DEVELOPMENT OF VACUUM HARVESTING EQUIPMENT FOR SMALL LEGUME SEEDS

By

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Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
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GEORGE BASSILY HANNA ABSTRACT

The interest in Ladino clover as a forage crop is constantly increasing and in spite of the gradual increase to nearly 8 million pounds in 1950, the USDA is anticipating a need for 12,384,000 pounds of Ladino seed by 1955, and 14,855,000 each year from 1960 on.

When cut for seed, the Ladino vegetation is from 4 to 10 inches tall, with many of the seed heads bent over almost to the ground. Growth of green material is continuous and the seed, when ripe, threshes out very easily. These conditions make the harvesting of Ladino clover seed difficult and inefficient when using the combine harvester.

Preliminary studies indicated a very definite possibility for the development of an effective vacuum harvester for small legume seeds. A review of the development of the earlier vacuum harvesters indicated that (a) the air flow inside the nozzles had not been investigated, (b) the existence of air pockets in the actual nozzles was to be expected, (c) no study has been made to find out the minimum velocity of air required to collect the crop, and (d) no self-cleaning device was provided in the gathering mechanism.

GEORGE BASSILY HANNA ABSTRACT

The minimum lifting velocities of different seeds and grains were calculated by means of the turbulent flow formula. The results were compared with the actual laboratory experiments.

A new vacuum harvester with no pick-up device was designed and constructed to harvest the clover seed from the windrow. Air flow investigations inside the nozzle indicated the absence of stagnant air regions.

This was followed by the design and construction of a cutter bar vacuum harvester which cuts and sucks the green clover in one operation.

Field experiments were conducted in order to compare the performance of the following methods of harvesting the Ladino clover seed: (a) A pan attached to the cutter bar; (b) vacuum harvesting from windrow; (c) vacuum harvesting from swath; (d) vacuum harvesting from the cutter bar; (e) combining from windrow; (f) combining from swath; and (g) sweeping the field with a brush vacuum harvester.

Vacuum harvesting from the windrow had a higher overall efficiency than any other method tested. However, the vegetative material dried most rapidly when left in the swath. Vacuum harvesting from the cutter bar was considered not practical because of the high percentage of water contained in the green material (70% to 75%) and the mechanical difficulties of artificial drying.

Investigation of the causes of seed losses during the different phases of harvesting procedure indicated that the most serious losses to be considered are the weather hazards, inefficient picking and inefficient threshing.

A design was made of a swath vacuum harvester featuring a detachable nozzle with an efficient and self-cleaning pick-up.

Ladino clover seed may be harvested by any of several methods, or by a combination of methods; the arguments for and against each procedure are discussed. Harvesting procedures are recommended for several conditions of vegetative growth under variable weather conditions.

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INTRODUCTION

White clover, Ladino clover, lespedeza, bur-clover, buffalo grass produce very short flower stalks. Many of these plants produce seed readily, but it fails to hang on the stem after it is ripe and, consequently, harvesting is almost impossible without very large losses. The seed from many of these plants is very high priced and in Michigan and neighboring states, the interest in Ladino clover and white clover as a forage crop is constantly increasing.

"The Michigan Farmer" (30), issue of April, 1951, stated that although Ladino clover was introduced into Michigan less than ten years ago it is now grown on an estimated 100,000 acres of pasture and hay land. It is taking its place among legumes familiar to Michigan farmers who are finding it a good source of highly nutritious forage for all classes of livestock.

The Implement and Tractor (16), issue of March, 1951, stated that three years ago the entire world production of Ladino clover seed was only 3,500,000 pounds. The commercial production of Ladino clover seed in the United States on which records are available started in 1936 with a production in

Oregon of slightly over 100,000 pounds. Since then, as shown in Figure 1, there has been almost a gradual increase to a high in 1950 of nearly eight million pounds with an average yield per acre of 127 pounds (31). In addition to the new record high production in 1950, figures collected by the Production Marketing Administration on production and need of Ladino seed (33) indicate that the acreages of Ladino clover farmers would have liked to plant in 1950 amounted to 9,012,000 acres while the amount they could plant with available seed was 2,370,000 acres. The seed production would have to be quadrupled to furnish the farmers the seed they desired for the 1950 crop.

In his address at the 1950 annual meeting of the American Society of Agronomy, George C. Edler (12) stated:

> The current supply of Ladino clover seed is the largest ever because of the record crop this year. California for the first time led Oregon in production of this seed. The total acreage harvested in these states and Idaho this year is two and one-half times that of last year and nearly four times the 1944-48 average. Demand for this seed has been keeping pace with the rapidly increasing production, and despite the large supply, retail prices this fall are practically at last year's rather high level.

The following figures were given by George C. Edler at the same meeting:

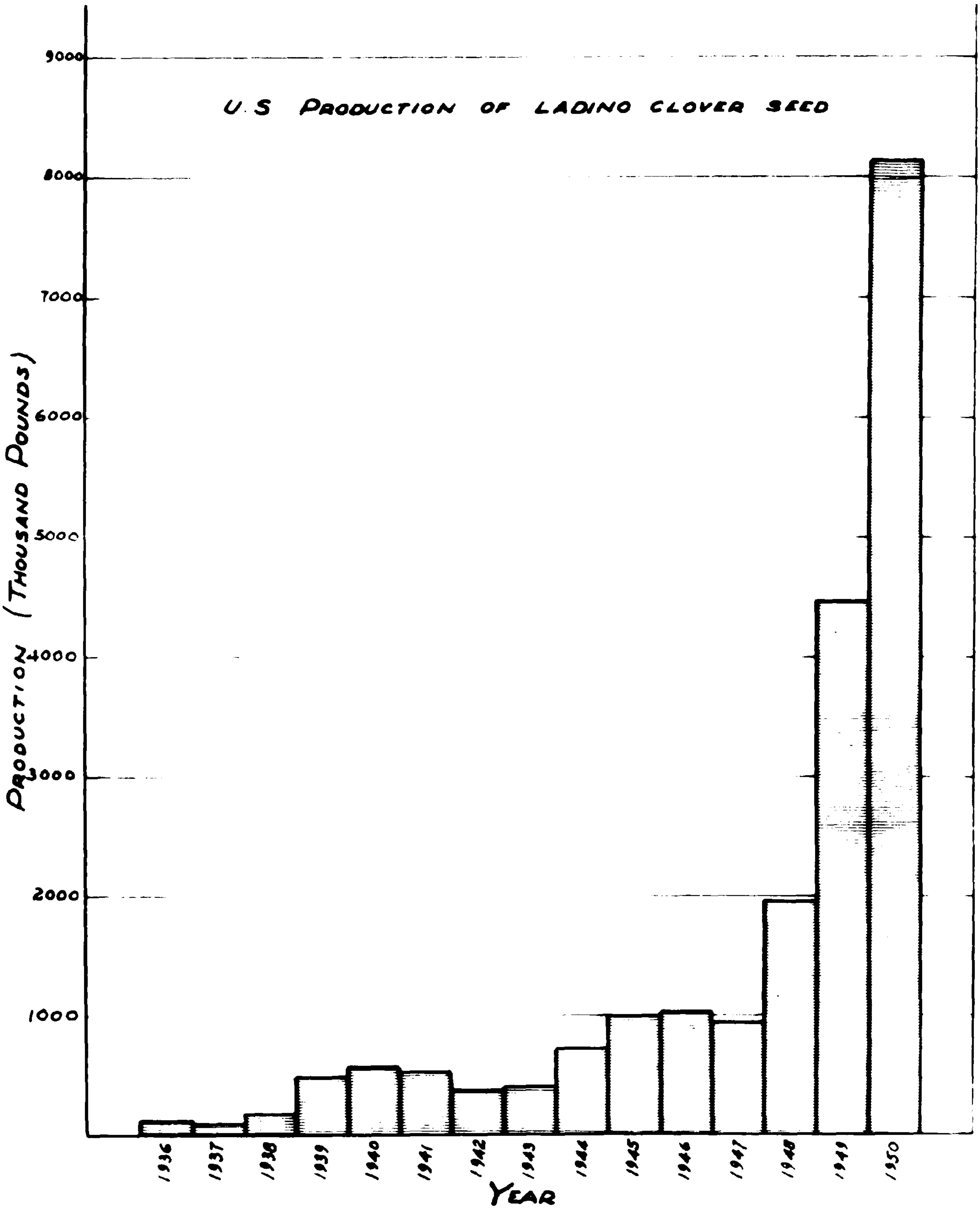


Figure 1. United States Production of Ladino clover seed.

	Average 1944-48	1949	1950
		Pounds of clean seed	
Ladino Clover	1,367,000	4,468,000	8,121,000

As an indication for the growing need of Ladino seed in the United States, the Implement and Tractor, in its February, 1951 (21) issue, stated:

> With the government calling for a 900 percent increase in Ladino clover in the next decade, California is already growing half the nation's supply of this droopey-headed white clover that came in from Italy scarcely a quarter century ago. The U. S. D. A. thinks we will need 12,384,000 pounds of Ladino seed by 1955, and 14,855,000 each year from 1960 on.

JUSTIFICATION OF THE STUDY

In preparation for a Ladino clover seed crop, the first cutting of hay is removed from the field usually in the early part of June. This decreases weediness, eliminates most of the alsike clover, and gives a more uniformly matured seed crop ripening during late July or early August. This is the most favorable time for drying vegetative material in the swath. When cut for seed, the vegetation is from four to six inches tall, with many of the seed heads bent over almost to the ground. Growth of green material is continuous if there is sufficient moisture in the soil and the seed, when ripe, threshes out very easily. These conditions make the harvesting of Ladino clover seed difficult and inefficient when using the usual grass seed harvesting equipment.

Previous work done by McKibben, Dexter, and Sheldon (10, 11, 28) has shown that, in these short stands of the crop, harvesting with a conventional combine was ineffective. Most of the seed was usually left in the field. Their preliminary study indicated a very definite possibility for the development of an effective vacuum harvester for Ladino clover, white clover, and other grass seeds.

Producers of clover seeds, and other very small seeds that are lost incident to the harvesting operation, are likely to find this type of equipment of real value. Furthermore, observations have indicated that losses in the various processes of harvesting and threshing may amount to a considerable portion of the total possible yield (5). Lack of specific information on seed losses at harvest time for Michigan and the surrounding area prompted the present investigation on the comparative efficiency of various methods of harvesting seed of small seeded legumes.

The purpose of this research work was:

(1) To compare the performance of the possible methods of harvesting Ladino clover seed;

(2) To investigate the sources of seed losses at harvest time;

(3) To study the air velocity required to lift different kinds of seeds;

(4) To design a new vacuum harvester based on the results of the above investigations.

REVIEW OF LITERATURE

Previous Experimental Works

The vacuum principle, applied to harvesting equipment, is by no means new. The Soil Conservation Service, in co-operation with several state experiment stations, particularly the Chillocothe Substation of the Texas Agricultural Experiment Station and the Fort Hays Branch of the Kansas Agricultural Experiment Station (20, 37), has worked with this type of equipment for several years as a part of their grass seed harvesting projects.

The performance of a vacuum-type collector for fallen peppermint leaves was reported by Wileman and Ellis of Purdue in the July, 1943 issue of Agricultural Engineering (36).

The Agricultural Experiment Station of Michigan State College developed in 1944 an experimental vacuum-type harvester for white clover seed and preliminary trials were reported by Dexter and McKibben of the Farm Crops and Agricultural Engineering sections of Michigan State College (10).

Dexter and Sheldon (11, 28) reported in 1947 and 1948 satisfactory results with an enlarged and improved vacuum harvester, built according to the recommendations in the Dexter and McKibben report.

Fortune magazine (19) reported, in its issue of October, 1948, on the development of an experimental seed vacuum harvester (Figure 2) by a California farmer, Albert Jongeneel, which was devised to lower the cost of collecting seed for cover crops needed to prevent erosion on the Great Plains.

Historical Review of Vacuum Harvesting Equipment

Fort Hays Vacuum Sweeper

The Fort Hays Branch of the Kansas Agricultural Experiment Station worked with vacuum harvesting equipment for several years as a part of their grass seed harvesting projects. Figure 3 shows a vacuum sweeper developed in 1935. It was reported that this machine was ninety-five percent efficient, if the overburden of hay was removed ahead of the sweeper. The blower was driven by a separate gasoline engine. The exhauster, the engine, and the hopper container were mounted on a carriage driven by a tractor.

Figure 2. California experimental vacuum seed harvester.

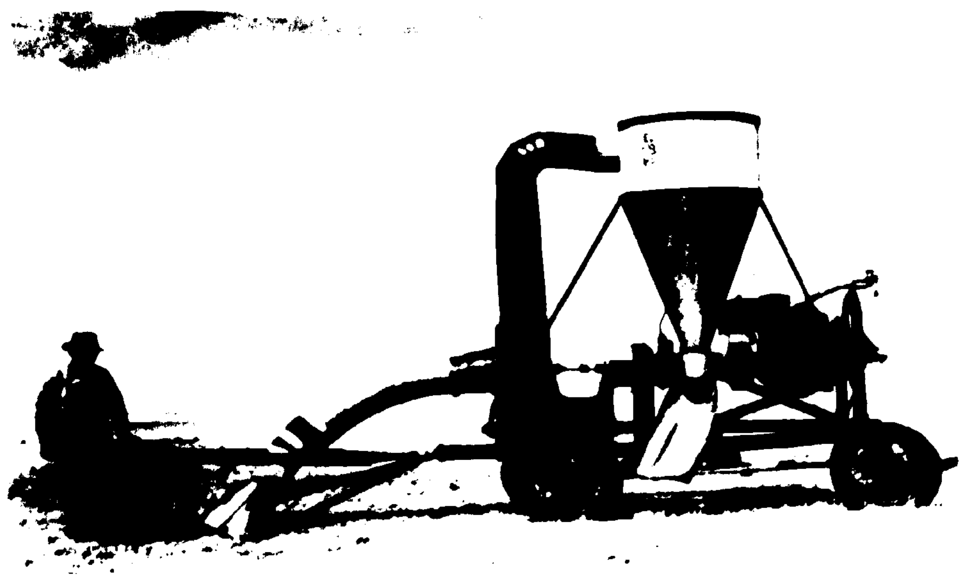


Figure 3. Fort Hays vacuum sweeper, 1935.

