

August, 1955

To the Graduate Council:

I am submitting herewith a thesis written by Charles Wesley Brown entitled "Development of Equipment for Spreading Lime and Fertilizer on Steep Slopes." I recommend that it be accepted for 9 quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

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DEVELOPMENT OF EQUIPMENT FOR SPREADING LIME
AND FERTILIZER ON STEEP SLOPES

A THESIS

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The Graduate Council
of
The University of Tennessee
in
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Master of Science

by

Charles Wesley Brown

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CHAPTER I

THE PROBLEM

Statement of the Problem

The purpose of this study was to develop equipment for the application of lime and fertilizer on slopes too steep for the use of conventional commercial machines. This equipment would enable farmers to expand the acreage devoted to improved pastures, increase production of livestock, improve the agricultural economy of the area, and provide protection for the steeper slopes against excessive erosion losses.

Importance of the Study

There were 5.6 million acres of land in plowable pasture in 1945 in the T.V.A. watershed. Of this area, approximately 2.2 million acres were cleared land having a slope of thirty to sixty per cent (11).^{*} This steeper land lies, for the most part, in the upper part of the watershed in the mountainous area of East Tennessee, Western North Carolina, Southwest Virginia and North Georgia.

In the program of rehabilitating and conserving the soil and protecting watersheds against excessive erosion and fertility losses, extensive use is being made of hay and pasture crops. Farmers are given encouragement to establish a balanced farm operation which includes, in

* Numbers in parenthesis refer to similarly numbered references in bibliography at end of paper.

most cases, an increase in the number of livestock and pasture acres. Much of the available acreage for increase is too steep for cultivation since approximately twenty-five per cent of the cleared land is above thirty per cent slope. A majority of this land is already in pasture of a type that could be improved through the proper use of lime and fertilizer. These steep slopes discourage the use of conventional lime and fertilizer distributors which results in the neglect of thousands of acres of potentially good pasture land. If these slopes are neglected and grazed without protective cover, much of the top soil which is so vitally needed for the production of desirable pasture grasses will be lost. The erosion loss is not only economically important to the individual farmer, but it likewise has important implications to T.V.A. in relation to the control of water in the stream and to sedimentation of T.V.A. lakes.

Analysis of the Problem

For the successful completion of this project, it was necessary to design and construct a maneuverable machine with a low center of gravity which could be operated with reasonable safety on steep slopes, and which could transport and apply ground limestone and fertilizer in desired amounts and ratios without previous mixing. Such a machine should be tractor driven or self-propelled.

Review of Related Studies

Although several types of fertilizer application equipment have

been developed by farm machinery manufacturers, by land-grant institutions, and by the U.S.D.A. (2,9,10), there is yet no suitable machine or method for spreading lime and fertilizer on steep slopes. Where only small amounts of high test fertilizers are distributed, airplanes and blowers have been used with some success (3). Neither method, however, appeared promising when distributing ground limestone on small irregularly shaped fields in mountainous terrain. Commercial machines, even when used on level land, were not adequate to distribute finely ground limestone at normal moisture content and showed an excessive variation of output with minor adjustments of rate (6). Further, they will not distribute fertilizer at the same time unless it is mixed into the ground limestone in the right proportion before being placed in the distributor.

A fertilizer distributor operates under a greater number of variable conditions than does any other agricultural machine. Many types are in use and may be classified as those which broadcast the material onto the surface of the ground, and those designed to place the material in rows or bands beneath the surface.

Centrifugal broadcasters meter the material from the hopper and distribute it by horizontally-rotating ribbed discs. Uniformity of the distribution becomes increasingly inadequate as the moisture content of the material increases and is adversely affected by wind (2). Truck bed and manure spreader attachments are generally of this type and are adequate for low-cost, large volume spreading on uniform, level terrain.

Drop-type or full width feed broadcasters have adjustable openings or other metering units spaced at regular intervals along the full length of the hopper. The majority of the commercial machines in use are of this

type and may be classified (9) according to the mechanical principles employed: bottom-delivery distributors--agitator, revolving plate, star wheel, chain, paddle wheel, endless belt, roller, screw; and top-delivery distributors--revolving cylinder, ascending hopper and descending hopper.

While many of the bottom-delivery distributors have a positive action in dispensing a portion of the material, most of them depend at least partially upon gravity to supply the increased flow obtained when the delivery opening is enlarged by means of a gate. Consequently, the delivery rates from most types of distributors are materially affected by changing conditions (the extent of the effects being related to the degree of dependence upon gravity flow). Top delivery distributors operate on the positive-displacement principle so that the discharge rate is independent of most of the variables affecting the bottom-delivery units. Since all types of distributors operate on a volumetric basis, the apparent specific gravity of the material affects the weight rate with any of them (9).

Agricultural limestone varies considerably in aggregate size depending on the process by which it is produced. The finer aggregates, when utilized under farm conditions, tend to acquire a high moisture content and adhere in such a manner as to make accurate metering difficult or impossible. One of the important factors affecting delivery rates is drillability. The drillability or ease of flow is affected by such factors as the hygroscopicity of the material, the relative humidity at which it is stored, the state of sub-division (sizes and shape of particles, presence of lumps, etc.), the apparent specific gravity, and the

compaction characteristics of the material. A measure of the drillability is the angle of repose. When this angle exceeds fifty-five degrees, no free flow can occur; and these materials are usually not drillable. Free flowing fertilizers and dry ground limestone have an angle of repose of approximately thirty-five degrees (9).

The majority of liming materials in the Valley are locally produced (5). Stockpiling of these materials on the farm and at the plant is outdoors where exposure to the weather keeps the materials at a high moisture level. When an attempt is made to spread these materials, their low drillability is manifest in caking or bridging in the hopper. The term "bridging over" is used to describe that phenomena peculiar to some seeds, most fertilizers and all agricultural limestone within certain moisture limits. This effect is observed when these materials are confined and when a withdrawal is affected at the base of the container. An arch is formed by the material after the manner of a bridge, and the material above is supported as if by some structural member. After the formation of the arch, inaccurate or incomplete flow results.

A comparison of the star-wheel and top-delivery feed type devices shows the advantage of a metering unit with positive volumetric displacement rather than one depending partially upon gravity feed. Closing the gate of the star-wheel feed tends to reduce the slope of the average delivery rate versus angle of repose curve because the positive action becomes relatively more important. With materials that do not flow by gravity, opening the gate does not materially increase the rate above that due to positive action (9).

In tests, Mebring and Cumings found that the depth of fertilizer in the hopper (using free flowing material) had little effect on the delivery rate of the belt-type and auger-type distributors (depths two to fourteen inches). With the star-wheel and revolving bottom types, there was little variation at depths greater than three to four inches; but the rates were reduced by eight to fourteen per cent at a depth of two inches and even more at a depth of one inch (9).

With the free flowing fertilizer, tilting the star-wheel or revolving-bottom hoppers ten degrees toward the discharge opening increased the delivery rate by eleven to twenty-one per cent while a ten degree tilt in the opposite direction decreased the rate by eleven to fifteen per cent as compared with the level rate (9).

Most distributors are equipped with rotating agitators in the hoppers or at least have agitators available. Mebring and Cumings found that the use of an agitator influences the delivery rate only with fertilizers that tend to cake or bridge (9). The increase in delivery rate obtained is a measure of the agitator's effectiveness in breaking up lumps and preventing caking or bridging. While the use of the agitator makes possible the dispensing of fertilizers that could not otherwise be handled, it does not completely compensate for the decrease in rate caused by low drillability. If the drillability is extremely low, the agitator will revolve within the mass without any beneficial effect.

Organization of the Study

A brief survey of finely ground liming materials was made to

determine those physical characteristics which govern time and weight rate of flow at various moisture levels. An analysis of various commercial and experimental distributors was undertaken to determine their adaptability to the problem of spreading wet, finely ground, limestone under field conditions of varying head, hopper inclinations, and uniformity of output. The results of the preceding observations were analyzed, and a hypothesis for the design of a distributor to adequately dispense the material was formulated.

The distributor was laboratory tested with variations, and results were statistically analyzed to determine the most efficient design. Field tests were then undertaken with this unit to ascertain if the distributor fulfilled original design specifications. Statistical analysis was applied to all results.

Various means of transportation for steep hillside use were examined, and that means which best conformed to safety and performance standards was chosen.

CHAPTER II

THE MATERIAL

Source

With the exception of one series of field tests using T.V.A. Concentrated Phosphate, all test work was performed with finely ground agricultural limestone produced as a by-product of the American Zinc Company operations at Mascot, Tennessee.

Physical Factors Affecting Distribution

The size of the particle had some effect upon evenness of distribution even when materials were dry, and a decided one when they were wet. The coarsest materials were distributed more and more irregularly as they became damper. Mebring and Cumings (9) found that in a two-hundred mesh powder in a dry state, cohesion exists between the individual particles. When the particles were damp, the forces attracting them to each other were very much greater due to the surface tension of the liquid films.

The Mascot ground limestone is among the finer ground liming materials produced in the State. Results of a screen analysis on the state of sub-division of the sample used in both laboratory and field tests are presented in Table I. The high percentage of material passing the forty to eighty mesh screen was indicative of the difficulties experienced on drilling this material when damp.

It can be shown that no free flow can occur in the case of a

TABLE I

A SCREEN ANALYSIS OF MASCOT GROUND LIMESTONE

Per Cent of Material Separated by Screens with a Mesh of				
Under 20	20 and 40	40 and 80	80 and 100	over 100
0.1	5.6	42.7	9.5	42.0

substance having a kinetic angle of repose greater than forty-five degrees (8). The uniformity with which a given fertilizer can be distributed decreased regularly as its angle of repose increased. In experiments by Mebring and Cumings (9), all materials with an angle of repose greater than thirty-five degrees issued from the delivery tubes irregularly and usually in lumps of varying size. When the angle of repose exceeded fifty degrees, the fertilizer was practically undrillable.

The angle of repose of the ground limestone used in tests exceeded fifty degrees above one per cent moisture content, as indicated in the data in Table II and Figure 1.

The combined effect of the size of grain and moisture content on the rate of flow was investigated by recording the time required for one hundred grams of material to flow through a glass funnel with sixty degree angle sides and a $13/32$ -inch diameter opening. The presence of any detectable moisture in the material restricted entirely its flow as shown in the data reported in Table III.

In this study, apparent specific gravity was of more interest than absolute specific gravity because it varied with the state of sub-division, moisture content, degree of packing, etc., while the absolute specific gravity remained the same. The ground limestone used in the tests varied twenty-five per cent in apparent specific gravity as shown in the data reported in Table IV and Figure 2. In a volumetric displacement type of distributor this effect of apparent specific gravity automatically induced up to a twenty-five per cent error in output as the moisture content of the material varied.

TABLE II

THE ANGLE OF REPOSE OF MASCOT GROUND LIMESTONE
AT VARIOUS MOISTURE LEVELS

	Per Cent Moisture Content			
	0	1	2	4
Angle of Repose (degrees)	38	50	53	58

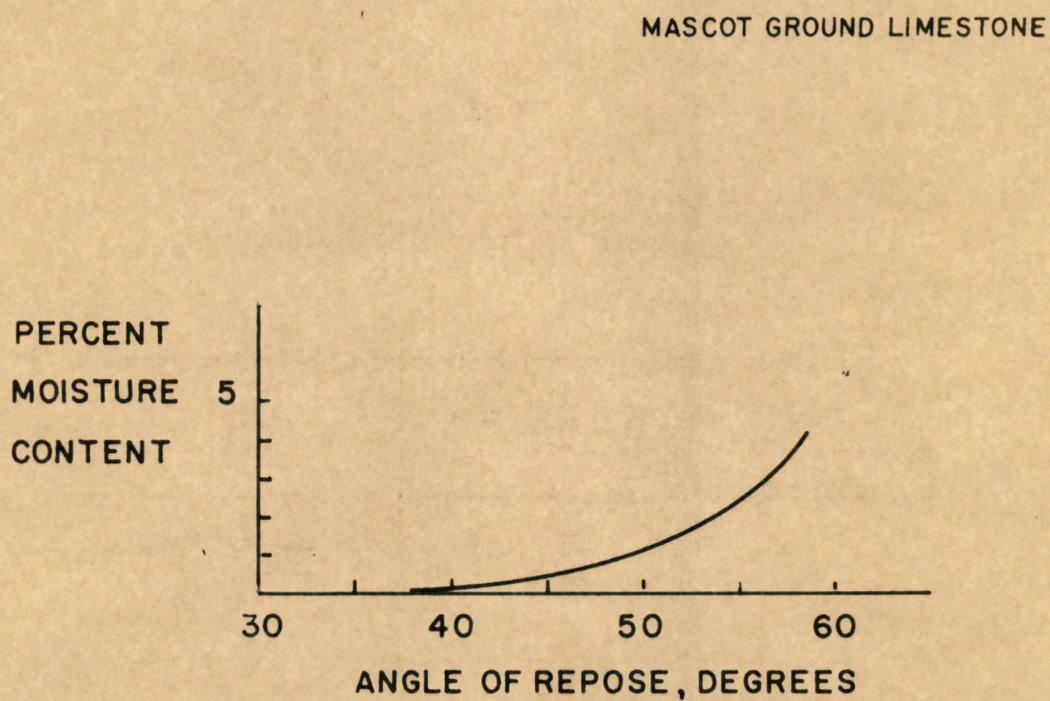


FIGURE 1
EFFECT OF MOISTURE CONTENT
ON ANGLE OF REPOSE

TABLE III

RATE OF FLOW OF MASCOT GROUND LIMESTONE
AT VARIOUS MOISTURE LEVELS

	Per Cent Moisture Content			
	0	1	2	4
Time (seconds)	2	(no flow)		



TABLE IV

APPARENT SPECIFIC GRAVITY OF MASCOT GROUND
LIMESTONE AT VARIOUS MOISTURE CONTENTS

Condition	Per Cent Moisture Content				
	0.5	1.2	5	8	13.5
Apparent Spec. Gravity	1.6	1.5	1.3	1.2	1.8
Weight per Cubic Foot	102	95	84.5	79	110

