WEED CONTROL BY MECHANICAL ENERGY AS A PRE-EMERGENCE SOIL TREATMENT

By

ruce
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A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
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for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Engineering

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AN ABSTRACT

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Approved ______________________________

It was estimated that there would have been from two to three million man hours of hand labor expended on weeding and thinning sugar beets in Michigan in 1954.

The best methods known to date could have reduced this hand labor for weeding and thinning sugar beets by approximately 40 percent, which would leave from one to two million man hours of hand labor.

Since labor is the most expensive item in the production of sugar beets, it behooves agricultural researchers, and Agricultural Engineers in particular, to help reduce the peak labor requirement in order that the farmers may not be as dependent upon transient labor.

One way to reduce the weed population in the row would be to sterilize a strip of soil approximately four to six inches wide in which the sugar beet seed could be planted. A review of literature indicated that it might be possible to reduce the weed seed germination by subjecting the soil to a high velocity impact. The literature indicated that under certain specified conditions a substantial reduction in the germination of seeds was obtained by impact.

Based upon the somewhat limited literature available, a field machine was designed to mechanically process a strip of soil approximately 3/4 inch deep by five inches wide in the row as sugar beets were being planted. The processing consisted of feeding the soil into the center of an impeller which varied in speed up to 3400 rpm. The impeller, which was 20 inches in diameter, threw the soil against an impact plate and from there the soil was directed back on to the planted seed.

Tests were conducted with the centrifugal machine on muck soil in the greenhouse and in the field and on mineral soil in the field.

The greenhouse tests using muck soil showed a significant reduction in the weed population at low speeds of 1500 rpm and a significant increase in the weed population at high speeds above 2500 rpm. The field tests resulted in no significant increase or decrease in the weed population on muck soil or on mineral soil. Use of mechanical energy in combination with herbicides significantly reduced the weed population in most of the tests, but the reduction was no greater than that obtained with herbicides alone.

When the centrifugal machine was used to process mineral soil and at the same time mix Krilium 9 with the soil, a significant increase in the emergence of the sugar beets was obtained in 1953. In 1954 a significant reduction in emergence was obtained when Krilium 212 was mixed while processing the soil.

An impact device was constructed to hammer the soil while in 1/8-inch and 1/2-inch layers. No significant reduction in the weed population was obtained at energy levels of 60 to 7000 foot pounds per pound of soil.

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INTRODUCTION

The Problem

The mechanization of a few of the farm crops in the United States can be considered as being complete. This does not mean that there is a satisfactory solution to all of the engineering problems concerning those crops, but that all of the hand labor has been eliminated in the production of those crops.

The same statement cannot be made about the production of sugar beets, although much progress has been made in the mechanization of this crop in the past dozen years.

With this crop, the most progress has been made in harvesting. Since 1943 when harvesters were first introduced into Michigan, the number of sugar beet harvesters has increased steadily so that in 1953 approximately 90 percent of the acreage in Michigan was machine harvested.

At present the greatest problem in production is in thinning the beets and in controlling the weeds in the row during the first two months after planting. Johnson (18) reports that in 1946 this task required 32 man hours per acre and was the largest single item in cost as well as labor in the production of sugar beets in Michigan.

Considerable progress has been made since 1946 in the use of mechanical devices for thinning the beets and removing

the weeds which are in the row. Some use has been made of standard farm implements such as spike-tooth harrows, weeders, rotary hoes and even row-crop cultivators. With the exception of the rotary hoe, the implements are operated across the rows of beets so as to remove some of the beets as well as a percentage of the weeds in the row.

A more useful implement is the spring-tine thinner developed by French (8) from the Dixie cotton chopper. However, even this machine does not completely eliminate the need for hand labor, but only reduces it by roughly 40 percent. Since mechanical thinners do not completely eliminate hand labor their use has not become widespread in Michigan. In 1953 only one acre out of 6½ was mechanically thinned and weeded.

The April 1954 Sugar Beet Journal published at Saginaw, Michigan by the Farmers and Manufacturers Beet Sugar Association estimated that there would be 95,000 acres of sugar beets in Michigan in 1954. Considering the rather limited use of the thinner, it would appear that there would be somewhere between 2 and 3 million man hours of labor expended in 1954 on thinning and weeding sugar beets in Michigan.

Part of the problem is due to the unpredictable germination of sugar beet seed under field conditions. As a result it is customary to plant approximately ten times as many seeds as are actually desired and to thin while hoeing to the desired stand. It does not appear that the problem of erratic germination is primarily an engineering one. If more information was available regarding the physical requirements of germinating sugar beet seed, then it would be more logical for engineers to be working on the problem. However, the problem of eliminating the weeds in the row most certainly should occupy the attention of Agricultural Engineers.

The Objective

This project has been directed the past three or four years toward the study of possible methods of sterilizing a strip of soil in which the sugar beet seeds could be planted. The sterilized soil would eliminate the need for any hoe work except for thinning the beets. The need probably is not for complete sterilization, but for partial or temporary sterilization of a strip approximately 4 to 6 inches wide.

The results obtained by Kinch (20) when using mechanical energy to reduce the germination of seeds mixed with the soil were so encouraging that it was decided to continue the investigation on the same train of thought. Some of the results he obtained will be discussed in more detail later on.

This investigation is a continuation of the study of mechanical energy as a means of reducing the vitality of weed seeds in the soil. The investigation is a study of the effects under field conditions of using a machine which will mechanically process a narrow strip of soil in the row for weed control.

REVIEW OF LITERATURE

The object of this investigation was to study the possibilities of mechanically sterilizing a narrow strip of soil in which the sugar beets are planted so that some, or perhaps all, of the hand labor of hoeing could be eliminated. Splinter (26) discussed the differential heating of various parts of seeds with the idea in mind of possibly being able to kill the weed seeds by dielectric heating. Kinch (20) discussed several other methods of applying energy to a strip of soil to kill or to reduce the germination vitality of the entrained weed seeds. Kinch listed the following possible methods of applying energy to a strip of soil.

(a) High frequency electrical energy
(b) Heat energy by conduction
(c) Ultrasonic energy
(d) High current electrical energy
(e) Light energy
(f) Mechanical energy

Kinch (20) studied three of these methods in detail, (b), (c), and (f) and concluded that the last of these methods had the best economic possibility. By mathematical analysis and laboratory investigation he designed a device which he called a "semocidometer". This machine was unexpectedly similar to a centrifugal machine called an

"ENTOLATOR" (7) made by the Safety Car Heating and Lighting Company Inc. of New Haven, Connecticut for the purpose of killing insects and insect eggs in grain and flour.

The principle on which the two machines work is very similar. The bulk material with the entrained pests, either insects and their eggs or germinating weeds and weed seeds, is fed into the center of a high speed centrifugal fan which accelerates the material toward an impact plate to injure the pests.

In the Patent Gazette, it was found that there are at least seven patents issued to F. R. Smith, et al, (25) and assigned to the Entolator Division. All of those patents are concerned with devices for controlling insects and, except for design details, all work on the same principle as the one shown in Fig. 1.

There is one major difference in the design of this machine and the machine designed by Kinch for control of weeds and that is the use of so-called impactors in the Entolator. From the description in the claims under patent number 2,339,732 it appears that the object of the impactors is to damage the insects while they are being accelerated in addition to when they hit the outside impact plate. Cotton (7) reports that when the machine was used at 1750 rpm 99.6 percent of the insects were killed, from which it appears that the machine is quite efficient.

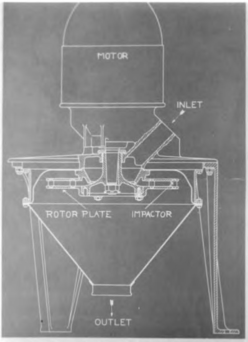


Fig. 1—Diagrammatic Sketch of the Mechanical Bulk Flour Entolator

Reprint from AMERICAN MILLER, October, 1942

Fig. 1. Schematic diagram of the ENTOLATOR machine made for controlling insects in wheat and flour

This idea of using so-called impactors is somewhat different from the design of the impeller in the machine used by Kinch (20). In Kinch's machine a soil particle is accelerated continuously from the center of the impeller to its edge and receives only one impact when it hits the impact plate. By studying the design of the impeller used on the Kinch machine it is obvious that all soil particles must reach about the same terminal velocity which is not true of the "Entolator".

From information supplied by Kinch (20) regarding the power required to operate a small centrifugal machine, it was estimated that a 20-inch diameter impeller running at 2600 rpm would require approximately 18 hp when processing 400 pounds per minute of soil. This value checks quite closely with that given by Huyett (16) who describes a centrifugal shot peening machine used for work hardening steel parts. This machine, when handling 300 pounds per minute at a velocity of 3000 in. per second, requires 15 hp.

In attempting to arrive at an energy level, either mechanical or otherwise, which will sterilize the weed seed, it is necessary to consider that there is a great variation in susceptibility to damage of weed seeds. Toole and Brown (27) said that large weed seeds do not live more than a year in the soil, but their final report on the Duvel Buried Seed Experiment showed that of 107 species buried in 1902, 51 of them were still viable after 20 years. Thirty-six species were still viable after being buried 39 years. Goss (9), in reporting on the same project, concluded that depth had little effect and also that most weed seeds will not perish when plowed under, or during a period of normal rotation. From this it would appear that no practical method of sterilizing the soil in the field could expect to be 100 percent effective.

Heise (14, 15), in a discussion of physical damage to weed seeds, showed that by dehulling Green Foxtail seeds, the germination was reduced from 87.5 percent to 15.5 percent and when the top of the embryo was skinned the germination was further reduced to 1.5 percent. In tests on Common Ragweed seeds he says that "removal of the pericarp, provided the 'seed' is not damaged in the process, does not result in excessive lowering of viability. But when the 'seed' is even slightly damaged, viability is reduced close to zero."

Porter and Koos (24) concluded about the same thing in reporting that "hulled fruits of Sour Dock, Black Bindweed, Small Ragweed, naked fruits of Green and Yellow Foxtail found in commercial seed samples showed little or no ability to produce plants".

Bass (2) confirms the results of other investigators in concluding that badly injured weed seeds have their vitality much reduced below that of uninjured seeds.

Koehler (21) has for several years been studying the effects of mechanical damage to seed corn. He says that "severe crown injury or an injury over the plumule resulted in less than 10 percent germination". Borthwick (3) and also Harter (13) attempted to classify the type of growth which resulted from physical damage to Lima Beans which are easily damaged. Borthwick (3) and Harter (13) did not give any values of mechanical energy or force necessary to cause certain types of physical damage.

The most complete study found of physical damage to seed, was by Bainer and Borthwick (1) who also made their study on seed beans of the lima type. They found when threshing baby lima beans at 9.1 percent moisture that the

mechanical damage increased from 7.6 percent to 52.5 percent as the cylinder speed of the threshing machine was increased from 770 fpm to 1560 fpm. In order to show that the velocity of impact was the cause of the damage they dropped the beans from various heights to give a velocity equivalent to the cylinder speed. The results are shown graphically in Fig. 2.

If information similar to that shown in Fig. 2 was available for all weed seeds then there would not be as large a problem in attempting to design a centrifugal machine or some other type of mechanical device to sterilize the soil.

The data by Bainer (1) shows clearly the energy level necessary to reduce germination almost to zero if the seed is dry. Unfortunately most weed seeds, except for those on the surface during a dry part of the season, have a relatively high moisture content and therefore are not as susceptible to physical damage as is indicated by the chart. Also the size of the seed must certainly be a variable which must be considered.

A recent unpublished paper by Bunnelle (4) presents information similar to that by Bainer (1) except that the seed being studied was alfalfa seed. Fig. 3 is a photographic copy of one of the charts presented in his paper. The moisture content of the seed is not specified, but it is assumed that it was dry enough to store and conceivably about 14 percent.

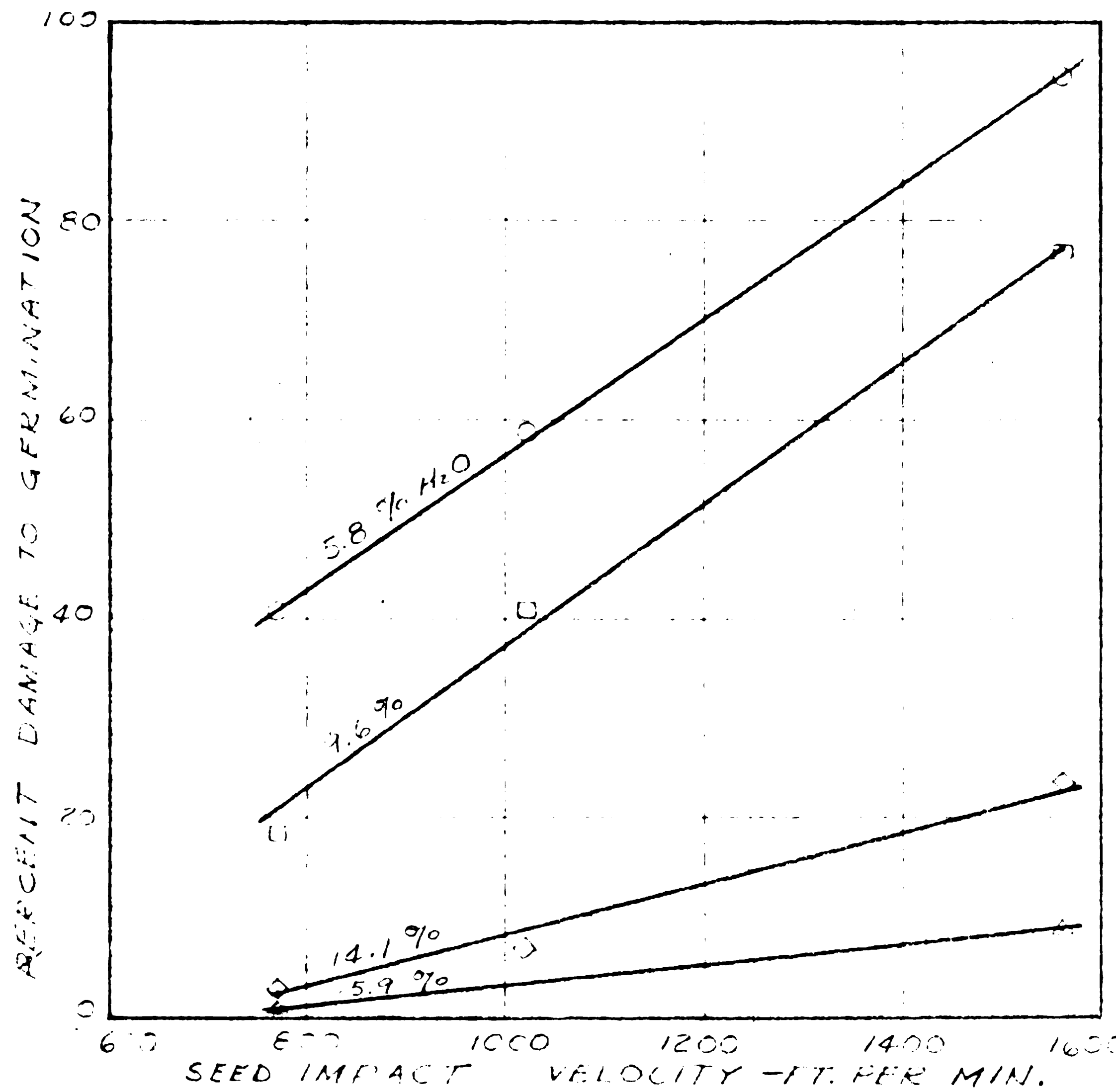


FIG. 2 EFFECT OF MECHANICAL INJURY ON GERMINATION OF BABY LIMA BEANS. PLOTTED FROM DATA PUBLISHED BY BAINER AND BORTHWICK (1).