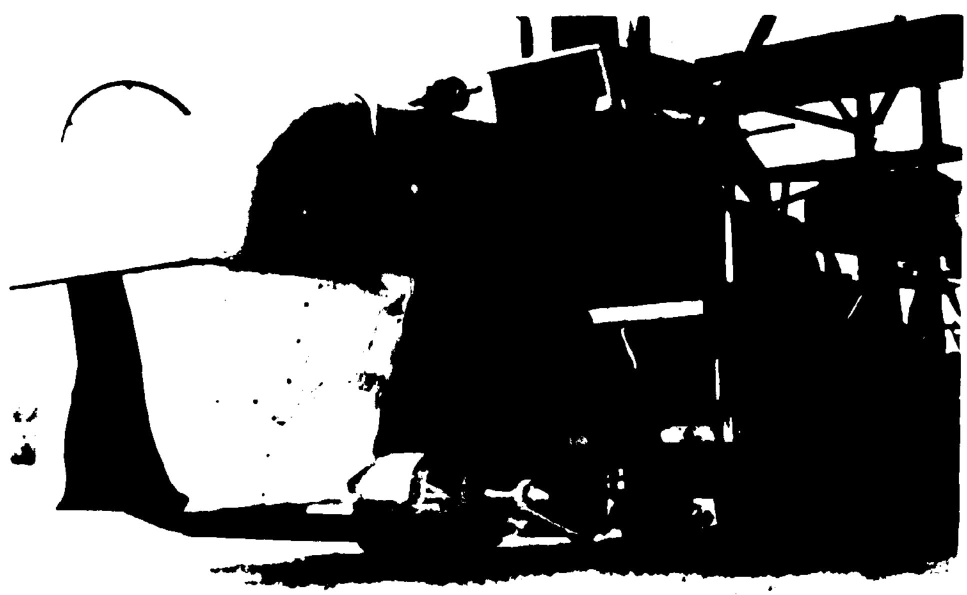


Figure 4. Combined beater and suction attachment used behind buffalo grass seed harvester, 1935.

Suction attachment on the Combine Harvester

Figure 4 shows the combined beater and suction attachment used as a gleaner attachment on a combine harvester to collect buffalo grass seed that the combine did not collect. This attachment, running at 1,700 r.p.m., was made up of four rows of flat hammers, fifty to each row, welded to a 2-inch diameter shaft. The shaft was five feet long and the hammers were staggered on the shaft, so that complete coverage of the ground was obtained. The seed was picked and sucked into the auger from which it was elevated to the body of the combine just behind the cylinder.

The attachment, shown in Figure 4, is in lifted position and part of the small flat hammers can be seen exposed under the housing.

The "Hosking" Grass Seed Harvester

This machine was developed in 1942 by J. E. Hosking and manufactured by Stanley, Ltd. in England for harvesting perennial rye grass seeds.

According to the manufacturer, the prime advantage of the machine in gleaning the seed direct from the stalk is that, after its passage over the crop, the field can still be harvested for hay and the recovery of seed is no mean consideration. The machine does not rub the seed from the stalk, but beats it off with metal-tipped flexible beaters revolving at 1,250 r.p.m. in a seven-foot, six-inch collector.

A six horsepower engine, in addition to driving the wheels through a chain-type gearbox and operating the beater, actuates a blower and an archimedian screw fixed in front of the beaters to carry the seed to one end of the collecting box. From there, the seed is drawn by the blower along a flexible pipe, through the blower, and into the box on the left-hand side of the machine (shown in Figure 5). It then drops into bags, the air escaping through the sacking.

Peppermint Leaves Vacuum Harvester

A machine for collecting peppermint leaves (Figure 6) was reported by R. H. Wileman and N. K. Ellis in 1943. It had two gathering nozzles, extending to the rear, which were attached to fans driven by the power take-off of the propelling tractor. These nozzles were pulled over the surface of the ground and collected the fallen mint leaves by means of the

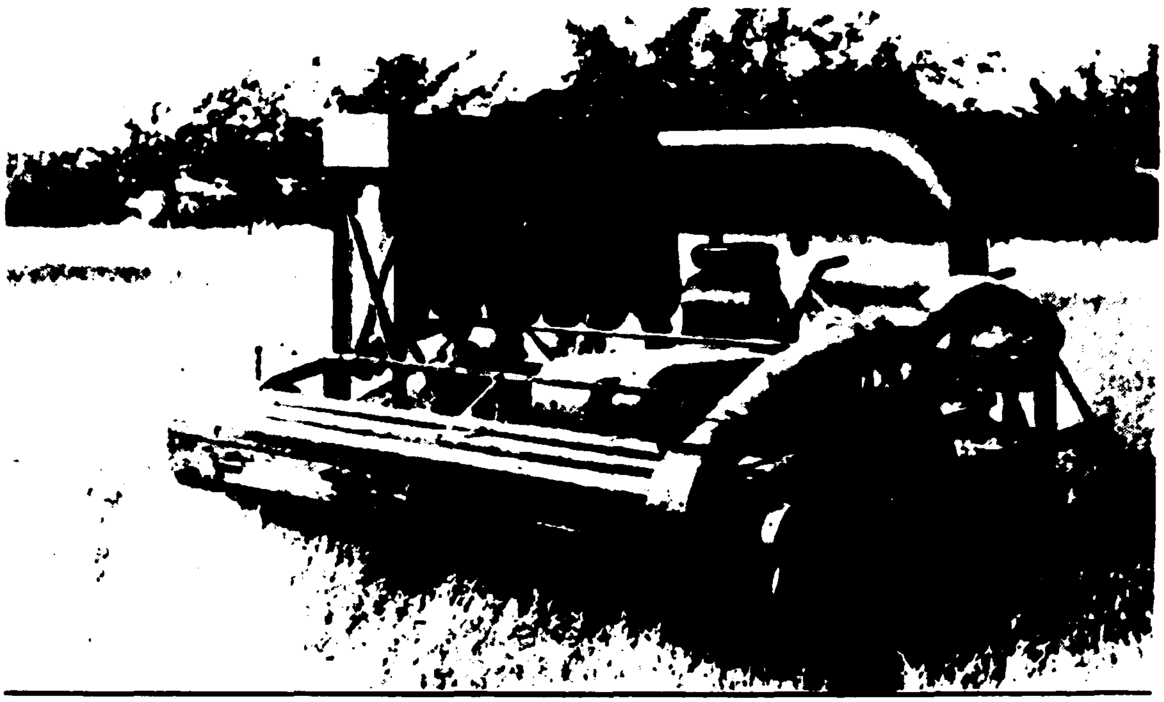


Figure 5. Hosking grass seed harvester, 1942.

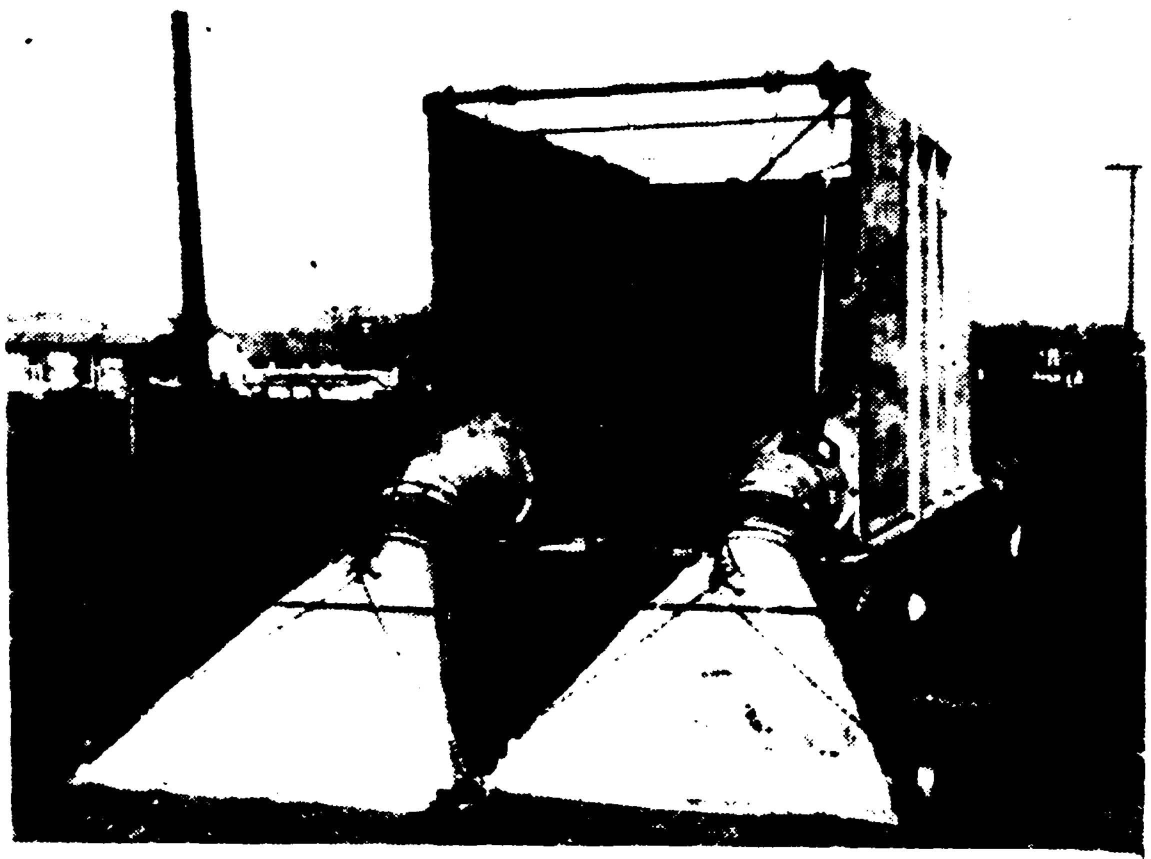


Figure 6. Peppermint leaves vacuum harvester, 1943.

partial vacuum created by the fans. A large hopper was provided for separating the leaves from the air stream created by the fans and it also served as a storage for the collected leaves.

Two 18-inch "axiflow" fans were mounted on the rear of the trailer with the intake side toward the back and spaced 4-1/2 feet between centers. To each fan was attached a gathering nozzle 4-1/2 feet wide where it contacted the ground and with an opening which could be adjusted from 1 to 3 inches in width. They were attached to the fan thimbles by means of a flexible connection and supported by hinged arms which allowed them to float when operating and thus followed the contour of the ground irrespective of the action of the trailer.

Experiences during the 1942 season indicated that an air velocity of about 2,300 feet per minute at the mouth of the nozzles gave the best results under most conditions. This velocity of air resulted in a vacuum of 2 inches water gauge in the throat of the nozzles and 0.95 in at the front of the nozzle apron. To secure these conditions the fans operated at a speed of 2,530 r.p.m. and each fan delivered air at 3,700 c.f.m.

It was reported, however, that this machine made a rather poor job of collecting in cases where heavy rains fell after the hay was raked and the leaves matted to the soil.

Dexter and McKibben Experimental Vacuum Harvester

An experimental vacuum harvester for white clover seed was assembled and tested in 1944 by S. T. Dexter and E. G. McKibben at Michigan State College (Figure 7). A No. 13 Improved Clarage Exhauster with slow speed impeller was mounted on the front of a two-plow all-purpose tractor. This blower was operated by the standard belt pulley which gave a fan speed of 1,800 r.p.m. with a demand of about eight horsepower. The discharge was into a large canvas container mounted on a two-wheel trailer. This container had a coarse mesh burlap top to permit the escape of air without loss of seed.

The gathering device, which was three feet wide, is shown in Figures 8 and 9. The beater, shown in Figure 9, was made of steel 3/16 inch rods and was twelve inches in diameter.

The 4.00" x 12" traction drive tires operating the 2" x 6" friction-driven beater tires gave the tips of the beater

Figure 7. Dexter and McKibben experimental vacuum harvester, 1944.

Figure 8. Gathering device in Dexter and McKibben vacuum harvester.

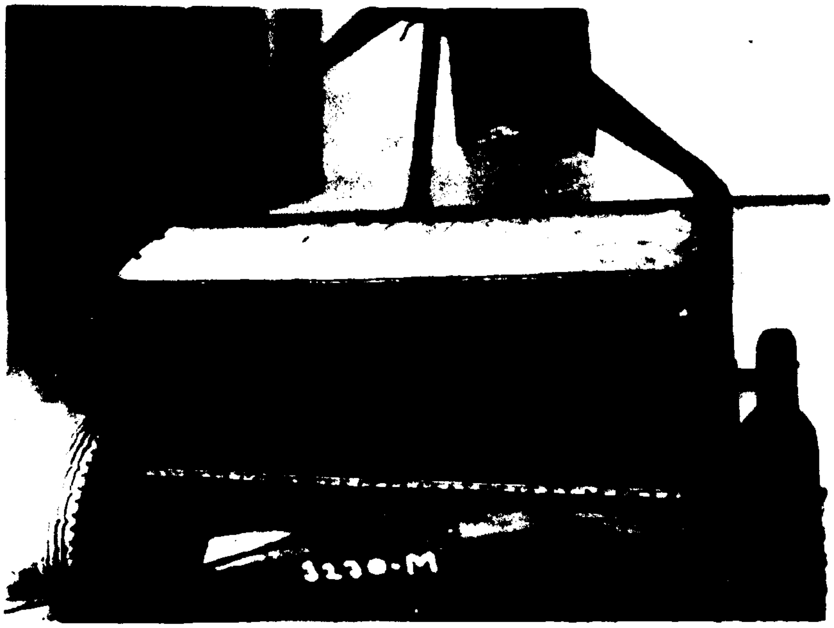


Figure 9. Pick-up in Dexter and McKibben vacuum harvester.

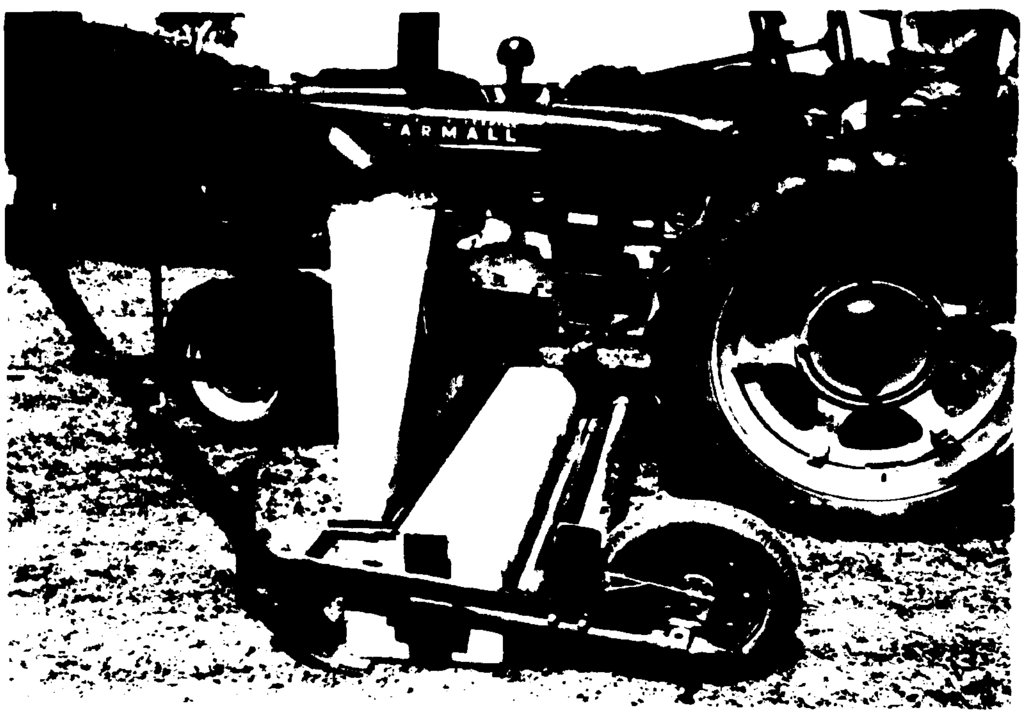


Figure 10. Dexter and Sheldon experimental vacuum harvester, 1946.

rods a forward speed with respect to the ground of three times the forward speed of the tractor.