CRANES  CREST

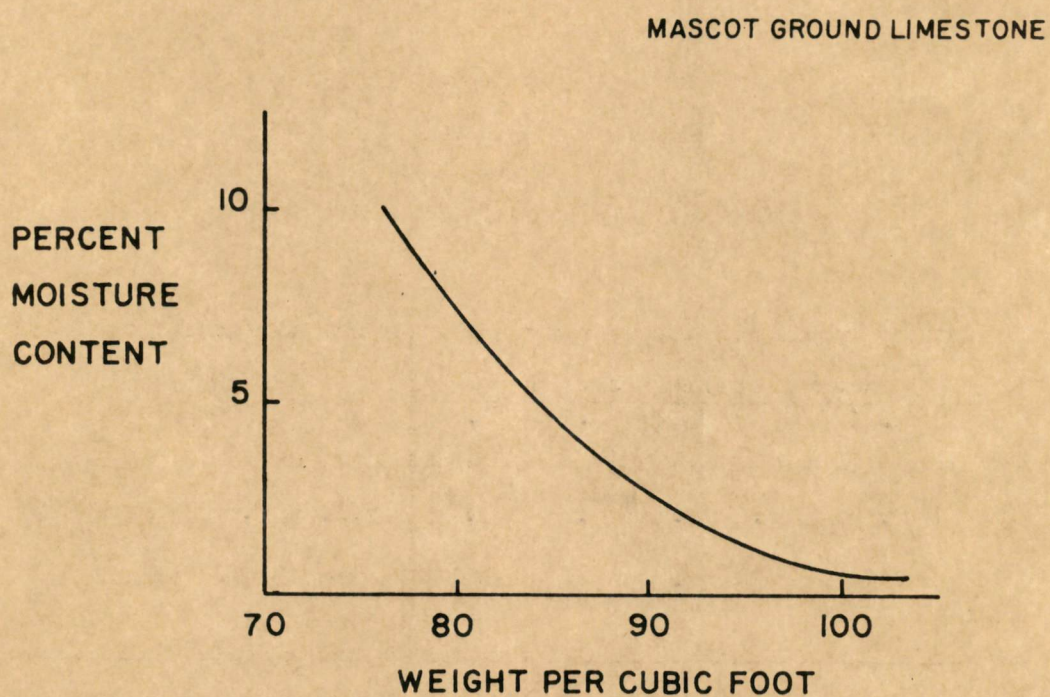


FIGURE 2
EFFECT OF MOISTURE CONTENT ON WEIGHT

Characteristics of the Material Under Flow

Moisture content of the ground limestone used in these tests ranged from zero to ten per cent. At zero per cent moisture content, the material flowed with exceptional uniformity and with only the slightest resistance, much as fine dry sand (Figure 3). At one per cent moisture content, the powdered material appeared to be slightly damp and partially retained its shape when squeezed in the hand. It evidenced a limited flow by gravity unless continually agitated and, like flour, tended to flow in lumps unless mechanically separated. At five per cent the material (Figure 4) appeared damp and retained its form when compressed in the hand, flowing by gravity only by breaking down in lumps, and having a loose or porous texture when thoroughly agitated and divided mechanically. At eight to twelve per cent, the material was very damp, forming a soft mass similar to well-mixed cement (Figure 5). At this moisture content the ground limestone flowed under pressure as a semi-solid, and under ordinary means of agitation it separated into very large lumps.

Summary

The finely ground limestone used in the test work was highly resistant to flow with the addition of only slight amounts of moisture. With a moisture content in excess of one per cent it no longer flowed freely by gravity but required mechanical division and ejection. The wide variation in apparent specific gravity through the addition of moisture induced an inherent error of as much as twenty-five per cent in volumetric flow.

Figure 3
Ground Limestone
at One Per Cent
Moisture Content

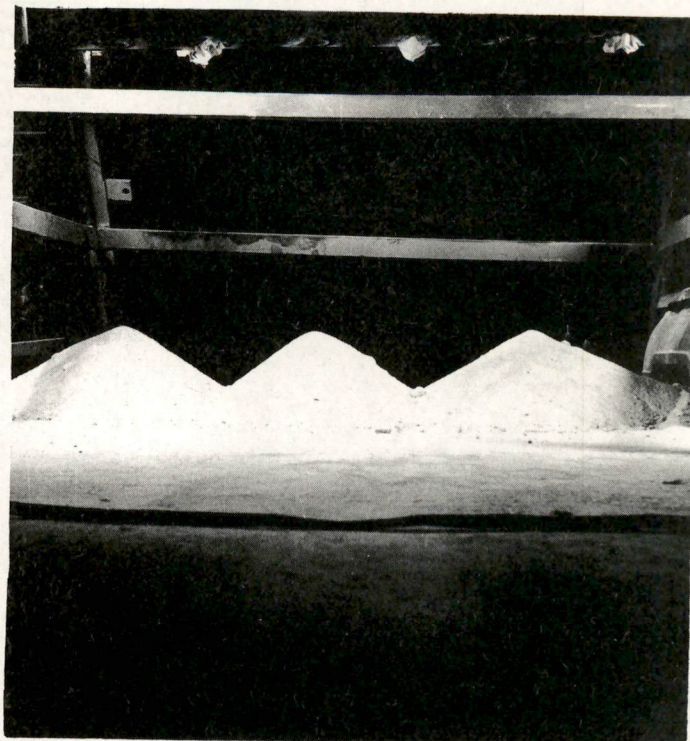


Figure 4
Ground Limestone
at Five Per Cent
Moisture Content

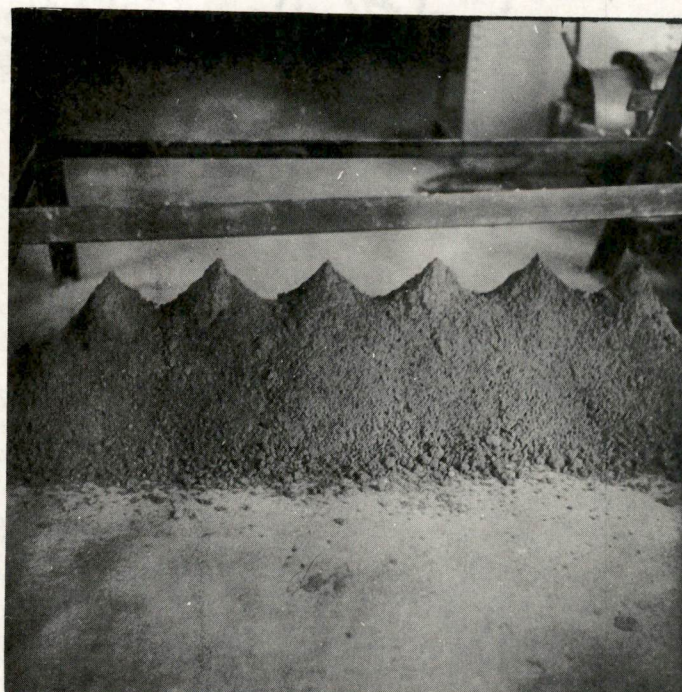
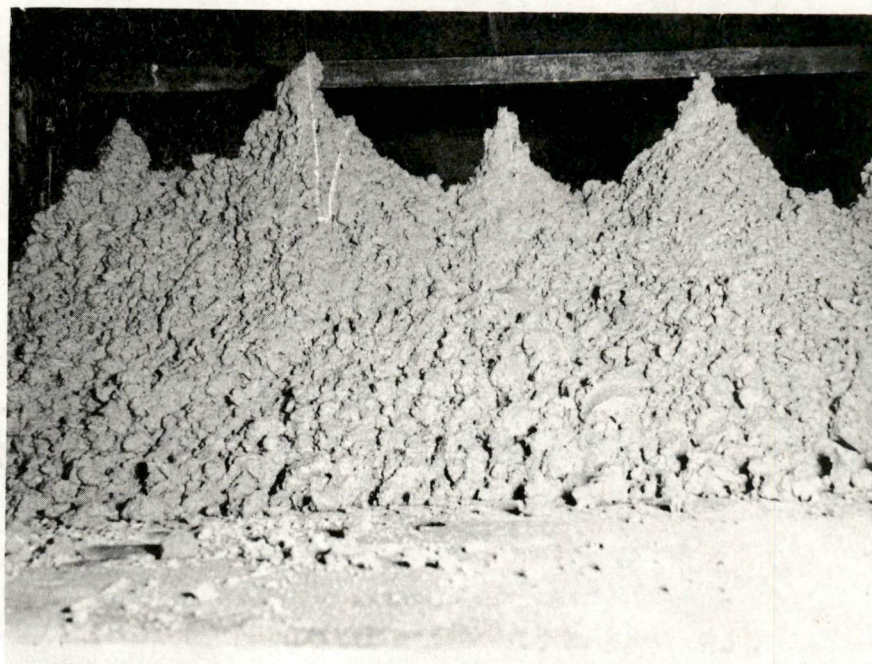


Figure 5

Ground Limestone at
Thirteen Per Cent
Moisture Content



Ground Limestone at
Thirteen Per Cent
Moisture Content
Showing Extreme Plas-
ticity and Cohesion
of Aggregate
Particles



CHAPTER III

AN ANALYSIS OF COMMERCIAL AND EXPERIMENTAL DISTRIBUTORS

Source of Information

Manufacturers of fertilizers and lime spreading equipment listed in the "Thomas Register" (11), land-grant institutions and other authorities were contacted to determine if any commercial equipment would be adaptable to the problem. Upon their recommendations two commercial machines were purchased, and two experimental machines were constructed. These machines were tested to determine their accuracy of metering under field operating conditions of various material moisture contents, slopes or hopper angle, and head or depth of material in the hopper.

The Commercial Disc-type Metering Device

The Ezee-Flow, pull type, spreader (Figure 8) was both laboratory and field tested for uniformity of flow of ground limestone at various moisture contents. At a ground limestone moisture content ranging from one to four per cent, output was uniformly decreased to one-third of rated output. At moisture levels above five per cent, bridging occurred; and when ground limestone in contact with the metering device was expelled, hopper discharge rate declined to zero. The addition of vertical hopper sides, mechanical agitators and vibrators were tried with no success.



Figure 7
Truck Bed Type
Lime Spreader

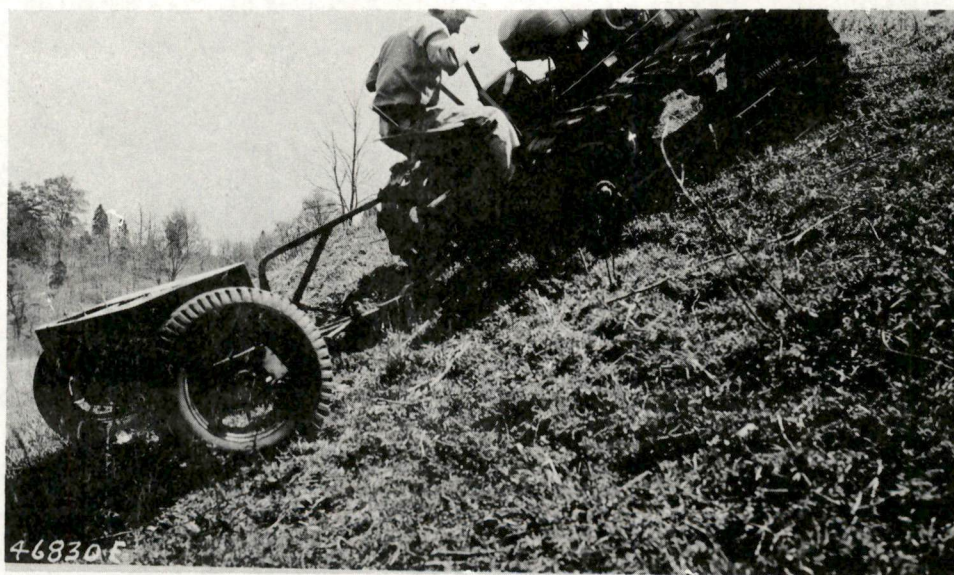


Figure 8
Commercial Pull-type Spreader (Ezee-Flow)
Pulled by Crawler Tractor on
Forty-five Per Cent Slope

Drag Bottom or Moving Belt Metering Device

A Farquhar moving belt metering device (Figure 9) was field tested. Performance was adequate at moisture contents below three per cent. Above this level, flow was discontinued when ground limestone contained in the agitator regions of the hopper was exhausted. The bridging phenomenon was again observed at five per cent moisture content, and any agitation device to remove such a condition results in a complex, expensive feeder with inadequate capacity and a high torque requirement.

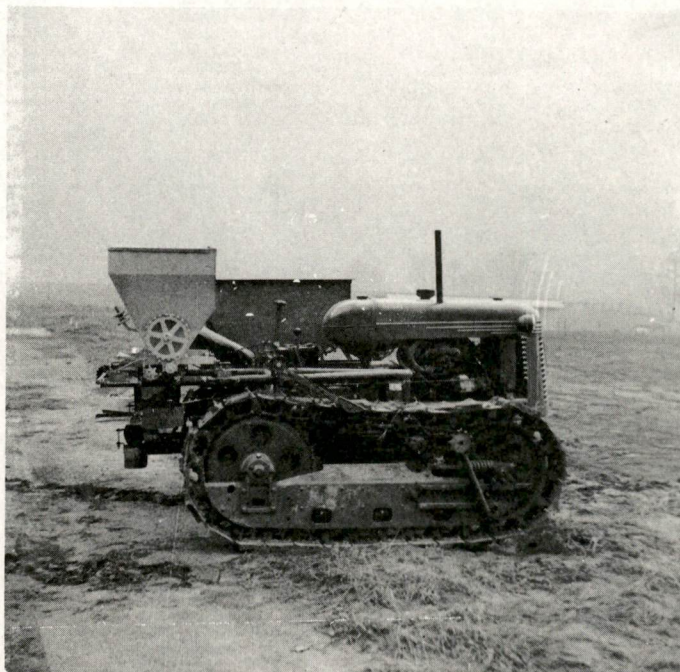
Experimental Moving Hopper-Positive Displacement Device

This machine (Figure 10) was designed and constructed by Mr. J. B. Liljedahl, Associate Agricultural Engineer, U. T. Agricultural Experiment Station. In operation, a rectangular hopper containing ground limestone was moved rearward. This forced the material into a mill mechanism, consisting of a moving ribbed belt, which removed a continuous layer of material at a constant rate. The material was then conveyed through a chute to rotating ribbed discs for dispersion on the ground. Although the principle of this device is satisfactory, the complexity of mechanism necessary for operation does not make it feasible for commercial production.