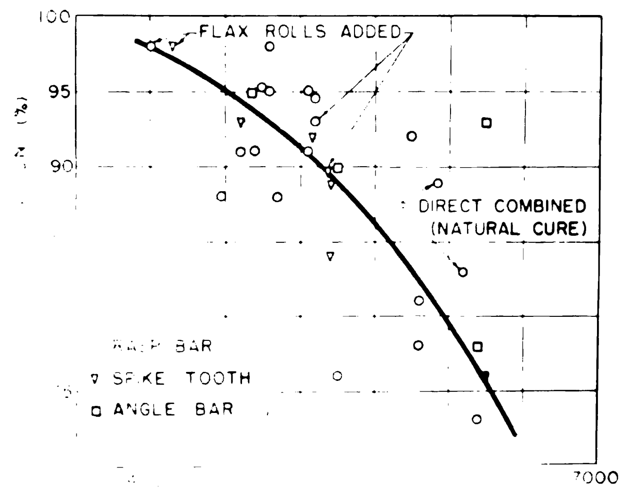


Fig. 3. Effect of combine cylinder speed upon the germination of alfalfa seed
From unpublished paper by Bunnelle (4)..

It is, of course, risky to generalize or draw conclusions from Figs. 2 and 3 in regard to impact damage to any seed. However, it is logical to assume that the smaller seeds would require a greater impact velocity to give the same germination reduction and this appears to be true as far as Figs. 2 and 3 are concerned.

For purposes of comparison assume that the moisture content of both the alfalfa seed and the lima beans is at 14.1 percent. Assume that the germination reduction of both is 20 percent. Then from Fig. 2 it may be seen that the impact velocity is roughly 1500 fpm for the lima beans and roughly 6000 fpm for the alfalfa seed. Under these conditions the kinetic energy required to reduce the germination to 80 percent is 16 times greater for the alfalfa seed than it is for the lima beans.

It would be very desirable to have similar information about several sizes of weed seeds, but this information is not available, or at least was not found.

The above comparison was made on the basis of a 20 percent reduction in the germination of the two types of seeds. However, for weed control a 20 percent reduction in the weed population would not be very useful.

How well the above type of information would apply to weed seeds is not known. Most weed seeds are inherently hard seeded; that is, they will not necessarily germinate when subjected to the correct moisture and temperature conditions. They usually become dormant shortly after maturing and may stay that way for several years, as was shown by the Duvel (9) buried seed experiment.

From the standpoint of designing a field machine to process the soil for the purpose of reducing the germination of the weed seeds it is essential that some positive information be obtained. Several questions have been prompted by this literature search.

1. What critical impact velocity will cause a specified reduction in the germination of various weed seeds?

2. What is the effect of the moisture content of the weed seeds on the critical impact velocity?

3. What is the moisture content of the weed seeds in the soil?

4. What is the effect on the critical impact velocity of mixing the weed seeds with soil?

5. How much soil would it be necessary to process in order to obtain reasonable weed control?

Of all these questions the last one is the easiest one to answer. Chepil (6) reports that by far the highest emergence of weed seedlings of the species studied was from the seeds lying on the surface of the ground. However, he does not give any percentage or exact depths from which the weed seedlings grew. He stated that from 60 to 99 percent of the weeds emerged before June 30.

Kinch (20) made a study of the depth from which weed seeds sprouted on disturbed soil. From his data the distribution chart in Fig. 4 was plotted. It is interesting to note that 96.3 percent of all the weed seeds which germinated were in the top three-fourths of an inch. From this information it is apparent that it would not be necessary to process more than three-fourths of an inch of soil or perhaps one inch at the very most.

When using the semocidometer at 4000 rpm Kinch reports that when processing a one-inch layer of soil only 4.8 percent as many weeds grew in the first 12 days in the processed layer as did in the unprocessed plot. His work was done with disturbed mineral soil and then exposed to

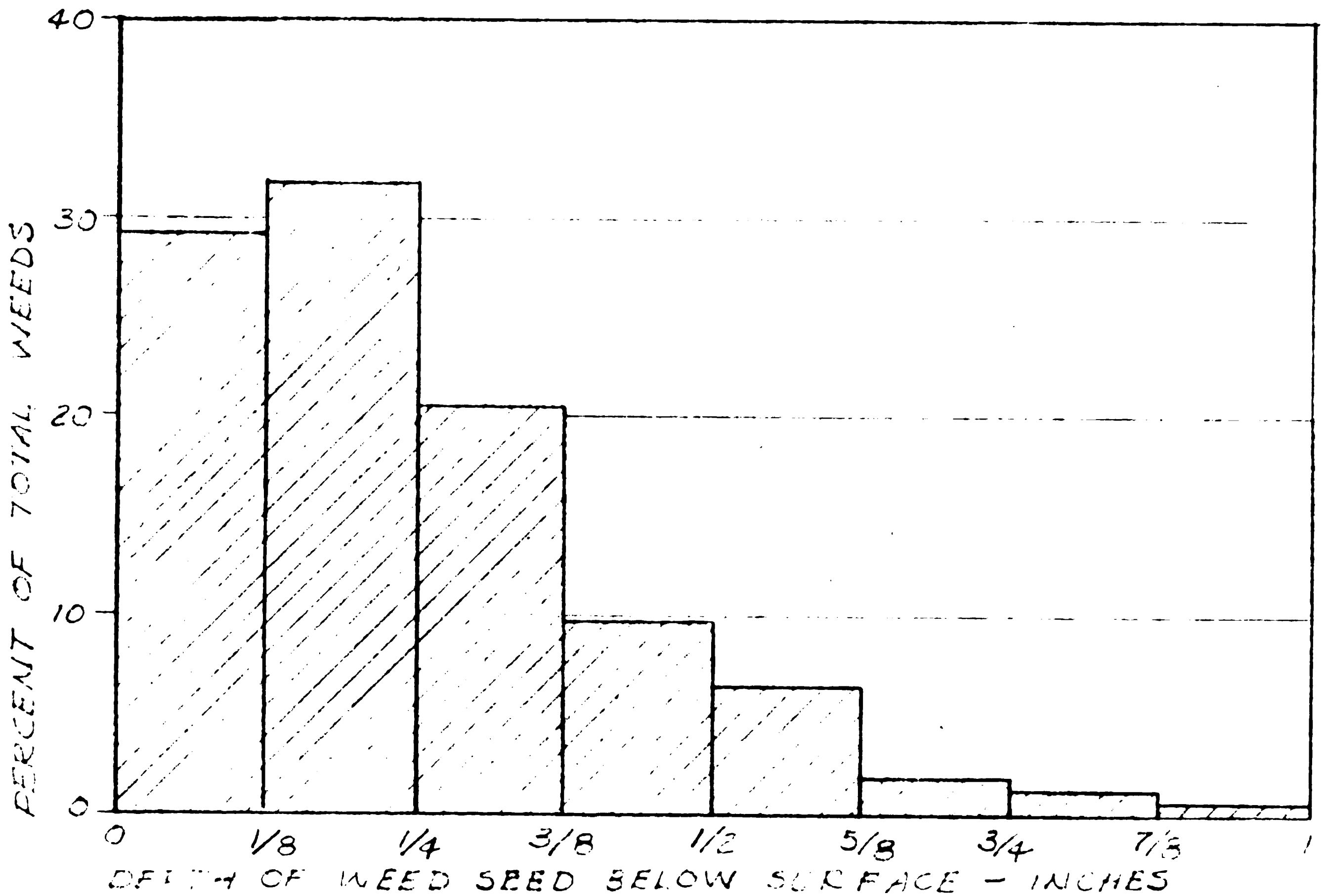


FIG.4 DISTRIBUTION OF GERMINATING WEEDS IN UNTREATED SOIL FROM A SUGAR BEET FIELD. PLOTTED FROM DATA PRESENTED BY KINCH (20).

fluorescent light indoors. With the equipment which he used the total velocity of the soil particles leaving the impeller was approximately 14,900 fpm.

In any complete study of the problems involved in sterilizing the soil some consideration must be given to the resulting changes in the soil properties. It is quite likely that any treatment to the soil, either mechanical or otherwise, would result in some damage to the soil structure. In most soils the crop yields are reduced when the soil is worked more than the minimum necessary in order to prepare the seedbed and to control the weeds. Keen (19) and many other soil physicists have said in effect that any implement or practice which tends to work the soil excessively causes the tilth to become less favorable to plant growth. However, because of time limitations this related problem of soil structure damage was only studied superficially.

Newhall (22), a plant pathologist, in a discussion of the theory and practice of soil sterilization says that complete sterilization is undesirable and that instead one should "partially sterilize" the soil. He was undoubtedly thinking of microorganisms as well as weeds and weed seeds. It is quite unlikely that any mechanical sterilization process, such as this project is concerned with, could ever achieve complete sterilization even if it was desired to do so.

INVESTIGATION

Part I

Design of the Centrifugal Soil Processing Machine

Functional requirements

The design of a machine to process soil was actually a secondary object in this investigation. The primary object of the study was to determine the effects of mechanical energy upon the germination and growth of weeds which have been subjected to various treatments. However, before any studies could be made some equipment had to be designed and constructed which would subject the soil to the desired treatment.

It must be kept in mind that a functionally adequate machine was necessary, but that no attempt was made to design a machine with much of a service life.

An experimental two-row sugar beet planter that had been used by Carleton *et al* (5) was available to be used on this research project. It was decided to mount the processing equipment on the planter in such a way as to have one row of the planter as a check row and the other row as a treated row.

From the review of literature and from the equipment available the following criteria were established:

1. The strip of soil to be processed should be approximately 0.75 inch deep by 4 to 6 inches wide.

2. The ground speed was established by the tractor available which had a low gear ground speed of 2.8 mph at 1500 rpm engine speed.

3. The experimental planter which was to be used as a basis for the machine was designed for the three-point hitch of a Ford type tractor. The height of the planter could be regulated by the hydraulic lift of the tractor and by an adjustable tail wheel. The row spacing was fixed at 26 inches.

4. It was estimated that an impeller 20 inches in diameter and with vanes two inches high would have sufficient capacity to handle the soil that would need to be processed.

Impeller design

Kinch (20) developed an equation (see Appendix) for the velocity of a soil particle being accelerated by an impeller of this type. The impeller shown in Fig. 5 was first designed with no more than a rough idea of what its speed should be in order to give the same particle velocity as the Kinch machine. If we assume that the impeller of the Kinch machine is turning at 400 rpm and that the coefficient of friction of soil on steel is 0.4 then it can be shown that the total velocity of a soil particle leaving the impeller is approximately 14,900 fpm.

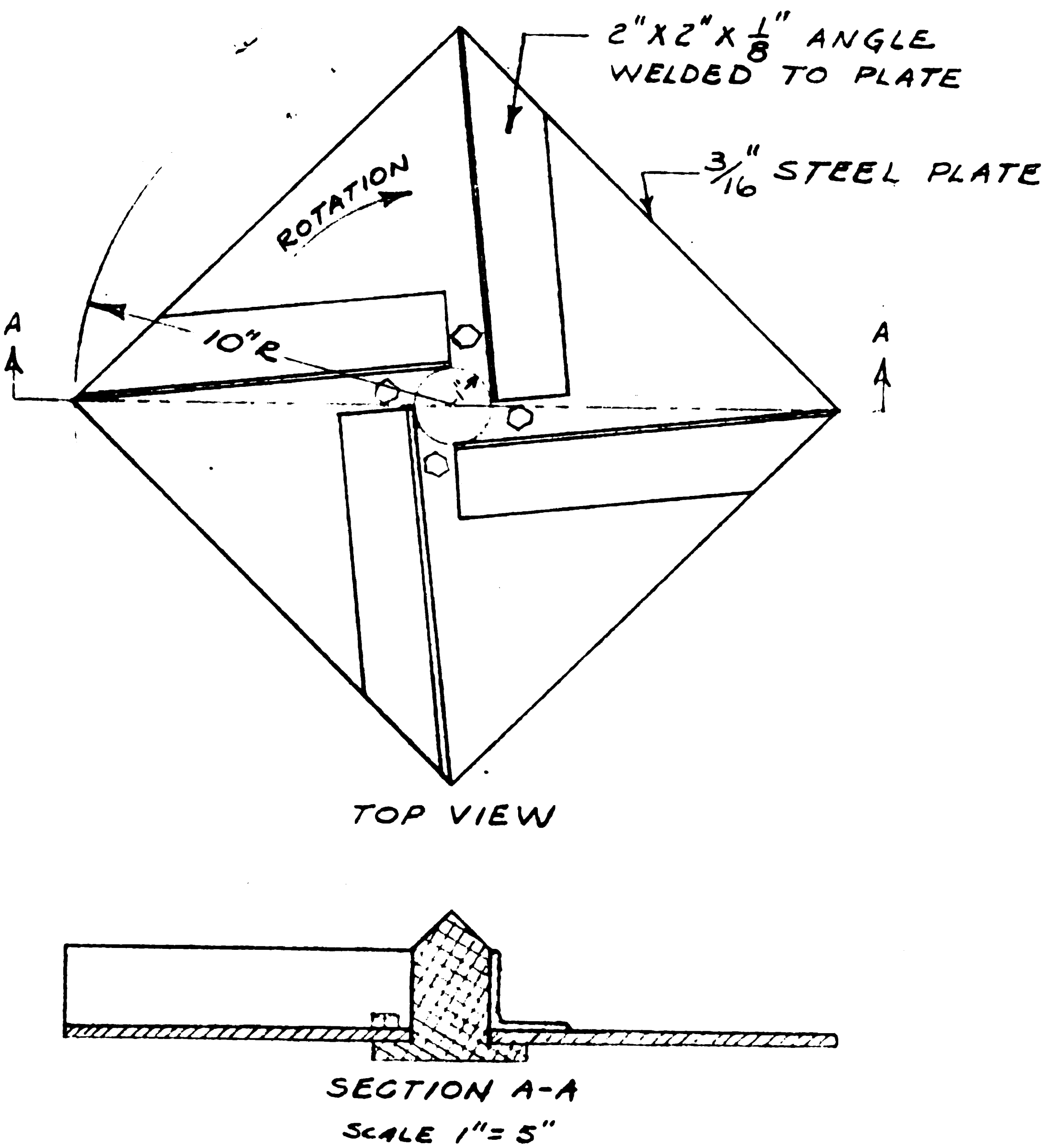


FIG. 5 DETAIL DRAWING OF THE SOIL PROCESSING IMPELLER.

For the conditions of the larger 20 inch impeller the equation of motion of a soil particle has been worked out and is shown in the Appendix. Since the coefficient of friction of soil on steel very definitely affects the radial velocity some attention was given to determining that effect. Values for the coefficient of friction of various soils on steel are given by Nichols (23) for several mineral soils, but no information was found for muck soils. By using the values given by Nichols the curve shown in Fig. 6 was calculated for the 20 inch impeller shown in Fig. 5 turning at 2600 rpm.

Complete machine

The design details of the field machine, with the exception of the impeller, are unimportant as far as this study is concerned. A few comments about the design of the machine will suffice.

A schematic diagram of the machine viewed from the left side is shown in Fig. 7. A photograph of the same machine viewed from the right side is shown in Fig. 8.

Power was transmitted from the tractor by the power take-off and from there to the impeller by means of roller chains, sprockets and shafting. The impeller itself was mounted on the pulley end of a Ford belt pulley attachment. This made an excellent dust tight bevel gear box in addition to having the necessary bolt holes for mounting the gear box on the frame of the planter.