As stated in their reports, the authors obtained very good results and at a speed of three miles per hour even the narrow three-foot nozzle would have a capacity of more than 3/4 acre per hour.

With this vacuum harvester, 120 pounds of cleaned seed (purity above 99%) were obtained from the 3/4 acre, a recovery of perhaps five to ten times that of an ordinary combine.

The gathering device was reported to be far from perfect. The authors recommended that teeth should be more flexible, the reel should be adjustable with respect to the housing, and the beater should probably be driven from the tractor rather than the ground.

Dexter and Sheldon Experimental Vacuum Harvester

The vacuum harvester for White Clover seed reported by Dexter and McKibben was rebuilt in 1945 and 1946 to incorporate recommendations made after the first year of operation. The machine, shown in Figure 10, was enlarged to take a six-foot swath and the fan speed increased to 2,600 r.p.m.

by using the oversize tractor pulley furnished by the manufacturers of the tractor. At this increased speed, the fan required approximately 15 horsepower and moved about 5,000 cubic feet of air per minute. The fan housing was rotated 90^{o} to discharge vertically, and a swivel elbow was used between the fan and the discharge pipe. This facilitated turning corners with the harvester and the 4-wheel trailer that was used for carrying the harvested material. The trailing wagon, 7 x 13 feet, had tight sidewalls six feet high, with a door four feet high in the rear. The top was of 1/4 inch hardware cloth, covered with burlap to prevent seed from blowing out. Spring teeth, from the Case combine pickup attachment, were used on the rotating beater, which was driven from the tractor rather than from the ground. These teeth were mounted on six pipes, parallel to the main rotor shaft. The rotor was made adjustable with respect to its housing. Either end of the rotating beater and its housing could be raised or lowered by the tractor operator by means of levers attached to the harvester wheels with pull rods and torsion arms.

Preliminary trials were conducted in 1945 on an 18-acre field of Ladino clover and in 1946 on 50 acres. In 1948 a field of 12 acres was used for further experiments and was divided into three areas to enable three different methods of harvesting to be tried so as to obtain comparative data.

Combining from windrow gave 100 pounds of seed recovered per acre, combining from swath gave 60 pounds and vacuum harvesting from swaths 160 pounds. Furthermore, reharvesting portions of these areas with the vacuum harvester obtained approximately 40, 20, and 7 pounds of seed per acre from the respective areas.

A total of 11 hours was required to combine from the first and second area with an average of 0.6 acre per hour whereas the vacuum covered 5.11 acres to gather four loads with 7-3/4 hours spent in the field loading and 2-1/4 hours unloading, making a total of 10 hours with an average of 0.5 acre per hour.

Interruptions due to coarse material winding around the beater, or otherwise clogging the suction nozzle, accounted for about half of the time spent in the field gathering the four loads, which averaged 200 pounds of seed per load. Later, first area and portions of second and third areas were reharvested with the vacuum harvester, which covered 7.52 acres in 6-1 2 hours, to give an average of 2.1 acres per hour on the area previously vacuum harvested, and an acre per hour in picking up material which had passed through the combine. The trials established that it is possible to recover a much larger percentage of the seed by the vacuum harvester than by conventional methods.

Gardiner Seed Collector

This machine was designed by Ernest Doe and Sons, Ltd., Ulting, Essex, England, in cooperation with one of their customers, A. H. Gardiner, in 1948.

It has been successfully used for the collection of wild oats, wild white clover and weed seeds and, in particular, has proved most effective after a crop has been harvested by a combine.

Figure 11 shows the Gardiner Collector mounted on a "Fordson Major." A transverse series of spring agitating tines have a slight stirring action on the surface of the ground to loosen the seeds on the stubble so that the following suction or vacuum fitting is assisted in the actual collection.

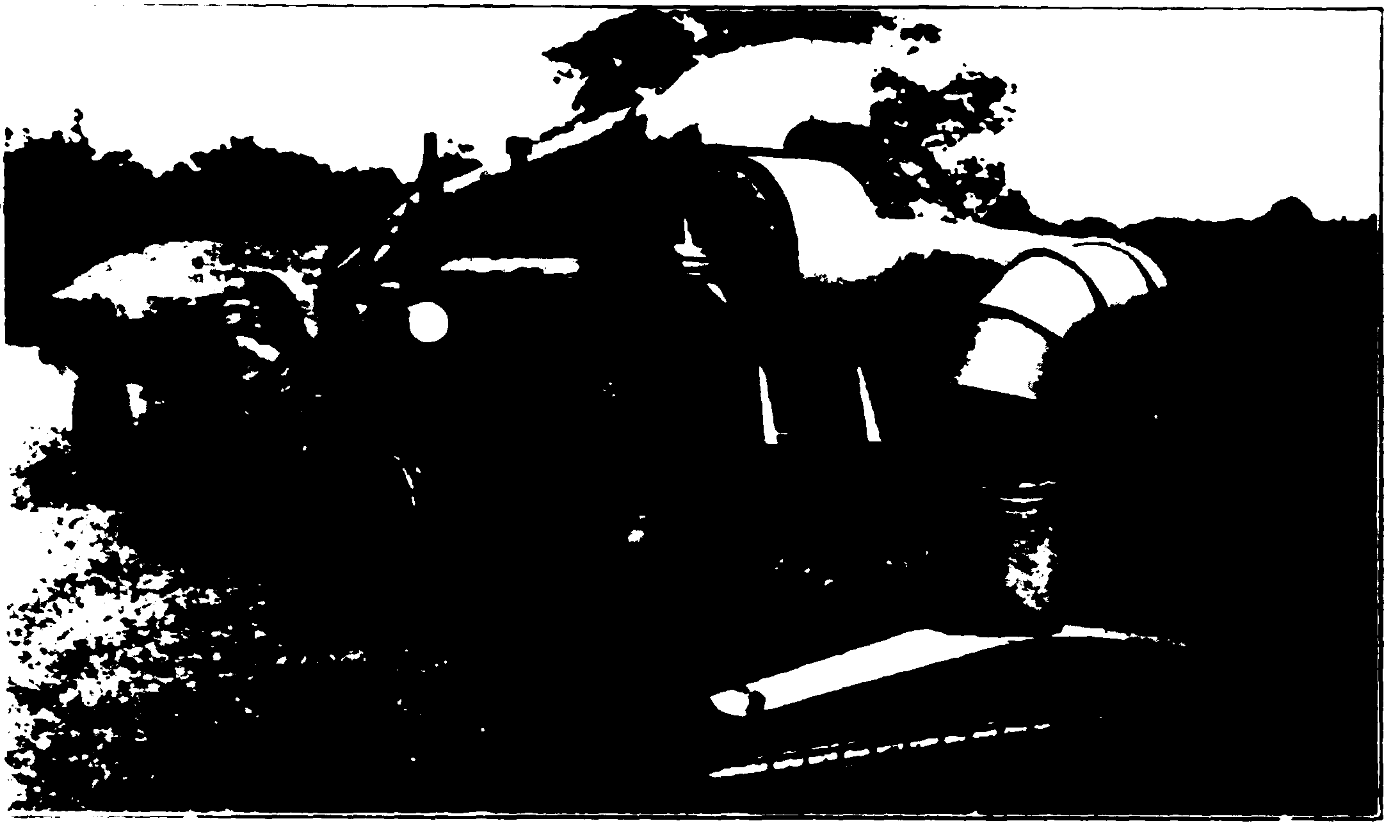


Figure 11. Gardiner seed collector, 1948.

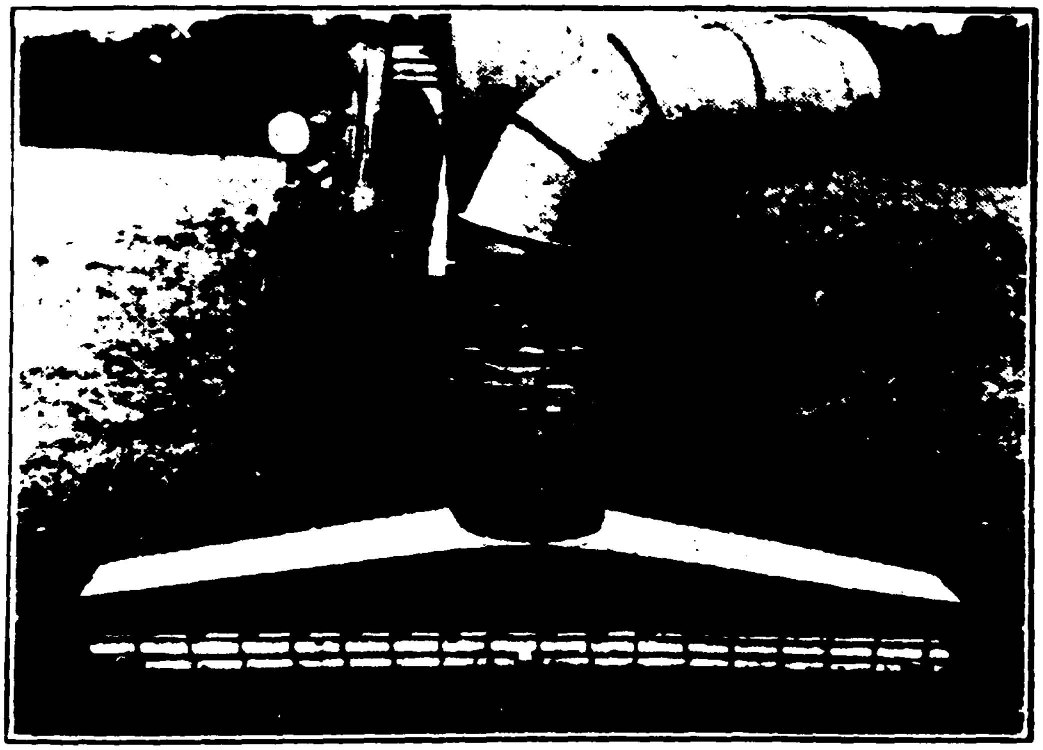


Figure 12. Nozzle pick-up in Gardiner seed collector.

A "Keith Blackman" fan, running at 2,500 r.p.m. and driven from the belt pulley, generates the necessary suction, and the seeds are then drawn up the ducting to be finally deposited in a covered trailer, where a blast of air is also used to disperse the seeds uniformly over the floor space, much on the cyclone principle.

A concertina-like fitting of the actual suction member to the first section of ducting gives the necessary articulation as the small front traveling wheels run over uneven ground (Figure 12). It will be further seen that the rear conveyor is flexibly mounted to the main unit and has a canvas-type final delivery. Both instances provide some accommodating arrangement for travel over uneven ground and, also, facilitate turning (which would not be so easy with a strictly rigid structure) so that both the front collecting unit with its caster wheels and the final conveyor are free to move according to surface conditions.

Brillion Vacuum Harvester

The Brillion Iron Works, Incorporated, of Brillion, Wisconsin, in cooperation with the Agricultural Engineering

Department of the University of Wisconsin designed an experimental vacuum harvester (Figure 13). This machine was further developed in 1948 into a commercial vacuum harvester (Figure 14) by the Brillion Iron Works Company.

A large Palmyra bristle brush, 5 feet wide, rotating at 120 r.p.m. picks up the seeds left in the field by conventional harvesting methods and sweeps them into the nozzle where they are drawn up into the fan and blown into the wagon.

The fan, driven by a four-cylinder Wisconsin air-cooled engine, is a heavy duty, high capacity suction-type and rotates at 1,750 r.p.m.

The brush is adjustable to give a sweeping action suitable to the ground on which it is being used and also to allow for wear. The entire nozzle assembly can be raised four inches off the ground for transporting. The nozzle opening is adjustable from two to four inches. For best clearing results, according to the manufacturer, the Brillion machine should not travel over one mile per hour, while in operation.

The commercial production of this machine has been discontinued since 1949.

Figure 13. Experimental Brillion vacuum harvester, 1948.

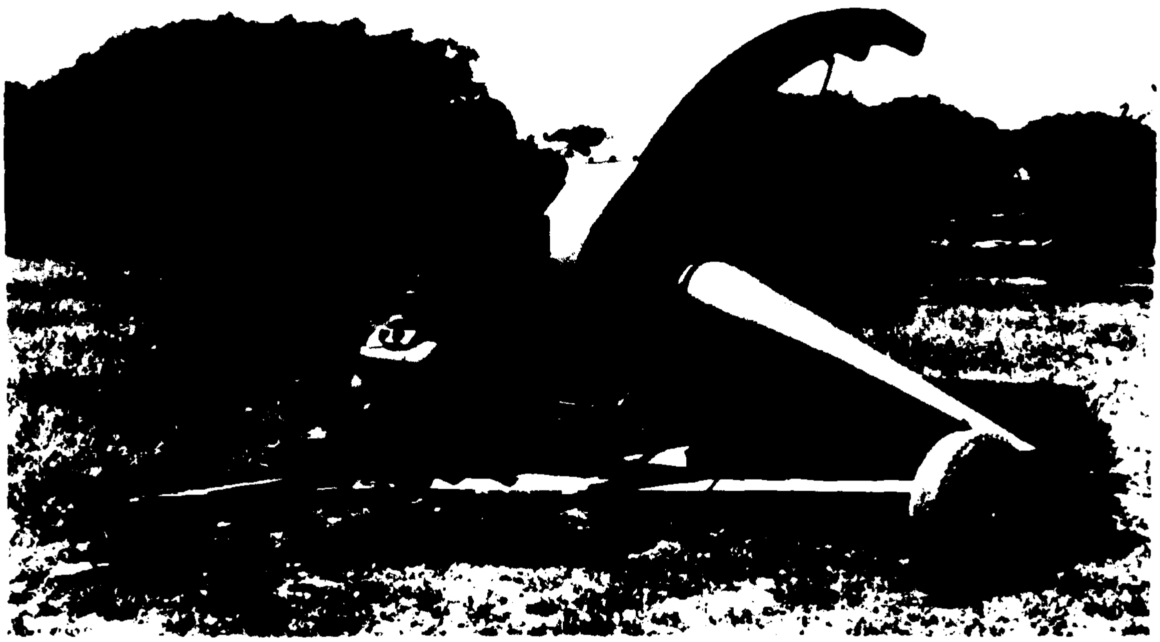


Figure 14. Commercial Brillion vacuum harvester, 1948.