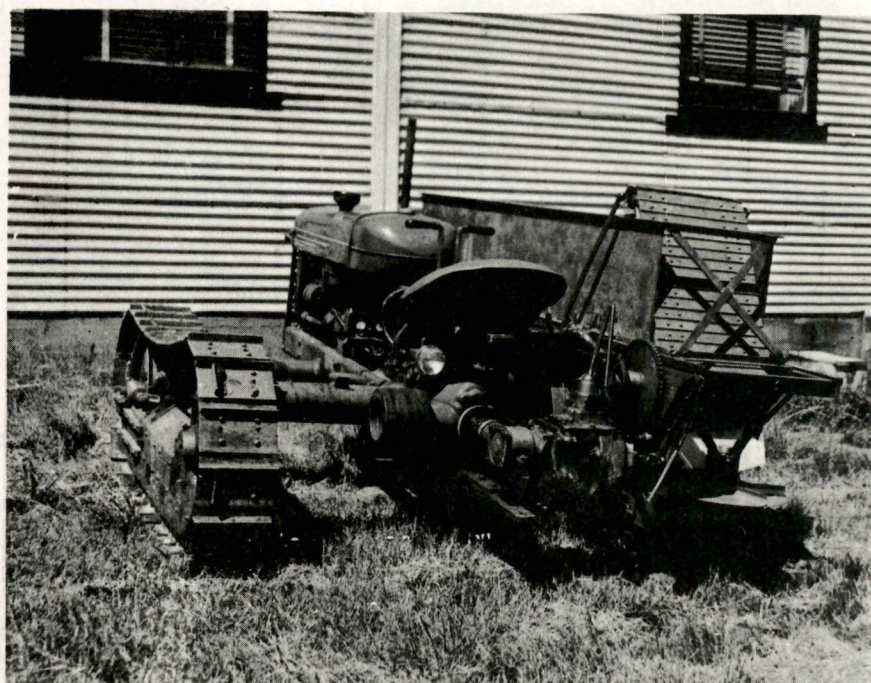
Experimental Top-feed Drag Link, Positive Displacement Distributor

This machine (Figure 11) was constructed utilizing an experimental design developed by the T.V.A. Agricultural Engineering Section. This device was both laboratory and field tested. It consisted of a rectangular

Figure 9
Farquhar Moving
Belt Type Distributor



Experimental
Moving Hopper
Machine



hopper, and a drag link mechanism of a ribbed belt with curved ribs. The hopper was filled and the feed mechanism placed on top of the ground limestone. The ribbed belt or drag link (Figure 12) was pulled over the material contained in the hopper and removed a thin layer as it progressed. This removed material was deposited in a chute which conveyed it to a rotating ribbed disc for dispersion.

The output characteristics at lower moisture contents were acceptable as shown in Figures 13 and 14. As the moisture content increased, erratic feeding became evident. At the higher moisture levels, metering was interrupted by the wet ground limestone adhering to the curved edges of the ribbed links. This difficulty might have been partially overcome through the use of overlapping links or rubber covered ribs. Cessation of feeding was due to compaction of the ground limestone and lack of weight in the drag link mechanism. Weight could have been added if a different means of loading the hopper were developed. The method of loading used necessitated removal of the top feed mechanism which was both awkward and cumbersome.

Field tests indicated (Figure 15) a serious discrepancy in feeding downslope. Rate of feed was not as consistent as would be desired through reasons developed above. The inherent difficulties of loading and the mass of the metering device in proportion to hopper capacity must be overcome before it can be acceptable.

Summary

None of the machines tested was adequate for the operation of

Figure 11
Experimental Top-Feed,
Drag Link Distributor

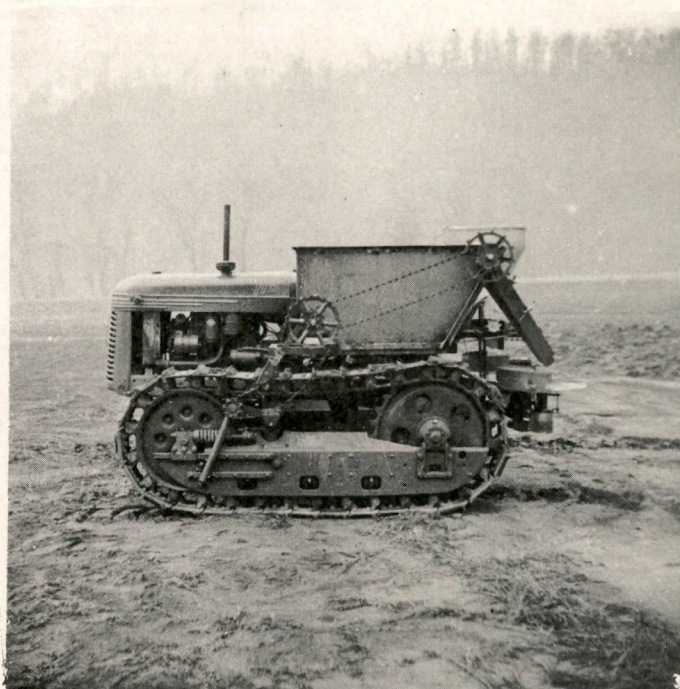


Figure 12
Experimental Drag-Link,
Top Feed Distributor
(top view)



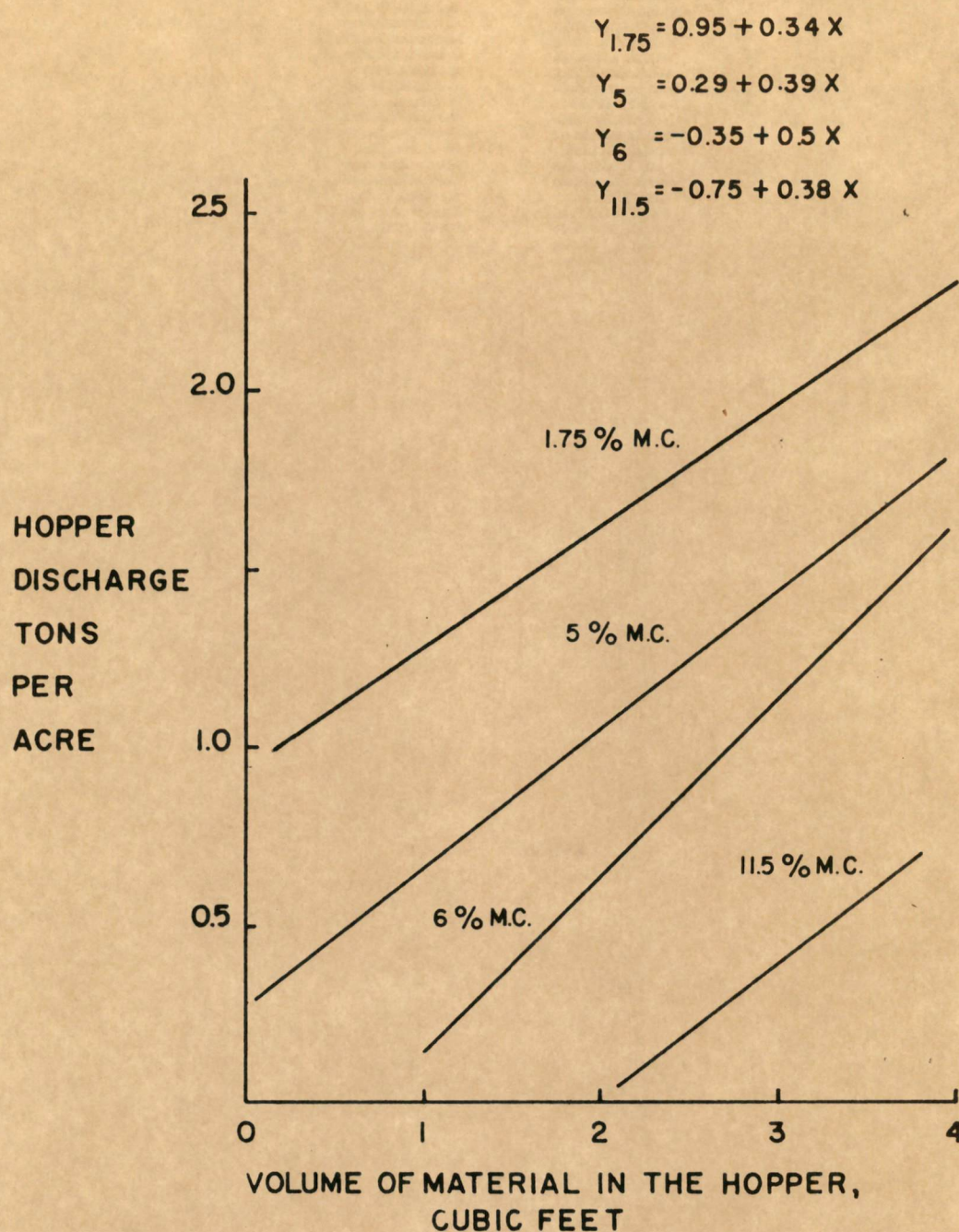


FIGURE 13
DRAG LINK DISTRIBUTOR
DISCHARGE AT ZERO PERCENT
SLOPE

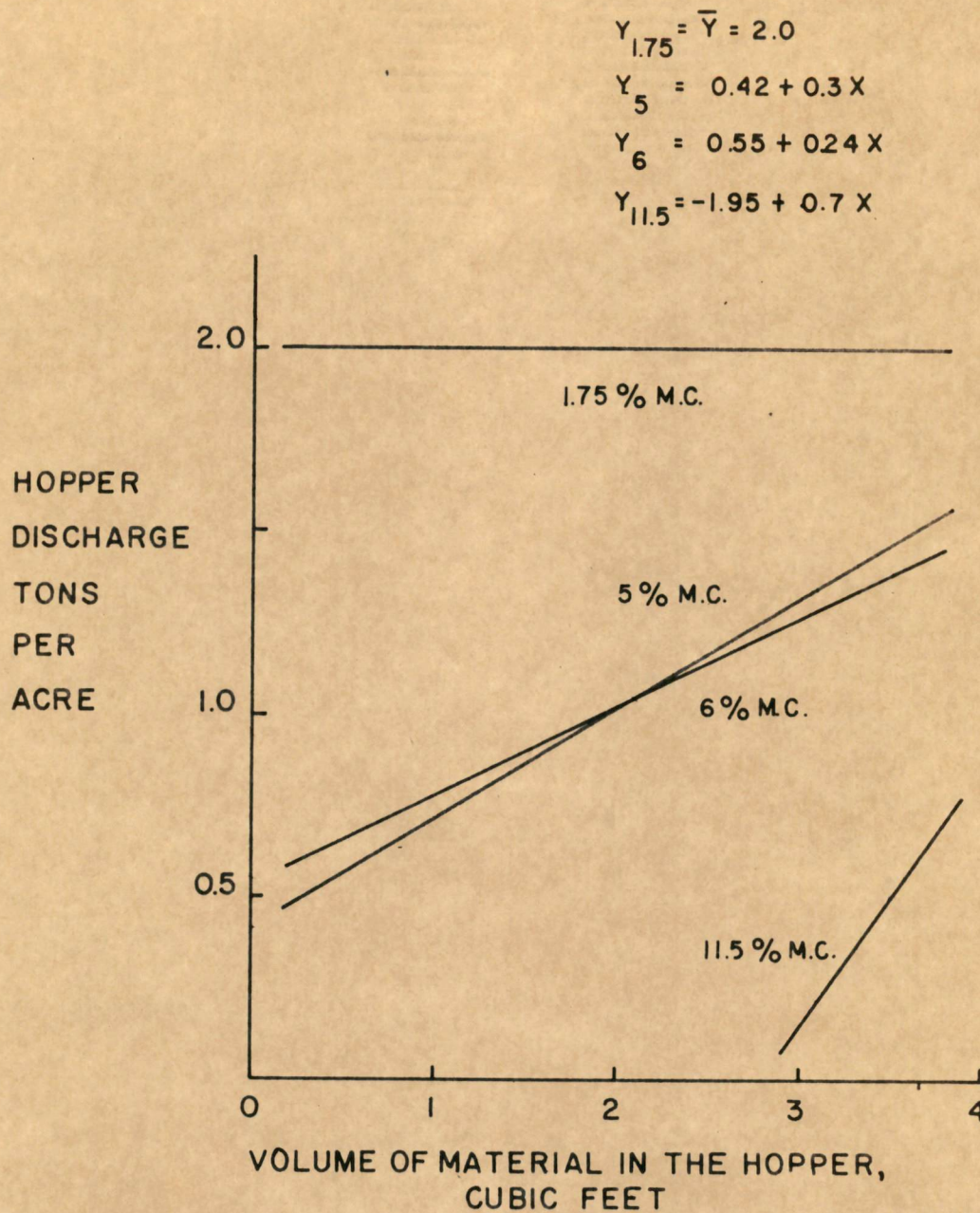


FIGURE 14
 DRAG LINK DISTRIBUTOR
 DISCHARGE AT 45 PERCENT SLOPE

HOPPER MOUNTED ON CRAWLER TRACTOR
GROUND SPEED 1.2 M.P.H.

