13 atmospheres), increasing compaction had either no effect on emergence or a slightly beneficial effect. The adverse effect at lower soil moisture tensions may be attributed to a mechanical restriction to emergence caused when the soil particles were forced together by compaction. If, however, the water content of the soil was high enough to fill most of the pores in the soil, oxygen could become limiting to germination and consequently to emergence. In this case, the seeds would absorb water and the weaker ones would be subject to attacks by micro-organisms. This condition might occur if the seeded area received rain for several days. These results in the laboratory showing an adverse effect of depth and compaction on emergence were not in agreement with field observations and agronomic recommendations that some coverage and a degree of compaction are beneficial in improving seedling emergence.

Field studies on the effect of depth of planting compaction and soil moisture on the seedling emergence of alfalfa were initiated in 1957 on two soil types and continued through 1958. Individual plots consisting of 100 seeds each were planted at depths of 0, 1/4, 1/2 and 1 inch and compacted with 0, 3, 6, or 12 psi. During the latter part of 1957, and 1958, the experiments were sheltered from rainfall by plastic covers and moisture control by irrigation was used. The soil moisture at the various depths of planting and levels of compaction was determined gravimetrically one to several days after planting.

When initial emergence of the seeds planted in the field in moist soil depended on moisture in the soil at the time of planting, (treatments A and C), emergence on both soil types was increased by increasing both the depth of planting and soil compaction. Under these conditions, the highest emergence occurred at a depth of 1/2 or 1 inch and a compaction of 12 psi.

The effect of depth and compaction on soil moisture was opposite to the effect on emergence. Soil moisture tension was decreased by increasing compaction at a given depth, and was also decreased as the depth of sampling was increased. The negative correlation between soil moisture tension one day after planting and emergence was highly significant for all dates of planting which had soil moisture determinations.

Total emergence of seeds for the treatments planted in moist soil (A and C) was obtained after natural precipitation. At this time, the seeds which had insufficient moisture for emergence initially were able to germinate and emerge. Compaction had little effect on total emergence of seeds planted 1/4 inch or deeper. The highest total emergence occurred at depths of 1/4 or 1/2 inch on the Hillsdale and Conover soils, respectively. Emergence from seeds planted 1 inch deep was significantly lower than when planted either 1/4 or 1/2 inch deep.

When the seeds were irrigated after planting, and the seed bed was watered daily so that the surface remained moist (treatment D), the highest emergence occurred at the 1/4-inch depth of planting and decreased with increasing depth to 1 inch. Increasing compaction had little effect on emergence of seeds planted 1/4 inch or deeper under this optimum moisture condition. When the seeds were irrigated once with 1/2 inch of irrigation after planting, initial emergence was the highest from the 1/4-or 1/2-inch depth of planting, depending on how fast the surface of the soil became dry (treatment B). If the surface of the soil lost moisture rapidly, then the emergence from the 1/4-inch depth was increased by increasing rates of compaction from 0 to 12 psi. Otherwise, compaction had little effect on emergence of seeds planted deeper than 1/4 inch or 1/2 inch on the Hillsdale and Conover soils, respectively. Emergence was essentially completed after 1/2 inch of water was applied after planting.

Emergence of seeds planted on the surface was increased as much as four to six-fold by increasing compaction from 0 to 12 psi. This response was present during each of the two years. The importance of compaction for emergence of surface-planted seeds was due to the coverage of the seeds with soil either by the compaction device or by rainfall. Unless the seeds were covered, their radicles had difficulty in growing down into the soil to enable the seedling to become established.

Alfalfa seeds did not survive and produce normal seedlings if they initiated germination and were then dried.

Multiple regression analysis of the emergence as affected by soil moisture tension, depth of planting, compaction, and evaporation showed that increasing soil moisture tension decreased emergence. Increasing depth of planting from 1/4 to 1 inch favored increased emergence if there was no rain after planting but was detrimental to emergence if there was a rain or irrigation. Increasing compaction was favorable to emergence whether there was a rain or not. Emergence was not affected by increased rates of evaporation (measured one day after planting) to any extent.

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