Vacuum Leaf Loader and Street Cleaner

This machine (Figure 15) is manufactured by the American Structural Steel and Tank Company of Detroit, Michigan. Similar to an oversized vacuum cleaner, it is manufactured mainly for removing leaves from the streets.

A gasoline engine is used to drive a large blower through V-belts. The engine and blower assembly are mounted on a two-wheeled trailer, which can be connected or disconnected from a truck. Piping from the suction side of the blower is connected to a wide nozzle, located approximately two inches above the street level. The discharge side of the blower is connected to a large metal duct which is led to the collecting truck. A section of reinforced rubber hose is used between the metal duct on the discharge side and the entrance to the truck to insure flexibility. During an average day, the vacuum leaf loader will cover from four to six miles.

Washtenaw Vacuum Harvester

This harvester, shown in Figure 16, was developed in 1950 by E. A. Wolter and John Yeakel of Washtenaw County, Michigan, to sweep Ladino clover fields.

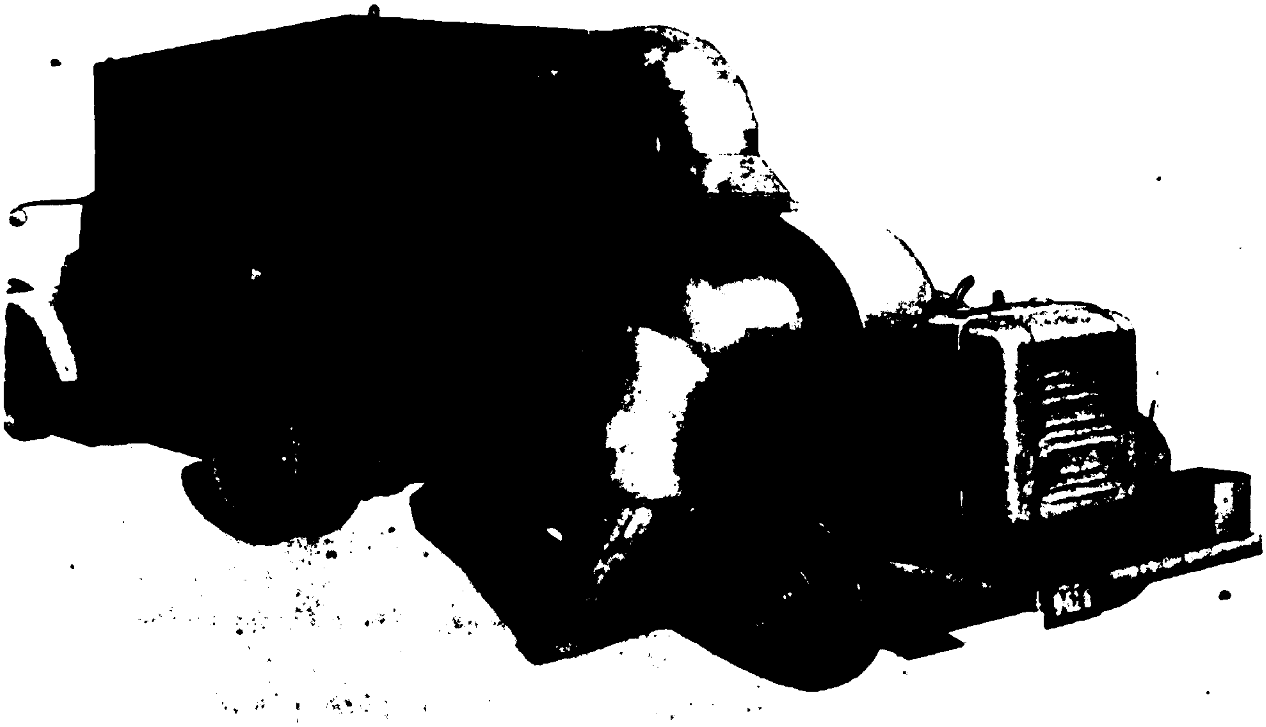


Figure 15. Vacuum leaf loader and street cleaner, 1948.

Figure 16. Washtenaw vacuum harvester, 1950.

The blower was mounted on a motor car frame and driven by its engine. The nozzle was six feet wide and supplied with a pickup device.

The wheels of the tractor, wagon, and harvester tramped on the clover before the nozzle got the chance to pick it up, thus decreasing its picking efficiency. There was no swivel joint between the blower and the collecting wagon, but a canvas tube was provided which could easily be closed in a sharp turn.

It was reported that this harvester saved more than 50 percent of the seed lost through combine harvesting.

DYNAMICS OF SMALL PARTICLES

The study of the minimum lifting velocity of the material to be picked from the field is of a prime importance in designing the vacuum harvester. Too high an air velocity will require a heavy blower with a high powered engine. In addition, dirt and stones will be sucked with the clover while too low an air velocity might not lift the seed from the stubble.

The various laws of lifting velocities were reviewed and applied to the Ladino clover seed along with some of the common grains and seeds.

Experimental works were made to compare the actual lifting velocities with the calculated ones using the rotameter principle.

Behavior of Particles in a Fluid

Equivalent Particle Shapes

For any irregular particle an equivalent particle may be substituted. For statistical purposes and for reasons of convenience it is customary to reduce a particle to an equivalent sphere. Determination of the nominal sphere is as follows: The volume is determined by displacement in water, and this volume is equated to the volume of a hypothetical sphere having an equivalent diameter.

The volume of a sphere is known to be $\pi D^3/6$, hence the nominal or equivalent diameter, Dn of the particle is that given by the equation

$$Dn = [(6 \times \text{volume of particle})/\pi]^{1/3}$$

Resistance to Motion

The general law of resistance of bodies to motion is represented by the following equation:

$$R = K D^n V^n \mu^{2-n} \rho_o^{n-1} \qquad [(9) \text{ p. } 12]$$

where

R = resistance of particle in motion

D = diameter of particle

V = velocity of particle

μ = viscosity of the medium

ρ_o = density of the medium

Resistance in the case of streamline or turbulent motion is determined by the exponent n, which in the first case is equal to 1 and in the second case equal to 2.

No sharp boundary exists between streamline and turbulent flow.

Terminal Velocities

If the density of the particle and fluid are ρ and ρ_0 respectively, and if the diameter of the particle is some arbitrary linear measurement, the gravitational pull F on the particle is

$$F = \alpha_v D^3 (\rho - \rho_0) g \qquad [(9)\ p.\ 16]$$

where $\alpha_v D^3$ measures the volume of the particle and g is the acceleration due to gravitation. When the particle has reached its maximum or "terminal" velocity, R = F so that in:

streamline motion,

$$Vm = K_s [(\rho - \rho_0)/\rho_0] D^2 Y^{-1} \qquad (1)$$

turbulent motion,

$$Vm = K_t [(\rho - \rho_0)/\rho_0]^{1/2} D^{1/2} \qquad (2)$$

intermediate region,

$$Vm = K_1 [(\rho - \rho_0)/\rho_0]^{2/3} Y^{-1/3} D \qquad (3)$$

where the K's are constants and Y is the kinematic viscosity or μ/ρ_0.

Values of K_s and K_t are given for sphere

$K_s = 54.5$ $\qquad\qquad$ $K_t = 25.4$

The constants are in cgs units. [(9) p. 16]

In general it is worth noting that the terminal velocities of a particle as given in equations (1), (2) and (3) are the square, the square root and the first power of the particle diameter, depending on the motion.

Lifting Velocities

The velocities required to lift particles are identical with those given by equations (1), (2) and (3). Thus, for particles of various sizes, the velocity required to lift and convey all of them must exceed the velocity required by the largest particle.

Several formulas for computing settling velocities have been presented. The constants contained in these formulas are assumed to be functions of particle shape but unfortunately there is limited information concerning them. Moreover, as has been pointed out, there are three formulas to consider since the size of the particle determines the nature of its movement through a fluid. Often it is difficult to determine precisely the boundary that distinguishes one type of movement from another, so that if a single curve could be drawn through the whole range of sizes, and an equation derived for it, some labor could be saved. This in fact was done by Rubey (9) whose procedure was as follows: The total force holding a spherical (or other) particle in suspension at a constant height in a rising current of a given fluid may be conceived as the sum of two forces—viscous resistance and fluid impact.

$$[(\pi D^3)/6][\rho - \rho_0]g = [3\pi D\mu v] + [(\pi D^2/4)v^2 \rho_0]$$

Solving for v, we obtain a quadratic which, on retaining the positive root, becomes

$$v = -\frac{6\mu}{\rho_0 D} + \sqrt{\frac{36\mu^2}{\rho_0^2 D^2} + \frac{2}{3} g [(\rho - \rho_0)/\rho_0] D} \quad (4)$$

Rubey states that this equation closely fits the entire range of particle size.

Transport of Particles

Pneumatic Transport

The whole field dealing with transport of particles has been in a state of flux for many years. Each investigation seems to have produced a separate concept of the importance of the variables affecting transport, and formulas developed are equally numerous.

Equations (1), (2), and (3) giving the terminal velocity of particles may be used to calculate the velocities required to move such particles through vertical pipes. The velocities calculated by these formulas are those required to support the particles in a vertical fluid stream. Motion in the direction of the moving stream will be imparted when the velocities exceed the calculated amounts. Little is known with regard to velocities for horizontal transportation of particles. In general, velocities capable of moving particles vertically will be more than sufficient for horizontal transportation.

There are two types of transportation: (a) _Transportation of low concentration_ in equations (1), (2), (3) and (4); (b) _Transportation of high concentrations of materials_, commonly referred to as pneumatic conveying. The former entails little difficulty in design of equipment, but the latter is complicated by many factors and is not well understood.

Transportation of Low Concentrations

While the equations cited above may be used with considerable certainty of success, one must remember that the usual particles encountered in industry are by no means regular in shape, nor do they move in straight lines. The continual rebound of particles in pipes, requires that more accurate equations be obtained. Dallavalle (9) p. 315 developed the following equations for transporting materials having specific gravities less than 3.0:

For horizontal transportation

$$V = 6{,}000\ [\rho/(\rho + 1)]\ D^{2/5}$$

and for vertical transportation

$$V = 13{,}300\ [\rho/(\rho + 1)]\ D^{3/5}$$

where

V = the lifting velocity in feet per minute

ρ = specific gravity of the particle

D = diameter in inches of the largest particle to be transported.

Transportation of Heavy Concentrations

The movement of large quantities of fine material, especially grains, was studied by Cramp (8). The analysis given here closely follows that developed by him. While theoretical developments were given by Jennings (23), no practical comprehensive work is available other than that of Cramp.

The generalized energy equation is:

$$F = \alpha (Va - V)^2$$

where

F = the gravitational pull

α = a constant having the dimensions (ML^{-1})

and

$(Va - V)$ = the relative velocity of the air with respect to that of the particle.

The value of α depends on the shape, density and other characteristics of the particle.

If $F = W$ = the weight of a single particle

$$Va - V = \sqrt{(W/\alpha)}$$

and this is the terminal velocity as discussed in equations (1), (2) and (3).

Computation of the Lifting Velocities of Seeds and Grains

The lifting velocities of different seeds and grains were calculated by means of the turbulent motion equation which states that:

$$Vm = K_t \ [(\rho - \rho_o)/\rho_o]^{1/2} \ D^{1/2}$$

where

V_m = lifting velocity in centimeters per second

ρ = density of particle

ρ_o = density of air

= 0.001293 grams per cubic centimeter at standard pressure and temperature

D = effective diameter of particle

K_t = constant

= 25.4 for sphere

In this computation, seeds and grains will be considered as spherical particles. The error in this assumption will be more pronounced for seeds and grains of irregular shape.

Ladino Clover Seed

2000 seeds weigh 1.036 gm.

2000 seeds occupy 1.00 c.c.

wt./seed = 0.000518 gm.

vol./seed = 0.0005 c.c.

density = 1.036 gm./c.c.

effective diameter =

$$[(6 \times .0005)/\pi]^{1/3} = .0985 \text{ cm.}$$

$$Vm = 25.4\ [(1.036 - .00129)/.00129]^{1/2} \times (.0985)^{1/2}$$

$$= 225 \text{ cm./sec.}$$

$$= 443 \text{ ft./min.}$$

Red Clover Seed

1000 seeds weigh 1.625 gm.

1000 seeds occupy 1.30 c.c.

wt./seed = .001626 gm.

vol./seed = .0013 c.c.

density = 1.250 gm./c.c.

effective diameter = .135 cm.

$$Vm = 25.4\ [(1.250 - .00129)/.00129]^{1/2} \times (.135)^{1/2}$$

$$= 290 \text{ cm./sec.}$$

$$= 570 \text{ ft./min.}$$

Reed Canary Grass Seed

500 seeds weigh 0.410 gm.

500 seeds occupy 0.40 c.c.

wt./seed = 0.00082 gm.

vol./seed = 0.00080 c.c.

density = 1.025 gm./c.c.

effective diameter = .1152 cm.

$$Vm = 25.4\ [(1.025 - 0.00129)/0.00129]^{1/2} \times (.1152)^{1/2}$$

$$= 243 \text{ cm./sec.}$$

$$= 478 \text{ ft./min.}$$

Field Peas

50 grains weigh 9.055 gm.

20 grains occupy 2.80 c.c.

wt./grain = 0.1813 gm.

vol./grain = 0.14 c.c.

density = 1.295 gm./c.c.

effective diameter = .534 cm.

$$Vm = 25.4\ [(1.295 - .00129)/.00129]^{1/2} \times (.534)^{1/2}$$

$$= 586 \text{ cm./sec.}$$

$$= 1150 \text{ ft./min.}$$

Soybeans

30 grains weigh 4.66 gm.

20 grains occupy 2.36 c.c.

wt./grain = 0.155 gm.

vol./grain = 0.118 c.c.

density = 1.313 gm./c.c.

effective diameter = 0.508 cm.

$$Vm = 25.4\ [(1.313 - 0.00129)/0.00129]^{1/2} \times (0.508)^{1/2}$$

$$= 574 \text{ cm./sec.}$$

$$= 1130 \text{ ft./min.}$$

<u>Field Beans (Pork Red Kidney)</u>

20 grains weigh 9.25 gm.