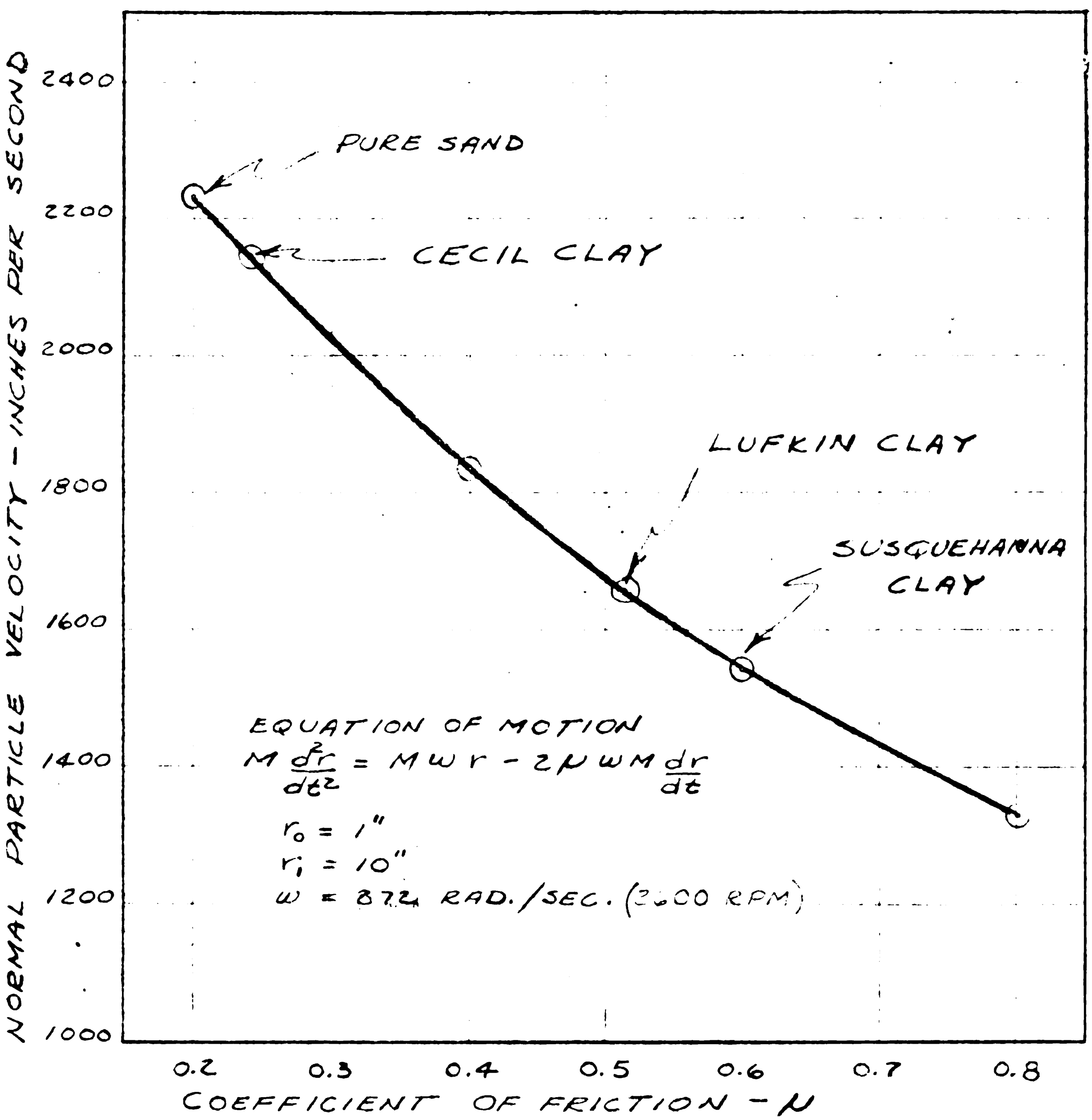


FIG. 6 CALCULATED PARTICLE VELOCITY NORMAL TO IMPELLER AS A FUNCTION OF THE COEFFICIENT OF FRICTION.

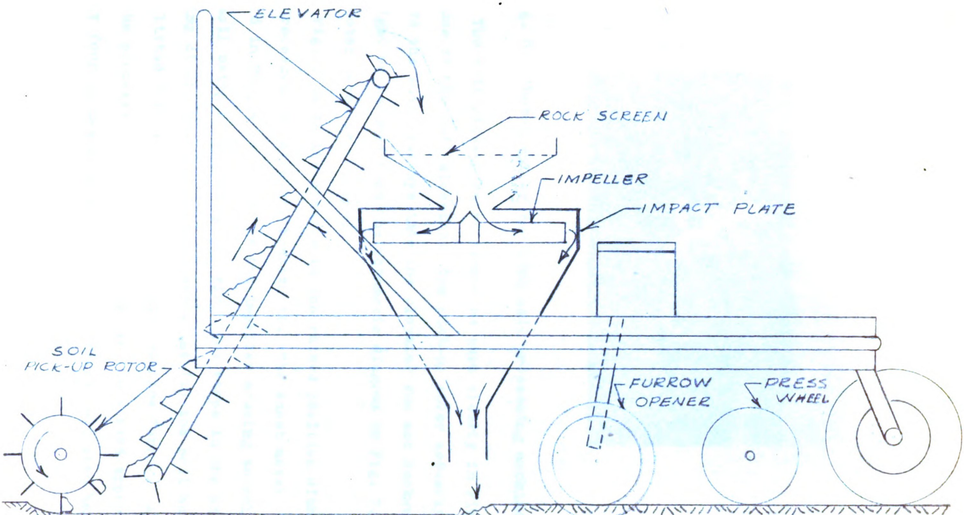


FIG. 7 SCHEMATIC DIAGRAM OF THE 1953 SOIL PROCESSING MACHINE

Fig. 8. Photograph of the 1953 soil processing machine

The soil pick-up rotor cannot be seen clearly in Fig. 8 because of the soil elevator. The pick-up rotor actually throws the soil sideways into the elevator and not backwards as might be assumed from the schematic diagram in Fig. 7. The rotor turns at 500 rpm.

Fig. 9 shows the planter in the raised position with the processed row directly beneath it. The sheet metal shield in Fig. 9 was added to the impeller housing to collect the soil being blown out by the air. The steps in the processing of the soil can be seen here. At (a) the soil has been lifted into an elevator leaving a shallow furrow. At (b) the processed soil has been deposited in a band approximately four inches wide and at (c) the sugar beet seed has

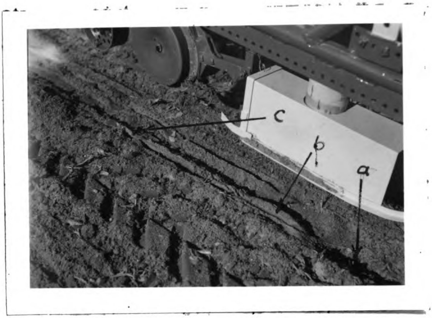


Fig. 9. Close-up view of the right-hand side of the planter lifted up to show the processed strip of soil

been planted in the processed soil which will then be packed down by the press wheel behind it.

Fig. 10 is a rear view of the rock screen which is necessary to remove the larger rocks when processing mineral soil. It was made with a wire screen having a one-inch by two-inch mesh. An eccentric with a one-half inch stroke shakes it at 540 cycles per minute.

Fig. 10. Rear view of soil processing machine showing rock screen

Part II

Field Tests in 1953

Mineral soil tests

The planter with the soil processing attachment was used to plant four replications of the following treatments in the Agricultural Engineering field at the corner of Harrison Road and Forest Road.

- C - no process (on left side of planter only)
- S_1K_0 - impellor speed 1600 rpm, no Krilium
- S_1K_1 - impellor speed 1600 rpm, 0.1% Krilium 9 by weight of soil processed
- S_2K_0 - impellor speed 2600 rpm, no Krilium
- S_2K_1 - impellor speed 2600 rpm, 0.1% Krilium 9 by weight of soil processed

Each row was 80 feet long and the row spacing was 26 inches. The soil conditioner (Krilium 9) was fed by hand into the rock screen so that it was mixed thoroughly with the processed soil. In all the treatments, with the exception of the check, the depth of the processed soil was roughly one inch. These plots were planted on July third and fourth and were preceded by a rain of about one-third of an inch. A half-inch rain fell on the fifth of July so that some crusting occurred. It was expected that the processed soil would crust more than the unprocessed soil so it was for that reason that the soil conditioner was added.

Due to late planting and the dry weather following the planting and processing of the mineral soil plots, very few weeds grew.

Table V in the Appendix shows the results of the weed count on the mineral soil plots, but it is obvious without any statistical analysis that the information is meaningless. There are not enough weeds in either the processed or the check plots to be a problem.

It was expected that the processed soil would tend to crust more than the check plots so it was decided to evaluate this problem by counting the emergence of sugar beets.

In Table I the emergence data of all of treatment S_1K_0 is missing because of faulty planting mechanism.

The analysis of variance is shown in Table VI in the Appendix.

TABLE I

EMERGENCE OF SUGAR BEETS ON MINERAL SOIL IN 1953
(Plants per 100 inches)

Replication	Treatment					
	S_1K_1	C_2	S_2K_0	C_3	S_2K_1	C_4
1	102	21	47	62	66	35
2	105	100	76	41	104	66
3	141	113	69	88	121*	92*
4	110*	72*	35	62	94	76
Average	116	76	57	63	96	72
Corrected average**	116	84	57	70	96	80

*Missing data filled in by method outlined by Goulden (10).

**Averages corrected because right hand planter (processed row) planted 10 percent more sugar beet seed than the left hand planter.

The F test shows the treatments to be highly significant which means that the averages of one or more of the treatments is significantly different than the others. Because of the missing data it was necessary to correct for the treatment sum of squares and when this is done the adjusted mean square for treatments is found to be 1960 which is still highly significant. By means of the "t" test where the standard deviation is corrected for missing data it can be shown that by using Krilium during the processing of the soil the emergence rate of the sugar beets is significantly higher than any of the check plots and that S_2K_1 is significantly better at the 99 percent confidence level than S_2K_0. There is not a significant difference between any of the check plots and the processed plots without Krilium (S_2K_0), although it should be noted that the processed plot S_2K_0 did have a lower emergence rate than the average of the check plots which is as expected.

It was surprising that the use of Krilium increased the emergence rate over the check plots. Figs. 11, 12 and 13 illustrate the appearance of the check row, and the processed row without Krilium and with Krilium.

The row is located at the three inch mark on the measuring tape. These photographs were taken three days after the sugar beet seeds were planted so the seedlings do not as yet show.

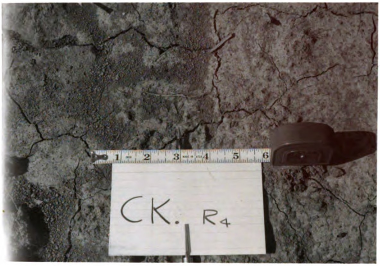


Fig. 11. Crusting of Brookston clay loam on check row three days after planting
A half-inch rain fell two days after planting.

Fig. 12. Crusting of Brookston clay loam on row processed at 2600 rpm and approximately one inch deep

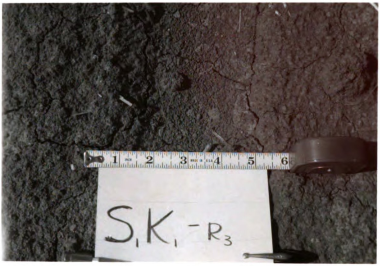


Fig. 13. Crusting of Brookston clay loam processed at 1600 rpm and treated with 0.1 percent Krilium

Muck soil tests

It has been estimated that approximately ten percent of the sugar beets in Michigan are grown on much soils. For the following reasons it would appear that the potential use of this machine would be greater on muck soils than on mineral soils.

1. In general, the weed problem is greater on muck soils than it is in mineral soils.

2. The bulk density of muck soil is roughly only one-half that of mineral soils. Assuming that the volume of soil is the same in both bases, then the power requirement to run the impeller would be approximately one-half.

3. Since muck soil has no structure then there would

not be any damage to the soil from that standpoint.

4. Since there are no rocks in muck soil, the design of the machines could be simplified.

The machine was used on muck soil to plant eight rows of sugar beets that were 200 feet long. Four of the rows were check rows, two rows were processed at 1600 rpm and two rows were processed at 2600 rpm. These planting were made on July 20.

Because the soil was quite dry when the above plantings were made and because it was difficult to control the depth of the processed soil it was decided to process some small plots of 200 square inches.from which the soil was scooped up manually, processed and laid back down manually. No sugar beet seed was planted with these plots. The following treatments were replicated three times.

S_0D_1 - no process, soil disturbed 3/4 inch deep

S_0D_2 - no process, soil distrubed 1½ inches deep

S_1D_1 - impellor 1600 rpm, soil processed 3/4 inch deep

S_1D_2 - impellor 1600 rpm, soil processed 1½ inches deep

S_2D_1 - impellor 2600 rpm, soil processed 3/4 inch deep

S_2D_2 - impellor 2600 rpm, soil processed 1½ inches deep

These manually lifted and replaced plots were on the same muck soil as was used for machine planting. All of the muck plots were located on Dr. Buford Grigsby's weed control field on Abbott road. These small plots were processed on

July 23 and since the soil was quite dry at the time 1.2 inches of water was applied to the plots on July 27. On August 2 approximately 2 inches of rain fell so that there was an ideal growing condition for the weeds. The muck plots which were planted and processed with the machine on July 20 did not receive any rain or irrigation water until it rained 13 days later.

The dry weather following the machine planting and soil processing on the muck soil plus the difficulty experienced in regulating the depth of the processed soil resulted in very erratic sugar beet emergence and weed growth. The observation showed that there was no measurable difference in any of the treatments, or between the treatments and the check rows.

The manually lifted and replaced small plots (200 square inches) also gave disappointing results, but were not completely worthless. These plots were replicated three times, but one of the replications was ruined by a mole and a second replication was badly flooded and covered with trash so all of the resulting information is from one replication only.

The small plots shown in Fig. 14 were treated on July 23 and the weed counts (Table II) were made on August 10 which was 18 days later.

Since there were no replications of the above tests there is no way in which an analysis of variance could be

Fig. 14. Weed growth on muck soil showing effect of six different treatments
Photograph taken 14 days after treatment.

TABLE II

WEED COUNTS IN 200-SQUARE INCH PLOTS ON MUCK SOIL

	Treatment					
	D_1S_0	D_2S_0	D_1S_1	D_2S_1	D_1S_2	D_2S_2
Grass	149	108	88	162	116	69
Broadleaf weeds	325	223	217	282	125	337
Total	474	331	305	444	241	406
Total each speed	805		749		647	

made. It is apparent that the weed count does go down as the speed of the impellor has been increased. The weed population has decreased approximately 20 percent where the impellor speed is 2600 rpm (S_2) as compared to the check plot (S_0).

Discussion of 1953 field tests

1. The results of the tests on mineral soil were negative as far as the weed control is concerned. This may be due partly to the dry weather, the lateness of the season and the poor depth control of the processed soil.

2. The results of the emergence data on the mineral soils were surprising. The data showed that by using Krilium in combination with this machine the sugar beet emergence was increased significantly over the check row or the processed row which was not treated with Krilium.

3. There were no observable differences on muck soil where the planter with the soil processing attachment was used as a field machine. The weed growth was adequate for the tests, but there was no difference in the treatments. Again difficulty was experienced in maintaining the proper depth of processed soil. Also considerable contamination of the processed soil was observed, coming from the furrow opener. This latter problem existed when the machine was used on both mineral and muck soil.

4. The processed muck soil, when it was scooped up and replaced manually, had fewer weeds than the unprocessed soil, but the difference was not large.

Part III

Greenhouse Studies

Centrifugal machine tests on muck soil

In order to eliminate as many of the field variables as possible it was decided to hand feed muck soil with the entrained weed seeds into the centrifugal field machine and then catch the processed soil in a bucket. The processed soil would then be spread out in frames in the greenhouse and kept moist, to germinate the weed seeds.

The equipment used in connection with the greenhouse tests using the centrifugal field machine was essentially the same as was used in the field tests during the summer of 1953. However, some slight changes were made in the design of the impeller. These are shown in Fig. 15.

When the cover was taken off of the impeller housing of the field machine after being used during the summer of 1953, it was observed that some soil tended to stick to the impact plate above the region in line with the impeller. Thus, it would seem that some of the soil was not being held in contact with the blades of the impeller until reaching the outside edge, but instead slipped off the blades.

