MECHANICAL REMOVAL OF STONES
FROM AGRICULTURAL LAND

Thesis for the Degree of M. S.
MICHIGAN STATE COLLEGE
Fred Warner Roth
1951

This is to certify that the

thesis entitled

"Mechanical Removal of Stones from Agricultural Land"

presented by

Fred W. Roth

has been accepted towards fulfillment
of the requirements for

M.S. degree in Agricultural Engineering

H. F. McColly
Major professor

Date June 29, 1951

O-169

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By

Fred Warner Roth

AN ABSTRACT

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

MASTER OF SCIENCE

Department of Agricultural Engineering

1951

THESIS

MECHANICAL REMOVAL OF STONES
FROM AGRICULTURAL LAND

Stones in agricultural land increase the cost and difficulty of producing crops by interfering with the use of farm machines, causing extra wear and breakage, and often reduce the rate of working in the field.

A study has been made of the developments in mechanical equipment for removing stones, and a stone-picking machine was tested in the field. There are at least four manufacturers making machines designed to pick stones of about nine inches or less in diameter. Each of these machines is described and the principle of operation explained.

The Bergman stonepicker was field-tested on three different farms in Jackson County, Michigan where stones were rather numerous. Stones on the surface were found in one field at the rate of 51 tons per acre.

Tests were made to determine the draft requirement of the machine, and the field work revealed several limitations of the stonepicker due to poor design. A number of suggestions have been made for improving the design.

The costs per acre of picking stones with a machine are analyzed and compared with the cost of hand-picking.

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ACKNOWLEDGMENTS

The author wishes to express his appreciation to the following:

Professor H. F. McColly of the Agricultural Engineering Department for helpful guidance and assistance in carrying out the project.

Professor A. W. Farrall, Head of the Agricultural Engineering Department for his assistance and granting a research assistantship.

All members of the Agricultural Engineering Department for various kinds of help, but especially to Professor C. M. Hansen and Mr. James Cawood for their valuable assistance.

Mr. William Bergman, Pigeon, Michigan, for his cooperation in loaning the stonepicker for the investigation.

Mr. Fred Sackrider, Agricultural Instructor at Hanover, Michigan, for his help in locating suitable fields in which to work.

The Messrs. Eslow Richards, Robert Folks, and Donald Conklin, farm operators in vicinity of Hanover, Michigan, for their cooperation in permitting the use of their fields and tractors.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

There are perhaps several million acres of agricultural land in the United States infested with stones to the extent that they interfere with the use of farm machinery and make the production of crops more difficult and costly. A survey by Hansen and Woodrick (1950) showed that there are over 750,000 acres of cropland in Michigan from which it is considered advisable to remove stones of nine inches or less in diameter. Many other states, particularly those in the area covered by the glaciers, have similar conditions, and in some places the numerous stone piles, stone fences, and stone buildings are mute evidence of the stone removal work done in the past. It would be difficult to determine how many acres of cropland in the United States still remain from which it would be worthwhile to remove the stones, but an estimate of a few million acres would not seem to be unreasonable.

The problem of clearing the soil of stones is not new; they have been a nuisance to farmers ever since the most primitive tillage tools began to be used. As agricultural machines were developed and put into use, stones became more than just a nuisance. They were obstacles to mechanization, and in some places prohibited the use of farm machines until at least some of the stones were removed. The methods and machines used in today's agriculture make it more important than ever to have stone-free soils on which to farm. It

is desirable to remove stones from cropland for the following reasons:

1. They cause breakage of machinery and equipment. Machines such as forage harvesters and combines may be extensively damaged by only one stone.
2. Stones increase the wear-out rate on most machines.
3. Valuable time is lost when broken equipment must be repaired.
4. Slower operating speeds must be used in the field when stones are present, thus decreasing the amount of work done and increasing the cost per acre.
5. Precision planting and cultivating equipment requires relatively stone-free soil for best operation.
6. Machines ride more smoothly and are easier to operate.
7. In extreme cases, stones interfere with the growth of plants.
8. Soil may be put to the use that will give maximum returns.

The stones on and near the surface of the soil are not at all uniformly distributed. In many areas there are only a few stones per acre and do not constitute much of a prob-

lem. In other places the stones are so numerous that they almost cover the ground. Then, of course, there are vast areas which have practically stone-free soils. Another aspect of their distribution is that the stony areas are frequently small and widely scattered, a situation which does not encourage the use of stone-removal machinery.

The size, shape, and composition of the stones varies widely, too, depending upon the nature of the parent rock material and the soil-forming agents which acted upon the parent material. The glaciers played an important part as they mixed and transported the soil and rock. In some places only large stones or boulders remain while other areas have only small stones, and still others have a combination of both large and small ones. The shapes vary from thin flat slabs, or rough angular fragments to nearly smooth almost spherical pieces, and it is not uncommon to find them all in the same field. Some stones are the hard granitic type while others such as the limestones and sandstones are relatively softer and more easily crushed.

It should also be remembered that stony soils are not always poor and unproductive. If they were, there would be no point in trying to clear them of the stones. To be sure, some of the stony soils are not level enough, or sufficiently productive to warrant clearing them, but we are primarily concerned in this study with the large amount of fairly level, good productive soil that needs only to have the stones removed to permit most efficient use of farm machinery and maximum returns.

Objectives and Reasons for the Study

The objectives in this investigation were two-fold. First, to make a general study of the problem of stone removal, and the developments in mechanical equipment for doing this work. Secondly, to study and test the Bergman stonepicker for the purpose of:

1. evaluating its performance in the field, and determining the draft requirement,
2. determining stone removal cost with the machine,
3. suggesting possible improvements in design, and
4. determining more accurately the requirements of a machine for picking stones from the field.

There is almost no information available about the stone-picking machines which have been developed in recent years, and are now being marketed. Strong advertising claims are being made and it would be desirable to have more objective information regarding their performance and cost of use.

REVIEW OF LITERATURE

Effects of Stones in the Soil

Lamb and Chapman (1943), reporting on studies made to determine the effect of surface stones on soil erosion, soil temperature, and soil moisture have this to say: "Since surface stones increase water absorption, decrease soil washing, and apparently reduce evaporation, there seems to be little reason for removing them from fields unless they definitely interfere with cultivation." Concerning the higher temperatures found under the stones, they commented as follows: "The high temperatures under stones may be one factor in the production of high-quality grapes on stony steep slopes, and may help explain yields of over 50 bushels of corn per acre at the high altitude (1200 to 1900 feet) of the Arnot station."

This study was made at the Arnot Soil Conservation Experiment Station located 17 miles southwest of Ithaca, New York, and operated jointly by the U. S. D. A. and Cornell University Experiment Station. Data was obtained from three types of plots: large field plots, small field plots, and soil boxes which were weighed.

The effect of stones on work accomplished was reported by Josephson (1928). At the Pennsylvania State College farm a two-plow tractor outfit plowed 42% less in a stony field than in a clean field. In another test a two-plow tractor outfit plowed 36% less in the stony field. The increase in

the cost of plowing due to rocks was 49% in the moderately stony field, and 75% in the very stony field. This amounted to as much as $1.64 more per acre.

The economic aspects of land improvement work are discussed by Creek, Hauck, and Hurlburt (1947). It is pointed out that capital invested in land improvement is no different from capital invested in land, buildings or machinery. There should be the prospect of recovering the costs through increased mechanization of farm operations, more efficient use of labor and machinery, less breakage and longer life of machinery, additional yields and values.

They present a table to show the additional yields per acre of several crops that are required to amortize the land improvement cost over a five-year period, and a ten-year period. The author is inclined to believe, however, that additional yields resulting from the removal of the smaller stones are not likely to be sufficient to pay the costs of removing the stones unless they were very numerous and interfered seriously with cultivation. Stony soils frequently produce as well as, or even better than neighboring soils that are far less stony. Recovery of the costs will, in most cases, more likely be achieved as a result of the other benefits previously mentioned.

Classification of Stony Soils

A distinction is made between rock and stone by Bowles (1939). The term rock refers to geologic formations in their crude form as they exist in the earth while the word stone more properly means the individual blocks, masses, or fragments that have been broken from their original ledges.

Nikiforoff (1948) suggests terminology and a method of classifying stony soils. He defines a stony soil as one that contains a certain quantity of stones either scattered on the surface or imbedded in the earthy material. The soil particles coarser than sand are divided into five categories as follows:

1. Grit -- angular fragments of rock less than one inch in size.
2. Gravel -- rounded, smoothly surfaced fragments about one to three inches in size.
3. Rubbles -- rough-surfaced, sharp-edged, angular fragments about one to eight inches in size.
4. Cobblestones -- rounded, smoothly-surfaced fragments which have been transported and are about three to ten inches in size.
5. Boulders -- stones larger than ten or twelve inches in size.

It is suggested that the terms gritty, gravelly, rubbly, or cobbly be used in conjunction with the soil classification terminology already in use to give some indication of the kind and size of stones present.

The author believes there is a need for more accurately classifying and describing stony soils, and it is further suggested that such terms as slightly, moderately, and very be used to indicate the amount of stones present. Thus a stony soil might be described as a Brookston silty clay, slightly gravelly, or a Miami sandy loam, moderately cobbly. A method such as this would seem to be quite satisfactory, and since it is based on fragment size and percentage distribution in the soil, it is consistent with the textural soil classification system already in use.

Stone-Clearing Costs and Methods

Nearly all of the information found in the literature pertains to clearing large stones, rocks and boulders. However, this is included here because the large stones are no less a problem than the smaller ones, and mechanical equipment plays a very important part in removing them speedily and economically. Furthermore, the removal of large stones is a necessary prerequisite to the use of a stonepicker for removing the smaller stones.