45 % SLOPE

$$Y_5 = 0.5 + 0.005 X$$

$$Y_7 = 0.3 + 0.0015 X$$

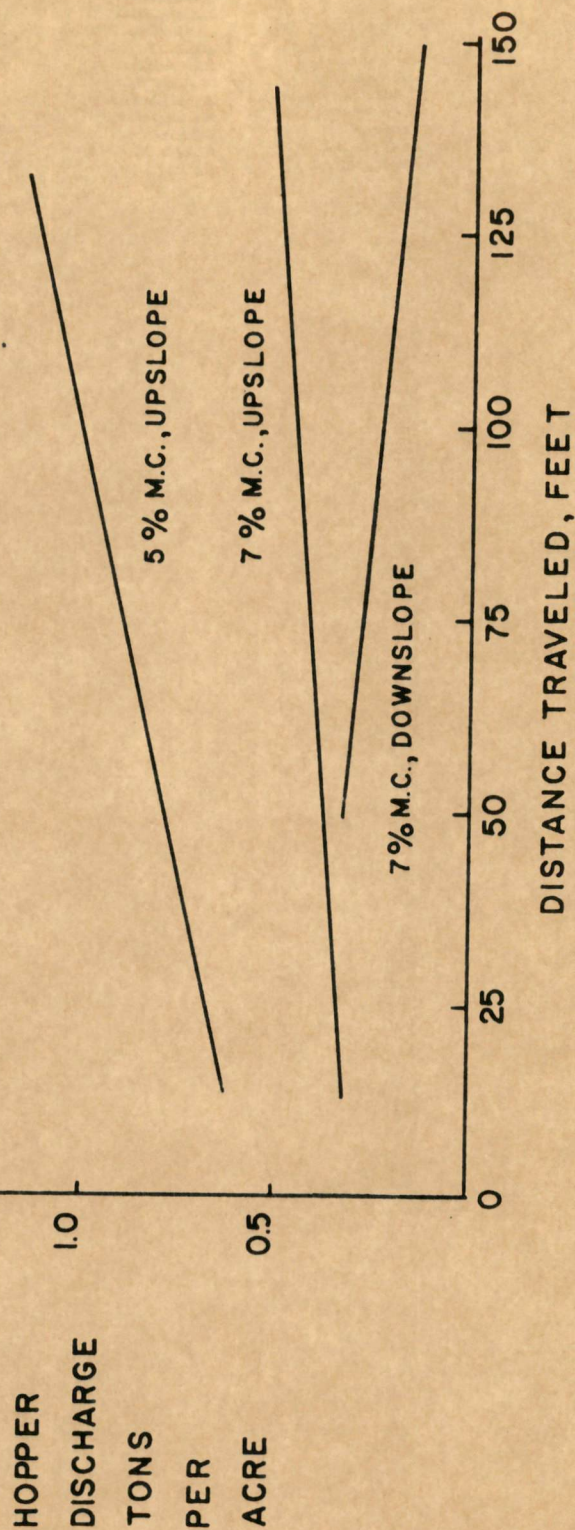


FIGURE 15
DRAG LINK DISTRIBUTOR
DISCHARGE, FIELD TEST

spreading wet, finely ground, limestone. There were no obvious alterations or conversions which would adapt these machines to the task without resulting in a complex, expensive, low-capacity device. An inspection of the deficiencies of these machines indicated the need for a completely new distributor.

CHAPTER IV

DESIGN SPECIFICATIONS FOR DISTRIBUTOR OPERATION WITH FINELY GROUND LIMING MATERIALS

Factors Affecting Operation of Distributors

All of the devices tested, with the exception of the top feed distributor, have one common fault--bridging. An analysis of the conditions resulting in "bridging" showed that if any of the following factors were present, inaccurate or incomplete flow would result:

1. Narrow width to height ratio with sloping sided (over fifteen degrees from vertical) hopper,
2. Ledges in the hopper, and
3. Intermittently located feeding means.

Agitation by mechanical fingers and rotating devices, if small enough not to impose severe torque loads on the drive mechanism, proved inadequate in influencing the material beyond the zone of intimate contact. Vibratory agitation serves only to increase packing of the material, contributing to "bridging" at a lower moisture content than was usual in conventional design hoppers.

Design Specifications for a Distributor to Dispense Finely Ground Liming Materials

As none of the above distributors tested would apply ground limestone with a positive dispensing action over the wide range of drillabilities encountered, the open-centered rotor distributor was

designed and developed.

The design objectives were:

1. To eliminate these sources of trouble outlined in the Factors Affecting the Operation of Distributors;
2. Provide a positive dispensing action covering a wide range of drillabilities; a
3. Low amplitude of cycles or impulses of delivery; and a
4. Delivery rate independent of head (depth) and reasonable inclinations of the distributor.

CHAPTER V

THE DEVELOPMENT OF THE EXPERIMENTAL OPEN-CENTER DISTRIBUTOR

Development of the Distributor

Description of the Distributor

Three distributors were constructed before the design was completed. The distributor means consists of a multi-bar, rotating cylinder (Figure 16) of large diameter extending the entire width of a hopper, bars axial to the cylinder shaft, rotating in close proximity to the walls of a semi-circular hopper base of slightly larger circumference than the cylinder and provided with adjustable diamond shaped egress openings (Figure 17) in the base of the semi-circular hopper bottom. The width to height ratio of the hopper is not less than 0.4, and the slope of the sides does not exceed fifteen degrees from the vertical.

In operation, a rotating motion is imparted to the cylinder in direct proportion to the ground speed of the vehicle by means of a chain and sprocket drive combination. The bars of the cylinder move through the material to be metered in close conjunction with and along the sides of the semi-circular hopper base and over and across the diamond shaped metering openings in the semi-circular hopper base.

Analysis of Operation

Analysis of operation of the device discloses that the passage of the multi-barred cylinder through the material mass accomplished two purposes:

Figure 16
Multi-Barred
Open-Center Rotor

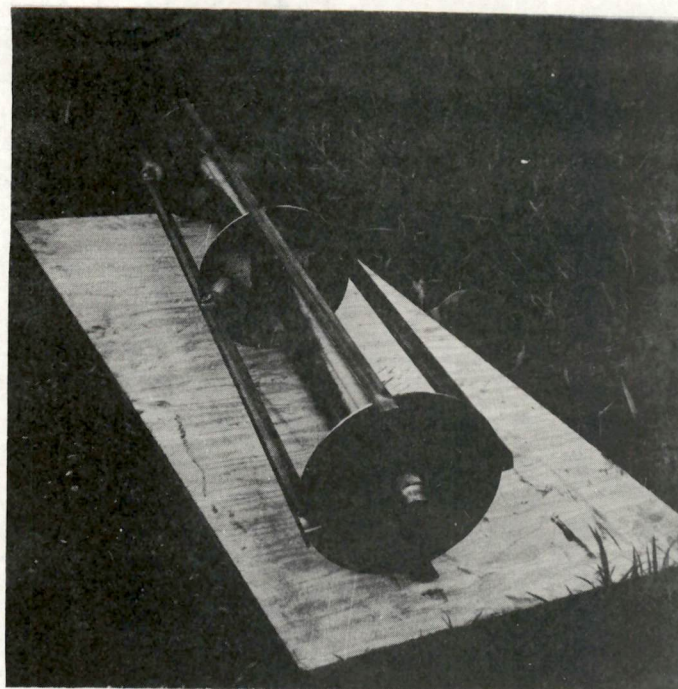


Figure 17
Semi-Circular Hopper
Bottom Showing Diamond
Shaped Metering Openings



1. To move a uniform amount of material to the openings in the hopper base and thus provide a constant metering influence from which the variable area openings permit a pre-determined amount of material to flow.
2. To impart a unique motion to the material in the hopper by means of the rotating, full length cylinder bars. The upward movement of the cylinder bar, in close conjunction with the hopper side, imparts a transverse shearing action to the material in intimate contact with the hopper side.

Laboratory Test of the Distributor

The Test Machine

The test machine was constructed incorporating the distributor. The machine consisted of a (1) hopper assembly, (2) hopper drive assembly, and (3) instruments for recording pertinent data.

The hopper assembly consists of a three-foot section (one cubic foot per foot length) of a twenty inch depth hopper (Figure 18) containing a nine inch diameter open-center rotor and having a diamond-shaped opening metering slide in the semi-circular base. The hopper has adjustable angle sides and is cradled on the rotor axis so that it may be rotated in either direction to simulate any hopper inclination up to one hundred per cent. The rotor is constructed so as to accommodate three or four bars of any shape.

The drive assembly (Figure 19) contains a cradled, variable speed, electric motor mounted with a torque arm and scales to measure torque

Figure 18
Laboratory Test Hopper

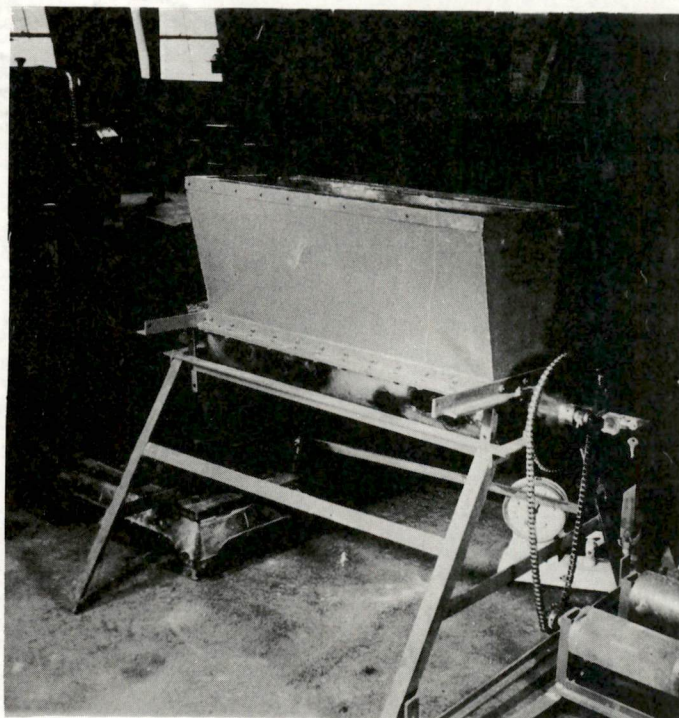
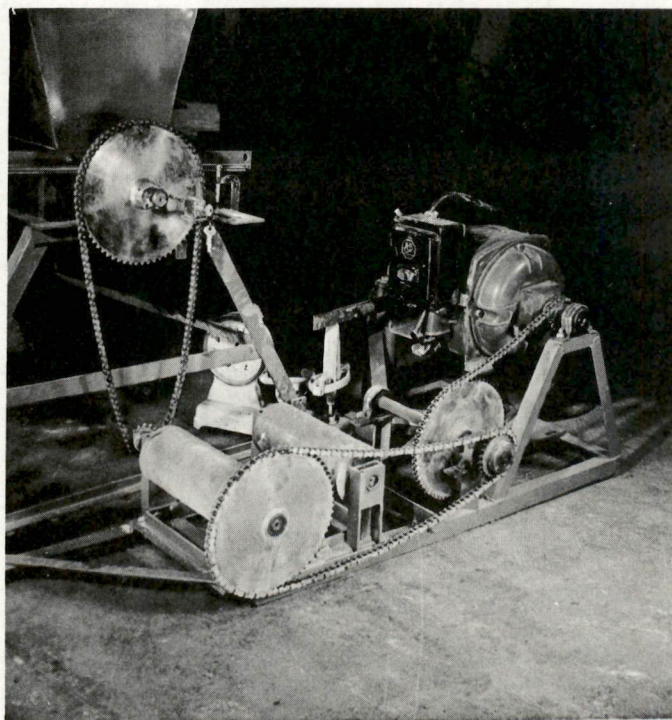


Figure 19
Drive Assembly For
Laboratory Machine



output. It is connected to the hopper rotor shaft through a chain reduction drive and provides a continuous range of rotor shaft speeds from zero to fifty revolutions per minute.

The hopper was mounted on scales (Figure 18) so as to provide a means of measuring output by differential weighing. A revolution counter was mounted on the rotor shaft to provide for the measurement of weighing increments.

The Data Recorded

Tests were undertaken to determine the following:

1. The effect of hopper inclination on discharge,
2. The effect of moisture content on uniformity of output,
3. The effect of head (depth of material) on uniformity of output,
4. The effect of the bar shape on uniformity of output,
5. The effect of rotor speed on uniformity of output,
6. The effect of bar shape and moisture content of the material on uniformity of output, and
7. The effect of bar shape and moisture content on the torque required to operate the rotor.

The Test Procedure

The following procedure was closely replicated in all tests.

1. The hopper was filled with lime.
2. The rotor was started and a torque measurement was made with the rate slide closed.

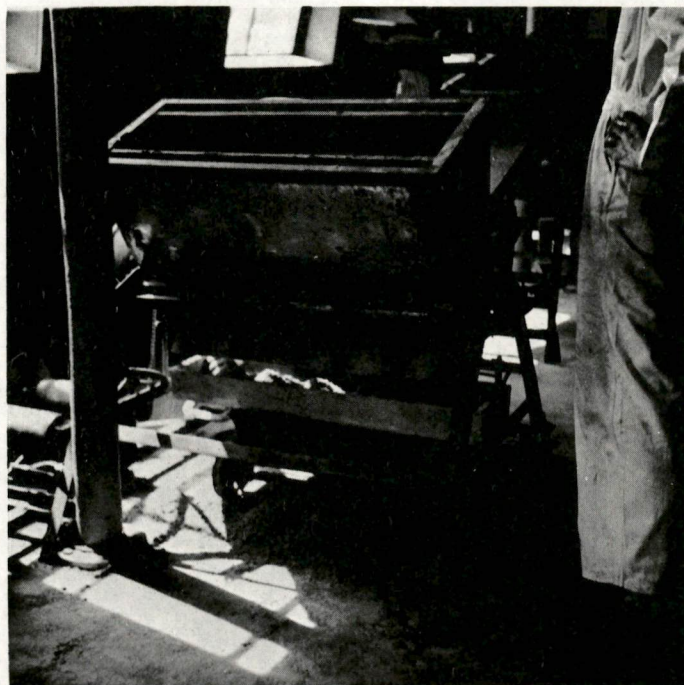


Figure 20

Weighing of Material Samples on
a Test Run

3. The rotor was started and a torque measurement was made with the rate slide opened.
4. For each twenty pounds of material removed, the revolutions of rotor required for removal and torque at that point was recorded. An average of six subsamples (Figure 20) was taken per run of material.

These tests were conducted for a

1. $3/4$ " square bar,
2. $3/4$ " diameter round bar,
3. $3/4$ " equal leg angle, face forward, and
4. $3/4$ " equal leg angle, edge forward;

at

1. 30 RPM of the rotor,
2. 40 RPM of the rotor, and
3. 50 RPM of the rotor;

at a hopper inclination of

1. zero per cent, and
2. 22.5 per cent;

and for a

1. 3-bar rotor,
2. 4-bar rotor, and a
3. 6-bar rotor.

At the termination of each test a moisture sample was collected and a moisture determination conducted by the air-oven method (1).

Results of Tests

Conformation of Rotor and Hopper. Observation of the series of initial tests made with rotors of varying diameters and hopper walls of varying slopes indicates that rotor diameters under six inches and hopper side slopes in excess of fifteen degrees from the vertical result in "bridging" under certain conditions of hopper inclination and moisture content.