20 grains occupy 8.14 c.c.

wt./grain = 0.4625 gm.

vol./grain = 0.407 c.c.

density = 1.136 gm./c.c.

effective diameter = 0.735 cm.

$$Vm = 25.4\ [(1.136 - .00129)/.00129]^{1/2} \times (0.735)^{1/2}$$

$$= 643 \text{ cm./sec.}$$

$$= 1265 \text{ ft./min.}$$

<u>Corn</u>

20 grains weigh 6.95 gm.

20 grains occupy 5.2 c.c.

wt./grain = 0.3475 gm.

vol./grain = 0.26 c.c.

density = 1.336 gm./c.c.

effective diameter = 0.645 cm.

$$Vm = 25.4\ [(1.336 - 0.00129)/0.00129]^{1/2} \times (0.645)^{1/2}$$

$$= 654 \text{ cm./sec.}$$

$$= 1290 \text{ ft./min.}$$

Sugar Beets

100 seeds weigh 1.932 gm.

100 seeds occupy 4.10 c.c.

wt./seed = 0.01932 gm.

vol./seed = 0.0410 c.c.

density = 0.471

effective diameter = 0.427

$$Vm = 25.4\ [(0.471 - 0.00129)/0.00129]^{1/2} \times (0.427)^{1/2}$$

$$= 316 \text{ cm./sec.}$$

$$= 623 \text{ ft./min.}$$

Laboratory Experiments to Determine the Actual Lifting Velocities of Different Seeds and Grains

Previous Experimental Work

The determination of the lifting velocity of seeds and grains is a subject that has not been completely covered. The only literature available was a paper by Brown and Reed (4) who made tests to determine the air velocity required to lift grains of oats, wheat and corn. One hundred kernels of the various grains were uniformly distributed in a single layer on a screen placed at the intake of a vertical air duct. By controlling the air volume they were able to determine the percentage of material moved at various velocities. They found that lift begins at the following velocities:

685 ft./min. for oats

985 ft./min. for wheat

1070 ft./min. for corn

All grains were removed when the velocities for the same grains were 1050, 1300, and 2000 ft./min. respectively.

Experimental Procedure

Experimental work was done in the laboratory to determine the lifting velocity of different seeds and grains. Large sized grains were also included in the experiment due to the possibility of converting the vacuum harvester into a grain unloader.

The theory of the experiment was based on the principle of the rotameter. The rotameter is a flow rate metering instrument. Fluid is discharged through an annular aperture or orifice formed between the periphery of the head of the float and the inside wall of the tapered tube in which it travels. The upward and downward forces acting on the float are in equilibrium so that the float assumes a definite elevation at a given flow rate.

The apperatus used to determine the lifting velocity consisted mainly of a rotameter and a graduated precision-ground tapered glass tube (Figure 17). Compressed air was passed through a reservoir tank to get rid of its moisture and pressure pulsation.

The rotameter, placed in series between the tank and the tapered tube, measured the air discharge **W**.

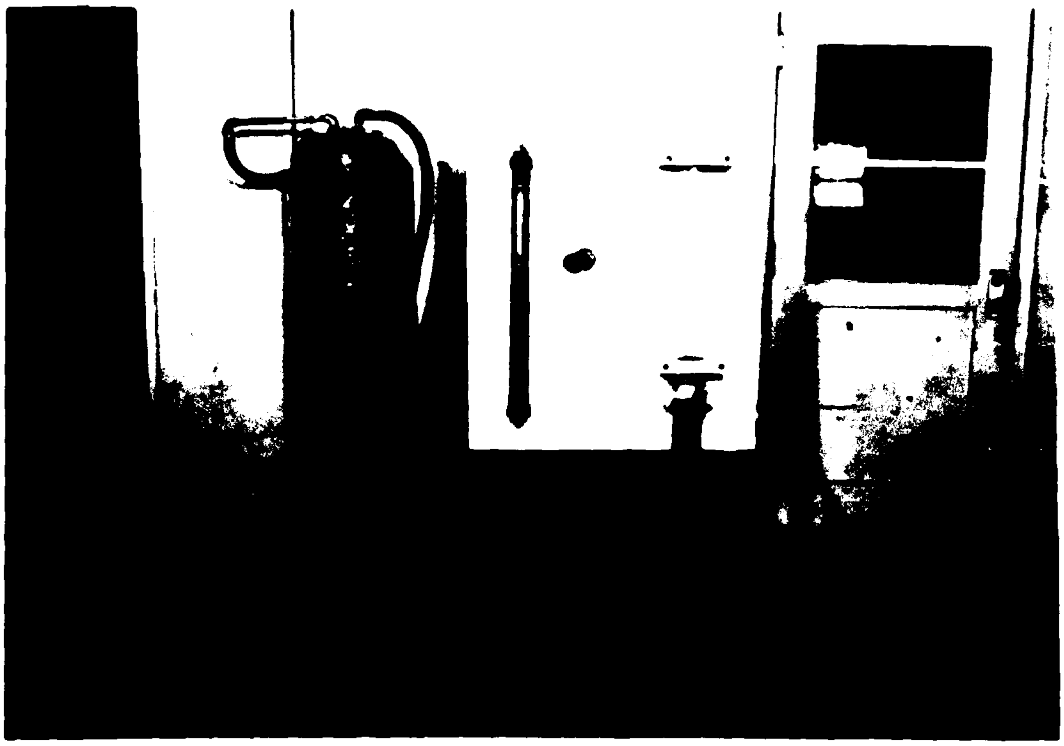


Figure 17. Apparatus for determining the lifting velocities of seeds and grains.

Figure 18. A field bean in its equilibrium position inside the tapered tube.

A regulator valve regulated the amount of air passing through the tapered tube. To prevent the whirling action of air flow inside the tube plastic straws were placed in the steel pipe connected to it. These straws helped maintain a vertical air flow inside the tapered tube. The seed was dropped in the open end of the tapered tube onto a screen placed at the bottom. Then the rate of air flow was adjusted with the regulator valve until the seed started to leave the screen and assume an equilibrium position in the tapered glass tube. Figure 18 shows a field bean in its equilibrium position inside the tube.

Knowing the air discharge W from the rotameter reading and the cross sectional area A of the tapered tube when the seed is floating, the minimum lifting velocity of the seed will be given by:

$$V = W/A$$

ACTUAL LIFTING VELOCITIES OF DIFFERENT SEEDS COMPARED WITH THE CALCULATED VELOCITIES

Seed or Grain	Calculated Lifting Velocity (ft./min.)	Actual Lifting Velocity (ft./min.)
Ladino	443	512
Red Clover	570	695
Reed Canary	478	440
Field Peas	1150	1450
Soybeans	1130	1412
Field Beans	1265	1334
Corn	1290	1130
Sugar Beets	623	850

One should keep in mind that the calculation of the lifting velocities of the mentioned seeds and grains was based on the assumption that they were perfectly spherical with a smooth surface.

DEVELOPMENT OF A NEW VACUUM HARVESTER

After a review of the different experimental vacuum harvesters so far developed, it was noticed that:

(1) The air flow inside the nozzles had not been investigated.

(2) The existence of air pockets in the actual nozzles was to be expected.

(3) No study had been made to find out the minimum velocity of air to collect the crop.

(4) The suction side of the blower was too long, giving a high frictional loss.

(5) Sharp bends in the suction side increased the tendency of the crop to clog the pipe.

(6) The gathering mechanism was frequently clogged with wild carrots, bull thistles, etc., winding around the beater. No self-cleaning device was provided.

(7) None was self-propelled.

Basic Features of the Vacuum Harvester Design

The Harvesting Procedure

The new vacuum harvester was designed to harvest Ladino clover from the windrow. The simplicity of the nozzle attachment when designed for windrows and the possibility of getting more seeds and less dirt from windrows than from swaths made this procedure very favorable. In addition, this method of collecting the clover from the windrow had not been previously tried, and, in order to make a complete comparison of all the possible methods of harvesting, this machine had to be constructed.

The Machine Drive

The vacuum harvester can either be self-propelled or trailed.

A. If self-propelled, either one or two engines might be used in the machine.

1. With one engine

If one engine were used to drive both the machine and the blower, the blower speed would be influenced by the load on the engine for moving the harvester. Frequent gear shifting or a variable speed drive would be needed to vary the forward speed.

2. <u>With two engines</u>

In this case, the blower speed would be independent of the forward speed of the harvester. The optimum suction air velocity could thus be adjusted for clover harvesting without affecting the forward speed. The over-all length of the harvesting unit would be shorter and the machine could be designed in a way that the operator could ride the harvester and be able to look forward to the suction nozzle.

B. If trailed, the harvester might be either mounted on a tractor or pulled by a tractor. In the latter case, the over-all length of the tractor and harvester would be greater than the self-propelled unit. Furthermore, larger space would be needed for turning. In case of a tractor mounted unit, the farmer would not be able to use the tractor for other farming purposes.

The vacuum harvester was built as a trailer-type unit to be hitched behind a 4-wheel tractor. A self-propelling unit was considered too expensive for an experimental harvester. A four-cylinder, V-type, air cooled Wisconsin Engine rated at 22 h.p. at 2,600 r.p.m. was used for the blower drive. Figure 19 shows a detailed drawing of the harvester frame.

Blower

Type of blower drive. The engine could be selected to make possible a direct drive with the blower, thus eliminating chain and sprockets or belt and pulleys, however, the engine available had to have a belt and pulley transmission.

Position of the blower. The blower was installed so that its axis would be parallel to the longitudinal axis of the machine frame. This arrangement would reduce the length of the blower suction side and the number of bends in the suction pipe to a minimum. This position would also allow the direct driving engine to be installed along the side of the frame and, therefore, give more stability to the frame of the machine.

Capacity of the blower. The same blower used in the Dexter and Sheldon experimental machine was used. It is a No. 13 Improved Clarage Exhauster with a long shaving impeller. The rotating blades in the long shaving impeller are

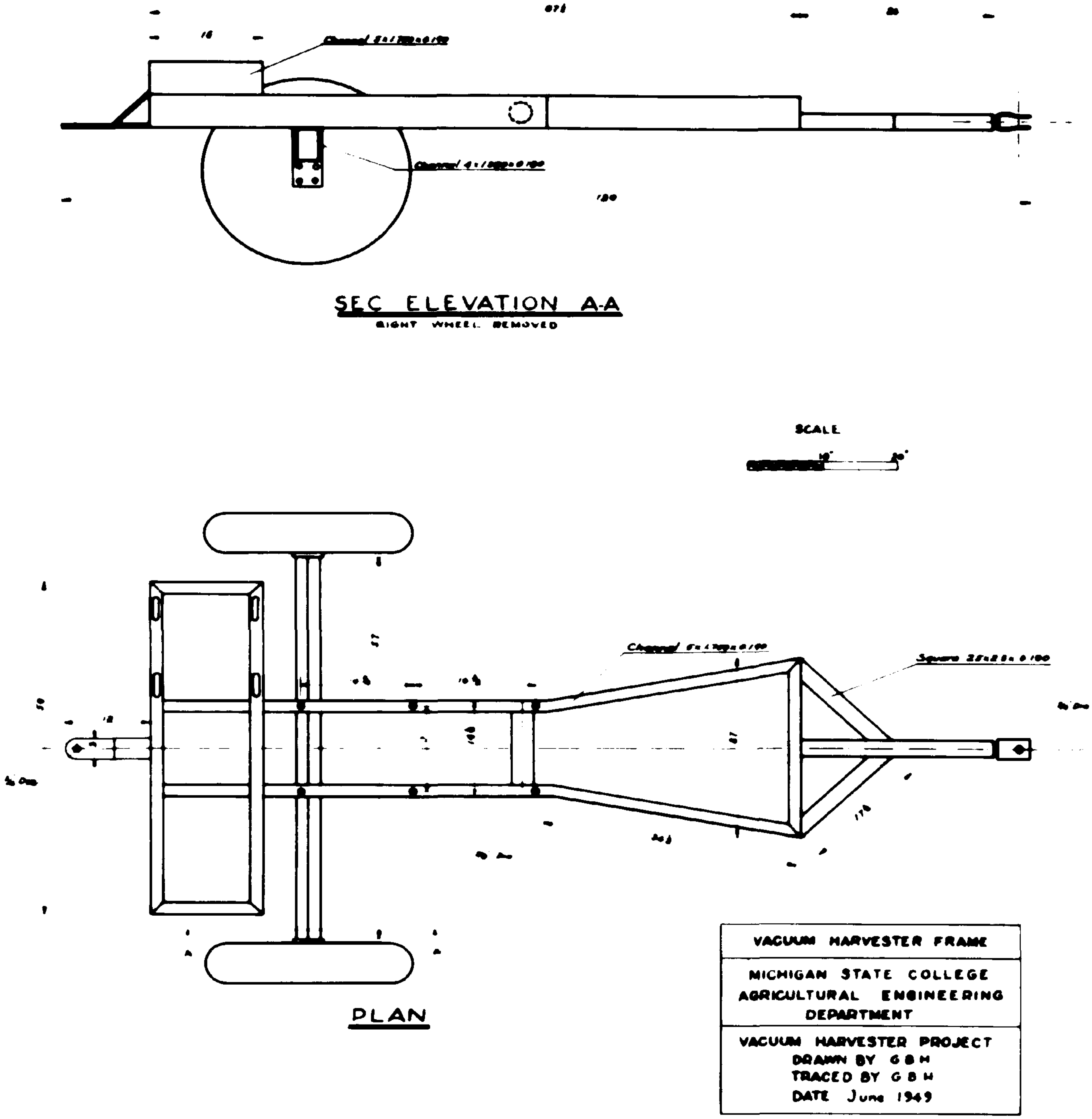


Figure 19. Vacuum Harvester Frame.

more widely spaced than in the low-speed impeller, thus reducing the tendency toward clogging with heavy material.

Suction Nozzle Design

Width of Nozzle

The width of the pick-up nozzle depends on both the blower capacity and the windrow width. However, a narrow pick-up width was desirable for the following reasons:

(1) More accurate fit to the ground would be possible.

(2) High air inlet velocity for a given air volume could be supplied.

(3) Higher forward speed for a given air volume was possible.

(4) Less change would occur in the direction of air flow.

A width of 24 inches for the nozzle inlet was considered sufficient for collecting the crop from the windrow.

Nozzle Shape

Dexter and McKibben reported that, in their experimental harvester, they tried to eliminate the need of the rotating pick-up but without success. A rotating pick-up was indispensable in their machine because:

(1) The air entering through the nozzle did not strike the clover strong enough to lift it from the ground.