Blasingame, Kessler, and Josephson (1930) reported that the cost of clearing limestone rock from a field on the Pennsylvania State College farm was reduced to $24.00 per acre by using a combination of methods including a subsoiler for hooking the stones loose, and dynamite for mudcapping and snakeholing. The cost per acre was 50% to 100% higher when the methods of mudcapping and snakeholing, or drilling and blasting were used alone. The cost per cubic yard of stone, which is a more comparative figure, was 25% to 35% less when the combination of methods was used.

Getze (1947) reports that in Connecticut steel stoneboats have been especially useful for hauling away old stone walls. Bulldozers are used to push the stones on the stoneboat, and walls three feet wide and three feet high have been removed at a cost of 18 cents per running foot. He claimed that the same job with a power shovel and dump truck would have cost one dollar per foot.

Studies in Minnesota by Thompson and Schwantes (1929) show that wagons are more efficient than stoneboats for transporting stones except where the distance is very short. Dump wagons were found to be more efficient than other types because they could be emptied faster. It would be logical to assume that a rubber-tired dump trailer might be most efficient for hauling stones on a farm.

A report of the State Agricultural Machinery Testing Institute in Sweden describes methods and equipment which have been used there for removing boulders too large to lift and handle. A hole is drilled in the stone and a pin with an eye wedged in so that the boulder can be lifted with a lifting device. The holes are drilled either with motorized drills or compressed air drills. The latter are considered to be better and work at the rate of 2 to 2½ inches per minute making 35 to 55 holes per hour. The drilling is usually done by contractors who charge .50 to 1.00 kronor[1] per hole. The lifting device may be separate, or a part of the transporting wagon. The transporting wagons investigated were grouped in four types as follows:

1. Wagons with a fixed lifting device.
2. Wagons with a gantry beam and trolley.
3. Wagons with a movable jib.
4. Wagons with some other type of lifting device.

Types 2 and 3 were considered most satisfactory; stones could not be piled with the other types. Boulders weighing up to seven tons could be handled and the total time per stone was three to ten minutes. The hourly charge for a boulder-removing wagon with operator and helper is 15 kronor. Where boulders are present in large numbers and do not have to be moved more than about 50 yards, a track-laying tractor with grubbing blade works best. The charge per hour for the tractor with driver is 40 to 50 kronor.

According to Hansen and Woodrick (1950) a stonepicker which they tested in Michigan would save 29 man-hours per acre when used under conditions similar to those in the test. To clear one acre, one man on a tractor and two men with pitch forks would require ten hours to load the stones which the

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[1] One kronor equals 21 cents, approximately.

stonepicker could pick up in 55 minutes.

Stone removal methods and equipment have not advanced very far compared to developments in most other phases of agriculture. There are a number of reasons for this lack of development. First, stones are not a universal problem. As was pointed out earlier they frequently occur in small, widely separated areas, and large sections of land are practically stone-free. Secondly, in many places the stones were not considered troublesome enough to make clearing them out worthwhile. A third reason would be the almost total lack of a market for the stones after they were gathered. They are, and always have been, an almost worthless commodity. Finally, disposal of the gathered stones in a satisfactory manner was not always easy and convenient.

Several methods of disposing of stones have been followed for years. Perhaps the easiest and simplest method is to dump them in a ravine, or some other spot where they will be out of the way, providing such a place is available. Another method is to pile them either in the field or along the fences. In either case, they take up space which could be used for growing crops and they provide a place for weeds and brush to grow as shown in Figure 1. Another objection to stonepiles is that they harbor rodents. Burying the stones in trenches or low places by the use of power shovels and bulldozers has become an increasingly popular method of disposal. A limited amount of stone is used in building work such as foundations, footings, wall and fences.

Figure 1. Stones waste land, harbor rodents, and provide a place where weeds and brush grow.

INVESTIGATION

Methods of Procedure

The methods of procedure were:

1. A study of the literature pertaining to the problem of removing stones from agricultural land. The information is rather limited, and consists primarily of reports on methods and cost of removing large stones. It did, however, give a clearer picture of the nature of the problem.

2. A search of the records in the Patent Office to determine the principles of mechanical stonepickers which have been patented.

3. Discovering the manufacturers of stonepickers and obtaining a description of each machine.

4. Testing a stonepicking machine to obtain data on performance in the field, and to observe operation of the machine.

5. Alterations and improvements in the design of the machine.

Stonepicker Principles Patented

A study of the records in the United States Patent Office revealed that there are about six basic stonepicker principles which have been patented.

The first patent on a stone-gatherer, as it was called, was granted June 29, 1852 to a J. T. Foster of Jersey City, New Jersey. The principle employed is that raking teeth gather the stones, and a toothed cylinder kicks them up into a hopper where they are collected for dumping. Figure 2 illustrates this principle. It is interesting to note that the principle is used in one of the stonepickers being manufactured today.

Six years later a patent was granted on another type of stonepicker. In this design raking teeth were used to gather the stones from the soil and a reciprocating scraper moved the stones up the inclined teeth into a hopper. This type is illustrated in Figure 3.

In 1865 the first patent was granted on the type using a toothed cylinder in combination with a traveling inclined apron to carry the stones up and back into a hopper. Figure 4 shows the principle involved in this type.

The next new stonepicker design was patented in 1908. Figure 5 illustrates how the stones would be raked up the inclined teeth by paddles on an endless chain. Two years later the first design using elevator buckets was granted a patent.

In 1919 a patent was granted on a machine using discs set at an angle and overlapping each other for windrowing the stones. Figure 6 shows this arrangement.

The last basic principle patented was the design using toothed-drum windrowers for collecting the stones in a row. This patent was granted in 1921. The principle is embodied

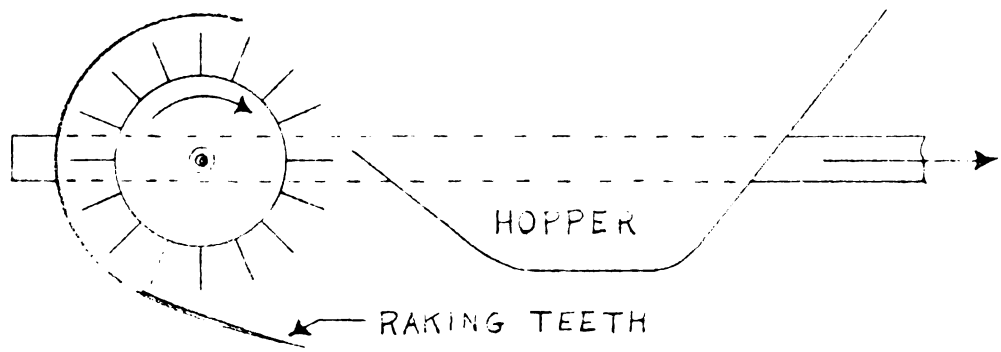

Figure 2. First stonepicker principle patented in 1852.

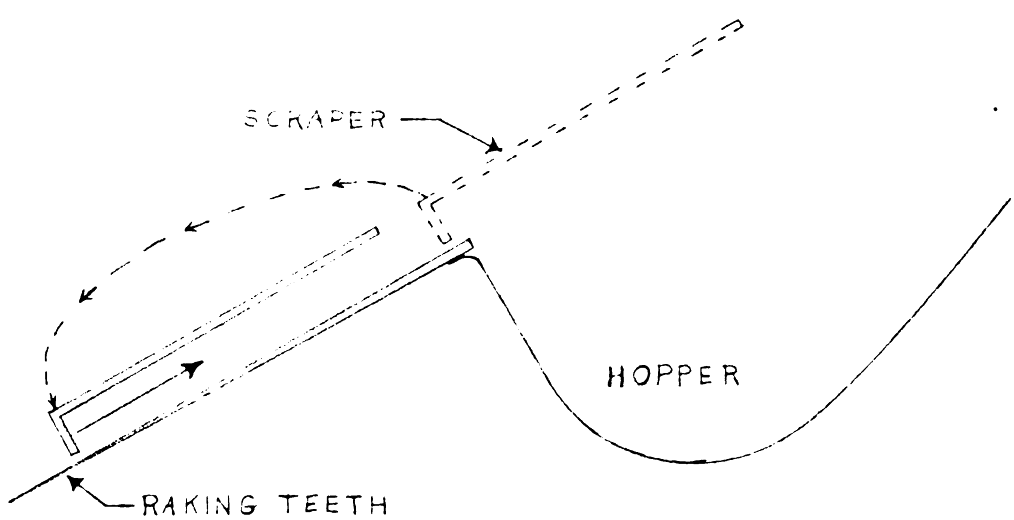

Figure 3. Principle of stonepicker patented in 1858.

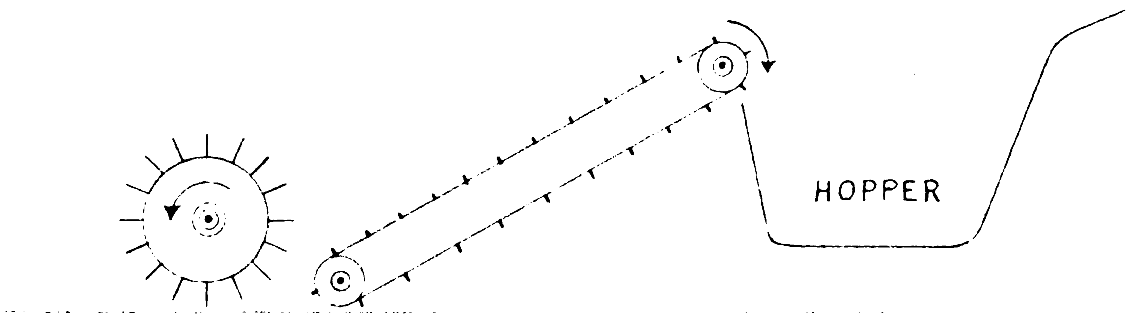

Figure 4. Stonepicker principle patented in 1865.