Rotor Design. In these tests it was found that an increase in the number of bars comprising the rotor resulted in a more uniform rate of output per unit time at moisture contents in excess of eight per cent. A reduction in the number of rotor bars decreased starting torque proportionately, increased handling efficiency of wetter material, but resulted in a pulsating ejection. Four bars were selected as the most efficient combination.

The analysis of variance in Table V indicates that the rotor shape significantly affects total output per unit of time. The round bar dispenses the most material per revolution of the rotor at all moisture contents. Data reported in Table VI indicate that there is a significant difference in the dispensing ability in volume per unit time between the leg forward angle, the face forward angle, and the square bar.

The rotor speed was only slightly significant in its effect on uniformity of rate of output between thirty and fifty revolutions per minute as shown in the analysis of variance in Table V. Examination of Table V will show that as the rotor speed increases, there is a slight decrease in output.

TABLE V

TEST MACHINE, POUNDS OF GROUND LIMESTONE DISCHARGED FOR
VARIOUS BAR SHAPES AND MATERIAL MOISTURE CONTENTS

Round Bar					Square Bar				
Moisture Content	Replicates				Moisture Content	Replicates			
	1	2	3	M		1	2	3	M
0	13.87	12.70	11.70	12.76	0	14.02	12.66	10.61	12.43
2.25	21.15	19.89	19.84	20.29	2.25	20.68	20.93	18.46	20.02
3.45	14.31	12.91	11.40	12.87	3.45	12.82	11.21	11.10	11.71
5.2	14.72	13.07	12.50	13.43	6.85	9.52	9.97	9.40	9.63
7.3	12.22	10.38	10.26	10.96	7.3	10.06	10.02	9.42	9.83
9.5	9.85	11.51	15.96	12.44	8.9	9.69	8.46	8.57	8.90
$\bar{R}$	14.35	13.41	13.61		$\bar{R}$	12.80	12.20	11.26	

Leg Forward Angle					Face Forward Angle				
Moisture Content	Replicates				Moisture Content	Replicates			
	1	2	3	M		1	2	3	M
0	12.43	13.03	11.72	12.39	0	13.89	12.94	11.01	12.61
2.25	16.76	14.97	14.96	15.56	2.25	16.58	15.01	14.59	15.39
3.45	13.22	13.00	13.41	13.21	3.45	14.06	13.88	13.31	13.75
5.2	11.38	14.02	11.54	12.31	5.7	12.70	18.83	10.33	13.95
7.3	7.61	8.81	8.29	8.24	7.3	10.74	10.17	10.10	10.33
9.5	8.79	8.26	8.05	8.37	8.5	10.30	10.22	9.09	9.87
$\bar{R}$	11.70	12.01	11.33		$\bar{R}$	13.05	13.51	11.40	

TABLE V

TEST MACHINE, POUNDS OF GROUND LIMESTONE DISCHARGED FOR
VARIOUS BAR SHAPES AND MATERIAL MOISTURE CONTENTS
(continued)

Analysis of Variance

	D/F	S.S.	M.S.	F		5%
Total	431	203.55				
Treatments	23	111.24	4.84	18.62	**	1.75
Devices	3	7.56	2.52	9.69	*	2.81
Moistures	5	84.61	16.92	65.06	**	2.42
Moist. x Dev.	15	19.07	1.27	4.88	*	1.91
Subsamples	360	77.56	0.22	0.85		1.51
Reps.	2	2.63	1.32	5.08	*	3.20
TMT x Rep.	46	12.12	0.26			

** Significant difference at one per cent level.

* Significant difference at five per cent level.

Laboratory test machine No. 2.

Rotor diameter nine inches

Each value in above table is a sum of six subsamples.

Replicate No. 1, Rotor speed 30 revolutions per minute

Replicate No. 2, Rotor speed 40 revolutions per minute

Replicate No. 3, Rotor speed 50 revolutions per minute

The analysis of variance in Table VI indicates that there is a definite interaction between rotor bar shape and the material moisture content in their effect on uniformity of output. The face forward angle has the most consistent rate of discharge over the entire moisture content range of all the shapes tested.

Material Moisture Content. The moisture content of the material metered was the most highly significant factor influencing rate of discharge curve. In Figure 23 it may be seen that material at two to three per cent moisture content was the most difficult to meter successfully on a total output per unit time basis. This tendency may also be noted by an inspection of the mean moisture content subsample average values in Table V.

Hopper Inclination. The curve in Figure 21 indicates that hopper inclination has some effect on the rate of discharge at the lower moisture contents. The effect becomes negligible at moisture contents above four per cent.

Depth of Material. The head or depth of material in the hopper had no effect on uniformity of discharge at moisture contents in excess of four per cent as is shown by the curve in Figure 22. When the material level reaches the last four inches of hopper depth the output rate increases in an amount proportional to the increasing angle of repose of the material.

Power Requirements. The moisture content of the material had a significant effect on the torque input to the machine as shown in Table VII. Torque requirements to move the rotor are greatest at zero moisture content and decrease uniformly to seven per cent moisture content (Figure 24).

TABLE VI

TEST MACHINE DISCHARGE, ANALYSIS OF VARIANCE
MOISTURE-DEVICE INTERACTION

Moisture Content	Devices				
	Round	Square	L.F.A.	F.F.A.	M
0	38.27	37.29	37.18	37.84	37.64
2.25	60.88	60.07	46.69	46.18	53.46
3.45	38.62	35.13	39.63	41.25	38.66
5.2	40.29	28.80	36.94	41.86	37.00
7.3	32.86	29.50	24.71	31.01	29.52
8.5	37.32	26.72	25.10	29.61	29.69
$\bar{D}$	41.37	36.27	35.04	37.96	

Each value in table is a sum of eighteen subsamples.