(2) It was more difficult to lift the clover from the swath than from the windrows.

The nozzle shapes, in most of the vacuum harvesters so far constructed, were far from perfect; the entering air did not touch a large area of cut clover under the nozzle. Consequently, for a given nozzle position, the entering air did not have enough effective lifting power.

The elimination of the pick-up has the following advantages:

(1) It decreases the suction opening area and hence increases the inlet air velocity for a given blower capacity.

(2) It prevents frequent stoppage due to clogging of the pick-up by heavy material.

(3) It eliminates extra transmission gears and chains.

(4) It simplifies the machine construction and makes it cheaper.

The only way that seemed possible to get rid of the pick-up device was to properly design the nozzle. A strong entering air velocity would whirl the clover and carry it in the air flow. Furthermore, the entering air flow must pass through the entire area covered by the nozzle. Figure 20 shows the design of the nozzle and the harvester assembly drawing. The possibility of getting air pockets or stagnant air zones in the nozzle was reduced to a minimum. The front part of the nozzle was designed to let the air strike the ground before entering the suction pipe. This helped to release the cut clover from the stubble. The rear part of the nozzle was shaped so that it would pick up the remaining clover. The side notch in the nozzle was made to break the possible region of stagnant air. The suction nozzle, in order to fit the irregularity of the covered ground, was to be made of the floating type. This was done by means of a telescoping joint made of canvas and connecting the nozzle to the upper suction pipe as shown in Figure 21.

Four spring attachments (Figure 22) kept the floating nozzle always in contact with the ground. The proper height of the nozzle from the ground depends on the amount of growth.

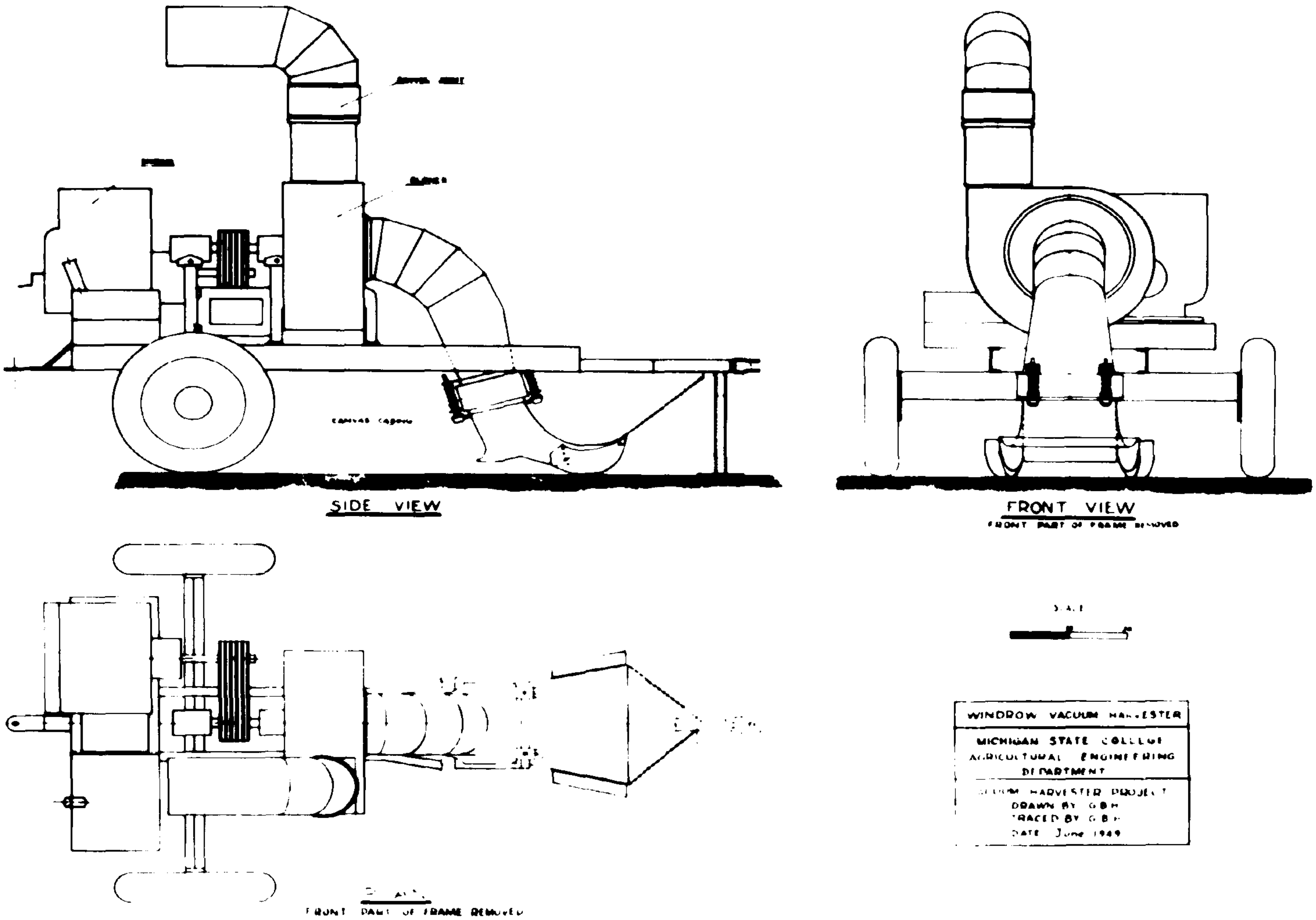


Figure 20. Windrow Vacuum Harvester - assembly drawing.

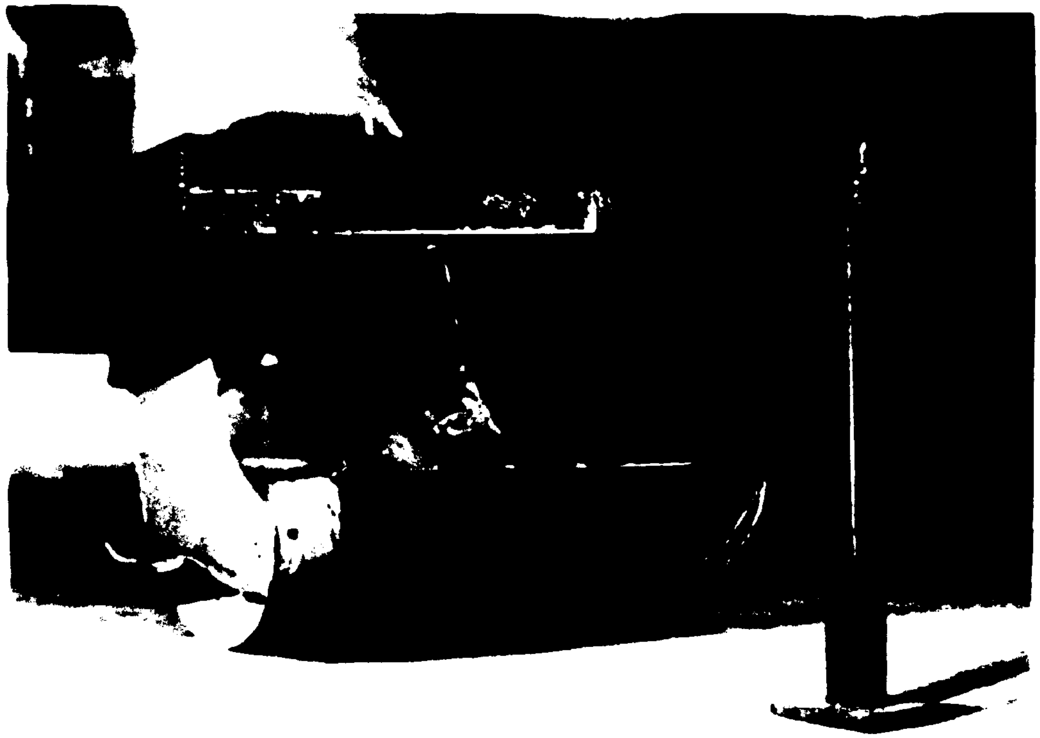


Figure 21. Telescoping joint made of canvas and connecting the nozzle to the upper suction pipe.

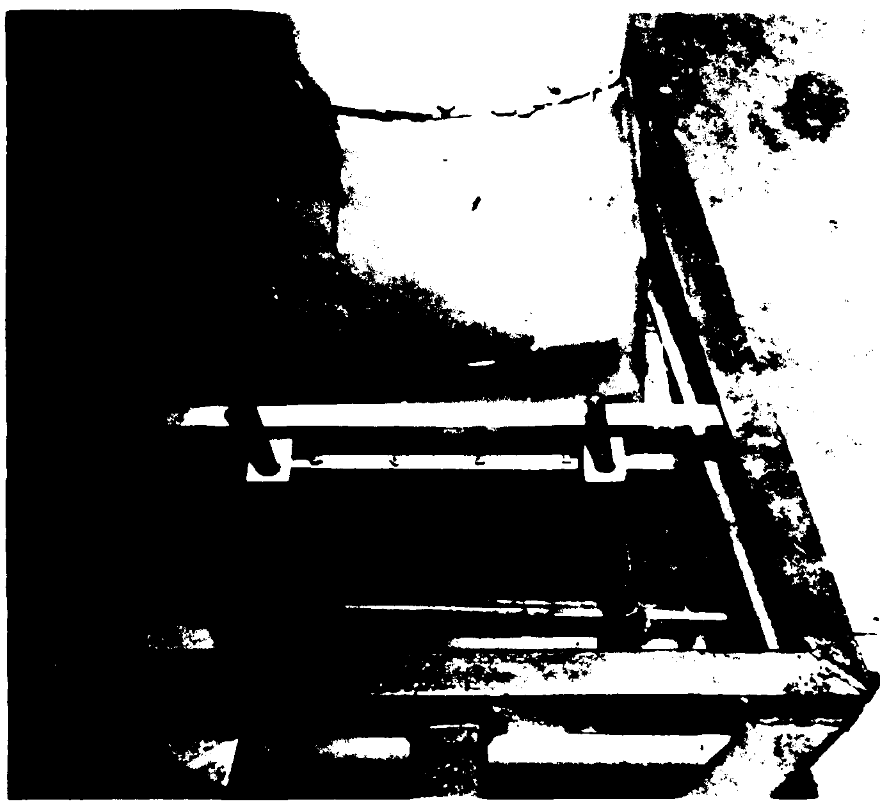


Figure 22. Spring attachments keeping the float-nozzle always in contact with the ground.

A pair of shoes, one on each side of the nozzle, regulated the height of the nozzle from 2 inches to 5 inches above the ground. The floating nozzle was attached to the frame by means of very light chains. Figures 23 and 24 show different views of the constructed vacuum harvester.

The table on page 59 shows the main features of the new vacuum harvester as compared to the two harvesters developed by McKibben, Dexter, and Sheldon.

Airflow Measurement in the Nozzle of the Vacuum Harvester

An air flow investigation was made in order to check the design of the nozzle. The vacuum harvester was set on a platform, as shown in Figures 25 and 26, in order to reach easily the bottom of the nozzle.

A pitot tube was mounted on a rotating frame under the nozzle, as shown in Figures 27 and 28. A rubber seal, shown in Figure 27, covered a 3-inch diameter hole on the platform, thus giving the pitot tube freedom to rotate with respect to a fixed quadrant without diverting the flow of air. Consequently, the pitot tube could be adjusted to be parallel

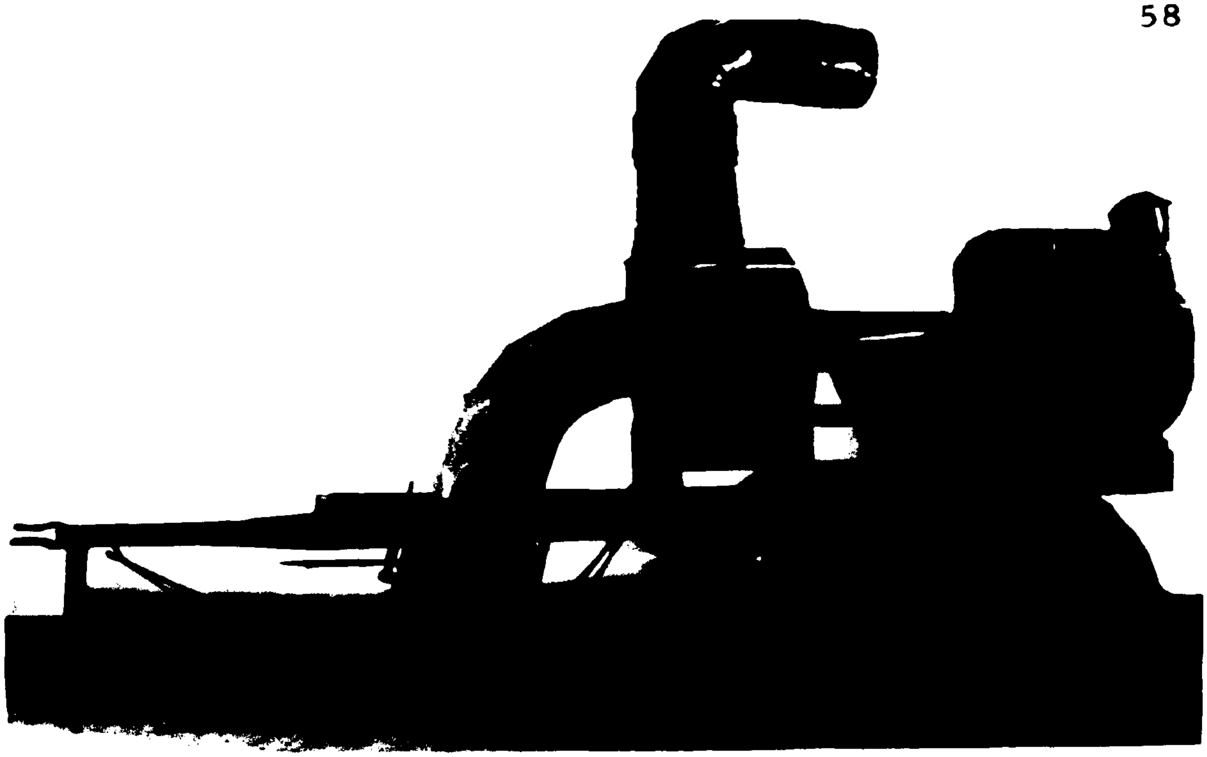


Figure 23. The windrow vacuum harvester.