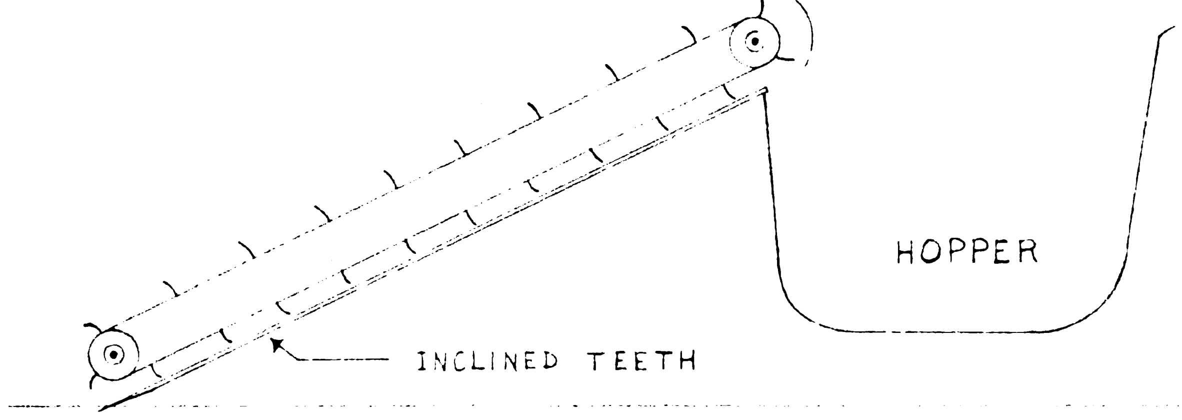

Figure 5. Stonepicker design patented in 1908.

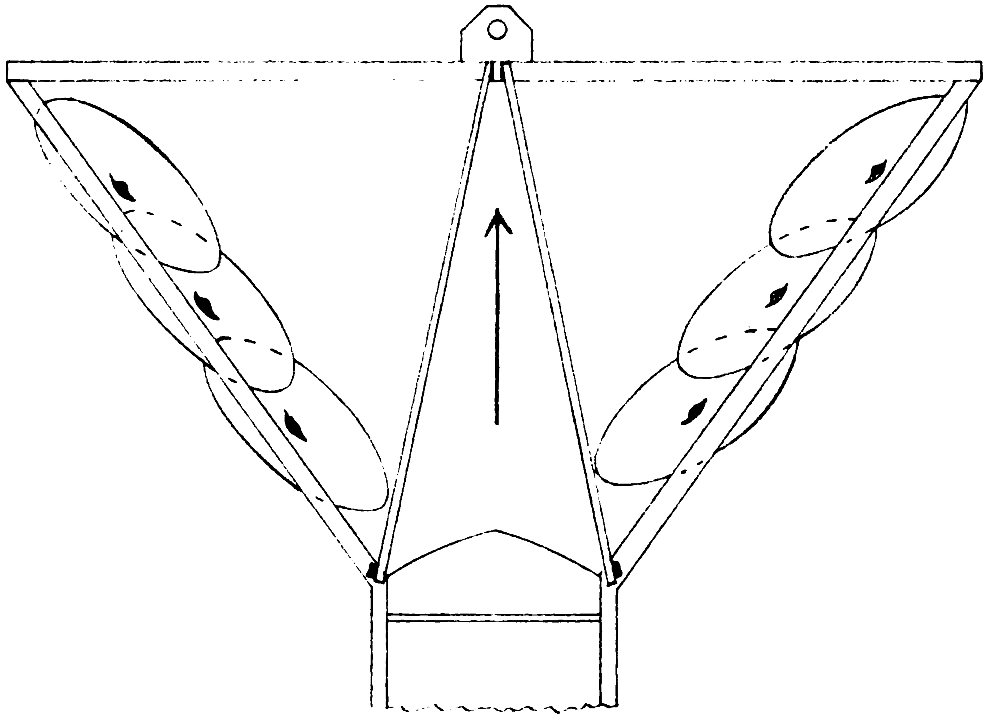

Figure 6. Stonepicker principle patented in 1919.

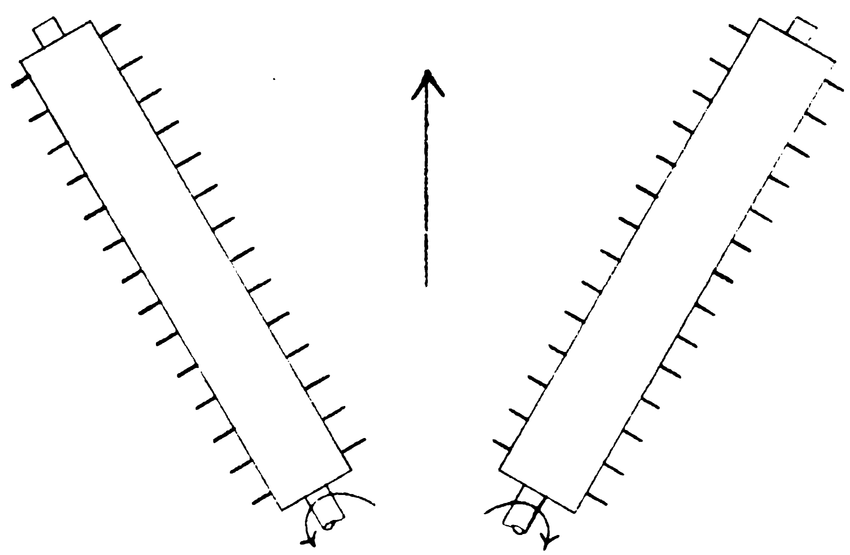

Figure 7. Windrower design patented in 1921.

in the machine which was used for the experimental work and is illustrated in Figure 7.

Description of Stonepickers Now Manufactured

The investigator has been able to locate but four manufacturers of stonepickers. A description of each machine follows:

The Lukens Stonepicker.

The Lukens Steel Company, Coatesville, Pennsylvania, has had a machine under development and test during the past two years. It is designed to pick up and pulverize the stones, returning the crushed material to the soil. The machine shown in Figure 8 weighs approximately 5000 pounds and requires a large tractor (3-plow size) to pull it. According to the company's Development Engineering Manager, the machine will handle stones up to eight inches in size, and cleans a strip of ground 26 inches wide at each pass. The scraper at the front is hydraulically controlled for depth and picks up both soil and stones which are transferred to a conventional potato digger chain conveyor where the soil is shaken out. "The stones then enter the breaker chamber where a set of specially designed revolving members rotate at high speed, causing the stones to disintegrate into particles ranging in size from ordinary sand up to 1½ inches. The larger size of particles are a very small percentage of the tonnage processed." Figure 9 is a photograph of some of the crushed material. It was reported that test results indicate a capacity of three-eighths to one-half acre per hour in a field where the calculated stone content was 40 to 50 tons per acre. At the time inquiry was made, the selling price of the machine had not yet been established.

Figure 8. The Lukens Stonepicker and Pulverizer.

Figure 9. Pulverized stone from the Lukens machine. Note the number of larger pieces.

The Fastpic Stonepicker.

The Fastpic machine shown in Figure 10 is made by the Coastal Machine Works, Inc., Bridgeport, Connecticut. It is the oldest of the four stonepickers which have been developed, and employs the principle first patented in 1852. According to the company spokesman, "the machine has been in use a number of years, and is being used in more than half of the 48 states as well as three foreign countries."

It is designed to pick surface stones ranging from two to eight inches in size, from a strip three feet wide. The revolving cylinder which kicks the stones up into the hopper is driven from the tractor power take-off shaft, and the hydraulic system is used to control the height of the picking mechanism. The hopper has a capacity of about 3000 pounds, and the operator, by pulling ropes, can dump from either side while standing still or on the move. The machine weighs 3600 pounds, and requires a tractor of 20 drawbar horsepower or larger. The selling price of the stonepicker is about $1600. It was reported by a New York farmer that 262 tons of stone were cleared from ten acres by one man in 24 hours.

The Jochim Stonepicker.

Figure 11 shows the stonepicker made by the Minn-Kota Manufacturing Company, Moorhead, Minnesota. The manufacturer claims that the machine has been field tested for five years, and that hundreds of them have been sold throughout the United

Figure 10. The Fastpic Stonepicker.

States and Canada. It is designed to pick surface stones from about 1½ inches in size to rocks 350 pounds in weight from a strip eight feet wide. The gathering tines are raised to dump the stones in the hopper by means of two double-acting hydraulic cylinders as shown in Figure 12. It is obvious that when stones are numerous frequent stops must be made to empty the gathering tines. The hopper, which has a 3000 pound capacity, is raised for emptying by another pair of hydraulic cylinders. The machine weighs approximately 2000 pounds, and although a 2-plow tractor will pull it, a 3-plow size is recommended. No information was given regarding the amount of stones that could be picked, or the number of acres that could be cleaned per hour. This would vary widely depending on the field conditions. The machine lists for about $800 at the factory.

The Bergman Stonepicker.

This machine, shown in Figures 13 and 14, has been developed since about 1946 and is being built by the Bergman Manufacturing Company, Sebewaing, Michigan. It uses revolving windrowers to gather the stones, and the elevator buckets pick up and dump them into the trailer which is attached at the rear. The machine is designed to pick surface stones ranging from two to nine inches in size from a strip about nine feet wide. The windrowing and elevating mechanisms are both ground driven. Roller chain is used in the first step of the drives

Figure 11. The Jochim Stonepicker with the Raking Teeth in Working Position.