ANALYSIS OF VARIANCE

	D/F	S.S.
Total	23	111.24
Devices	3	7.56
Moistures	5	84.61
M x D	15	19.07

L.S.D. Moisture = 0.6
L.S.D. Devices = 0.7

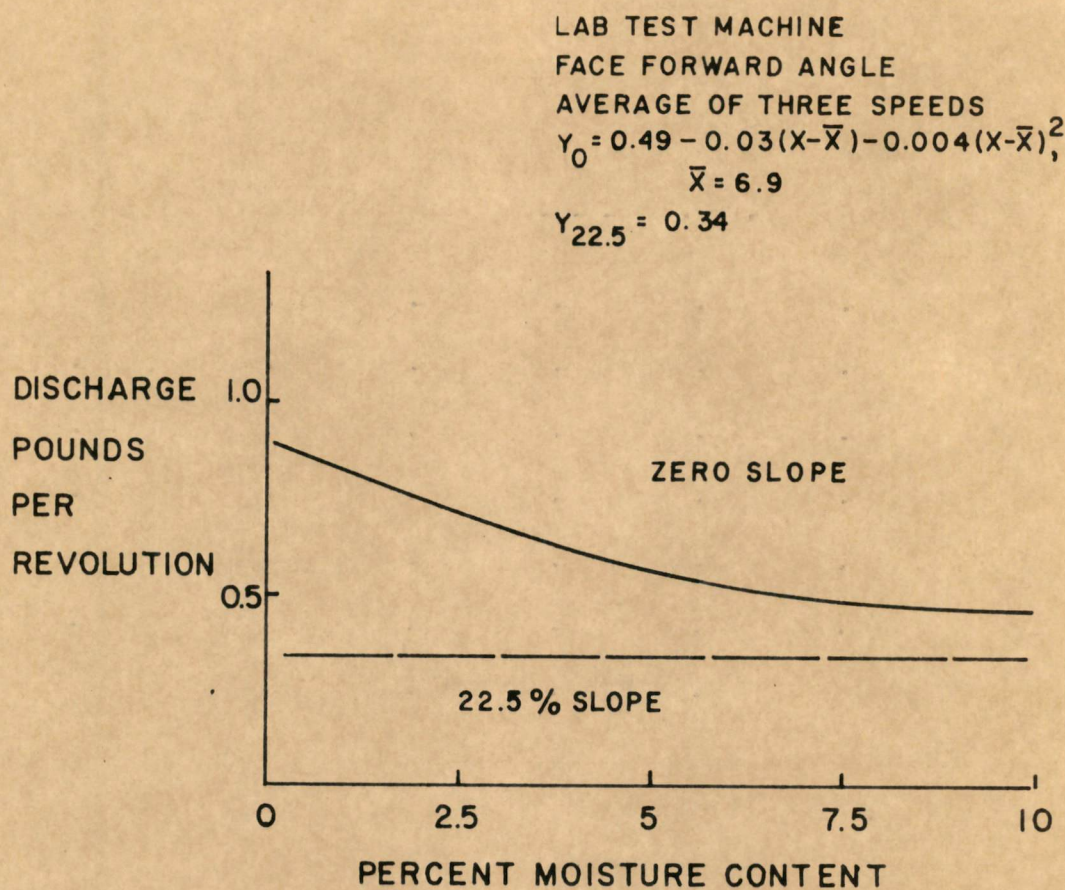


FIGURE 21
EFFECT OF HOPPER INCLINATION ON DISCHARGE

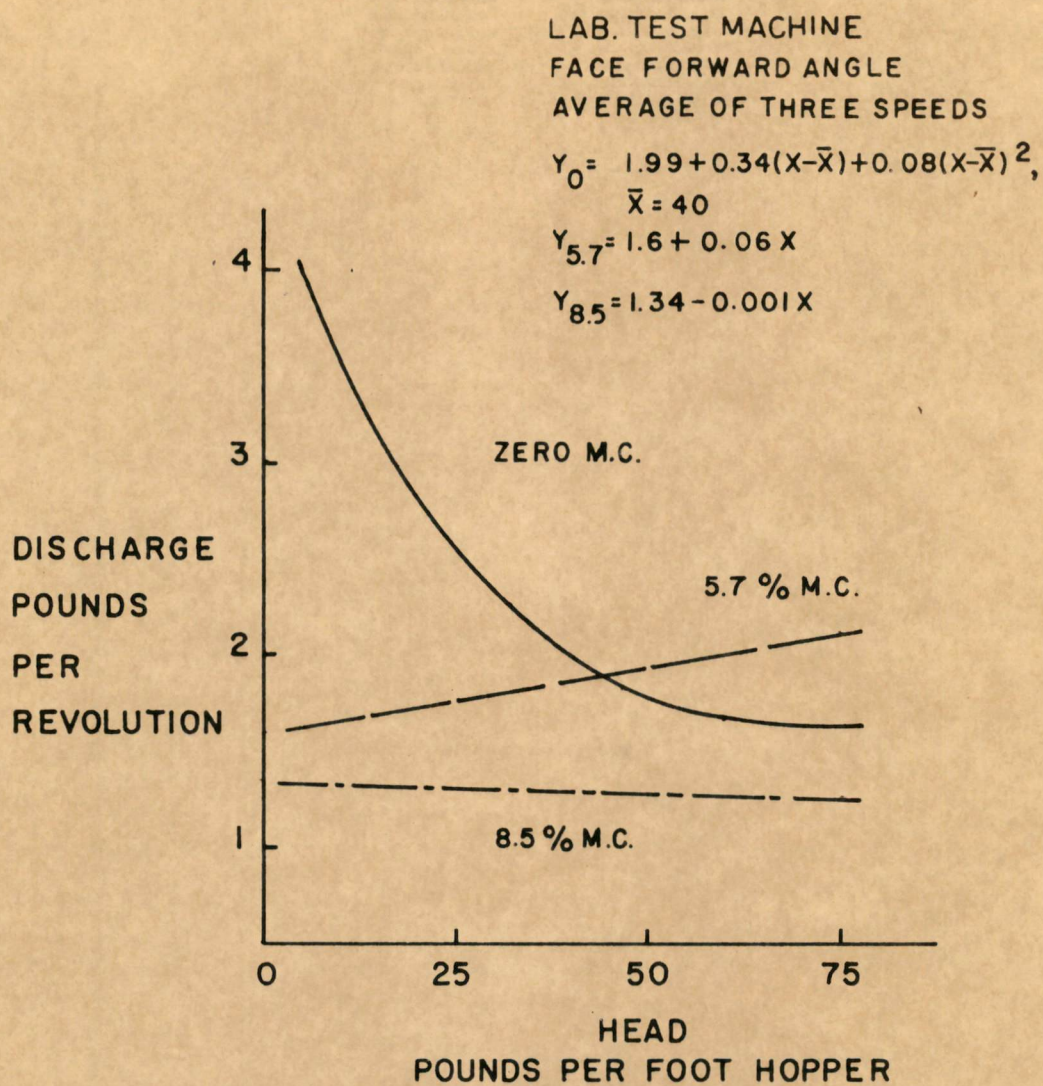


FIGURE 22
EFFECT OF HEAD ON DISCHARGE

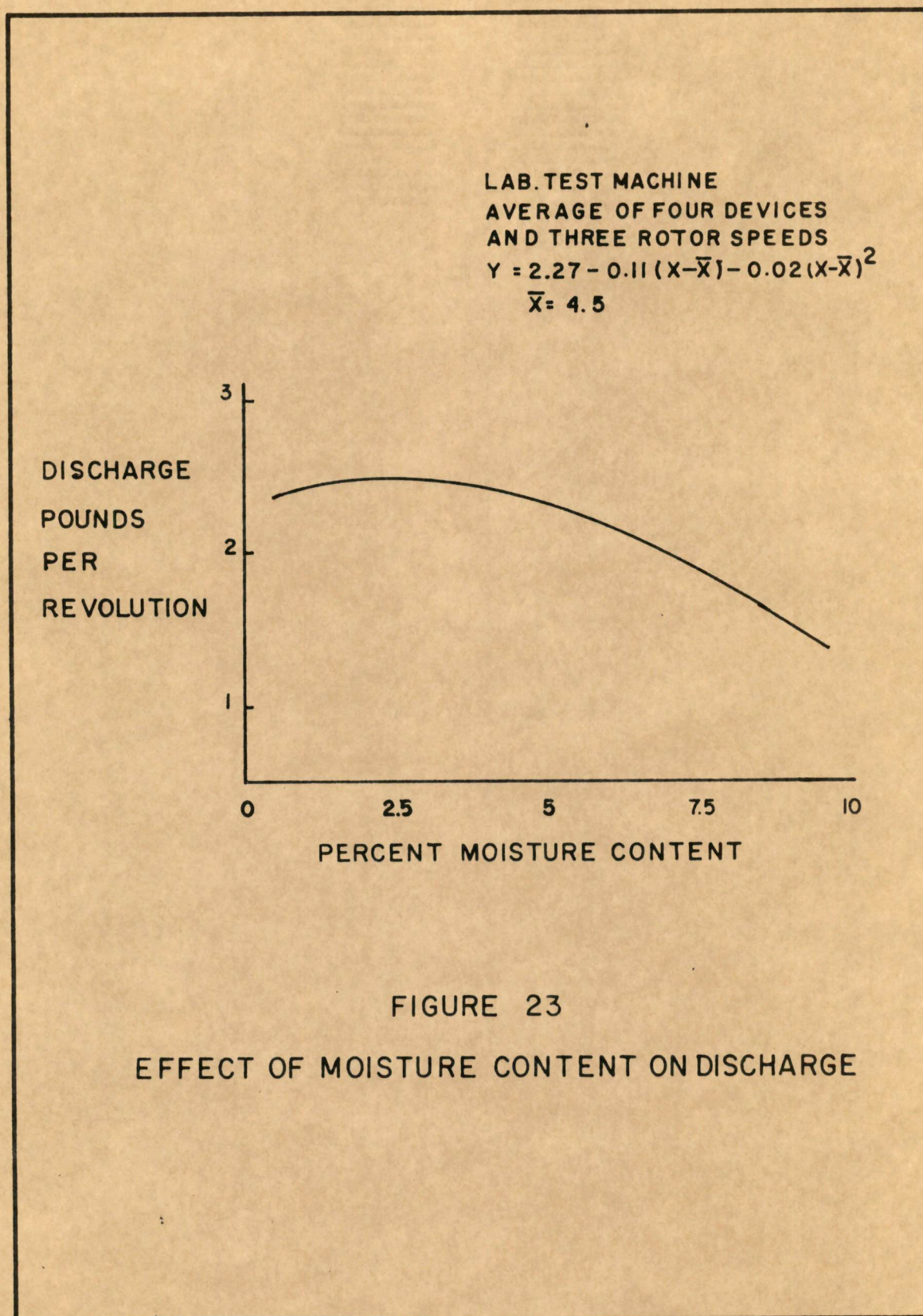


FIGURE 23

EFFECT OF MOISTURE CONTENT ON DISCHARGE

The rotor shape has a significant effect on the torque input to the machine. Table VII indicates that the face forward angle requires the greatest force for movement and the leg forward angle the least.

The machine torque with the rate slide closed and the rotor revolving in the material was fifty per cent greater than the values recorded with the slide open, the depth of material remaining the same. The average force for movement of the rotor decreases at a rate which is proportional to the decrease in the depth of the material as is shown in Figure 25.

Prediction of Values. Statistical analyses using the method of least squares were made on the data to determine which of the straight line, quadratic or cubic equations expressed the data best. The equations for this data shown in Figures 21, 22, 23, 24 and 25 were found to be as follows:

$$\text{Figure 21, } Y_0 = 0.49 - 0.03(X-\bar{X}) + 0.004(X-\bar{X})^2, \bar{X} = 6.9$$

$$Y_{22.5} = 0.34$$

$$\text{Figure 22, } Y = 1.99 + 34(X-\bar{X}) + 0.08(X-\bar{X})^2, \bar{X} = 40$$

$$Y_{5.7} = 1.6 + 0.06X$$

$$Y_{8.5} = 1.34 - 0.001X$$

$$\text{Figure 23, } Y = 2.27 - 0.11(X-\bar{X}) - 0.02(X-\bar{X})^2, \bar{X} = 4.5$$

$$\text{Figure 24, } Y = 17.6 - 0.02X$$

$$\text{Figure 25, } Y = 2.1 + 0.27X$$

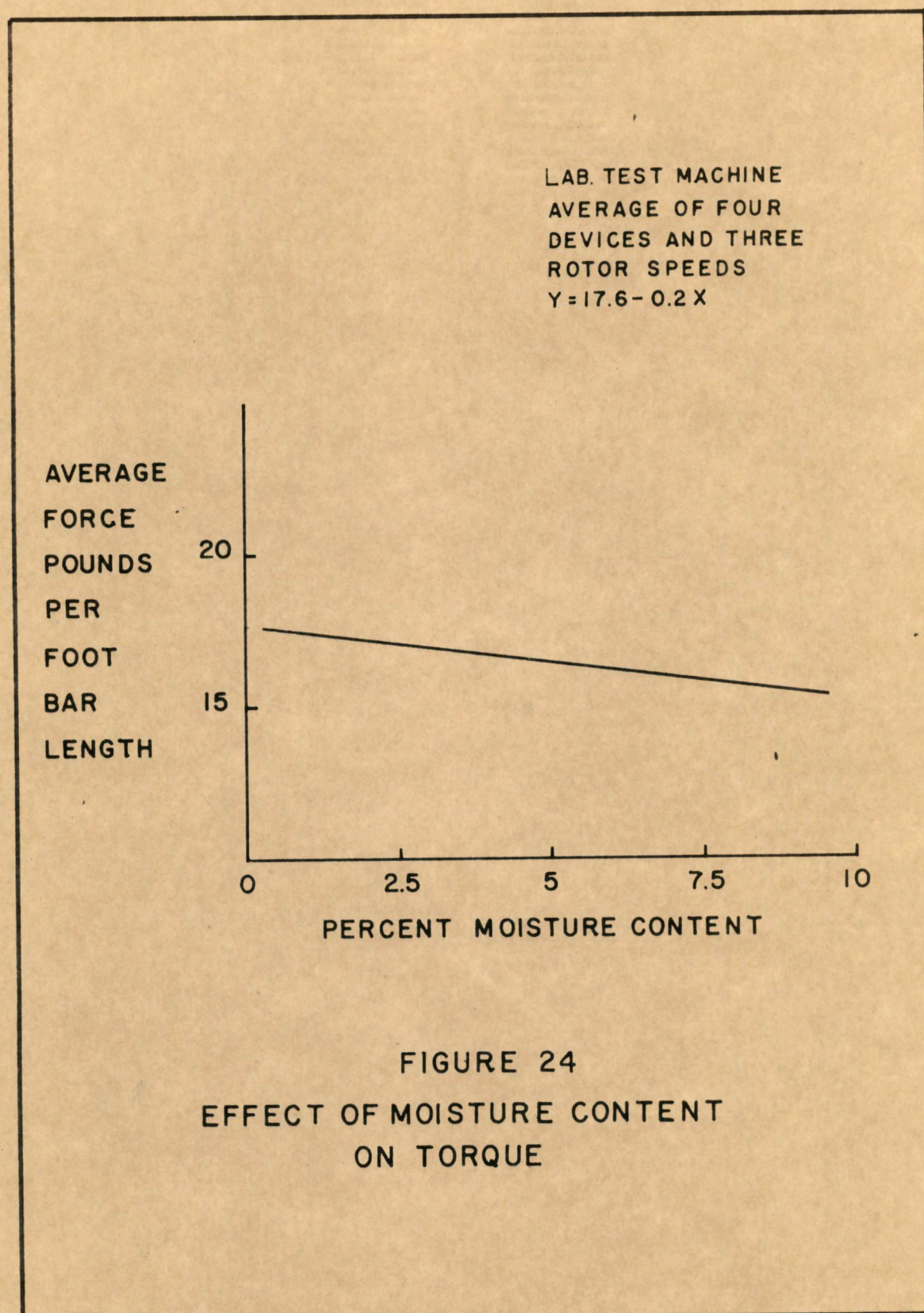


TABLE VII

TEST MACHINE, AVERAGE FORCE PER FOOT BAR LENGTH FOR VARIOUS
BAR SHAPES AND MATERIAL MOISTURE CONTENTS

Device	Moisture Content						$\bar{D}$
	0	2.25	3.45	5.2	7.3	9.5	
Round	16.34	17.27	19.47	15.98	16.53	14.87	16.74
Square	17.08	16.44	14.64	13.91	16.69	15.64	15.73
L.F.A.	17.63	13.51	15.83	13.67	14.43	15.30	15.06
F.F.A.	21.34	16.11	18.23	16.11	18.01	16.86	17.78
$\bar{M}$	18.10	16.58	17.04	14.92	16.42	15.67	

Laboratory test machine No. 2

Rotor diameter nine inches

Each value average of six subsamples

Each subsample average of three replicates

Replicate speeds as in Table V

ANALYSIS OF VARIANCE

	D/F	S.S.	M.S.	F	5%
Total	23	76.58			
Devices	3	25.46	8.49	4.99*	3.29
Moistures	5	25.59	5.12	3.01*	2.90
M x D	15	25.53	1.70		

* Significant difference at five per cent level

L.S.D. moisture = 1.6 pounds

L.S.D. devices = 2.0 pounds

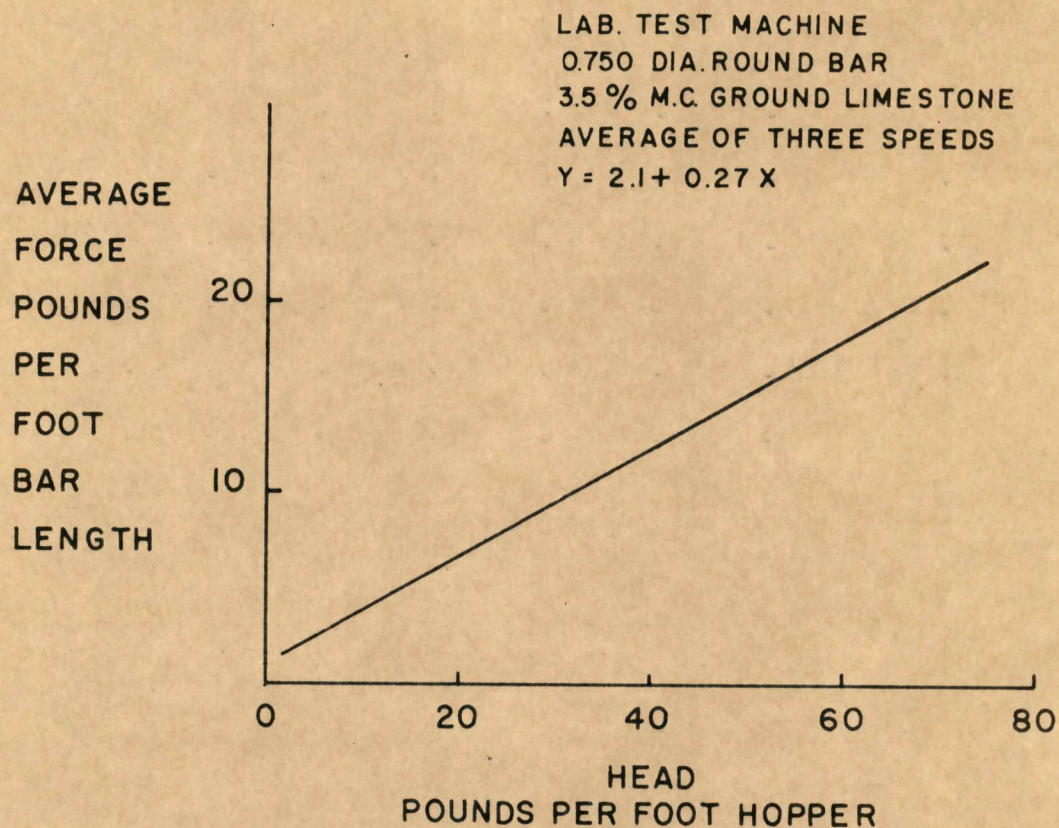


FIGURE 25
EFFECT OF HEAD ON TORQUE

Field Test of The Distributor

The Test Machine

The open-center rotor metering device was incorporated into a ten-foot width, dual hopper, broadcast spreader. This assembly was mounted on the front of a farm-type crawler tractor (Figures 26, 27 and 28).

The hopper assembly consists of a dual, ten-foot section of a twenty-inch depth hopper, containing a nine-inch diameter open-center rotor, and having a diamond-shaped opening, metering slide in the semi-circular base of each section. The forward section had a capacity of 1500 pounds of ground limestone. The rear section, which was designed to apply seed or fertilizer with the ground limestone in designated amounts or ratios without previous mixing, has a capacity of 500 pounds of commercial fertilizer. The metering means of this section is an adaptation of the Masters patent (7).

The unit was mounted as described above by means of an I-beam supporting frame attached to the front and rear track frame supports of the crawler tractor. The hopper was driven by a roller chain-sprocket type drive actuated from the crawler track pins (Figure 27).

Calibration pans were attached below the metering slide openings of the hopper to obtain material output data. A revolution counter was mounted on the hopper drive shaft to provide a means of measuring output increments.