To improve upon this apparent difficulty the impeller was redesigned as follows:

1. A short piece of angle iron was welded to the top edge of each blade to form a trough to guide the soil while

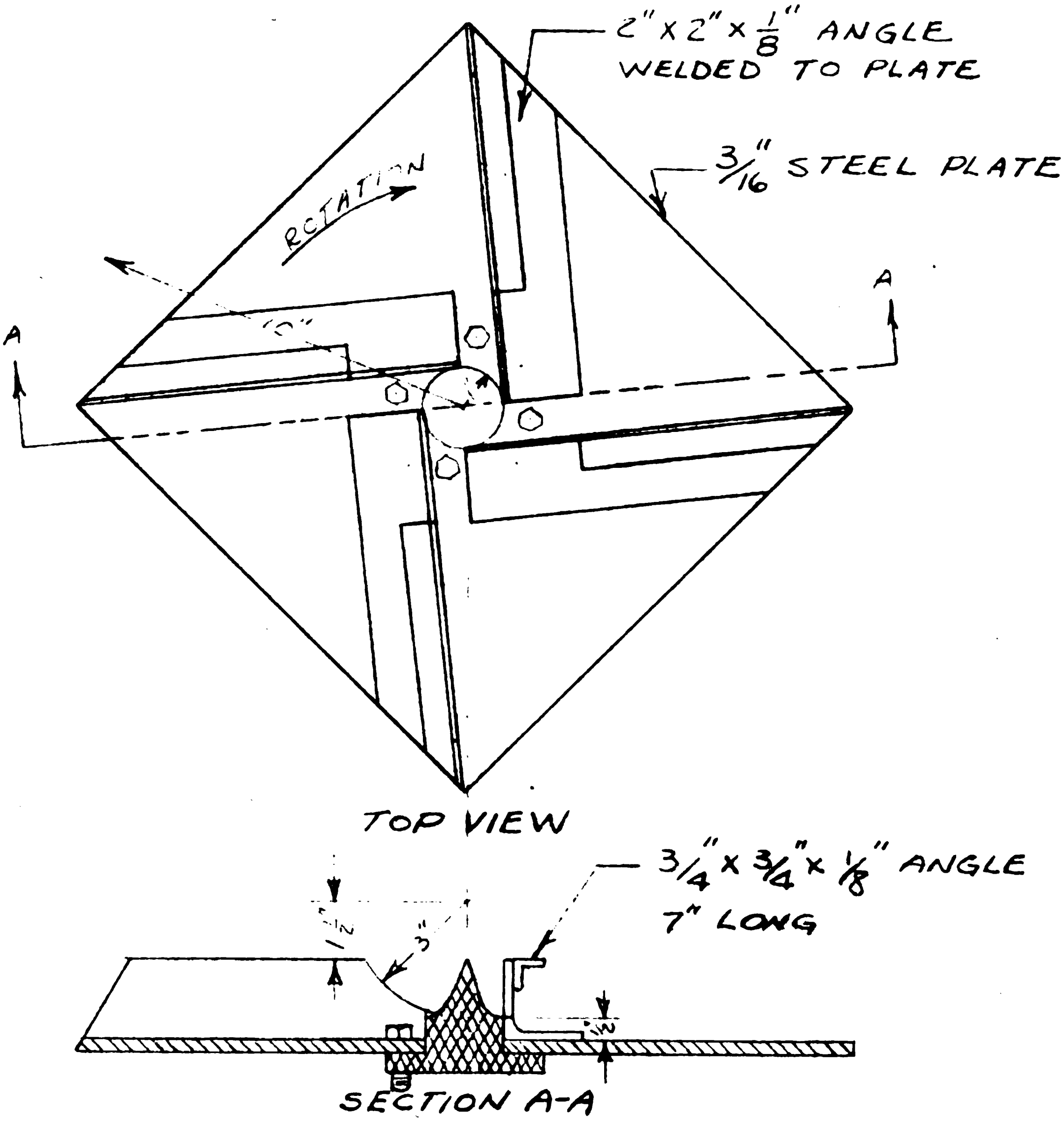


FIG. 15 REDESIGNED SOIL PROCESSING IMPELLER

it was being accelerated.

2. The center post of the impeller was lowered.

3. The inner ends of each blade were lowered. This in addition to lowering the center post allowed the soil to drop further into the center of the impeller before being accelerated outward.

Procedure. Muck soil was brought into the greenhouse from a field which had a high population of weeds and was allowed to soak for a period of 11 days before processing. The treatments applied were as follows:

Code	Depth in inches	Impeller rpm
C	-	--
D_1S_1	½	1400
D_1S_2	½	1870
D_1S_3	½	2600
D_1S_4	½	3470
D_2S_1	1	1400
D_2S_2	1	1870
D_2S_3	1	2600
D_2S_4	1	3470
D_3S_1	2	1400
D_3S_2	2	1870
D_3S_3	2	2600
D_3S_4	2	3470

Each of the treatments was replicated three times and within each of the replications the treatments were randomized.

Each plot consisted of a rectangular frame open at the top and bottom, 4 inches wide by 25 inches long so that each contained 100 square inches. Three days after the treatments were applied all of the plots were watered lightly to keep the surface from drying out before the weed seeds had a chance to sprout.

In order to get the correct depth of processed soil, each plot was partly filled with unprocessed soil and then filled to the top with the correct depth of processed soil. Thus, the depth of processed soil was controlled quite closely, and since the soil was placed in the plots manually, there was very little chance of it being mixed with any soil from another treatment. This last item was one of the most difficult variables to control in the field and made comparison of treatments difficult.

Results. Weed counts were made eleven days after the treatments were applied. Grass and broadleaf weeds were counted separately in order to determine whether or not there might be any differential killing effect by the centrifugal machine. The complete data for this test are shown in Appendix Table VII.

Fig. 16 is a photograph of the second replication taken 12 days after the treatments were applied. It is apparent that there are some differences in the treatments.

A scatter diagram is shown in Fig. 17 comparing the number of grass and broadleaf weeds in the various plots. It was thought that this ratio might change as the speed of

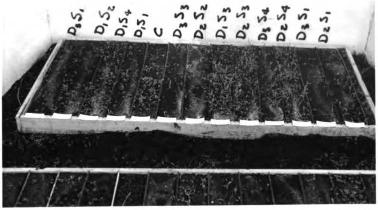


Fig. 16. Photograph of weed growth 12 days after treatments were applied
Greenhouse tests with centrifugal machine on muck soil.

the impeller was increased, but this is apparently not true. In other words, there was not any differential effect so far as treatment was concerned and the ratio remains constant. The curve in Fig. 17 was sketched in by eye.

A statistical analysis of this data was made and is shown in Appendix Table VII. It should be noted that impeller speed is highly significant, but that the depth of processing appears to have no effect. If the depth of processing had been much less then it might have had an effect.

Even though the speed of the impeller was highly significant, the results were not those desired. Fig. 18 shows the

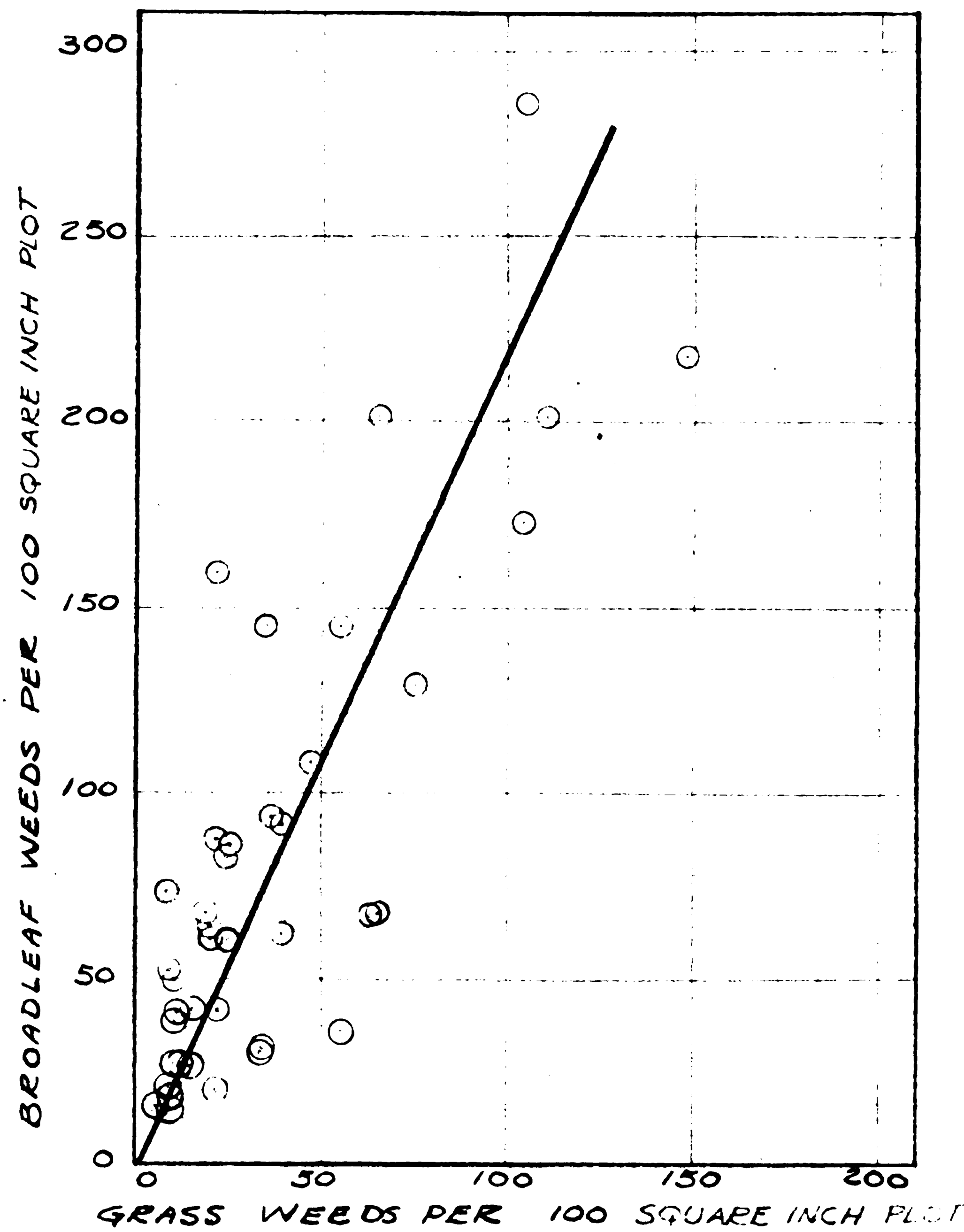


FIG. 17 SCATTER DIAGRAM OF NUMBER OF GRASS AND BROADLEAF WEEDS PER PLOT. GREENHOUSE TESTS WITH CENTRIFUGAL MACHINE.

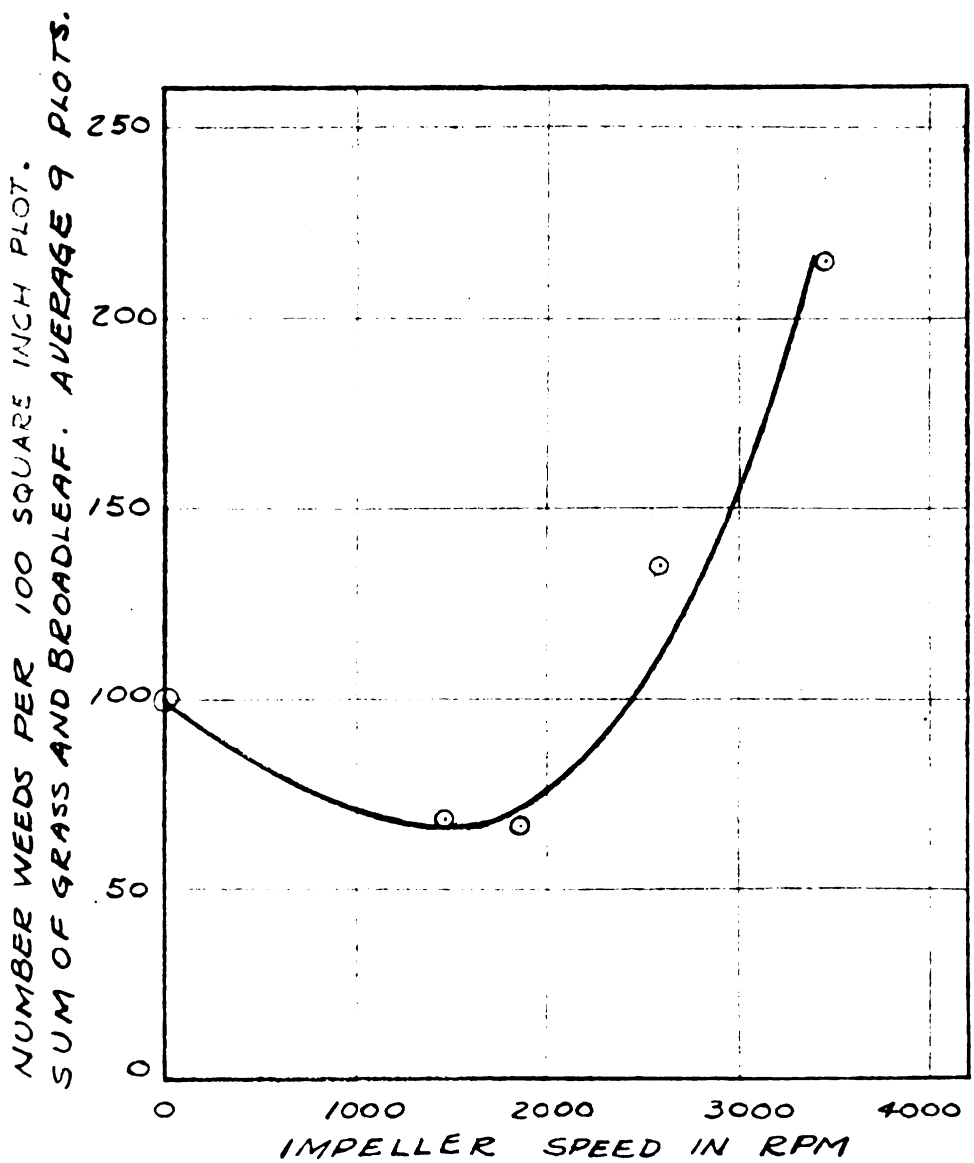


FIGURE 18 EFFECT OF IMPELLER SPEED ON AVERAGE NUMBER OF WEEDS PER PLOT ON 11 TH DAY AFTER PROCESSING.

results of plotting impeller speed against average weed count. The point of the curve represented by zero speed is the check plot. There was a decided drop in the weed count at 1400 and 1870 rpm, but at the higher speeds this trend was reversed.

Impact device tests

One of the problems involved in using the centrifugal machine is that there is no convenient way to actually measure the power absorbed by the soil. As a result the soil particle velocity and the energy per unit weight of soil could not be determined except by approximation. The soil particle velocity could be calculated rather closely if the coefficient of friction for the soil in question was known, but for muck soil this information was not available.

A more basic way of approaching this problem of mechanically sterilizing the soil was to use an impact device by which a predetermined amount of energy could be applied to a known weight of soil. The impact device shown in Fig. 19 was constructed for this purpose.

The impact device consists of a weight of 82.2 pounds which can be lifted to a height of eight feet. It is guided by 2 one-inch pipes which are welded to a steel plate which in turn is bolted to the floor. The weight is lifted to the desired height by a fork lift truck which can be seen in the background in Fig. 19.

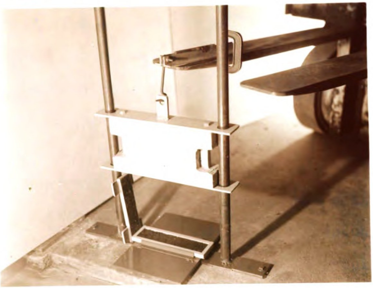


Fig. 19. Impact device for mechanically treating soil to devitalize the entrained weed seeds

The die to hold the soil during the impact is 10 inches long by 2.32 inches wide by 0.5 inch deep. When full the die holds about 114 grams of muck soil or about 215 grams of mineral soil.