Figure 12. The Jochim Stonepicker with the Raking Teeth in Dumping Position.

Figure 13. The Bergman Stonepicker Used in the Investigation.

Figure 14. Side View of the Bergman Stonepicker.

and V-belts in the final drives. The trailer is a dump type and will hold about 4500 pounds of stone. It is easily detached and hauled away for dumping by the tongue at the rear. One farmer in Huron County, Michigan, reported that 43 cubic yards of stones were removed from 17 acres in seven hours with the Bergman machine, and another farmer in the same area reported that 61 trailer loads of stone were picked by this machine in 8½ hours. The weight of the machine, including the trailer, is 4550 pounds, and the selling price is about $2100. A 3-plow tractor is required to pull this machine in most places.

Experimental Work

The experimental work was done with the Bergman stonepicker which has already been described in some detail. All of the field trials were made during July and August 1950 on three farms in the vicinity of Hanover, located in Jackson County, Michigan. The soil ranged from sand to clay loam, but most of it was a silt or sandy loam. One field was very stony, while the other two were less so. Two of the fields had moderate slopes while one was nearly level. Each of the farm operators agreed to furnish a tractor for pulling the stonepicker and if possible another one to be used for emptying the trailer.

Because of the difficulties experienced, and the fact that certain changes were made in the equipment as the research progressed, it is considered best to present the experimental work in chronological order.

Conklin Farm.

Field conditions. The field on this farm was rectangular in shape, about seven acres in size, and the soil mostly a sandy loam. It had been harrowed deeply four times to work the stones to the surface and was very loose and dry on top. The stones were not evenly distributed, but they were fairly thick over most of the field. A few stones larger than nine inches were scattered about, and several tight stones were sticking out of the ground. Quack grass roots were quite numerous having been brought to the surface by harrowing. The field was highest through the middle and the slopes ranged up to about eight percent.

Equipment. A John Deere Model G tractor was obtained for pulling the stonepicker. The dynamometer used was the liquid compression type with Bristol recorder described by Sauve (1927). A stopwatch was on hand along with a steel tape and stakes for measuring distances.

Procedure. After the machine was readied for operation and adjusted, the plan was to pick the stones from this field noting the time required, the quantity of stones, the area covered, and any operational difficulties. Several tests were to be made to determine the drawbar pull required.

It became apparent almost immediately that the John

Deere G could not pull the stonepicker in this field. The slightest grade would cause slipping of the tractor driving wheels even though they were liquid-weighted. An Allis-Chalmers WC tractor was then hitched to the front of the John Deere G and together they were able to pull the machine any place in the field. The machine was operated at a speed of about three miles per hour and an attempt was made to drive over the field so as to avoid climbing the steeper slopes. When the trailer was loaded, the Allis-Chalmers WC was used to haul it to a corner of the field where the stones were dumped.

The dynamometer was connected between the stonepicker and the tractor pulling it, to make the draft tests. After placing a chart on the recorder and checking its operation, the stonepicker was operated along a straight course for one minute from a moving start. The beginning and end of each test run was marked with stakes, and the distance covered was measured with a steel tape. After the test the dynamometer and recorder was calibrated on the Olsen testing machine in the Mechanical Engineering Department to determine whether the calibration curve available could still be used. The calibration results agreed very closely with the curve.

Results and observations. Most of the results of this test are observations of difficulties which were experienced. They are listed here as they were recorded on 8 July 1950, the day of the test.

1. The John Deere G tractor was unable to pull the machine in this field.
2. Quack grass roots wound on the windrowers and the V-pulleys on the windrower shafts. They also accumulated on the dirt separation grid at the rear of the machine and interfered seriously with separation of dirt from the stones.
3. Stones lodged frequently at various places in the elevating part of the machine, stopping the elevator. These stones, usually 1½ to two inches in size, were difficult to locate and remove.
4. Considerable difficulty was experienced in adjusting the depth of the pick-up buckets. When they were lowered sufficiently to pick up the stones which were windrowed, the buckets frequently started picking up dirt and very quickly loaded up to the extent of stalling the machine.
5. The small caster wheels on the front end of the windrowers did not serve their intended purpose which was to support the outer end of the windrowers. The yokes in which the wheels were mounted gouged a furrow most of the time, and the wheels, carrying little or no weight, rotated

only occasionally.

6. The elevator driving belts slipped at times even when there were no obstructions, and some slippage of the windrower belts was noted.
7. It was observed that at times there was considerable slippage of the driving wheels on the stone-picker.
8. Fewer than one-half of the visible stones were picked from the area over which the machine was operated.

Due to the various difficulties encountered it was possible to make only three draft tests, and pick only two trailer loads of stone in about four hours of time. Results of the draft tests are shown in Table I. The average draft for the three tests was 2166 pounds with the maximum pull as high as 3270 pounds. The horsepower requirement averaged 17.1 for the tests.

It was estimated on the basis of volume that the two loads of stone weighed about 7000 pounds, and that the machine had been operated over approximately one-half acre. The frequent stopping that was necessary made it impossible to obtain data on the rate of working. Because of the unsatisfactory operation of the machine, and the fact that one tractor could not pull it in this field, it was considered inadvisable to attempt any further work here.

Folks Farm.

Field conditions. A square ten-acre field which was being summer fallowed was used for the test work on this farm. The soil was mostly sand and silt loam with some clay over the higher parts of the field, and was well firmed. The surface was ridged and wavy, and a little green grass showed through over most of the field even though a spring-tooth harrow was used just prior to the test work, and also two or three times previously. The harrowing had brought quite a large number of quack grass roots to the surface. Nearly all parts of the field had some grade and the slopes ranged up to about eight or ten percent. In general, the stones were quite numerous, but in some areas of the field they were relatively few. The large, tight stones were somewhat more numerous than on the Conklin farm. The moisture condition of the soil was judged to be just about ideal for doing tillage work.

Equipment. The same equipment was used as on the previous test except that a Coop E-4 tractor was used here to pull the stonepicker. In an attempt to overcome the difficulty experienced with the small caster wheels on the outside ends of the windrowers, one of them was modified to give more clearance under the wheel mounting yoke.

Procedure. On July 11, 1950 the stonepicker was moved to the test field on the Folks farm, and made ready for operation. This involved greasing the machine, checking for loose or damaged parts, tightening the belts, installing the modified caster wheel, and straightening a few windrower teeth which were bent during the previous test.

The purpose of the work on this day was to operate the stonepicker so that adjustments and further observations could be made in an effort to overcome some of the difficulties previously encountered, and make the machine work better. With the Coop E-4 tractor pulling it, the machine was operated along the east and north sides of the field where the stones were more numerous, and the slopes less steep than in some other parts of the field. Various speeds of travel from about two to five miles per hour were tried in an attempt to determine the best operating speed. A tension spring was attached to the chain holding the V-drag for the purpose of making the drag do a better job of smoothing and leveling. The dirt separation grid at the rear was adjusted at various angles in an effort to obtain better separation of dirt and stones. By driving over the field in different directions the effect of ridges, dead furrows, and backfurrows on machine operation was noted. The elevator unit was adjusted at different heights, as were also the windrowers.

Approximately 3½ hours were spent making these trials, and a total of about 1½ trailer loads of stone were picked in that time.

On July 13, draft tests and field trials were made with the assistance of Professor H. F. McColly. Limited trials in the forenoon indicated that the field was a little too damp as a result of rain during the previous night. Too much soil adhered to the stones and clogged the dirt separation grid. However, by noon, it had dried off sufficiently to resume work.

Three draft tests were made using the Sauve dynamometer previously described. In making these tests the stonepicker was operated over a distance of 300 feet (200 feet in one test) and the time measured to the nearest tenth of a second. After the tests the dynamometer and recorder were calibrated again, and a new calibration curve was prepared. This was necessary because the arm carrying the inking nib in the recorder was repositioned after the previous tests.

The remaining time, about 2½ hours, was spent in operating the stonepicker in all parts of the field while attempting to pick as many stones as possible. Several trips were made across the slopes in order to check operation of the machine on the contour. A movie camera was used to take pictures of the machine in operation.

Results and observations. Most of the difficulties experienced on the Conklin farm were also encountered here, in perhaps a slightly milder form. It was found that the Coop E-4 tractor did not have sufficient traction to pull the machine uphill on even a slight slope after the trailer became partly filled. It was necessary to disengage the driving mechanism when climbing a slope, and the machine was then operated going downhill. The tractor and stonepicker became stuck even on a level place where the soil was quite sandy.

The machine seemed to operate best and with the fewest stoppages when pulled at speeds of $3\frac{1}{2}$ to $4\frac{1}{2}$ miles per hour. At slow speeds the stoppages were most frequent; in fadt it was almost impossible to get started. It was observed that stones became stuck in the elevator unit most frequently while starting and stopping. Speeds greater than about $4\frac{1}{2}$ miles per hour seemed to put considerable strain on the windrower teeth as well as the elevator buckets when they hit the larger stones. After two days operation about a dozen of the windrower teeth were bent and one was broken off. Most of the elevator buckets also had some bent teeth.

Improved operation of the V-drag which smooths a path just ahead of the elevator, was obtained after adding the tension spring to the drag chain. The quack grass roots kept the dirt separation grid clogged most of the time regardless of the angle at which it was adjusted.

Cleaner picking and fewer stoppages resulted when the direction of travel was parallel with the furrows. There was trouble with belt slippage and clogging nearly every time a dead furrow or backfurrow was crossed if it was fairly prominent. Operation of the machine across the slope was not successful because the drive wheel on the downhill side sank too deep in the soil as a result of the shift in weight.