The Data Recorded

Tests were undertaken to determine the following:

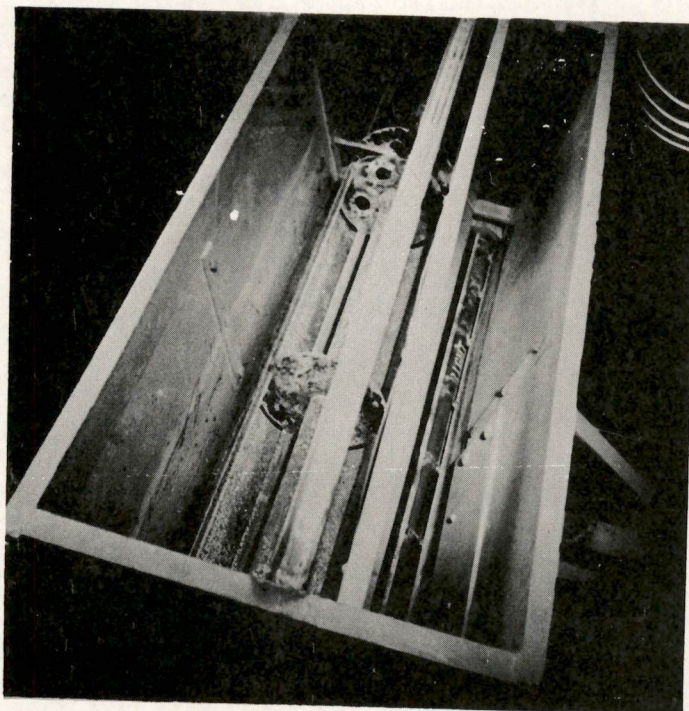


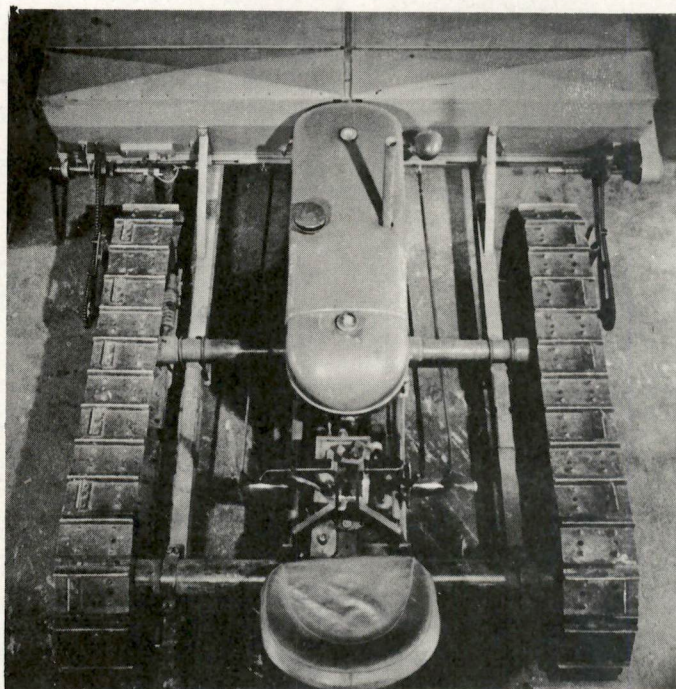
Figure 26

Dual Hopper Broadcast Type Spreader

Figure 27
Spreader Mounted on
Farm Crawler Tractor



Figure 28
Spreader Mounted on
Farm Crawler Tractor
(top view)



1. The effect of hopper inclination on discharge,
2. The effect of moisture content on uniformity of output,
3. The stability of the machine on various slopes, and
4. The feasibility of the machine.

The Test Procedure

The following procedure was closely replicated in all tests.

1. A 100-foot test run was laid out on slopes of zero and thirty-five per cent.
2. The machine hopper was filled to the required test depth and the test run was made both up and down slope for each of the following lime moisture contents: 1.3, 4.7, 7.5 and 12.5 per cent.
3. Each test run was replicated four times.
4. The hopper discharge for each run was collected in the calibration pans suspended under the hopper, and the number of revolutions of the rotor shaft required to traverse the 100-foot run was recorded.

These tests were conducted for a slope of

1. zero per cent,
2. thirty-five per cent,

and slide openings of

1. full,
2. 50 per cent,
3. 25 per cent,
4. 15 per cent,

and at a tractor speed of 1.15 miles per hour and a rotor speed of twelve revolutions per minute.

At the termination of each test a moisture sample was collected and a moisture determination conducted by the air-oven method (1).

Results of Tests

Hopper Inclination Test. Inspection of the curve of Figure 29 shows that slope does not affect metering efficiency above the four per cent level of moisture content. Below the four per cent level, operation on a thirty-five per cent slope resulted in a twenty-five per cent decrease in output over zero slope operation. Output downslope averaged less than ten per cent greater than operation upslope on the soil conditions tested.

Depth of Material Test. The head or depth of material in the hopper has no effect on uniformity of discharge as is shown by the curve in Figure 30.

Moisture Content Test. As with the laboratory test, moisture content of the ground limestone was highly significant in its influence on the metering of the output. An examination of the data in Table VIII indicates a similarity of decrease in output paralleling the laboratory data in Table V. A greater differential in the discharge rate was experienced at the lower moisture contents, due to shock agitation by the moving machine, than was found in the laboratory tests.

Machine Performance. Observation during the various field tests indicated the forward mounted hopper increased the machine stability on steep slopes. Sideslopes greater than forty-five per cent presented a

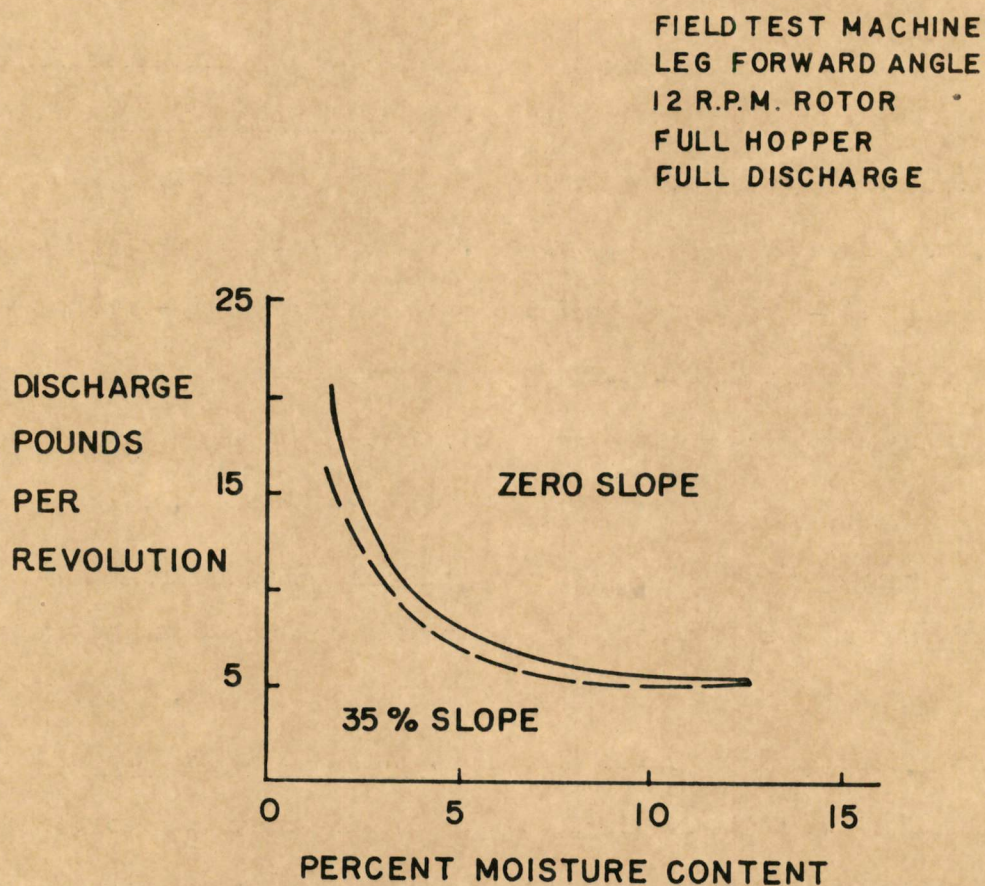


FIGURE 29
EFFECT OF HOPPER INCLINATION
ON DISCHARGE

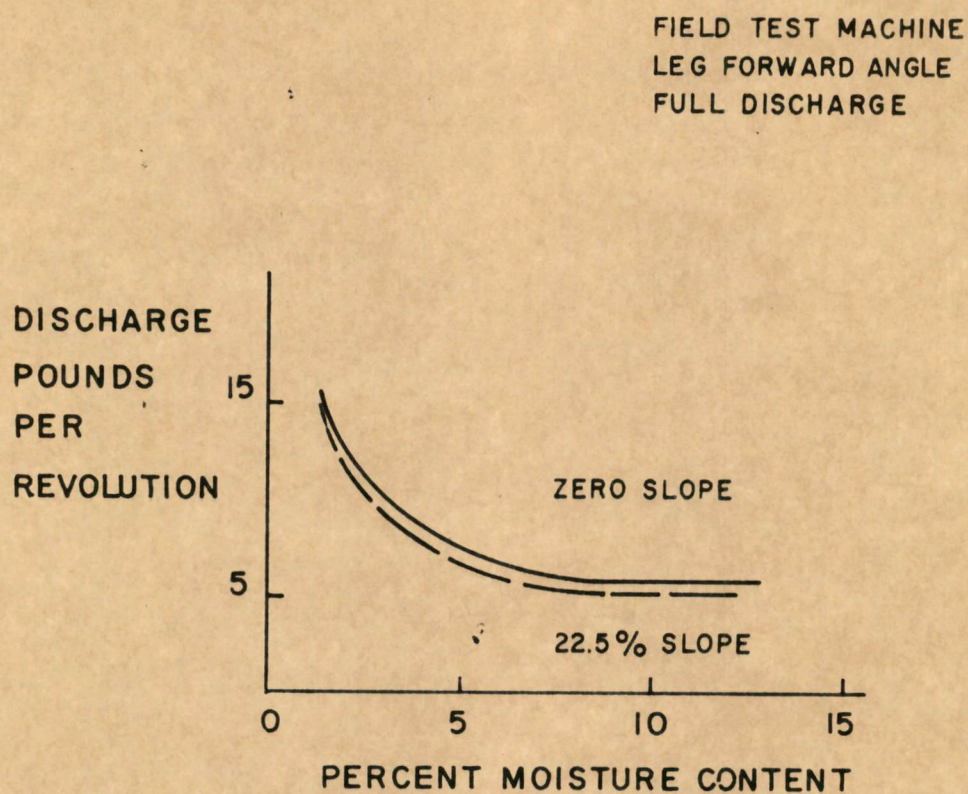


FIGURE 30
EFFECT OF HEAD ON DISCHARGE

TABLE VIII

FIELD TEST, DISCHARGE ANALYSIS AT VARIOUS RATES, HEADS,
SLOPES AND MATERIAL MOISTURE CONTENTS

Operating Conditions			Per Cent Moisture Content				L.S.D.
Slope	Slide Opening	Hopper	1.3	4.7	7.5	12.5	
0	100%	Full	20.8	8.2	6.3	5.8	0.9
35%	100%	Full	15.1	7.1	5.4	5.7	
0	100%	Half	20.3	9.1	7.0	5.5	1.5
35%	100%	Half	15.4	7.7	6.4	5.7	
0	75%	Full	16.2	6.6	4.9	4.3	1.2
35%	75%	Full	11.3	5.0	4.3	4.1	
0	75%	Half	16.8	5.6	4.4	4.2	0.8
35%	75%	Half	12.4	6.2	3.7	4.4	

100 foot test run

1.15 miles per hour speed of run

Each value average of four replicates

Average error variance 0.45 for total mean square of 250

Each value is an average of two upslope and two downslope runs

problem in slippage when loose soil was encountered. This slippage had a detrimental effect on uniform metering of the materials.

Some difficulty in steering was also encountered when traversing downslope with a full hopper. The tractor as modified was adequate to traverse all the slopes encountered.

Summary

The metering device was both laboratory and field tested. Practicability of the machine under farm conditions was not fully tested. The device meters lime at moisture levels that are inoperative in present commercial design. It provides adequate hopper capacity for the applications of liming and fertilizing materials on slopes that conventional equipment cannot traverse. It is a low cost machine with one moving part, easily cleanable and through the use of commercially available mounting parts may be used either on crawler tractors or as a pull-behind machine for conventional farm operations. The device does not positively displace ground limestone at the lower moisture levels with a resultant unevenness of calibration across the various moisture content levels. The high torque requirement with the slide closed poses a problem in designing an adequate drive mechanism.

CHAPTER VI

THE HOPPER DRIVE AND TRANSPORT MEANS

Design Requirements

Design difficulties were encountered in the construction of a simple drive mechanism. The relatively high power requirements of the metering device under certain conditions of material moisture content, particle size, and rotor operation with metering slide in the closed position, necessitated a structurally heavy and strong drive mechanism.

The design speed of the metering rotor is thirty revolutions per minute at a hopper ground speed of 1.15 miles per hour. This condition requires an input of three horsepower to the rotor shaft with a full hopper.

The Sprocket-type Drive

This drive (Figure 31), operating on the crawler track pins, was obtained from the Oliver Corporation. The drive as delivered proved structurally inadequate. When the frame was strengthened, the sprocket tooth shape was found to be incorrect for supplying the power required. Addition of steel wedges (Figure 32) to change the tooth contour of the track pin sprocket raised the capacity of the drive, but it was not sufficient to meet the minimum requirements. Lowering the design speed of the rotor to twelve revolutions per minute raised the capacity of this drive to approximately two horsepower. This supplies a minimum

Figure 31
Details of Hopper Drive

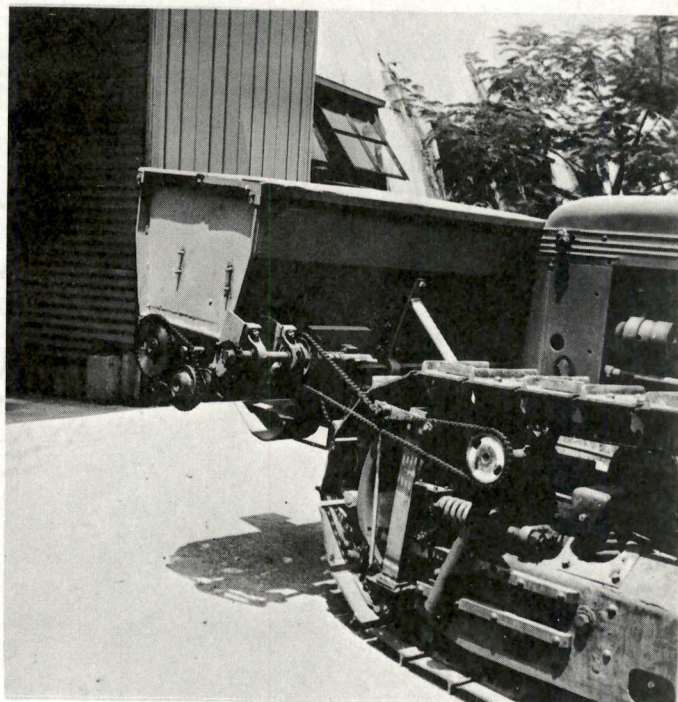
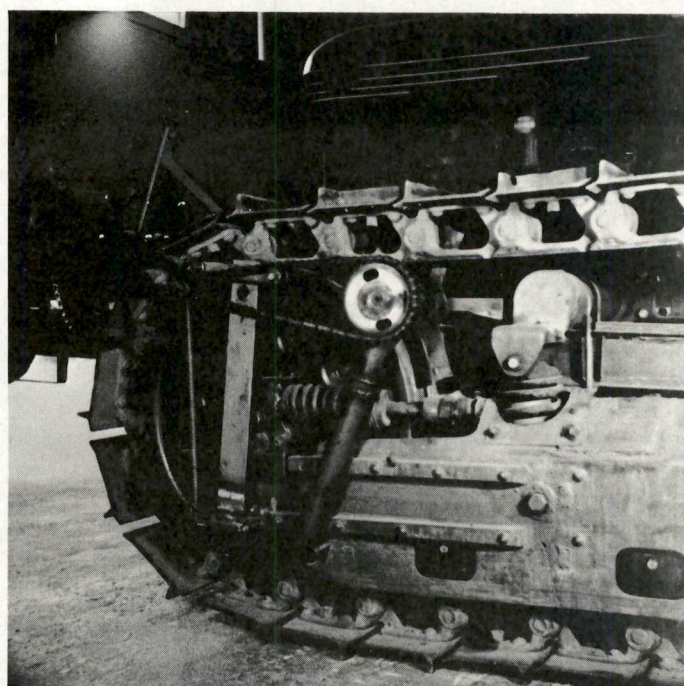


Figure 32
Hopper Sprocket-Type Drive



horsepower drive with a high cyclic amplitude, not satisfactory in view of the design requirements.