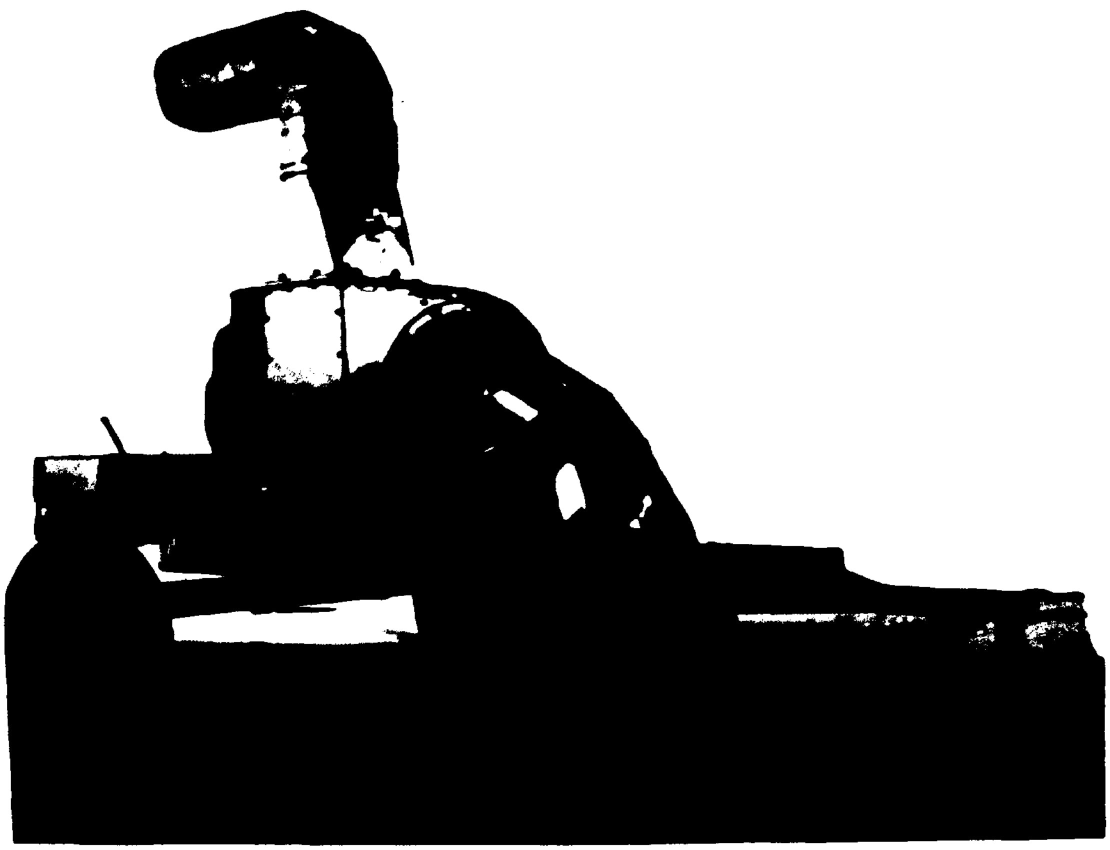


Figure 24. Another view of the windrow vacuum harvester.

COMPARISON OF THE NEW HARVESTER WITH THE TWO HARVESTERS DEVELOPED BY McKIBBEN AND SHELDON

Features	McKibben and Dexter Harvester	Sheldon and Dexter Harvester	Present Features in New Harvester
Method of Harvesting	From Swath	From Swath	From Windrow
Machine Drive	Tractor Mounted	Tractor Mounted	Trailed
Blower Drive	From Tractor Engine	From Tractor Engine	From an Individual Engine
Blower Size	No. 13 Improved Clarage Exhauster	No. 13 Improved Clarage Exhauster	No. 13 Improved Clarage Exhauster
Blower Speed	1800 r.p.m.	2600 r.p.m.	2400 r.p.m.
Impeller	Low-speed Impeller	Long Shavings Impeller	Long Shavings Impeller
Blower Position	Propeller Axis Parallel to the Wheel Axis	Propeller Axis Parallel to the Wheel Axis	Propeller Axis Vertical to the Wheel Axis
Width of Pick-up	3 feet	6 feet	2 feet
Gathering Device	3/16" stiff Rods	Flexible Teeth	No Gathering Device

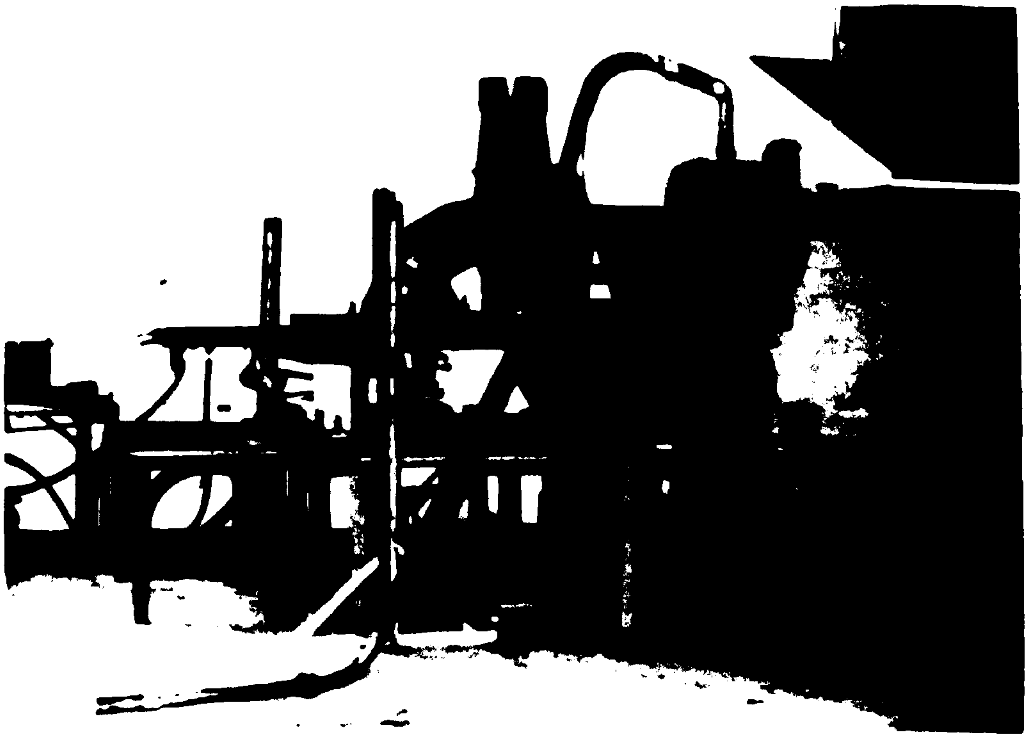


Figure 25. Machine set-up for air flow measurement.

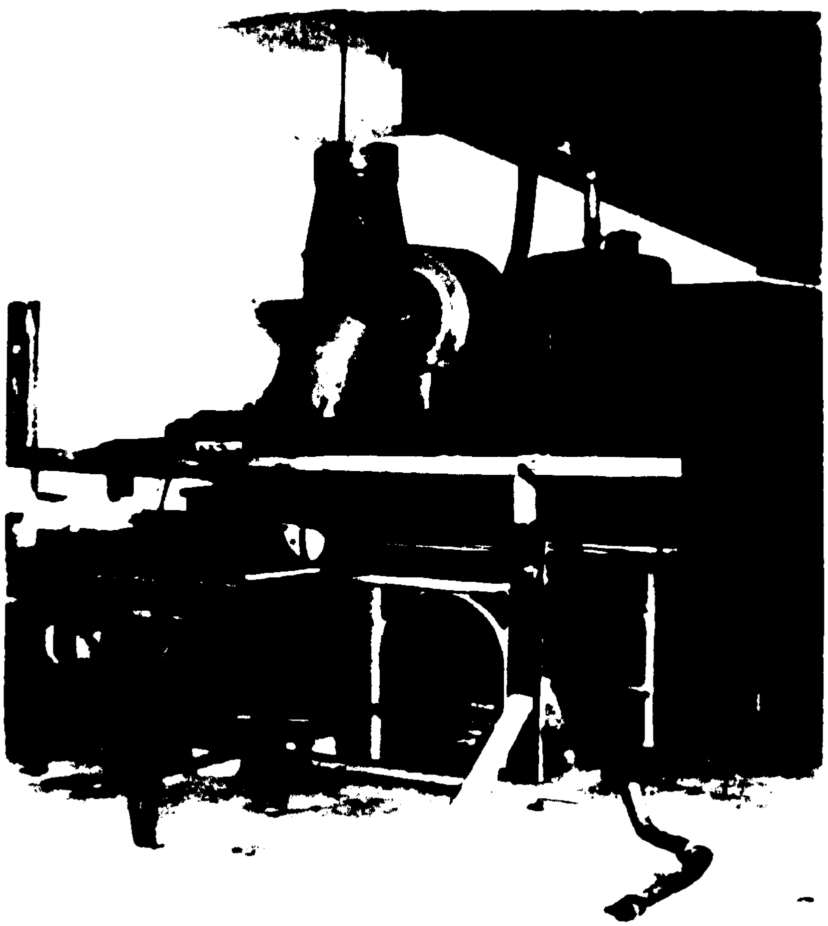


Figure 26. Machine set-up for air flow measurement.

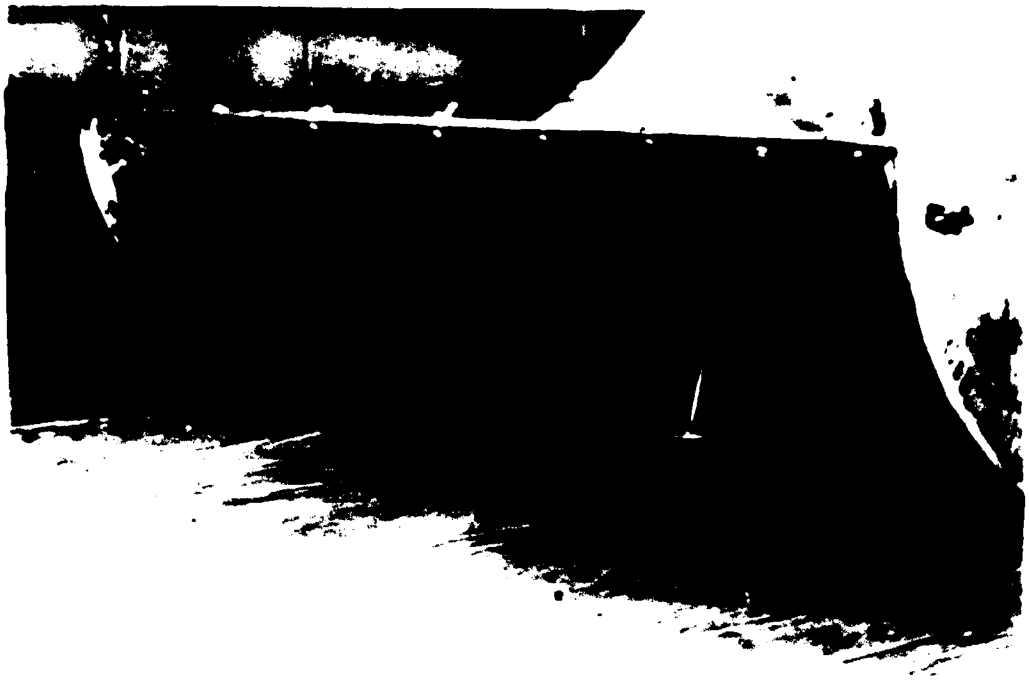


Figure 27. Measurement of the air velocity by means of the pitot tube.

Figure 28. Lower end of the pitot tube showing how it rotates to detect the direction of air flow.

to the direction of air flow, recording the maximum air velocity and its direction of flow.

Furthermore, the air velocity measurement was checked by a direct reading air velometer, shown in Figure 29.

The air flow was further studied by means of a smoke machine. This consisted of two bottles in series, one containing ammonium hydroxide and the other hydrochloric acid. Blowing air in the first bottle provided a white smoke of ammonium chloride. The flow of smoke indicated the path of air through the nozzle and this is shown in Figure 30.

To study the air flow in the nozzle three blower speeds were used—1140, 1530 and 2000 r.p.m. Air velocities in feet per minute were measured at different heights in sections A, B, C, D and E and average velocity curves were plotted as shown in Figure 31. From the result of this air flow investigation the following conclusions were drawn:

(1) No "vena contracta" was present in the nozzle.

(2) Stagnant air flow was absent except in a very small region.

(3) The air speed in the nozzle was proportional to the speed of the blower.

Figure 29. Air flow measurement by means of the velometer.

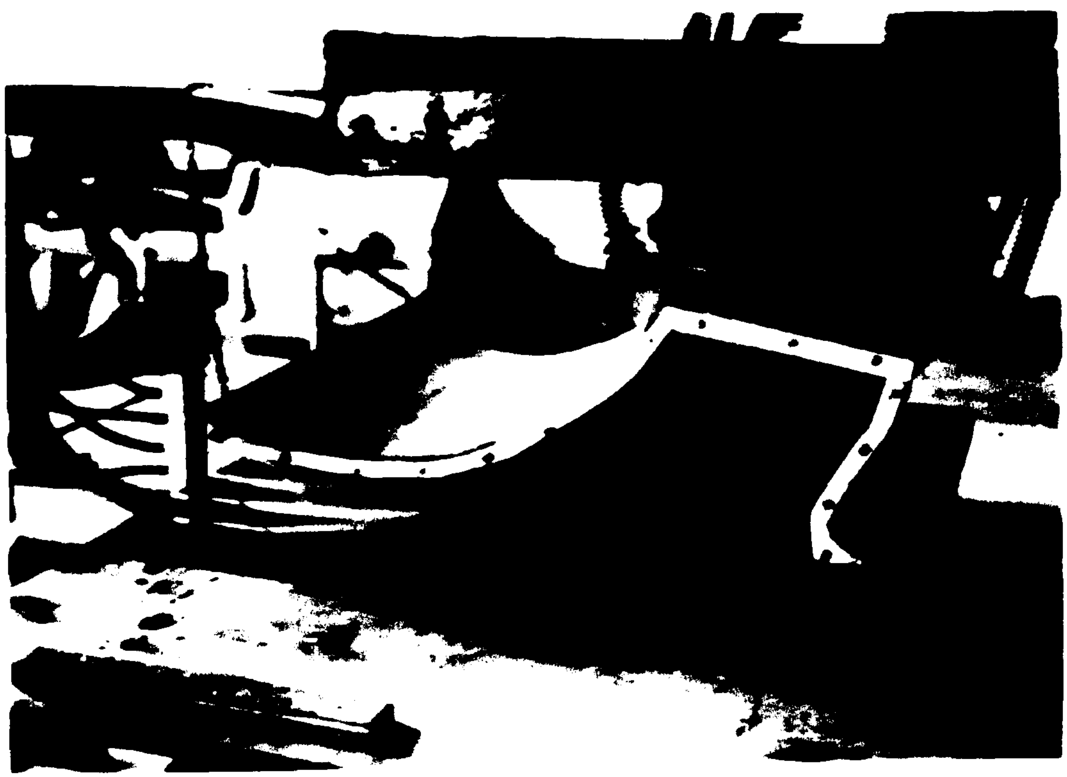


Figure 30. Air flow study by means of a smoke machine.