The small caster wheel with modified mounting worked but little better than the original, and it was decided that the two by four inch tires were simply too small for supporting 50 pounds or more in loose soil.

A new difficulty was discovered in these trials when it was found that the tongue of the loaded trailer could not be raised high enough for attachment to the higher drawbar on the Coop tractor. It was necessary to stop the trailer with its wheels on a high spot, and the tractor rear wheels sometimes had to be dug in slightly in order to make the attachment. Even so it did not require more than about 15 minutes to dump the trailer and re-attach it to the machine because the hauling distance was only a few hundred feet.

Slippage of the V-belts was observed whenever the windrowers or elevator buckets dragged the ground a little heavily. When the windrowers stopped turning the stones were merely passed over, but slippage of the elevator belts usually resulted in stoppage of the elevator due to the stones and dirt piling up in front of it. Each time this happened it was necessary to disengage the driving mechanism, raise the elevator, and pull over the pile to make a fresh start.

There was also some slippage of the stonepicker driving wheels, and whenever it occurred the wheels made a deeper track thus lowering the elevator unit too close to the ground with the result that belt slippage and complete stoppage usually followed.

It appeared that the machine picked the stones a little more cleanly than it did on the Conklin farm. This was attributed to the firmer soil in this field which favored the action of the windrowers and pick-up teeth on the elevator buckets.

The draft tests indicated an average horsepower requirement of 14.6 and a maximum draft of about 2980 pounds which was somewhat less than on the Conklin field. Table I shows the test results.

While the draft tests were being made the trailer was nearly filled with stones, and three loads averaging about three-fourths full were picked during the remaining 2½ hours. The distance travelled to pick such a load was estimated at about 1500 feet. The total quantity of stones picked in this field on both days was estimated at about 21,000 pounds. During the 2½ hours when the machine was operated solely for the purpose of picking stones, the quantity picked was estimated at about 10,000 pounds.

The acreage covered could not be determined because the machine was operated in all parts of the field and in all directions; however, it was estimated to be about two acres.

It was decided not to do further work here because the field was not prepared for best operation of the machine, and its use on the slopes was a one-way proposition.

TABLE I

Summary of Draft Tests on Bergman Stonepicker

Test Farm	Test No.	Elapsed Time (Sec.)	Distance Travelled (Feet	Recorder Reading (Average)	Actual Load (lbs.)	Maximum Load (lbs.)	Horse-power Required
Conklin Farm	1	60.0	255	650	2200	2780	17.0
	2	60.0	260	600	2050	2780	16.1
	3	60.0	266	660	2250	3270	18.1
Folks Farm	1	59.2	300	500	1620	2280	14.9
	2	54.4	300	440	1400	2980	14.0
	3	35.4	200	450	1450	2175	14.9

Richard Farm.

Field conditions. There were about 19 acres in this approximately square field, and as shown in Figure 15 it was nearly level, but very stony. Most of the stones were less than seven inches in size, the larger ones having been picked off by hand. The soil ranged from silt to sandy loam, and was completely free of quack grass roots and other trash. It had been fairly well worked down by spring-tooth harrowing several times. The farm operator reported that 70 bushels of oats and 50 bushels of corn per acre had been raised on this field indicating that it was productive soil even though it was stony. Moisture conditions at the time of the tests were considered quite ideal for stonepicking.

Equipment. The stonepicker as used here was the same as for the previous tests except for two modifications. A redesigned caster wheel and mounting bracket was built to replace the small caster wheel at the front end of the left windrower. The new assembly using a four by eight inch tire is shown in Figure 16. The other change was the installation of compression springs for holding down the rear ends of the windrowers to maintain more uniform tension on the V-belts and keep the raking teeth in contact with the ground. This involved making two guide rods over which the springs were placed, and four simple brackets which were bolted on the frame members.

Figure 15. View of the test field on the Richard farm.

Figure 16. Experimental caster wheel and mounting using a four by eight inch tire. Standard wheel shown for comparison.

A steel tub with chains attached to make it suitable for weighing purposes, and a spring scale were used to weigh the stones from a sample area. For making torque tests on the windrowers a special drum, 12 inches in diameter, on which stranded clothesline wire was wound, and a spring scale was used as shown in Figure 17.

Procedure. After moving the machine to the farm, the redesigned caster wheel was mounted on the front end of the left windrower, and the pressure springs were attached at the rear end of the windrower frames. Because the standard caster wheel was too small to carry the weight, the front end of the right windrower was suspended from the support arm used to carry the windrower when in transport position.

The principal objective here was to pick as many stones as possible noting the time required for loading and unloading, and the area covered. Using a McCormick-Deering W-9 tractor, the machine was operated first along the west side of the field and later along the north side as well as through the middle. A John Deere B tractor was used to haul the trailer for emptying.

About a week later it was decided to use the Dodge Power Wagon for pulling the machine because a suitable tractor was not available. The work was begun by making three tests to determine the torque required to turn the windrower while it was raking stones. The scale, attached to the wire, was an-

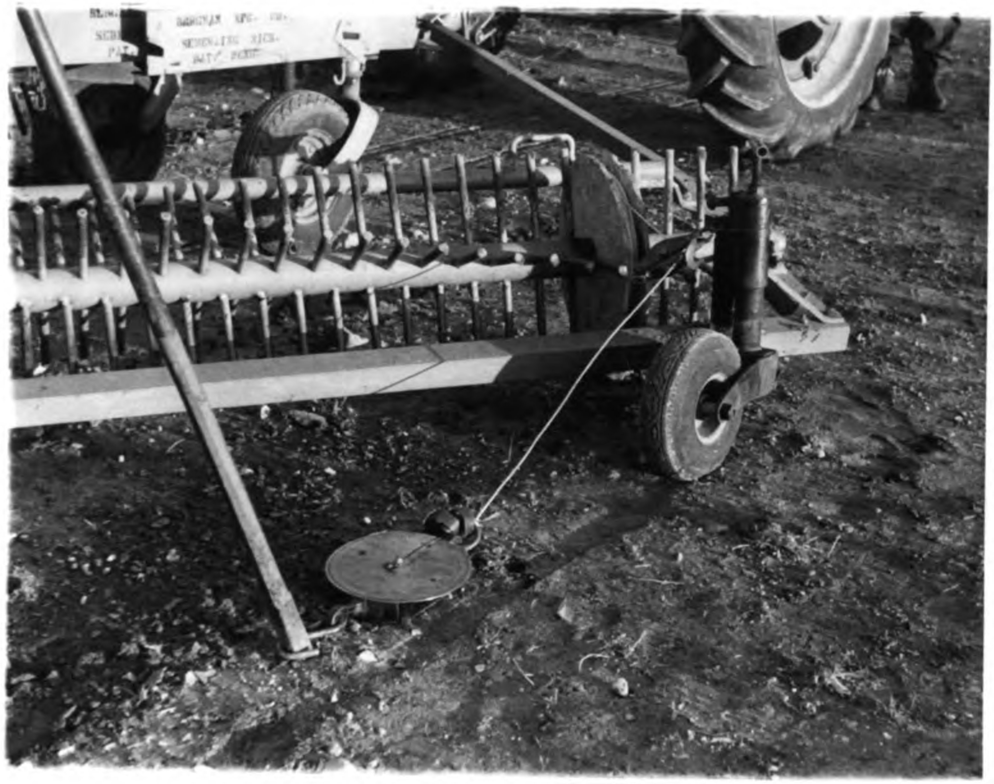

Figure 17. Special drum mounted on windrower shaft for making torque determinations.

chored on a stake, and the forward motion of the machine revolved the windrower while scale readings were noted. At a speed of three miles per hour the windrower was revolved at about 84 revolutions per minute which is about 1½ times faster than its belt-driven speed.

A draft test was attempted, but could not be completed due to malfunction of the recorder. The machine was then operated in the field using the Dodge Power Wagon. While picking the second load of stones the elevator belts were tightened again to reduce their slippage, and shortly thereafter the belt on the left side broke, halting further operation.

In order to determine the approximate quantity of stones on the surface, a plot ten by fifteen feet was picked by hand and the stones weighed.

Rainy weather and the lack of more time forced discontinuance of any further field work.

Results and observations. The experimental caster wheel performed well, and at the end of the test work there was no evidence of bending or weakness of the wheel mounting. The regular mountings had both been straightened once, and when the tests were finished the mounting on the right windrower was bent again.

The pressure springs attached at the rear end of the windrowers held the raking teeth down and reduced slippage of the V-belts which resulted in cleaner raking of the stones. The machine still did not pick up all the stones over which it passed, but there was some improvement. Figure 18 shows a portion of the field where the stonepicker was operated.

Even though the field was level and a large tractor was being used there was difficulty in pulling the machine. When the trailer became loaded the tractor was not always able to make a turn with the machine operating. On one occasion the tractor and machine became stuck to the extent of requiring the assistance of the John Deere B tractor before it could be extricated. Somewhat surprising was the fact that the Dodge Power Wagon, operating in 4-wheel drive and with about 400 pounds added weight, was able to pull the machine rather easily, and during the limited time that it was used, there was no difficulty in obtaining sufficient traction.

Slippage of the elevator V-belts continued to be a problem, and after repeated tightening, one of them broke as previously mentioned. That these belts were excessively stretched was obvious from observation of the machine in operation.

The stonepicker driving wheels slipped some of the time in this field, and it was observed that this generally occurred when only one wheel was driving as when making a turn, or whenever one of the driving pawls became disengaged. Although this latter trouble interfered with the work considerably it

Figure 18. View along west side of Richard field where stone-picker was operated.

was not a serious mechanical fault in that it could be rather easily corrected.