Pin and Gear Drive

An investigation was made of a pin and gear drive operating on hardened steel studs on the crawler tractor front idler wheel (Figure 33). The gear was designed for continuous driving and has a cycloidal tooth shape. This drive was unsuccessful because of the high rate of gear tooth wear due to the high power requirement of the metering device. Induction hardened tooth surfaces are a possible solution to this problem. The compactness, strength and low unit cost of this design would recommend its further investigation.

Summary

The sprocket-type drive meets the minimum specifications set up in the design requirements. It is not satisfactory for prolonged field usage. The gear and pin drive shows the greatest promise of success if the tooth wear problem can be overcome.

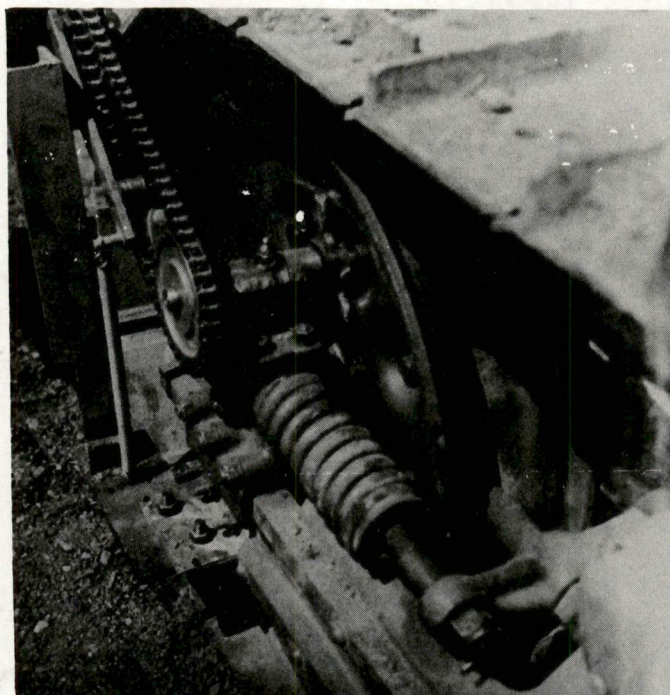


Figure 33

Pin and Gear Drive Assembly

CHAPTER VII

THE TRANSPORT MEANS

Design Requirements

A maneuverable machine with a low center of gravity which can be operated with reasonable safety up, down and on side slopes of a maximum of sixty per cent was necessary to fulfill the requirements of the project.

Information (4, 6) was obtained from manufacturers of wheel-type and tracklayer-type farm tractors as to the maximum recommended slope on which these tractors are designed to operate with or without special equipment. Inquiries were made to determine if any special equipment, such as fuel system changes, oil pump changes and the addition of special track grousers, could be furnished to increase performance on steep slopes.

Although the static tipping angle for most wheel-type tractors is forty-eight degrees, safe operation limits the use of these tractors to slopes under thirty per cent. Crawler or track-layer tractors are commonly used on slopes of sixty to seventy per cent (4). Since two large manufacturers of farm machinery produce a small, reasonably priced farm crawler tractor, this type was chosen for the operation.

Modification and Field Test

Carburation difficulties were encountered in initial tests on slopes in excess of forty-five per cent because of fuel level fluctuations

in the carburetor and sticking of the fuel float. The addition of a Carter, Model 110 NR, electric fuel pump eliminated this difficulty. A by-pass valve was installed on the pump to remove it from the fuel circuit for level ground operation.

Side slope slippage becomes critical on steep slopes devoid of vegetation. To minimize this slippage, cleats of the same height as the grouzers were bolted to alternate shoes parallel to the direction of travel (Figure 34). This addition offers some resistance to slippage. The amount of slippage is dependent on the soil type and condition and weight and speed of the tractor.

Low speed operation is necessary for complete control and safe operation of the tractor. A commercially available, fifty per cent speed reduction gear box was added between the engine and transmission of the tractor. This addition lowered the rated speeds of the tractor to one-half their former value as shown in Table IX and doubled the effective low speed torque output.

The addition of the one ton, loaded weight hopper on the front end of the tractor created suspension difficulties. It was necessary to replace the track frame guide and spring assemblies with a heavy duty set provided by the manufacturer for use with front end loaders, high lift buckets, etc. This additional weight materially shifted the operating unit center of gravity and adversely influenced the handling ability of the tractor, particularly on downslope operation. A counterbalance weight (Figure 35), similar in effect to the one provided by the manufacturer for blade or bucket loader use, was added to the rear of the machine. This did not prove satisfactory on steep slope operation; the machine still tended

Figure 34
Cleats to Minimize
Side Slippage

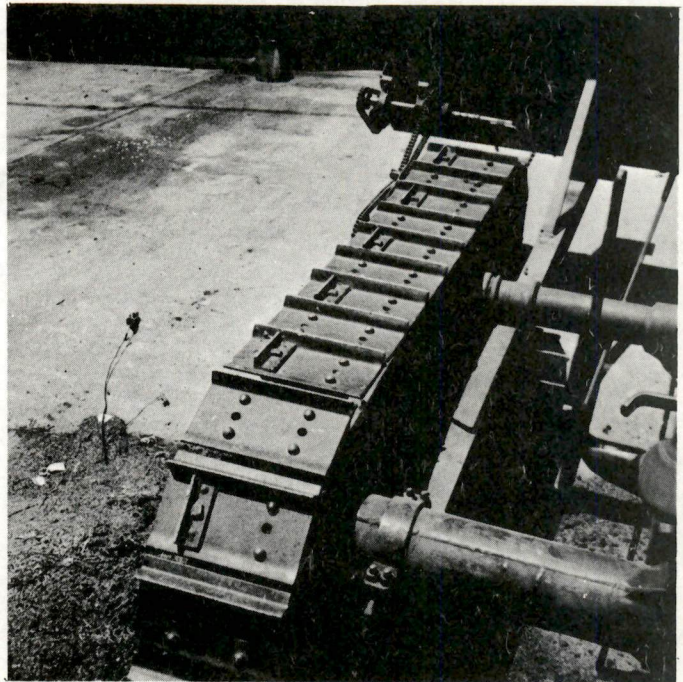


Figure 35
Spreader Showing
Rear Mounted
Counterweight



TABLE IX

GROUND SPEED, OLIVER HG TRACTOR
WITH GEAR BOX

	Gear	Speed, M.P.H.
Standard	low	2.02
	2nd	3.19
	3rd	5.25
Gearbox	low	1.15
	2nd	1.81
	3rd	2.98

to nose in on downhill operation with heavy front-end loads. At the suggestion of the manufacturer, the standard procedure of rolling forward the rear axle housing was undertaken with improved performance resulting. The roll forward does not eliminate the need for a counter-balance.

Summary

The track-layer type tractor is the safest and most efficient carrier for steep slope operation. Addition of an electric fuel pump and a low speed gear box was necessary to prevent stalling of the tractor on slopes in excess of forty-five per cent. Rolling forward of the rear axle housing and the addition of a rear mounted counter-balance improved downslope handling characteristics of the tractor.

CHAPTER VIII

FINDINGS AND CONCLUSIONS

Findings

Agricultural ground limestone which will pass through screens of a smaller mesh than fifty mesh size exhibits strong cohesive qualities at moisture levels above one per cent. These moisture levels are common to this material which is generally stockpiled exposed to weather.

This finer ground liming material when dispensed by usual methods exhibits a strong tendency to "bridge" when damp, making distribution inaccurate or impossible.

Since no commercial product capable of operation on steep slopes as required by the project was available, a means to distribute this material was necessary.

Testing of five methods of feeding disclosed that all but one, the top feed distributor, have one common fault--bridging. An analysis of the conditions resulting in bridging shows that if any of the following factors is present, inaccurate or incomplete flow will result:

1. Narrow width to height ratio with sloping sided (over fifteen degrees from vertical) hopper,
2. Ledges in the hopper, and
3. Intermittent feeding means.

The experimental machine described above was designed and constructed. An analysis of operation of the device discloses that the passage of

the multi-barred cylinder through the material mass accomplished two purposes:

1. To move a uniform amount of material to the openings in the hopper base and thus provide a constant metering influence from which the variable area openings permit a pre-determined amount of material to flow.
2. To impart a unique motion to the material in the hopper by means of the rotating, full length cylinder bars. The upward movement of the cylinder bar, in close conjunction with the hopper side, imparts a transverse shearing action to the material in intimate contact with the hopper side, thus preventing the formation of the "bridging" arch base. The further vertical and lateral movement of the cylinder bar in its motion across the hopper section imparts the same transverse shearing action in the material occupying the upper hopper section and results in a pulsating movement of the material body eliminating any arch formation. This action in combination with aforementioned physical limitations on the hopper design permits a metering of material of such moisture content as to be impossible to meter by any known applicable method.

An analysis of test results, both laboratory and field, permitted the following assumptions:

1. Slope does not affect uniformity of discharge. It has a significant effect on output at moisture contents below four per cent.

2. Small rotor diameters and side slopes in excess of fifteen degrees from the vertical result in bridging. One vertical slide on the hopper permits the sloping of the other side slightly in excess of fifteen degrees.
3. Upslope travel results in a lower discharge rate.
4. Moisture content of the material was the significant factor influencing output under all operating conditions.
5. Moisture content has a significant effect on the torque input to the machine. Requirements are greatest at zero per cent and indirectly proportional to the apparent specific gravity of the material.
6. Rotor bar shape significantly affects the total amount of output per unit time. The round bar dispenses the most material per revolution of the rotor.
7. There is a definite interaction between bar shape and moisture content. The face forward angle has the most consistent discharge over the moisture content of all the shapes tested.
8. The bar shape also has a significant effect on torque requirements. The face forward angle has the greatest requirement and the leg forward angle has the least.
9. The number of bars on the rotor influenced slightly the total output. Reduction in bar numbers decreases the starting torque but results in pulsating ejection.
10. Rotor speed has little effect on output uniformity at moisture contents in excess of one per cent.

11. Head has no effect on uniformity of discharge until the last four inches of material in the hopper is reached.
12. Torque with slide closed and rotor revolving in the material is fifty per cent above slide open valves, head remaining the same. Torque is proportional to head.

Conclusions

The metering device described above has been incorporated into a ten-foot width, dual hopper, broadcast type spreader. The rear hopper of the unit was designed to apply seed or fertilizer with the ground limestone output of the front hopper in desired amounts and ratios without prior mixing. The total capacity of the unit is one ton-sufficient material, applying ground limestone at the rate of two tons per acre, for a run of one thousand feet and return. This capacity is judged adequate for steep slope usage since most slopes above thirty per cent have a very short run.

The device meters lime at moisture levels that are inoperative in present commercially designed machines. It provides adequate hopper capacity for the application of liming and fertilizing materials on slopes that conventional equipment cannot traverse. It is a low cost machine with one moving part, easily cleanable and, through the use of commercially available mounting parts, may be used either on crawler tractors or as a pull-behind machine for conventional farm operation. The device does not positively displace ground limestone at the lower moisture levels. This deficiency results in an increase in slope at the low moisture content end

of the average delivery rate versus angle of repose curve. The increase in apparent specific gravity of the material in this region also tends to amplify this discrepancy. Since the moisture content of the material increases above the two per cent level, opening the metering slide does not materially increase the rate of output above that due to positive action, as no free flow results. This lack of volumetric displacement of the material at the very low material moisture contents limits the device's adaptability for metering dry materials at low rates of application.

The design specifications as set forth in Chapter IV have been adequately filled. Bridging has been eliminated; a positive dispensing action for all drillabilities above the three per cent material moisture content has been provided with a low cyclic amplitude; and the delivery rate is independent of the depth of the material at reasonable inclinations of the distributor.

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APPENDIX

CSVME2 (A) CSF2.1

APPENDIX A

Patent Review

A patent review was conducted by Cameron, Kerkam and Sutton, 700 Tenth Street, N. W., Washington 1, D. C.

The following patents were developed as being pertinent to the search:

808,799	2,193,253	2,526,609	2,626,729
1,957,594	2,323,995	2,541,008	2,645,384

The Masters' patent (2,193,253) most closely approaches the device, and the variation is a matter of degree rather than novelty. A review of the claims does not seemingly disclose any attempt to secure the conflicting features.

Stratification of material between the feeder discs of both the Stahmer (2,541,008) and Juzwiak, et al, (2,645,384) devices provides the base for the arch formation of "bridging", and both of these distributors have proved unsatisfactory in field use for the handling of wet materials.

The diagonal or spirally contoured blade of the rotating cylinder of the Woolman patent (808,799) would closely approach the influence of the axially mounted bars of this invention; however, its relationship to the other distributor parts would prevent it from functioning adequately with wet materials. The operating means of the Hiroshima patent (2,323,995) are quite similar to the Woolman patent, and the claims seem to be entirely based on the outlet metering control.

Due to the high development of the art and the difficulties of

basing patent claims on degree, it was recommended by the investigators that a patent application not be made.

An investigation as to possible infringement was undertaken, and in their letter of March 30, 1954, to Mr. J. P. Hess, Business Manager, University of Tennessee, Cameron, Kerkam and Sutton state:

"In view of the state of art, it is probable that there is no subsisting claim of sufficient breadth to be infringed by the Brown structure."