The following treatments were applied to both mineral and muck soil, and replicated three times in both cases.

Code	Depth of soil in inches	Drop height in inches
C	check	
d_1h_1	1/8	4.5
d_1h_2	1/8	9.0
d_1h_3	1/8	18.0
d_1h_4	1/8	36.0
d_1h_5	1/8	68.0
d_2h_1	1/2	4.5
d_2h_2	1/2	9.0
d_2h_3	1/2	18.0
d_2h_4	1/2	36.0
d_2h_5	1/2	68.0

The treatment of the 1/8 inch depth of soil consisted of four pooled samples so that the amount of soil for the 1/8 inch treatment and the 1/2 inch treatment were the same.

The hammer which in Fig. 19 is standing on end beside the die was made to fit inside the die with about 1/64 inch clearance.

Both the muck soil and mineral soil used in this experiment were taken from fields badly infested with weeds. The moisture content of the muck soil was approximately 150 percent and the mineral soil was approximately 15 percent.

The treated soil samples were each placed in a 12-ounce cottage cheese carton and pressed with a weight which applied a pressure of approximately three psi. The open cartons were placed in a greenhouse and the soil was watered daily so that the surface remained moist.

The results of these two tests are shown graphically in Figs. 20 and 21. Because of the small size of each treatment the total number of weeds in each carton was quite small.

Discussion of greenhouse tests

There appeared to be no selective effect upon the grass weeds and the broadleaf weeds when using the centrifugal machine at various speeds. This is indicated by the straight line relationship between the grass and broadleaf weeds as the number of each increased.

When using the centrifugal soil processing machine to treat muck soil in the greenhouse the effect was to decrease

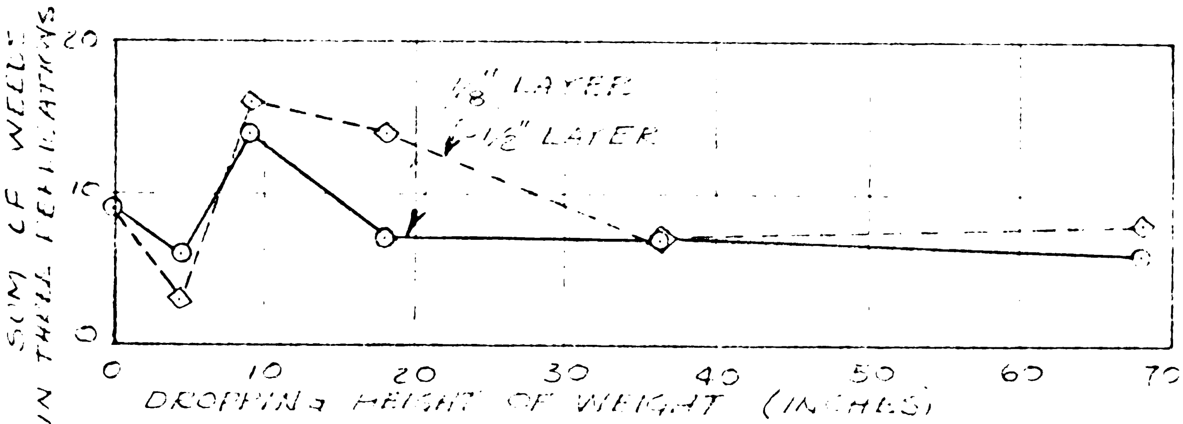


FIG. 20 EFFECT OF IMPACT DEVICE SOIL TREATMENTS UPON WEED COUNTS IN MINERAL SOIL 11 DAYS AFTER TREATMENT.

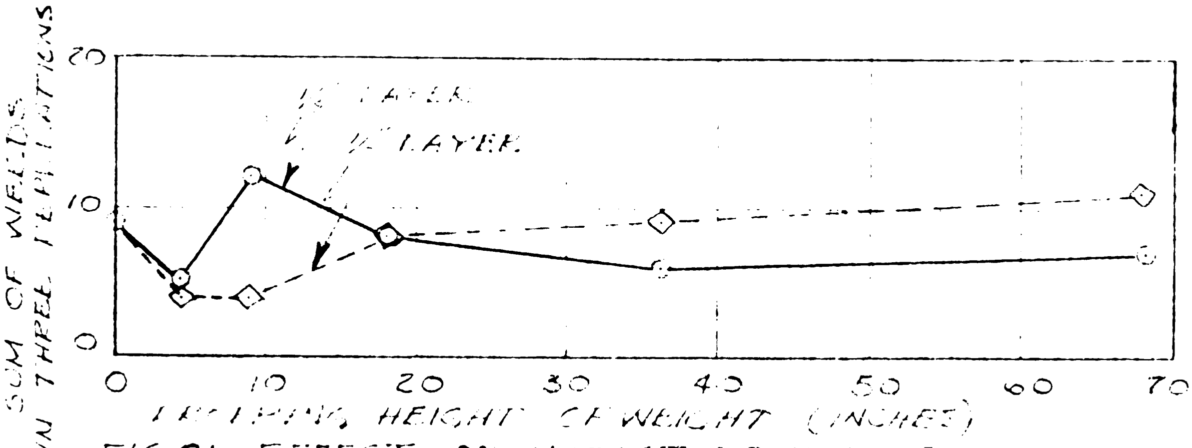


FIG. 21 EFFECT OF IMPACT DEVICE SOIL TREATMENTS UPON WEED COUNTS IN MUCK SOIL 14 DAYS AFTER TREATMENT.

the total number of weeds when the impeller was running at slow speeds, while at high speeds the number of weeds was significantly increased. There are two possible explanations for this result.

1. The data may be from a sampling freak, but this possibility is rather remote since the "F" test shows that the effect of impeller speed is highly significant.

2. An explanation which seems much more reasonable is that there may be considerable scarifying of the hard-seeded weed seeds at the higher speeds, while at the low speeds the germinating weed seeds are killed. It should be remembered that muck soil was used for this test. It is reasonable to assume that the abrasive action of mineral soil would cause much more damage to the weed seeds than muck soil, and therefore, the expected results may be considerably different.

It was quite disappointing to find that there was no effect on the weeds when using the impact device. The range in the amount of energy being imparted to the soil was much greater with the impact device than it was with the centrifugal machine. Using the impact device, the energy ranged from approximately 60 foot-pounds per pound of soil to 7000 foot-pounds per pound of soil. The energy imparted to the soil in the centrifugal machine was about 1100 foot-pounds per pounds of soil when the impeller turned at 2600 rpm.

Compared to the diameter of a weed seed, the thickness of soil in the impact device was quite thick. This may have protected the weed seeds during the impact by supporting the weed seeds on all sides. In the centrifugal machine the layer of soil striking the impact plate was much thinner and therefore the weed seeds received much less protection. Also in the centrifugal machine there was a shearing and abrasive effect because the seeds would hit the impact plate at an angle of roughly 40 degrees from the tangent.

Part IV

Field Tests in 1954

Changes in the centrifugal field machine

After using the centrifugal field machine in 1953 it was obvious that its functional design could be improved.

When using it on mineral soil there was a tendency for soil to build up on the impact plate so that the impeller actually rubbed on the deposit of soil. This was improved by placing the impact plate at a 30 degree angle from the vertical. Reference to Figs. 22 and 25 will show how this was accomplished. With the impact plate at an angle, the soil particles are directed downward when they hit thereby keeping the impact plate clear. According to Kinch (20) this soil deposit on the impact plate had no effect on the damage to the seeds which he studied. However, in the 1953 field machine it did build up so much that it had a serious clogging effect. The change in the impact plate made it similar to the design of the impact plate of the ENTOLATOR shown in Fig. 1.

Another difficulty experienced was in maintaining a constant depth with the soil pick-up rotor. It was mentioned in the review of literature that it was desired to process a strip of soil approximately three-fourths of an inch deep, but because the soil pick-up rotor was attached rigidly to the frame of the planter in 1953 it did not closely follow

Fig. 22. Redesigned impeller and impact plate

the contour of the soil. Reference to the schematic diagram in Fig. 25 and the photograph in Fig. 23 shows how this difficulty was overcome. The soil pick-up rotor and suspension were redesigned so that the soil pick-up rotor would float with respect to the soil surface by use of a parallel linkage and an adjustable depth gage wheel.

In the 1953 field tests Krilium was added to the processed soil by manually shaking it onto the rock screen as the machine was traveling across the field. The accuracy of this method was questionable. A knapsack sprayer was added in 1954 to spray the soil conditioner and herbicides onto the rock screen before the soil had been mechanically processed.

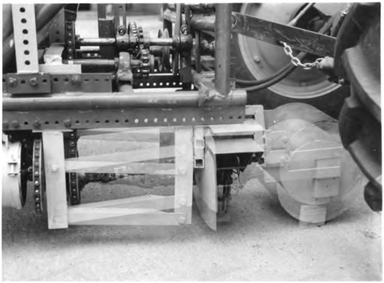


Fig. 23. Double exposure showing the floating action of the soil pick-up rotor
Elevator removed.

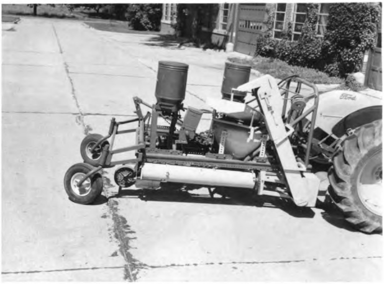


Fig. 24. Photograph of the complete centrifugal field machine as used in 1954

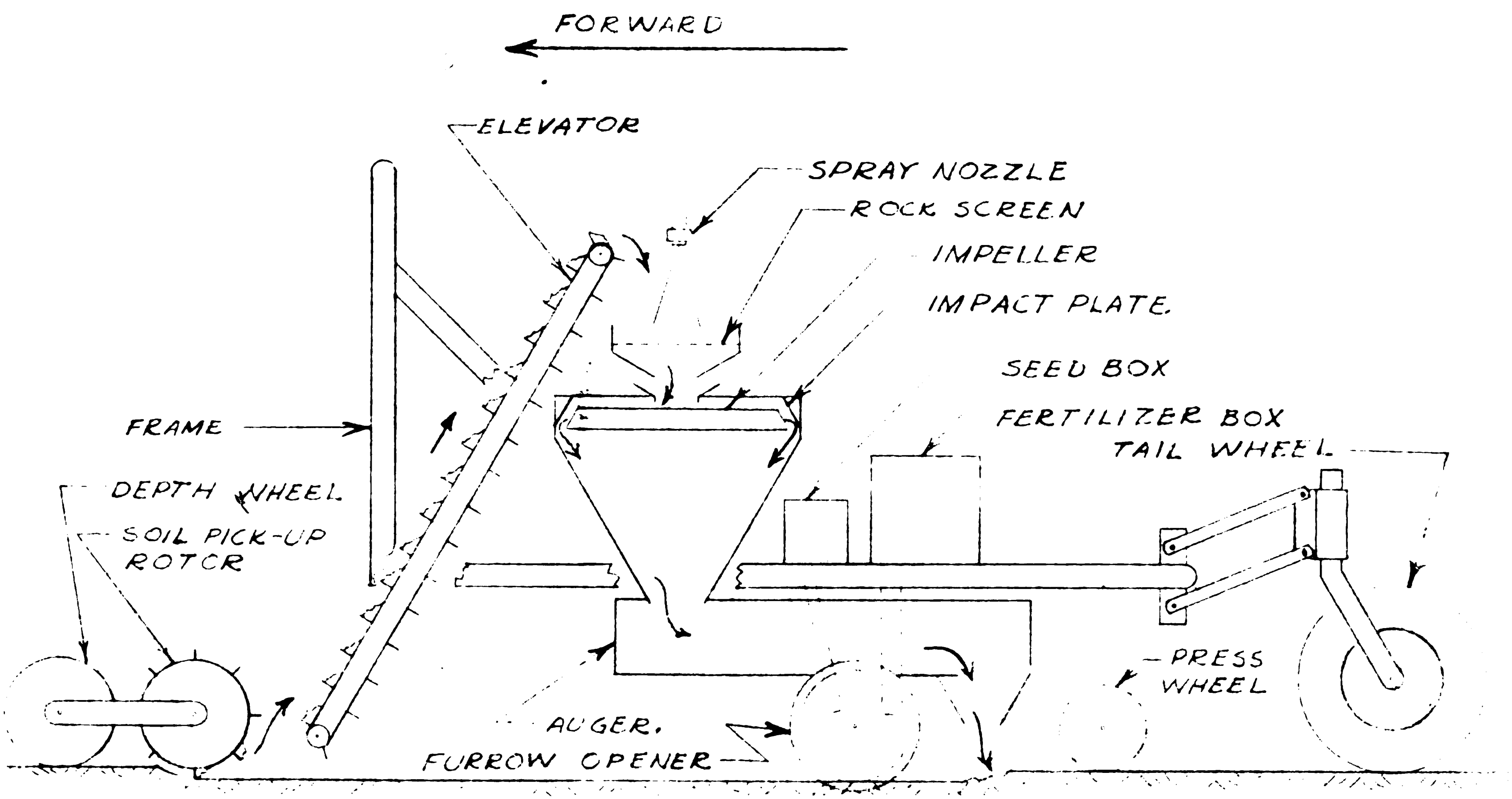


FIG. 25 SCHEMATIC DIAGRAM OF 1954 SOIL PROCESSING MACHINE

To avoid any possibility that emergence of the sugar beet seedlings might be affected by a lack of fertilizer two fertilizer boxes were added to place the chemical fertilizer with the seed at a depth of one and one-fourth inches below the surface. They were calibrated and adjusted to apply approximately 200 pounds of 4-16-16 fertilizer per acre.

In the 1953 field tests the processed soil was replaced in front of the furrow opener. After the 1953 tests it was thought that replacing the soil in front of the furrow opener might have resulted in some contamination of the processed soil because of some unprocessed soil having been picked up by the furrow openers from below the processed soil and then dropped on top of the processed soil. The easiest way to correct this was to add an auger to move the processed soil from the impeller housing to the rear of the furrow opener to be followed by the press wheel. Obviously a better way to have accomplished this would have been to locate the soil processing impeller housing behind the planter furrow opener, but to do so after the machine had been constructed would have required much work and time. The use of the auger appeared to be functionally satisfactory, and therefore was added.

During the 1953 field tests a tractor was used which traveled approximately 2.8 mph in low gear at an engine speed of 1500 rpm. It was obvious when using it that it did not have sufficient power to always maintain correct engine speed when processing a strip of soil three-fourths of an inch deep by five inches wide.

By referring to Appendix I it can be seen that the soil particle velocity is approximately 275 fps when the impeller runs at 2600 rpm. Under the above conditions approximately 7.4 pounds of soil per second would be processed. It can be shown that the theoretical power under these conditions would be 15.8 hp to run the impeller. Since some power was needed to run other parts of the machine and to propel the tractor, it is conceivable that the requirements might exceed the power available from a Ford tractor.

For the 1954 field tests it was decided to use a different Ford tractor which had a special transmission which allowed the tractor to travel at 0.9 mph in low gear at 1500 rpm engine speed. At this speed the power needed was approximately one-third of what was required in the 1953 field tests.

These changes just described are shown in Figs. 24 and 25.

Variables in the 1954 field tests

From an examination of the 1953 field tests and the greenhouse tests which followed, it appeared that the mechanical treatments alone have very little or no beneficial effect for controlling weeds.

It was therefore decided to devote the 1954 field work to a study of mechanical treatments in combination with chemical treatments.

It was thought that this machine offered an excellent means for mixing a soil conditioner with a narrow strip of soil. In the 1953 field tests this appeared to give a promising increase in the emergence of sugar beets, therefore it was decided to enlarge upon these tests.