Stoppage of the elevator by small stones which became wedged in the lower part of the unit was the most troublesome difficulty. This usually happened three to four times while a trailer load of stones was being picked. The apparent cause of this difficulty was finally discovered while working in this field. As shown in Figure 19, the arrangement of the buckets at the upper end of the elevator permitted small stones to fall down within the unit where they became wedged in the bottom end. This usually happened while starting or stopping and at other times when the elevator was moving slowly.

The torque tests made on the windrower indicated a range of force on the scale from 50 to 150 pounds. The scale pointer fluctuated constantly but was in the 80 to 100 pound range most of the time. Since the winding drum had a radius of six inches the torque varied from 300 to 900 inch pounds.

During the first day of work in this field five loads of stones each requiring about 1200 feet of machine travel were picked in about four hours. Emptying the trailer required about 20 minutes from the time the machine was stopped until the trailer was re-attached. The stones were hauled a distance of 80 to 100 rods to a steep bank where they were dumped. One trailer load of stones was weighed and found to contain

Figure 19. At slow speed stones emptied from top bucket onto the back of the preceding bucket, and small stones fell inside the elevator at (a).

4580 pounds. Here again the acreage covered could not be conveniently measured, but was estimated at about one acre.

On the second day of work about one hour was spent in picking the first load of stones which weighed approximately two tons. The elevator belt broke while working on the second load after about one ton of stones had been picked.

The plot (150 square feet) from which stones were picked by hand is shown in Figure 20, and yielded 350 pounds of stones. Only those on the surface and larger than two inches were picked. Figure 21 shows the stones taken from this plot. At this rate the quantity of stones per acre on the ground surface was 51 tons; however all parts of the field were not equally stony. It was estimated that the average for the field was perhaps 25 to 30 tons per acre.

A final incident to be reported was the loss of one of the elevator buckets when crossing a railroad track while towing the machine back to the Agricultural Engineering Laboratory. The bucket teeth caught on the roadway between the tracks, and tore the bucket from the elevator chain by fracturing a weld on each side of the bucket. This suggests the need for more clearance under the elevator when the machine is being transported.

Laboratory work.

The stonepicker having been returned to the Agricultural Engineering Building some further work was done to obtain in-

Figure 20. Ten by fifteen foot plot on Richard farm from which stones were picked by hand.

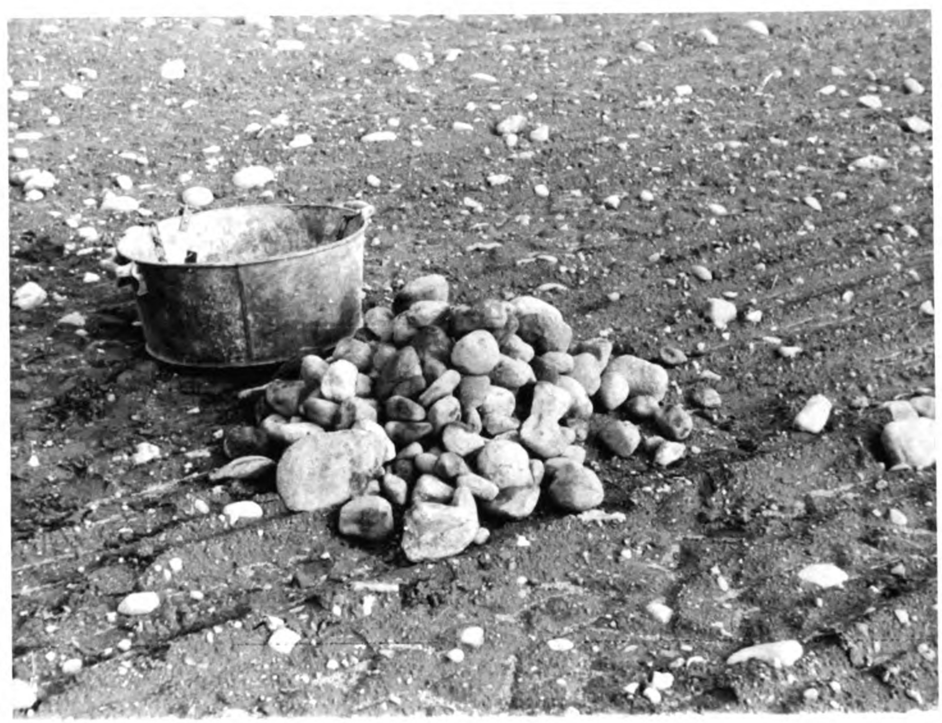

Figure 21. Stones picked from plot shown in Figure 20.

formation necessary for making some design checks, and an attempt was made to overcome the problem of stones falling inside the elevator.

A test was made to determine the torque required for turning just the elevator unit without any load on it. The apparatus used is shown in Figure 22. A pulling force was applied at F and the beam rotated through an arc about three feet long while observing the scale reading. The C-clamp was then loosened and the beam repositioned approximately horizontal. In order to revolve the elevator chain at least one complete revolution, ten such trials were made. The data obtained in shown in Table II.

Assuming a torque of 2000 inch-pounds at 106 revolutions per minute (approximately five miles per hour) the horsepower required to turn the elevator unit alone is 3.4. This is given by the formula

$$HP = \frac{\text{Torque (inch-pounds) x revolutions per minute}}{63,000}$$

Another method of doing this, perhaps more accurately, would have been the use of a calibrated electric motor for operating the elevator at the proper speed and measuring the electric power input with a watt meter.

Figure 23 shows the one-eighth inch strap iron, two inches wide, which was welded to the top edge on the back of each bucket to prevent stones from falling through the space between the buckets. There was no opportunity to test this

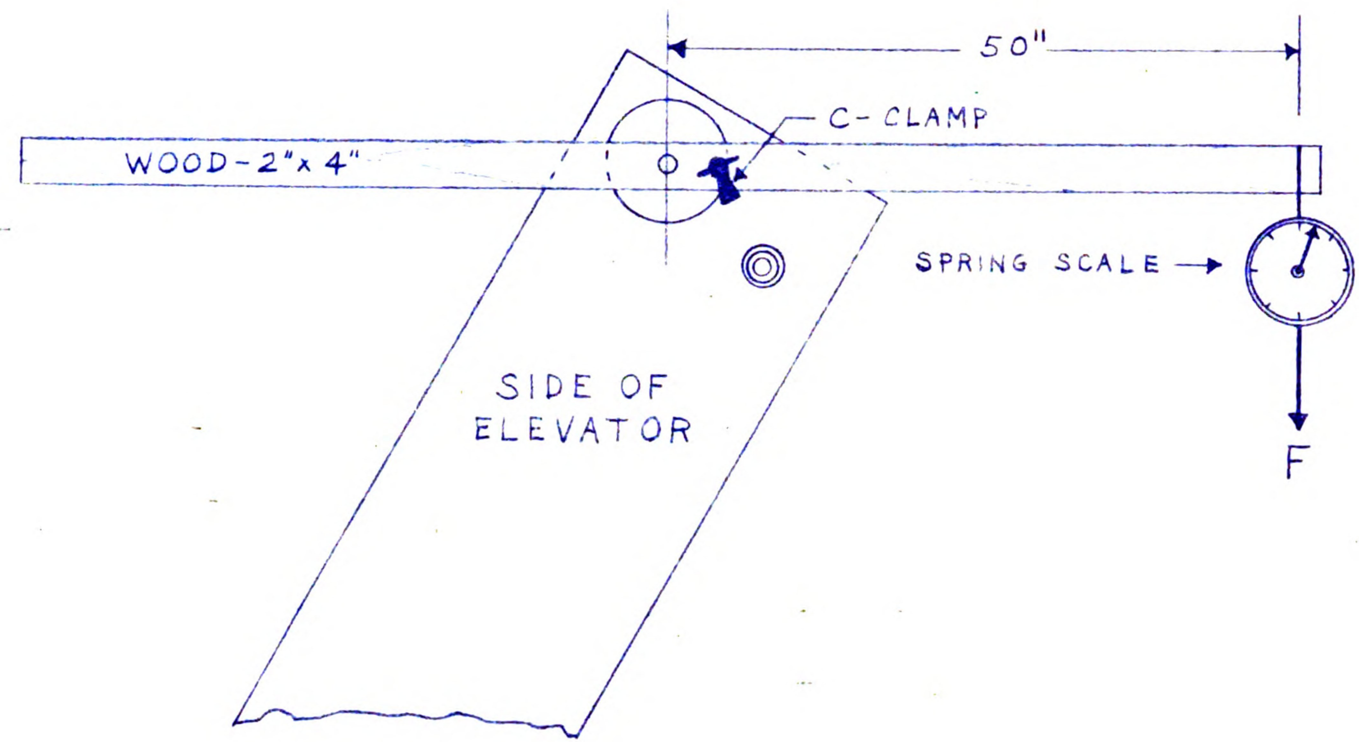

Figure 22. Apparatus used for determining torque requirement of the elevator unit.

machine after these pieces were added, but the author later saw another machine in operation on which the same change had been made. During a two-hour demonstration west of Jackson, Michigan the machine was not stopped once by stones becoming wedged in the elevator.

TABLE II

Data on Torque Test of Elevator Unit

Trial No.	F (pounds force)	Torque (in. - lbs.)
1	20	1000
2	21	1050
3	26	1300
4	27	1350
5	31	1550
6	28	1400
7	15	750
8	28	1400
9	36	1800
10	26	1300

Costs of Machine Stonepicking

The cost of picking stones with a machine depends upon the number of stones present, the capacity of the machine (picking width), the percent of time lost, distance stones must be hauled, cost of the machine; and includes charges for the tractor, stonepicker and labor time.