It had been suggested that there was a possibility that some herbicides might be more effective if thoroughly mixed with a layer of soil instead of being sprayed on the soil surface as is the usual custom. The hypothesis is that there would be more area of the weed in contact with the herbicide and therefore there would be a better chance of killing it. In addition it was thought that the mechanical action upon the weed seeds would tend to make them more susceptible to injury by the herbicide.

In summary the variables in the 1954 field tests were as follows:

1. Two soils (Brookston clay loam and muck)
2. Five herbicides (CMU, CIPC, TCA, Dalapon, Endothal)
3. Three herbicide rates
4. Two impeller speeds (1730 and 2600 rpm)
5. Three Krilium rates (18, 36, and 72 pounds per acre) (for crust control, Monsanto recommends 18 pounds per acre)
6. Two crops (sugar beets and onions)

The herbicide rates were determined by using the rate suggested by the manufacturer plus one rate greater and one less.

Muck soil field tests

It was decided to again include tests on muck soil because there is a greater weed problem on muck soils than on mineral soils and also because muck soil is more adaptable to mechanical treatments than mineral soil.

The procedure in these tests was as follows: The depth gage wheel in front of the soil pick-up rotor was adjusted to pick up a strip of soil three-fourths of an inch deep. This strip was approximately five inches wide and in the shape of a segment of a cylinder.

The furrow openers were adjusted so as to plant the seed approximately 1.25 inches below the surface for both the treated and the untreated row. Since the machine was originally constructed as a two-row planter with only one row being treated there were as many check rows as there were treated rows. The row spacing was fixed at 26 inches.

The planter was adjusted to plant approximately 96 sugar beet seed segments per 100 inches in both treated and untreated rows. The sugar beet seed used was US 400.

The same planter box seed plates were used for onion seed, and since the seed was smaller and the adjustment was not changed there were approximately 200 onion seeds planted per 100 inches.

To pull the planter a Ford tractor was used which had a 3 to 1 underdrive so that in low gear with the engine running at 1500 rpm the ground speed of the tractor was approximately 0.9 mph.

Each treatment consisted of one 300-foot row from which four samples were taken.

The moisture content of the soil was not ideal for these tests or for the growth of sugar beets and weeds. Only 0.3 inch of rain fell from June 1 to June 29. The sugar beet seed was planted on June 14, 15 and 17.

The results of these tests are shown graphically in Figs. 26 and 27. The original data is in the Appendix. A more complete description of the herbicides used is in the Glossary.

It was assumed that the weed seed population and the soil were uniform, and that it would not be necessary to randomize each treatment within each block. However, it was obvious when looking at the plots three weeks after the treatments had been applied, that there was considerable variation in the weed population in the field. It was observed that there was more variation due to location in the field than to treatments so that Fig. 26 is not a true representation of the effects of the treatments. In other words, the treatments also include an effect due to location in the field which in this case is impossible to separate from the treatments.

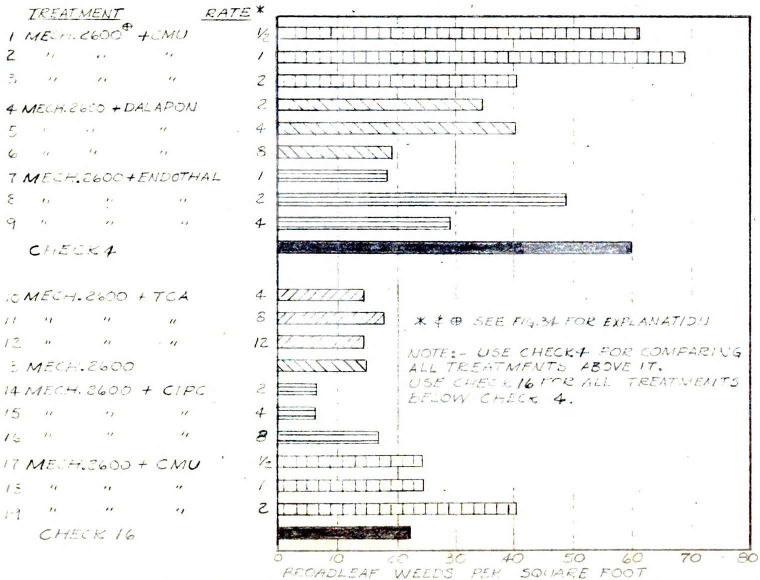


FIG. 26 NUMBER OF BROADLEAF WEEDS 25 DAYS AFTER TREATMENT AT PLANTING TIME ON MUCK SOIL.

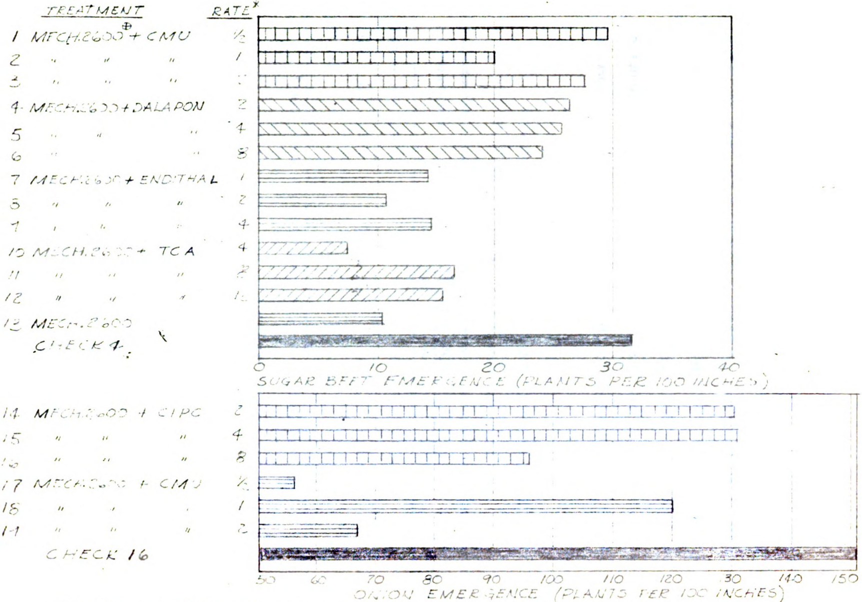


FIG. 27 EMERGENCE WITH VARIOUS TREATMENTS ON MUCK SOIL.
*$⊕ SEE FIG.34 FOR EXPLANATION.

The check plots used for comparison were not selected at random. The entire area that had been planted to sugar beets and onions was divided into two areas which by observation apparently had different weed populations. From the center of each of these two areas a check plot was selected to be used in comparing other treatments in that area.

For comparison Table III is included. The data are from an unpublished report by Grigsby (11) and is the only information which could be found to compare with Fig. 26.

TABLE III

EFFECT OF PRE-EMERGENCE HERBICIDE TREATMENTS*

(Sugar beets grown on muck soil)

Treatment	Weeds per square foot			Percent of total
	Broadleaf	Grass	Total	
TCA - 10 lbs/A	37	2.6	39.6	75
TCA - 20 lbs/A	14.6	0	14.6	28
Check	46.4	6.3	52.7	100

*Data from unpublished report by Grigsby (11).

By comparing Fig. 26 and Table III it is apparent that the percentage reduction in weeds by using mechanical treatment plus TCA is no greater than TCA alone.

When using CMU, for example, with the mechanical treatment the weed counts were actually greater than the check plots in five out of the six treatments. Since it was not possible to calculate the LSD it is not possible to state whether or not any one treatment is significantly different from another. However, since most of the treatments have roughly about the same weed counts as the check, it would appear that the combination of mechanical treatments plus the herbicides is no better than the herbicides alone. Therefore it would seem that the combination of mechanical plus herbicide is less effective than the herbicide by itself. A possible explanation for this apparent phenomenon is that the organic matter in soil "ties up" or neutralizes the herbicides before they have an opportunity to affect the weeds.

This possible neutralizing effect seems to also be an explanation for the small reduction in the emergence of sugar beets even at the rate of two pounds per acre of CMU which on mineral soil applied to the surface of the soil is usually fatal to sugar beets (see Fig. 34).

The emergence of the sugar beets and the onions shown in Fig. 27 is of no particular value in this test since the weed control was not an improvement over that which could have been obtained by surface application of the herbicide. However, had there been a significant improvement in the weed control by any of the herbicides then it would have been useful information in determining the tolerance limit of the sugar beets to that particular herbicide in combination with the mechanical treatment.

Mineral soil field tests

The procedure in the mineral soil field tests was much the same as it was in muck soil with the following exceptions. There were no tests made on onions on mineral soil and therefore the chemical CIPC was not used. Two impeller speeds were used whereas on muck soil only one was used. On the muck soil it was impossible to use the fertilizer boxes because there was not enough traction for the drive wheel to turn both the fertilizer boxes and the planter boxes. Therefore the fertilizer boxes were disconnected. However, on the mineral soil the traction was adequate so fertilizer was applied at the same time at the rate of 200 pounds of 4-16-16 per acre in the same furrow with the seed. In Part II it was mentioned that in the 1953 field tests the use of Krilium resulted in a considerable increase in the emergence of the sugar beets. In the 1953 tests Krilium 9 was used, whereas in the tests being described the newer Krilium 212 was used since it could be sprayed and therefore could be used more easily. According to Monsanto Chemical Co., Krilium 212 is two to five times more effective than Krilium 9.

The original data and the statistical analysis for the mineral soil tests are shown in the Appendix.

A clear picture of the process to which the soil is subjected is shown in Fig. 28. At (a) the strip of soil to be processed has been picked up and at (b) the sugar beet seed

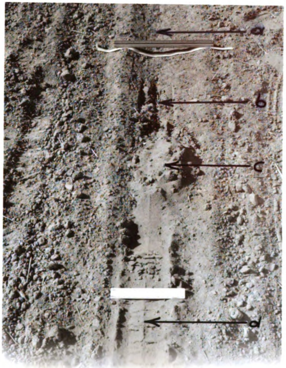


Fig. 28. Steps in mechanically processing soil

has just been planted. At (c) the processed soil has again been deposited upon the ground after the seed has been planted. At (d) the soil has been compacted by the press wheel. In this photograph the movement of the machine is away from the observer.

The next photograph (Fig. 29) was taken a week after a 2.5-inch rain. The processed row on the right received a mechanical treatment plus one pound per acre of CMU. It is obvious that the mechanical treatment has increased the amount of crusting of the soil. The crusting is not severe, but is obviously more than the check row C on the left. No

Fig. 29. Comparison of check row and treated row

attempt has been made here to evaluate this crusting except by the emergence of the sugar beets.

Figs. 30 and 31 show the damage to the structure more clearly. The first photograph (Fig. 30) was taken immediately after the soil was processed, while Fig. 31 is a photograph taken one year after the soil was processed. It is interesting to note that in this second photograph of soil structure damage the soil has partially reaggregated while it remained in a closed container with no other treatment. This would indicate that the damage to the soil structure is not permanent.

Fig. 30. Soil structure damage immediately after processing

Fig. 31. Soil structure damage one year after processing

In the mineral soil test each block was randomized so that in the statistical analysis the effect of location in the field could be removed from the treatment effect.

Figs. 32 and 33 summarize the weed counts on the mineral soil. It is obvious that the herbicides have a greater effect on mineral soil than on muck soil. The LSD is rather large, yet most of the treatments were significantly lower than the check plots. To have made this test more complete the chemical tests by themselves should have been included, but this would have created more work than could have been accomplished in the allowed time.

For comparison purposes the work of Grigsby (12) and Ilnicki (17) is included in Tables XVI and XVII in the Appendix. However, in this form these tables are somewhat difficult to compare with Figs. 32 and 33 therefore the information from the two tables and the two figures has been combined into Table IV for easy comparison.

TABLE IV

SUMMARY OF FIGS. 32 AND 33 COMPARED WITH TABLES XVI* AND XVII*

		Sum of grass and broadleaf weeds expressed as percent of check	
		Herbicide alone	Herbicide plus mechanical
TCA	10 lbs/acre	48	26
CMU	½ lb/acre	70	108
Endothal	2 lbs/acre	50	94
Endothal	4 lbs/acre	42	110

*From data by Grigsby (12) and Ilnicki (17) respectively.

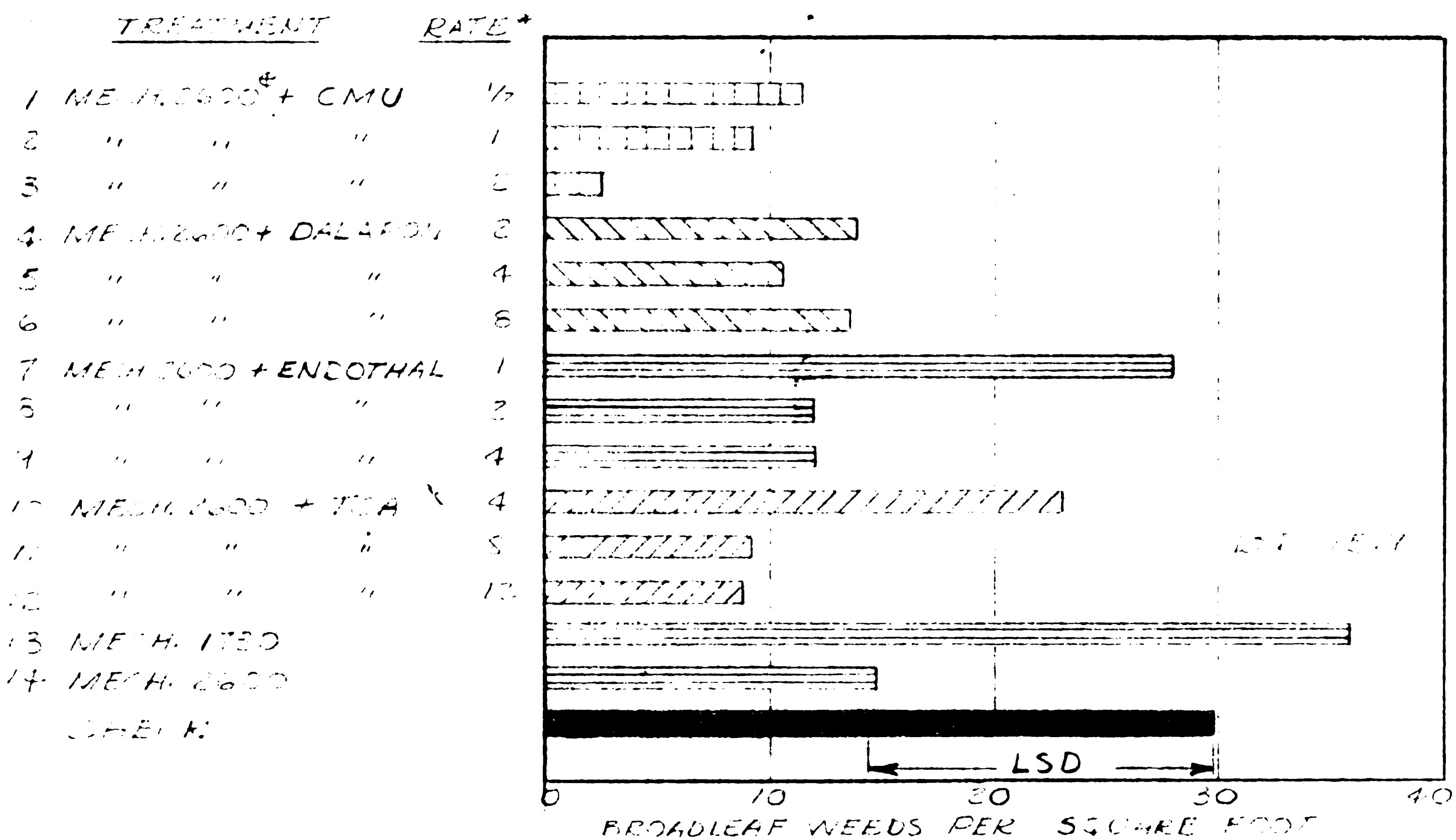


FIG. 32 NUMBER OF BROADLEAF WEEDS 22 DAYS AFTER TREATMENT OF MINERAL SOIL AT PLANTING TIME.