Based on the field tests made in this study, the average time per acre was calculated at three to 3½ hours when one trailer was being used. This calculation included only the time when the machine was operated principally for

Figure 23. Strip welded to back side of bucket at top edge is shown at (a).

the purpose of picking stones, which was about 7½ hours.

If the time per acre is three hours and the machine cost is taken at 11 cents per hour of use per $100 new cost, the cost per acre of using the machine is $6.93. The tractor cost for three hours at 95 cents per hour equals $2.85 and the labor cost at $1.00 per hour equals $3.00. This makes a total cost per acre of $12.78.

The use of a second trailer would reduce the time per acre approximately one-half when the hauling distance is long (one-fourth mile or more). On short hauls the saving in time would be less. With the extra trailer, costing about $250 additional, the machine cost per acre is $3.87 when the time per acre is reduced to 1½ hours. The tractor and labor costs per acre would be the same, $2.85 and $3.00 respectively, making a total cost per acre of $9.72 when using a second trailer and tractor. Actually, the difference in cost is even greater than shown because even when only one trailer is used a second man is needed to assist with unhitching and re-attaching the trailer.

In order to pick the same quantity of stones by hand, two men would require nearly six hours, and even without a tractor driver included the cost per acre would be $17.41.

The costs per acre of using the four machines, based on their picking width is shown in Table III. In order to obtain figures which would be comparable, it was assumed that

TABLE III

Comparative Costs of Using Four Stonepickers

Make of Machine	Selling[1] Price	Picking Width	Time[2] per acre	Machine[4] Cost per acre	Tractor[5] Cost per acre	Labor[6] Cost per acre	Total Cost[7] per acre
Lukens	$2400.00	26"	92 min.	$4.05[8]	$1.45	$1.53	$7.03
Fastpic	1600.00	3'	67 min.	1.97	1.06	1.12	4.15
Jochim	800.00	8'	33 min.[3]	.49	.53	.56	1.58
Bergman	2100.00	9'	22 min.	.85	.35	.37	1.57

[1]Price of Lukens machine estimated.

[2]Based on speed of three miles per hour and 17½ percent lost time in the field.

[3]Based on speed of 2¼ miles per hour and 17½ percent lost time in the field.

[4]Cost per hour of use per $100 of new cost = .11 Based on ten-year life; 150 hours use per year.

[5]Based on .95 per hour.

[6]Labor charged at $1.00 per hour.

[7]Time for hauling and unloading stones not charged.

[8]Fuel and lubricant figured at .40 per hour.

that the operating speeds and percentage of time lost in the field were the same for all machines except the Jochim. Because this one must be stopped frequently to empty the raking teeth, its speed was assumed to be one-fourth less. The hourly cost of tractor power and labor were also considered to be equal for all machines although it is realized that they probably would vary somewhat in actual field practice. It will be noted that the machine cost of the Jochim stone-picker is lowest, but due to its slower rate of working the total cost per acre is about the same as for the Bergman machine. The higher cost per acre of the Lukens machine is due to its narrow picking width; however, this is offset to a large extent by elimination of the problem and expense of stone disposal.

Design Analysis

A computational check on the design of several of the machine parts was made to obtain additional information which might help explain some of the difficulties encountered with the machine.

<u>Elevator.</u>

The layout of the elevator drive is shown in Figure 24. To analyze this drive a force F must be assumed because the power required to drive the elevator when the machine is picking stones is not known, whereas there is some informa-

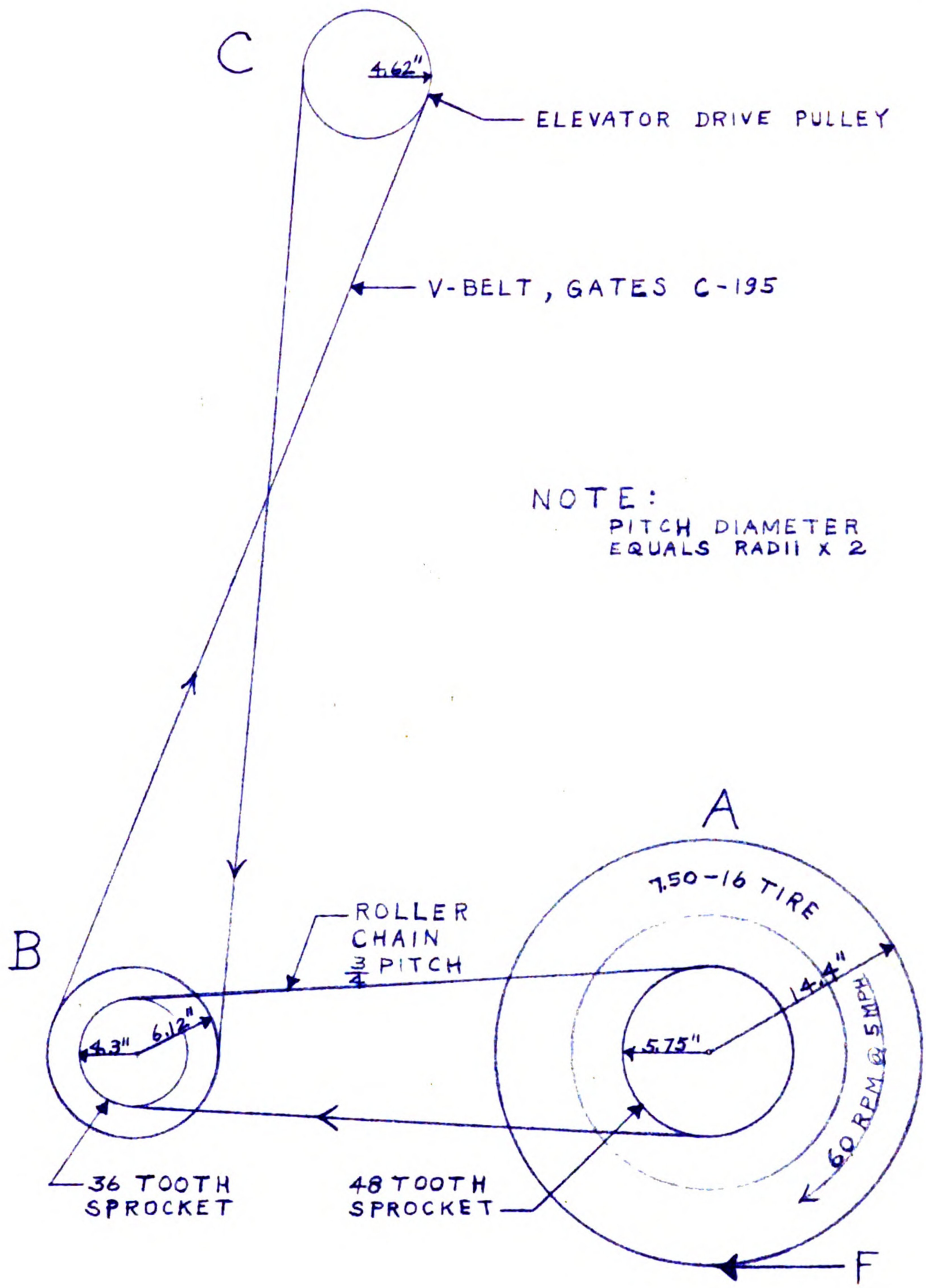

Figure 24. Layout of elevator drive.

tion about the draft requirement. The maximum pull recorded during one of the draft tests was 3270 pounds. Let it be assumed that the net force acting on the two drive wheels to turn the elevator is 1400 pounds making F equal to 700 pounds. The balance of the force is used in operating the windrowers and overcoming the rolling resistance of all the wheels. The torque at A is then 10,100 inch-pounds, and the tension in the roller chain is 1,750 pounds. The allowable working tension for a single strand roller chain is given by the following equation recommended by the American Standards Association.

$$F_W = \frac{2,600,000A}{600 + V} - \frac{WV^2}{115,900}$$

F_W = allowable tension per strand, pounds

A = projected bearing area, square inches

V = chain speed, feet per minute

W = weight of chain, pounds per foot

Substituting values:

$$F_W = \frac{2,600,000\ (.161)}{600 + 181} - \frac{(.97)\ (181)^2}{115,900}$$

$$F_W = 536 \text{ pounds, approximately}$$

Thus it can be seen that for the conditions assumed the allowable tension is exceeded by nearly three times.

The torque at B is 1,750 pounds x 4.3 inches, or 7,525 inch-pounds, from which the belt tension is calculated at 1,230 pounds. If the machine is operated at four miles per hour the belt transmits 7.7 horsepower which is about twice the value recommended on the manufacturer's charts. The following equation for determining the horsepower that can be transmitted by one V-belt comes from Black's "Machine Design."

$$\text{Hp per belt} = \frac{v\left[F_1 - \frac{w\,v^2}{g}\right]}{K \times 550} \cdot \frac{e^{f'\theta} - 1}{e^{f'\theta}}$$

V = belt speed, feet per second

F_1 = allowable tension, pounds

w = weight of belt, pound per foot

f' = effective coefficient of friction

θ = angle of contact of belt with pulley

K = service factor

$$f' = \frac{\text{coefficient of friction}}{\sin \frac{\text{groove angle}}{2}} = \frac{.13}{\sin 18}$$

$$= \frac{.13}{.309} = .42$$

$$\theta = \pi + \frac{\text{diameter large pulley} + \text{diameter small pulley}}{\text{center distance}}$$

$$= 3.14 + \frac{12.25 + 9.25}{80}$$

$$= 3.14 + .27 = 3.41$$

Substituting values:

$$Hp = \frac{3.42\left[126 - \frac{(.2)\ (3.42)^2}{32.2}\right]}{1.5 \times 550} \cdot \frac{e^{(.42)\ (3.41)} - 1}{e^{(.42)\ (3.41)}}$$

$$= (.522)\ (.76) = .4$$

This very low value is obtained because the belt speed is much too slow for good design.