* RATE IN POUNDS PER ACRE OF TREATED SOIL.

⊕ MECH. 2600 = MECHANICAL TREATMENT AT 2600 RPM.

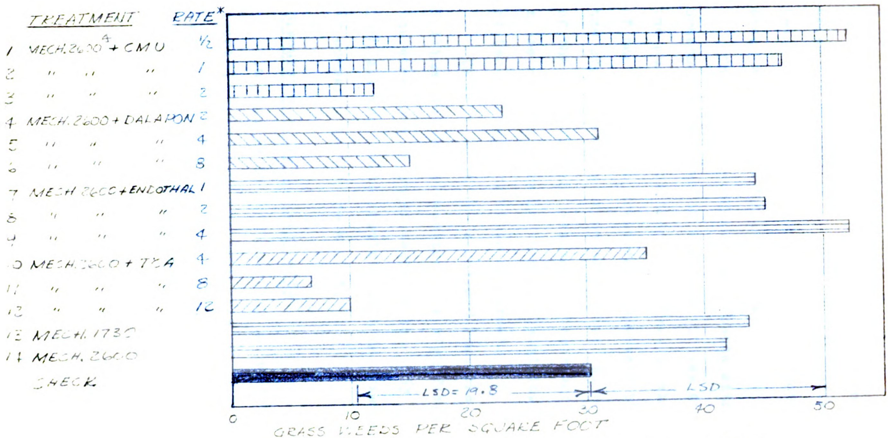


FIG. 33 NUMBER OF GRASS WEEDS 22 DAYS AFTER TREATMENT OF MINERAL SOIL AT PLANTING TIME.

* RATE IN POUNDS PER ACRE OF TREATED SOIL.

⊕ MECH.2600 = MECHANICAL TREATMENT AT 2600 RPM

Only four of the treatments could be compared, but these are sufficient to show that the effect of the mechanical treatment in combination with the herbicides is no greater than the chemicals by themselves.

The emergence of the sugar beets with the various treatments is shown in Fig. 34. It was stated earlier that the purpose of this information was to show the tolerance of the crop to the treatment. However, the emergence of the sugar beets is of no particular value since the combination of the herbicide and mechanical treatments has been shown to be no more valuable than the herbicide treatments alone as far as weed control is concerned.

In Part II it was mentioned that the mechanical plus Krilium treatments resulted in a significant increase in the emergence of sugar beets in the 1953 tests. However, in 1954 all treatments resulted in a decrease in the emergence as compared to the check plot.

<u>Discussion of 1954 field tests</u>

In Fig. 33 it is disturbing to note that most of the treated plots contained more grass than the check plot. It is possible that this was the result of a mischance in sampling of the check plot, or perhaps the scarifying effect on the weed seeds more than offset the effect of the herbicides.

In three of the four comparisons on mineral soil the

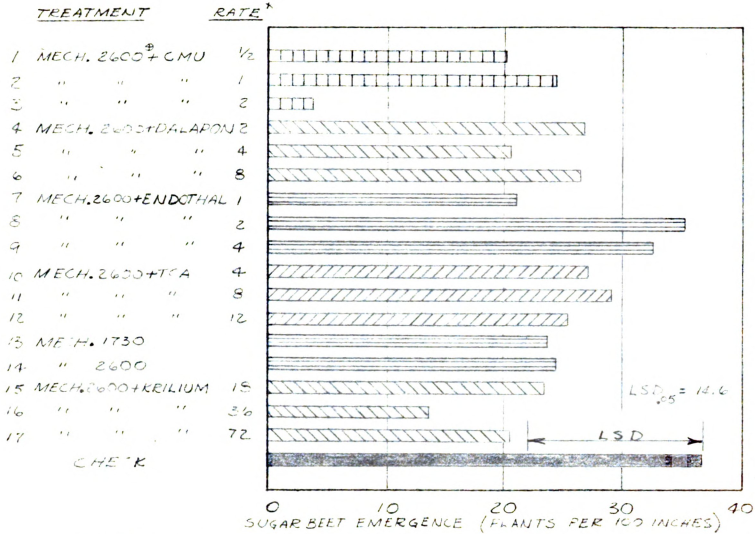


FIG. 34 EMERGENCE OF SUGAR BEETS WITH VARIOUS TREATMENTS ON MINERAL SOIL AT PLANTING TIME.

* RATE IN POUNDS PER TREATED ACRE.

⊕ MECH. 2600 = MECHANICAL TREATMENT AT 2600 RPM IMPELLER SPEED.

combination of herbicide plus the mechanical treatment resulted in less weed control than the herbicide alone. In one case the opposite was true. When TCA at 10 pounds per acre was applied in combination with the mechanical treatment it resulted in better weed control than the herbicide alone. However, since this is an isolated case it would appear, if we consider all the paired data, that the mechanical treatments did not add anything to the herbicide treatments.

In Fig. 32 an interesting, but disconcerting phenomenon is observed. The mechanical treatment alone at 1730 rpm resulted in a greater broadleaf weed count while at the higher speed of 2600 rpm the weed count was much less than the check plot. In neither case is the difference from the check plot significant. However, the difference between the two mechanical treatments is significant. The disconcerting aspect of this phenomenon is that the result is opposite to that obtained in the greenhouse tests using muck soil (see Fig. 18).

The emergence of the sugar beets is shown in Fig. 34. It should be noted that all the treatments reduced the emergence of the sugar beets as compared with the check plot. However, in only one-third of the treatments was the reduction in emergence significant.

A reduction in the emergence of the sugar beets as a result of some weed control treatment is not necessarily serious. A reduction in the population of the crop being

grown will not necessarily reduce the yield unless the population drops below the optimum. In the case of sugar beets the optimum population is about one plant per ten inches of row when the rows are spaced 28 inches apart. However, if the weed control treatment seriously stunts the plants, then the yield may be reduced even though the plant population is at the optimum. A better measure of the effect of the weed control treatment upon the crop being grown is to actually measure its yield, but time did not permit this. Therefore, the next best measure of the effect of the treatment upon the crop was used. That next best measure is the emergence of the planted crop.

The treatments of Krilium plus mechanical processing reduced the emergence for all three rates of Krilium. Two of the three Krilium treatments significantly reduced the emergence. This reduction in emergence is in contrast to the results obtained in 1953 when the Krilium significantly increased the emergence of sugar beets. In 1953 Krilium 9 was used while in 1954 Krilium 212 was used.

No explanation can be given for the fact that the effect of the Krilium plus mechanical processing in 1953 was opposite to the effect in 1954. The weather may have had an effect. In 1953 a one-half inch rain fell soon after planting followed by dry weather. In 1954 the planting was followed by two weeks of dry weather and then a 2.5-inch rain fell. There is also the possibility of a mischance in sampling.

CONCLUSIONS

1. There was no reduction in the weed population in the 1953 field tests when using the centrifugal machine to process muck and mineral soil in the field.

2. A significant increase in the emergence of sugar beets was obtained in the 1953 field tests when the mechanically processed soil was mixed with Krilium 9 at the rate of 0.1 percent by weight of the soil processed.

3. In the greenhouse tests the centrifugal machine significantly decreased the number of weeds at low impeller speeds and significantly increased the number of weeds at high impeller speeds when processing muck soil.

4. No significant changes in the weed population could be detected when using the laboratory impact device to process the soil. Neither the height from which the weight was dropped or the thickness of the soil being processed had any effect.

5. During the 1954 field tests the mechanical treatments alone resulted in no significant weed control in both muck and mineral soil.

6. During the 1954 field tests most of the chemical treatments in combination with mechanical treatments significantly decreased the weed population. However, the decrease in weed population was no greater than that obtained by chemical treatments alone.

7. During the 1954 field tests the Krilium 212 soil treatments applied by use of the centrifugal machine significantly reduced the sugar beet emergence in two of three rates. This is in contrast to the 1953 field tests in which the emergence was increased when using Krilium 9.

8. The review of literature indicates that for each seed there is an impact velocity which will reduce the germination of that seed a specified amount depending upon its moisture content.

DISCUSSION AND RECOMMENDATIONS FOR FUTURE WORK

Although the data presented here is almost entirely negative, it is felt that the possibilities have not been exhausted for using mechanical energy to process soil for weed control.

1. Research most certainly should be continued on the engineering aspects of weed control with emphasis upon the control of those weeds which grow in the row.

2. Equipment should be devised to subject the soil to shear to determine its effect upon the weed seeds.

3. Tests should be conducted with mineral soil similar to those described in Part III of the investigation using the centrifugal machine at a wider range of impeller speeds.

4. Static crushing tests should be made on several sizes of seeds including weed seeds to determine the force and energy required to fatally crush the seeds.

5. If the equipment can be devised, impact velocity tests on various seeds should be made to determine the percent reduction in germination. These impact velocity tests should determine the effect of seed size and the moisture content as well as the impact velocity upon germination reduction. Seventy-five to 100 percent germination reduction would be required for satisfactory weed control. However the

same type of information applied to grain grown for seed should include the range from zero to 20 percent reduction in germination. This type of information applied to field crops would be useful in the design and operation of seed handling and processing equipment including combines.

6. In order to use the type of information listed under item 5 for weed control, it would be necessary to determine the equilibrium moisture content of weed seeds in the soil.

7. When mechanically processing the soil, the damage to the soil structure becomes important, however no attention should be given to this subject until a practical method has been found to mechanically sterilize the soil.

APPENDIX

Mathematical Analysis of Soil Particle Velocity Attained when Accelerated on a Centrifugal Impeller

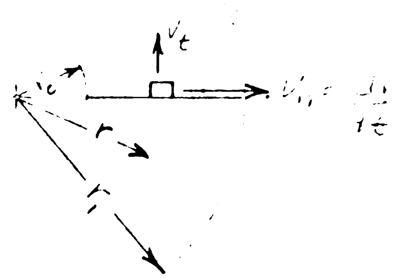
Kinch[20] derived this equation of motion (1)

$$a_c - \mu \frac{V_c^2}{R_c} + 2\mu\omega V_c - r\omega^2(\cos\alpha + \mu\sin\alpha) = 0 \qquad (1)$$

for a particle being accelerated by a centifugal blade rotating on a vertical axis. This equation is a general equation which considers the shape and the length of the blade, but does not consider air resistance. For a straight radial blade, which the design described in this report closely approximates, he shows that this equation reduces to:

$$\frac{d^2r}{dt^2} + 2\mu\omega\frac{dr}{dt} - \omega^2 r = 0 \qquad (2)$$

This equation applies to a centrifugal impeller illustrated by this schematic diagram.



The solution to equation (2) is:

$$r = C_1 e^{-\omega(\mu+\sqrt{\mu^2+1})t} + C_2 e^{-\omega(\mu-\sqrt{\mu^2+1})t} \qquad (3)$$

and when differentiated yields

$$\frac{dr}{dt} = -C_1\,\omega\left(\mu + \sqrt{\mu^2+1}\right) e^{-\omega\left(\mu+\sqrt{\mu^2+1}\right)t}$$
$$-C_2\,\omega\left(\mu - \sqrt{\mu^2+1}\right) e^{-\omega\left(\mu-\sqrt{\mu^2+1}\right)t} \qquad (4)$$

These two equations (3) and (4) cannot be solved directly for $\frac{dr}{dt}$ in terms of r, but by trial substitution for values of t and by applying boundary conditions, it can be shown that the second term can be ignored when considering slide rule accuracy, so that we have:

$$\frac{dr}{dt} = \frac{r\,\omega}{\mu + \sqrt{\mu^2+1}} \qquad (5)$$

For example, when $r_1 = 10$ inches and $r_2 = 1$ inch,
$\omega = 272$ radians/sec.
$\mu = 0.4$ (coefficient of friction)

then $\frac{dr}{dt}$ = 1840 inches/sec.

The velocity tangent to the impeller is

$V_t = r\omega =$ 2720 inches/sec.

and the total velocity is 3270 inches/sec.

TABLE V

1953 FIELD TEST DATA. MINERAL SOIL PROCESSED WITH CENTRIFUGAL MACHINE

Number of weeds in each sample of 100 in. row by 4 in. wide
Count made on July 22, 18 days after planting

Replication	Treatment							
	S_1K_0	C_1	S_1K_1	C_2	S_2K_0	C_3	S_2K_1	C_4
1	1	0	1	0	0	4	0	1
2	0	3	1	5	2	0	0	5
3	1	2	2	3	2	0	-	-
4	1	5	0	0	1	2	1	1

TABLE VI

ANALYSIS OF VARIANCE OF 1953 EMERGENCE OF SUGAR BEETS ON MINERAL SOIL*

Source of error	Degrees of freedom	Sum of squares	Mean square
Total	19	21,258	
Treatment	5	12,571	2,514
Replications	3	6,401	
Error	11	2,286	208

*See Table I

TABLE VII

WEED COUNT AND STATISTICAL ANALYSIS OF GREENHOUSE TESTS USING CENTRIFUGAL MACHINE ON MUCK SOIL

	Replication 1			Replication 2			Replication 3		
	Grass	Broad-leaf	Total	Grass	Broad-leaf	Total	Grass	Broad-leaf	Total
C	9	30	39	35	146	181	21	62	83
D_1S_1	8	38	46	9	73	82	20	63	83
D_1S_2	8	36	44	22	87	109	19	67	86
D_1S_3	23	43	66	111	201	312	9	52	61
D_1S_4	58	144	202	66	201	267	22	159	181
D_2S_1	6	32	38	40	63	103	25	85	110
D_2S_2	8	21	29	39	92	131	15	42	57
D_2S_3	13	27	40	148	218	366	25	61	86
D_2S_4	76	128	204	104	173	277	105	286	391
D_3S_1	15	26	41	11	41	52	22	42	64
D_3S_2	11	26	37	11	40	51	11	50	61
D_3S_3	54	33	87	35	32	67	36	93	129
D_3S_4	63	68	131	65	68	133	47	108	155

Analysis of Variance of Total Weeds per Plot

Source of error	Degrees of freedom	Sum of squares	Mean square	"F"
Total	35	321,888	9,200	
Replications	2	40,428	20,214	
Speed	3	132,950	44,300	9.5**
Depth	2	29,077	14,500	3.1
S x D	6	15,950	2,660	
Error	22	103,483	4,700	

**Indicates that speed is highly significant or that this value of F is larger than the tabulated value given in Goulden (10) in the 1% column

TABLE VII Continued

Table Summarizing Data from Greenhouse Centrifugal Machine Test

Depth in inches	Impeller speed in rpm				Total	Average
	S_1 1400	S_2 1870	S_3 2600	S_4 3470		
$D_1 = 1/2$	211	239	439	650	1539	128
$D_2 = 1$	251	217	492	872	1832	152
$D_3 = 2$	157	149	283	419	1008	84
Total	619	605	1214	1941	4379	
Average	69	67	135	215		122

TABLE VIII

EMERGENCE PER 100 INCHES. 1954 FIELD TESTS ON MUCK

Treatments 1-13 on sugar beets and 14-19 on onions

Treatment*	Replication 1	Replication 2	Replication 3	Replication 4	Average
1	30	31	30	28	29.8
2	31	21	20	8	20.0
3	32	24	25	30	27.8
4	30	28	22	25	26.2
C_4	35	40	24	28	31.8
5	33	31	13	26	25.8
6	12	32	23	29	24.0
7	6	13	19	19	14.2
8	15	10	10	8	10.8
9	22	4	19	13	14.5
10	4	10	10	6	7.5
11	17	18	11	20	16.5
12	13	19	14	16	15.5
13	6	19	6	10	10.2
14	125	118	106	172	130.2
15	140	147	122	114	130.8
16	103	88	104	89	96.0
C_{16}	194	146	160	104	151.0
17	93	33	46	54	56.5
18	185	139	104	54	120.5
19	100	59	60	50	67.2

*See Fig. 26 for explanation of treatments

TABLE IX

NUMBER OF BROADLEAF WEEDS PER SQUARE FOOT. 1954 FIELD TESTS ON MUCK

Treatment*	Replication				Average
	1	2	3	4	
1	56	58	72	60	61.5
2	81	73	68	55	69.2
3	66	35	28	34	40.8
4	27	33	37	42	34.8
C_4	34	24	57	125	60.0
5	47	33	26	55	40.2
6	15	13	21	28	19.2
7	10	7	24	34	18.8
8	29	30	81	56	49.0
9	56	20	24	17	29.2
10	19	10	13	17	14.8
11	31	17	9	14	17.8
12	22	11	12	13	14.5
13	9	22	18	11	15.0
14	4	12	4	7	6.8
15	6	11	4	5	6.5
16	7	6	10	46	17.2
C_{16}	12	37	23	18	22.5
17	23	48	16	10	24.2
18	10	42	21	26	24.8
19	12	55	81	15	40.8

*See Fig. 26 for explanation of treatments

TABLE X

NUMBER OF BROADLEAF WEEDS PER SQUARE FOOT.
1954 FIELD TESTS ON MINERAL SOIL

Treatment*	Replication					Average
	1	2	3	4	5	
1	18	27	1	8	3	11.4
2	14	8	5	16	3	9.2
3	1	2	2	4	4	2.6
4	22	27	6	12	2	13.8
5	23	15	1	8	6	10.6
6	20	33	4	10	1	13.6
7	30	81	6	18	5	28.0
8	20	13	12	8	7	12.0
9	31	4	19	3	3**	12.0
10	47	30	10	25	3	23.0
11	20	4	7	10	5	9.2
12	11	25	0	7	1	8.8
13	63	83	7	14	13	36.0
14	21	29	3	4	17	14.8
15	21	28	0	25	16	18.0
16	22	26	7	15	13	16.6
17	30**	42	5	19	10	21.2
C	29	67	19	18	16	29.8

*See Fig. 32 for explanation of treatments
**Missing data supplied by Goulden's (10) method

TABLE XI

STATISTICAL ANALYSIS OF BROADLEAF WEED COUNTS ON MINERAL SOIL. 1954 FIELD TESTS

Analysis of Variance
(completed values)

Source of variation	Degrees of freedom	Sum of squares
Total	87	23,381
Treatments	17	5,451
Blocks	4	8,113
Error	66	9,817

Analysis of Variance
(corrected for missing data)

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F"
Total (original)	87	23,008		
- Error (completed)	66	9,817	148.7	
= Blocks + treatments	21	13,191		
- Blocks (unadjusted)	4	7,989		
= Treatments (adjusted)	17	5,202	306	2.06

$$\sigma_{(\bar{T}_i-\bar{T}_j)} = \sqrt{ms\left(\frac{1}{5}+\frac{1}{5}\right)} = \sqrt{148.7\left(\frac{2}{5}\right)} = 7.72$$

$$\text{LSD} = (t)\,\sigma_{(\bar{T}_i-\bar{T}_j)} = (2.0)\ 7.72 = 15.4$$

for comparing any two treatments except 9 and 17

TABLE XII

NUMBER OF GRASS WEEDS PER SQUARE FOOT.
1954 TESTS ON MINERAL SOIL

Treatment*	Replication 1	2	3	4	5	Average
1	47	76	15	47	76	52.2
2	56	48	12	54	64	46.8
3	2	16	4	9	30	12.2
4	19	27	4	35	30	23.0
5	43	30	9	36	38	31.2
6	35	13	3	15	10	15.2
7	22	72	6	79	43	44.4
8	34	34	28	52	78	45.2
9	65	78	38	17	63**	52.2
10	49	33	26	24	44	35.2
11	7	2	4	12	9	6.8
12	10	2	1	15	22	10.0
13	27	53	38	65	36	43.8
14	27	65	24	26	67	41.8
15	28	38	10	76	65	43.4
16	19	64	50	59	51	48.6
17	60**	87	20	76	79	64.4
C	13	39	6	55	38	30.2

*See Fig. 32 for explanation of treatments
**Missing data supplied by Goulden's (10) method

TABLE XIII

STATISTICAL ANALYSIS OF WEED COUNTS OF GRASS ON MINERAL SOIL. 1954 FIELD TESTS

Analysis of Variance
(completed values)

Source of variation	Degrees of freedom	Sum of squares
Total	87	50,263
Treatments	17	23,326
Blocks	4	10,844
Error	66	16,093

Analysis of Variance
(corrected for missing data)

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F"
Total (original)	87	48,920		
- Error (completed)	66	16,093	244	
= Blocks + treatments	21	32,827		
- Blocks (unadjusted)	4	10,652		
= Treatments (adjusted)	17	22,175	1,304	5.3**

$$\sigma_{(\bar{T}_i-\bar{T}_j)} = \sqrt{244\left(\frac{1}{5}+\frac{1}{5}\right)} = 9.93$$

$$\text{LSD} = (t)\ \sigma_{(\bar{T}_i-\bar{T}_j)} = (2.0)\ 9.93 = 19.9$$

for comparing any two treatments except 9 and 17

TABLE XIV

SUGAR BEET EMERGENCE PER 300 INCHES.+
1954 FIELD TESTS ON MINERAL SOIL

Treatment*	Replication 1	2	3	4	5	Average per 100 in.
1	30	39	70	63	99	20.1
2	25	73	82	98	88	24.4
3	1	1	14	3	40	3.9
4	64	130	55	106	46	26.8
5	17	24	89	111	67	20.6
6	23	14	69	95	46	26.5
7	17	17	113	120	48	21.0
8	80	102	131	111	104	35.2
9	33	105	115	132	103**	32.6
10	16	84	116	90	100	27.1
11	61	74	116	116	70	29.2
12	26	84	79	119	73	25.4
13	46	38	83	101	86	23.7
14	67	23	105	106	64	24.3
15	40	35	100	50	124	23.3
16	10	32	81	17	65	13.6
17	29**	30	88	83	107	20.6
C	5	170	142	147	88	36.8

+Sum of three 100-inch samples
*See Fig. 32 for explanation of treatments
**Missing data supplied by Goulden's (10) method

TABLE XV

STATISTICAL ANALYSIS OF SUGAR BEET EMERGENCE.
1954 FIELD TESTS ON MINERAL SOIL

Analysis of Variance
(completed values)

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F"
Total	87	129,662		
Treatment	17	31,444	1,850	1.55*
Blocks	4	19,751		
Error	66	78,467	1,190	

$$\sigma_{(\bar{T}_i - \bar{T}_j)} = \sqrt{1{,}190\left(\frac{1}{5} + \frac{1}{5}\right)} = 21.9$$

$$\text{LSD (300 inches)} = (t)\,\sigma = (2.0)\,21.9 = 43.8$$

$$\text{LSD (100 inches)} = \frac{43.8}{3} = 14.6$$

*The Treatment sum of squares has not been corrected for missing data, but this is not necessary since the correction would make the Treatment sum of squares smaller and therefore "F" would be smaller. "F" is not significant unless greater than 1.8.

TABLE XVI

EFFECT OF PRE-EMERGENCE HERBICIDE TREATMENTS UPON ALL WEEDS IN SUGAR BEETS GROWN ON MINERAL SOIL*

Herbicide	Rate	Number of broadleaf and grass weeds (percent of check)
TCA	5 lbs/acre	67
TCA	10 lbs/acre	48
Endothal	2 lbs/acre	50
Endothal	4 lbs/acre	42
Check		100

*Data from unpublished report by Grigsby (12)

TABLE XVII

EFFECT OF PRE-EMERGENCE HERBICIDE TREATMENTS UPON WEEDS AND SUGAR BEETS GROWN ON MINERAL SOIL*

Herbicide	Rate	Sugar beets (% of stand)	Weed control
CMU	2 lbs/acre	10	---
CMU	1 lb/acre	85	---
CMU	½ lb/acre	100	70 percent
TCA	5 lbs/acre	--	Good grass and smartweed control
TCA	7½ lbs/acre	--	Good grass and smartweed control
TCA	10 lbs/acre	stunted	
TCA	15 lbs/acre	stunted	

*Data from unpublished paper by Ilnicki (17)

GLOSSARY

Definition of units and terms

Impact Velocity - The velocity with which the soil particles and weed seeds hit the impact plate

K E = Kinetic Energy = $\frac{1}{2}MV^2$

Theoretical horsepower = $\dfrac{\frac{1}{2}MV^2/\text{sec.}}{550 \text{ ft-lbs/sec.}}$

where mass is in slugs
and V is in fps

LSD = Least Significant Different
= $(t_{0.05})$ x (Standard Deviation for the difference between two treatment averages)
= Difference for significance between averages of any two treatments unless a one in twenty mischance in sampling has occurred.

Herbicide - A chemical known to be toxic to some chlorophyll-bearing plants

Soil Conditioner - A material which improves the physical properties of the soil

Pre-emergence applications - Those made after the crop is planted but before it emerges

Emergence - The number of plants per 100 inches of row which emerge from the soil and continue to live

Description of chemicals used

Krilium 9 - A soil conditioner made by Monsanto Chemical Co. A carboxylated polymer in powder form.

Krilium 212 - A soil conditioner made by Monsanto Chemical Co. A carboxylated polymer powder soluble in water.

CMU - 3-p-chlorophenyl-1-1-dimethylurea, a herbicide.

CIPC - Isopropyl-N-(3-chlorophenyl) carbamate, a herbicide.

TCA - Trichloroacetic acid, a herbicide.

Endothal - 3,6-endoxohexahydrophthallic acid, a herbicide.

Dalapon - Dichloropropionic acid, a herbicide.

REFERENCES CITED

1. Bainer, Roy and H. A. Borthwick. Thresher and other mechanical injury to seed beans of the lima type. Calif. Ag. Exp. Sta. Bull. 580, July, 1934.

2. Bass, C. M. Viability of injured weed seeds. Proc. Assoc. Official Seed Analysts 30:

3. Borthwick, H. A. Thresher injury in baby lima beans. J. Agr. Res. 44: 503-510, 1932.

4. Bunnelle, Philip R. Combine performance in small legume seed harvesting. Unpublished paper presented at ASAE Annual Meeting. Minneapolis, Minn. June 21-24, 1954. Dept. Agr. Engr., U. of Calif., Davis, Calif.

5. Carleton, Walter M. Principles affecting the performance of mechanical sugar beet planters. Unpublished Ph.D. Thesis. Michigan State College, 1948.

6. Chepil, W. S. Germination of weed seeds; the influence of tillage treatments on germination. Sci. Agr. 26: 347-457, 1946.

7. Cotton, R. R., and J. C. Frankenfeld. Mechanical force for the control of flour mill insects. Amer. Miller, Oct., 1942.

8. French, George W. A double-counter rotating-head mechanical sugar beet thinner. Mich. Agr. Exp. Sta. Quar. Bull. 34: 403-411, May, 1952.

9. Goss, W. L. The vitality of buried weed seeds. J. Agr. Res. 29: 349-392, 1924.

10. Goulden, Cecil H. Methods of statistical analysis. 2nd ed. John Wiley & Sons, Inc., New York, 1952.

11. Grigsby, B. H. Unpublished Annual Report. Weed Division, Bureau of Plant Industry, USDA. Submitted Feb. 1, 1951 from Michigan State College, East Lansing, Michigan.

12. Grigsby, B. H. Unpublished Annual Report. Weed Division, Bureau of Plant Industry, USDA. Submitted Feb. 1, 1953 from Michigan State College, East Lansing, Michigan.

13. Harter, L. L. Thresher injury a cause of baldhead in beans. J. Agr. Res. 40: 371-384, 1930.

14. Heise, A. C. Germination of common ragweed seeds. Proc. Assoc. Official Seed Analysts 35: 67-68, 1944.

15. Heise, A. C. Germination of green foxtail seeds. Proc. Assoc. Official Seed Analysts 34: 48, 1942.

16. Huyett, R. B. Shot peening. Steel Processing 33: 553-557, 1947.

17. Ilnicki, R. D. and Willard, C. J. Unpublished paper presented to North Central Weed Control Conference. Kansas City, Mo. Dec. 8-10, 1953. Workers from Ohio Agr. Exp. Sta. Ohio State Univ., Columbus, Ohio.

18. Johnson, C. E. and Wright, K. T. Reducing sugar beet costs. Mich. Agr. Exp. Sta. Circ. Bull. 215, June, 1949.

19. Keen, Bernard A. The physical properties of soils. Longman, Green & Co., New York, 1931. p. 272.

20. Kinch, D. M. Physical factors affecting the germination vitality of weed seeds. Unpublished Ph.D. Thesis. Michigan State College, 1953.

21. Koehler, Benjamin. Corn seed-coat injuries increase seedling blight. Ill. Agr. Exp. Sta. 9-Year Report, 1938-1947. pp. 28-29.

22. Newhall, A. G. Theory and practice of soil sterilization. Agr. Eng. 16: 65-70, 1935.

23. Nichols, M. L. The dynamic properties of soil. II. Soil and metal friction. Agr. Eng. 12: 321-324, 1931.

24. Porter, R. H. and Katherine Koos. Germination of injured weed and crop seeds. Proc. Assoc. Official Seed Analysts 28: 68-73, 1936.

25. Smith, F. R. Method and apparatus for destroying insect life. U.S. Patent Number 2,339,732, 1944.

26. Splinter, W. E. A consideration of weed control through physical properties of seeds. Unpublished M.S. Thesis.

27. Toole, E. H. and M. Brown. Final results of the duvel buried seed experiment. J. Agr. Res. 72: 201-210, 1946.

OTHER REFERENCES

1. Bainer, Roy and J. S. Winters. New principles in threshing lima beans. Agr. Eng. 18: 205-206, 1937.

2. Chepil, W. S. Germination of weed seeds: longevity periodicity of germination and vitality of weeds in cultivated soils. Sci. Agr. 27: 307-346, 1946.

3. Church, Austin H. Centrifugal pumps and blowers. John Wiley & Sons, Inc., New York, 1944.

4. Cross, Hope. Laboratory germination of weed seeds. Proc. Assoc. Official Seed Analysts 24: 125-128, 1931.

5. Entoleter. Continuous insect control. Engineering specifications. Form No. 3994c-6-47. Entoleter Division. The Safety Car Heating and Lighting Co., Inc., New Haven, Conn.

6. Heise, A. C. Report of sub-committee on the evaluation of weed seeds. Proc. Assoc. Official Seed Analysts 32: 41-42, 1940.

7. Hibbs, Arthur H. and R. B. Dodds. Continuous insect infestation and insect fragment control. Modern Sanitation, Feb., 1950.

8. Hentschel, Herbert E. A study of principles affecting the performance of mechanical sugar beet planters. Unpublished M.S. Thesis. Michigan State College, 1946.

9. Hodgson, J. M. Electrocution of weeds, widely advertized, not successful in Idaho field experiments. Crops and Soils 3: 25, Dec., 1950.

10. Koehler, Benjamin. Corn pericarp injuries and seedling diseases. Phytopath. 36: 403,

11. Koehler, Benjamin. Seed-coat injury in hybrid corn causes yield losses. Ill. Agr. Exp. Sta. Ann. Report, 1937-1938. p. 45.

12. Lambert, D. W., et al. Devitalization of cereal and weed seeds by high frequency. Agron. J. 42: 304-306, 1950.

13. Patten, H. E. Heat transference in soils. U.S. Dept. Agr. Bull. 59, 1909.

14. Swanson, S. L. W. and H. G. M. Jacobson. Influence of cultivation and weed killers on soil structure and crop yield. Soil Sci. 69: 443-457, 1950.

15. Thompson, V. J. Sub-committee report on the viability of injured weed seeds. Proc. Assoc. Official Seed Analysts 31: 70-71, 1939.

16. Whitney, W. A. Mutilated seed - a contributing factor in defective stands of lima beans. (Abstract). Phytopath. 20(1): 134-135, 1930.