Roller chain of one inch pitch carries the buckets. The drive sprocket at the top has 30 teeth with a pitch diameter of 9.6 inches, and rotates at 85 revolutions per minute when the machine is pulled at four miles per hour. The bucket teeth lie on a circle approximately two feet in diameter, and have a velocity about 1½ times the ground speed.

Windrowers.

In a similar manner it can be shown that the B section V-belts driving the windrowers are highly over-stressed. Based on the torque determinations which were made the tension in the belt may be 200 pounds or more. The allowable working load for this size belt is 55 pounds when making design calculations.

The possibility of using flexible shafting for driving the windrowers was investigated. A one-inch core, Stow number 2057, is the smallest which could be used, and in order to transmit the necessary horsepower it would have to rotate at least 300 revolutions per minute. This would necessitate a speed reducer, which together with the shafting would cost $100 or more for each windrower.

The peripheral speed of the windrower teeth when belt-driven is about three-fourths that of the ground speed. It can be shown with a vector diagram that increasing the speed of the windrower with respect to the ground speed results in a more efficient raking action.

Stonepicker drive wheels.

The drive wheels with 7.50 - 16 tires had a loaded radius of 14.4 inches when the tire pressure was about 35 pounds per square inch. If the tractive force exerted on the tire by the ground is 700 pounds the torque developed is 10,100 inch-pounds. A tire of larger diameter requires a smaller tractive force to develop the same torque thus reducing the tendency to slip. In addition, a larger tire gives better flotation which is important on soft ground in order to maintain uniform height of the pick-up buckets above the ground.

RECOMMENDATIONS FOR DESIGN CHANGES AND FURTHER WORK

1. The machine should be made lighter in weight and easier to pull so that a 3-plow tractor can handle it successfully on sloping fields and on the lighter soils. Considerable weight could be eliminated by improved design of the frame.

2. Over-all length of the machine should be reduced to permit easier maneuvering and turning on a shorter radius. This could be done by separating the windrower unit from the rest of the machine, and mounting it on the tractor where it could be used separately, or in combination with the elevator. The windrower might also be a separate towed machine and used in the manner of a hay rake.

3. The windrowers and elevator should be driven from the power take-off on the tractor to permit varying the speed of these units in relation to the ground speed, and also reduce the draft required to pull the machine.

4. Tires of larger diameter should be used on the main axle even though the ground drive was eliminated. A 7.50 - 20 tire would be more appropriate for this machine because of the reduced rolling resistance and better flotation which would result.

5. A positive drive, protected with a slip clutch,

should be used on both the elevator and the windrowers. Roller chain is probably the most satisfactory for this application.

6. Some means should be provided to prevent clogging of the dirt separation grid. Agitation of the unit may be a solution to the problem.

7. The type of windrower shown in Figure 25 should be tried for raking stones. The spring-steel teeth are mounted on a bar which lies at an angle of approximately 30 degrees from the line of travel. Spacing of the teeth would be such as to gather stones of the minimum desired size. If this device could be made to work it would be much simpler than the revolving windrower.

8. The possibility of using one shaft and larger sprockets at the top end of the elevator should be investigated. This would largely eliminate the problem of stones falling inside the elevator.

9. The idea of using a potato digger for picking stones should be further investigated. Figure 26 shows a two-row potato digger which was modified for stone-picking work, and given a very limited trial at the University of Maine Experiment Station. Some investigators feel that all of the stones within plow depth should be removed in a once-over operation.

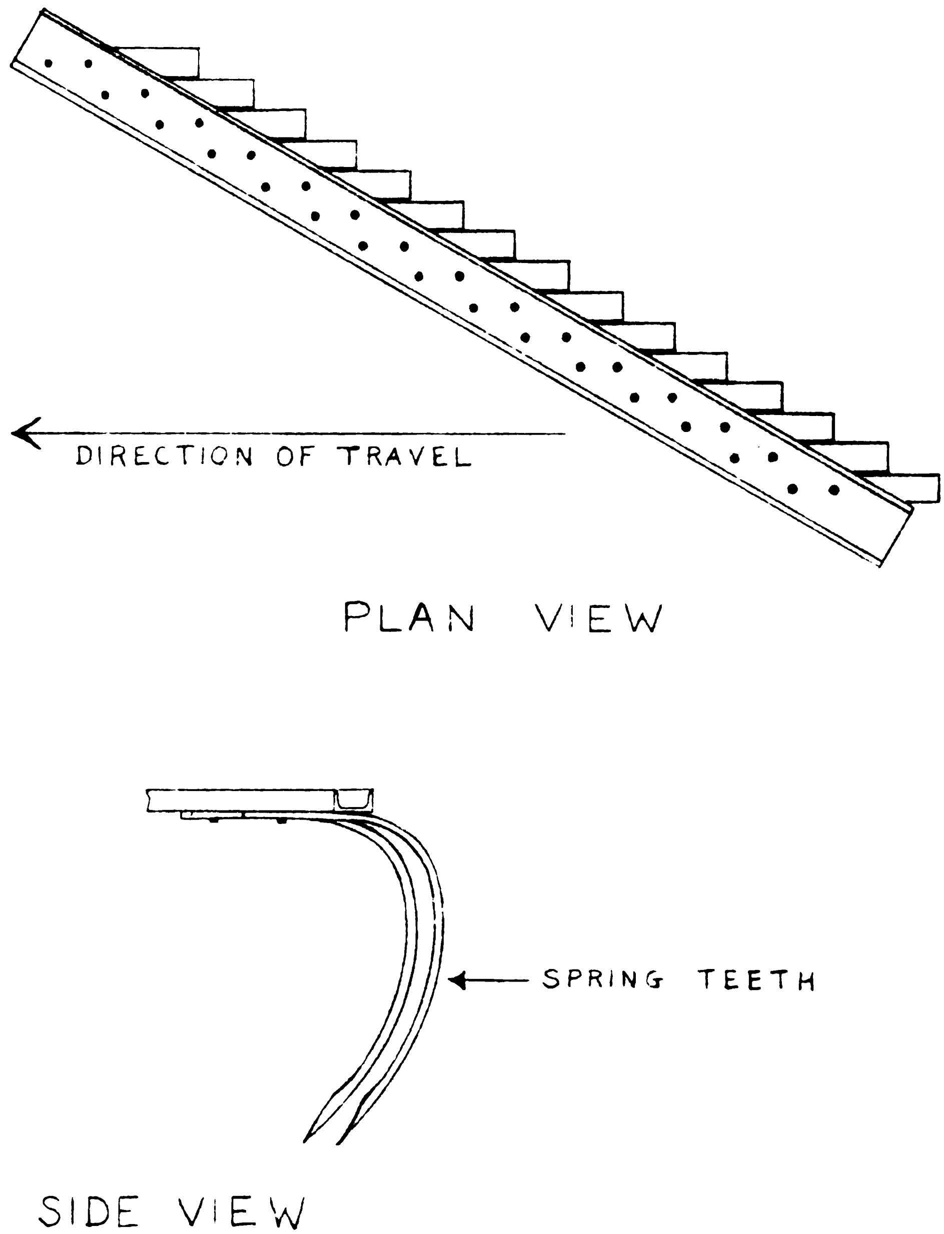

Figure 25. Suggested windrower design.

Figure 26. Two-row potato digger modified for stonepicking. Cross elevator which attaches at rear is lying on the left conveyor.

SUMMARY AND CONCLUSIONS

Clearing stones from agricultural land has always been a costly and laborious process. Removal of the large stones has been made easier and cheaper by the use of explosives and mechanical equipment such as bulldozers and power shovels. At least four machines are now being manufactured for picking the smaller stones that ordinarily are picked by hand.

The stonepicker as tested represents a good start toward the design of a successful machine, but in its present state of development it cannot be expected to operate satisfactorily in all of the conditions under which it might reasonably be expected to operate. The principal troubles encountered during the field trials were as follows:

1. The 3-plow tractors which were used could not pull the machine uphill on even a slight slope and became stuck on level ground several times.
2. Frequent slipping of the V-belts.
3. Slipping and sinking in of the stonepicker drive wheels resulting in clogging of the elevator.
4. Stoppage of the elevator by stones which fell inside the elevator and wedged in the bottom end.
5. Quack grass roots wound on the windrowers, and clogged the dirt separation grid when they were numerous in the field.

Suggestions have been made for correcting each of these difficulties.

Dynamometer tests indicated a maximum pull of 3270 pounds, and the horsepower requirement at about 17. The best operating speed was considered to be about 3½ to 4½ miles per hour.

The experimental caster wheel with 4.00 - 8 tire performed satisfactorily during the test work, and the addition of pressure springs at the rear ends of the windrowers resulted in cleaner raking of the stones.

Each windrower requires about one horsepower, and the elevator without load a little over three. The V-belts are considerably overloaded, and because of their slow speed cannot transmit the necessary horsepower.

The rate of picking averaged a little more than one load per hour, and about 3½ hours per acre during the time when the machine was operated principally for the purpose of picking as many stones as possible. The heaviest concentration of stones where work was done was 51 tons per acre.

When using one trailer and tractor the cost per acre of picking stones with this machine was $12.78; with two trailers and tractors the cost would be $9.72 per acre. These figures are based on a working time of three hours per acre. The cost per acre for two men to pick the same quantity of stones was calculated at $17.41.

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