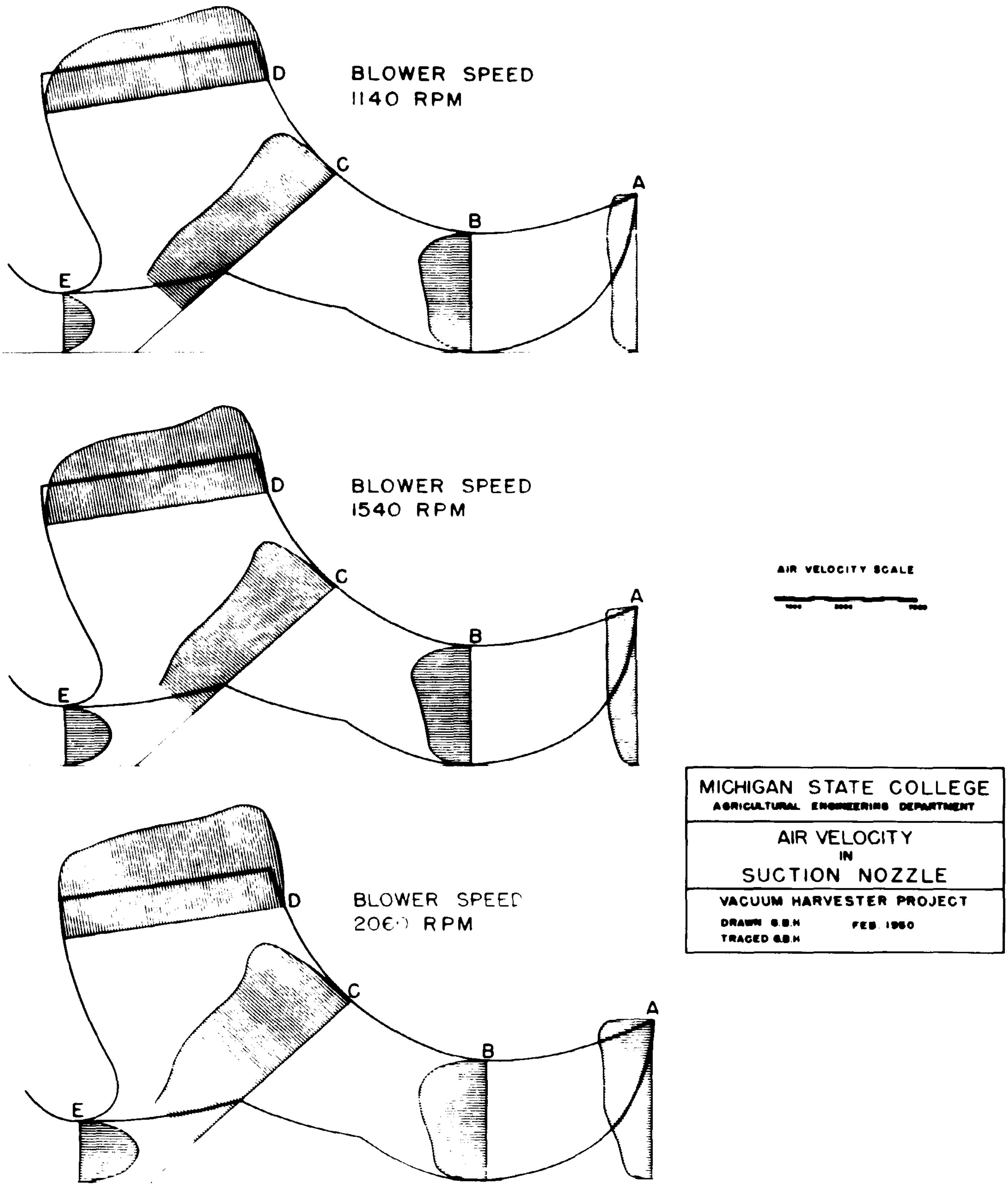


Figure 31. Air velocity in suction nozzle.

(4) Section D was the maximum speed region while Section A was the minimum speed region, Figure 31.

(5) The air flow in the nozzle was a turbulent flow.

When designing a nozzle for picking Ladino clover seed, one must choose a velocity by far higher than the lifting velocity of the seed as both the clover and the heads will be sucked together. In addition, many heads are laid flat on the ground or tangled in the stubble, a condition which requires a still higher air velocity to release them.

DESIGN AND CONSTRUCTION OF THE CUTTER BAR VACUUM HARVESTER

This method of harvesting consists of sucking the green clover immediately after it is cut by the mower cutter bar and drying the clover by means of an artificial drier.

The same windrow vacuum harvester was used except that the nozzle design and arrangement were changed, and a five-foot Ford mowing machine was mounted on the pulling tractor.

Figure 32 shows views of the machine. By means of swivel joints, the nozzle rotated around a vertical axis at the point of hitch of the harvester with the tractor.

A light rod connecting the nozzle to the mower frame allowed the nozzle to have a fixed position with respect to the tractor.

The automatic safety release in the mower is a feature that helps prevent injury to the mower when an obstruction is hit. It allows the cutter bar to swing to the rear away from the obstruction. For this reason the nozzle was not fixed to

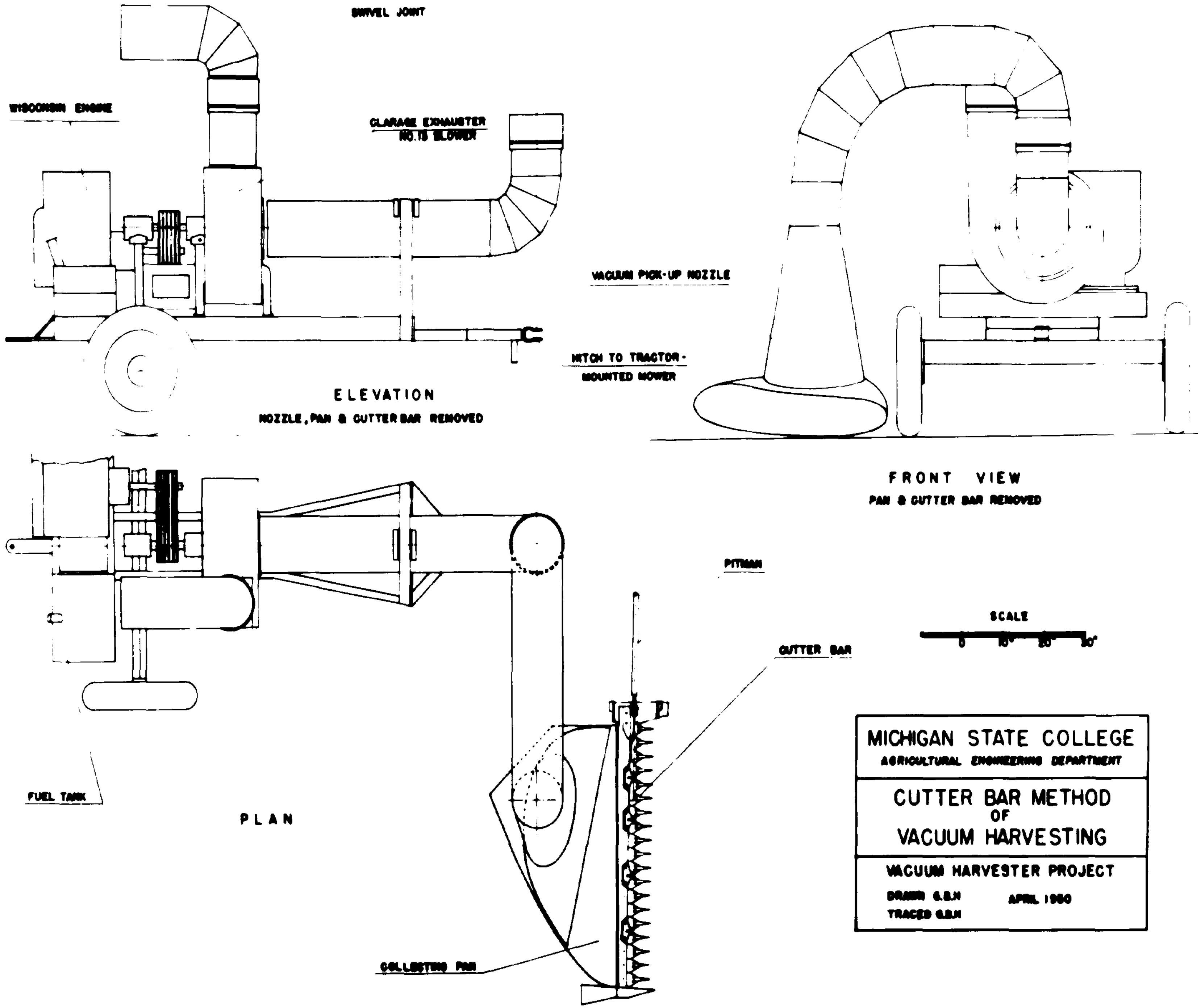


Figure 32. Cutter bar method of vacuum harvesting - assembly drawing.

the cutter bar as this would prevent the cutter bar from swinging to the rear when the safety device happened to be tripped.

A pan collector was attached to the cutter bar and the nozzle inlet was made to rest on the pan and to fit its curvature.

FIELD TRIALS

Design of Experiment

Field No. 1

Field No. 1 was located on the college farm in East Lansing. It was seeded in the spring of 1949, but had not been clipped. Due to the fact that the field was small, only eight plots were used. The area of the field available was a determining factor for the number of replicates.

Each plot was 5 feet wide and 174.24 feet long which made it equivalent to an area of 1/50 of an acre. Evidence seems to indicate that long and narrow plots, which may cut across areas of greater field variation, tend to have smaller error.

In order to get exactly a 5-foot cut and to avoid having the tractor wheels run over the plots it was necessary to provide an additional strip of land 5 feet wide between plots as shown in the field layout (Figure 33).

The following were the four harvesting methods used:

(1) The pan method.

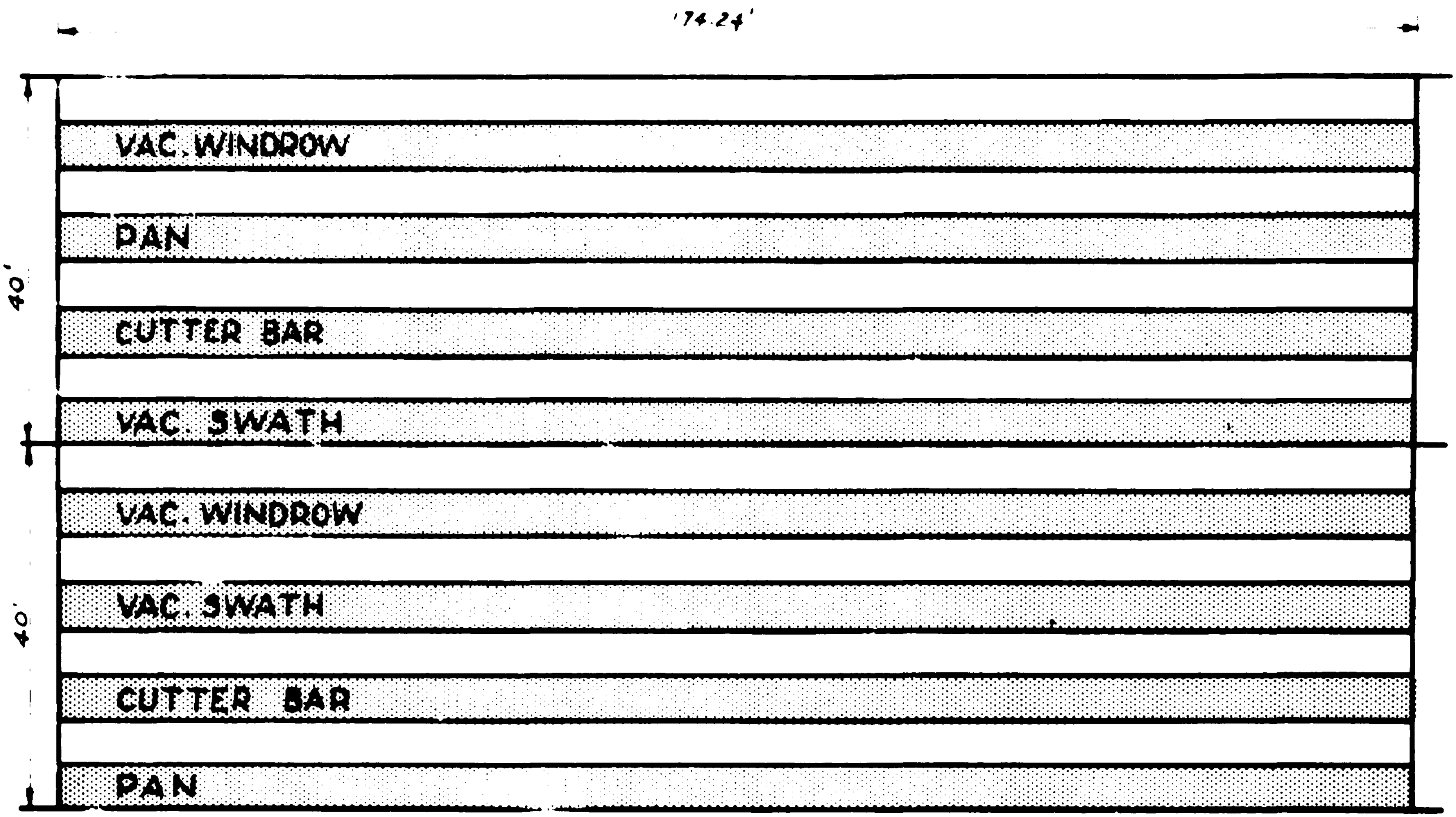


Figure 33. LAYOUT OF FIELD NO. 1
COLLEGE EXPERIMENTAL FARM
E. LANSING

(2) The cutter bar method.

(3) The windrow method of vacuum harvesting.

(4) The swath method of vacuum harvesting.

These four methods were distributed at random throughout the eight experimental plots.

Before starting the actual experiment, a preliminary study on the condition of the field was made. A steel frame of 2 feet by 2 feet was used for this purpose. This frame was thrown at random on the strip of land between the experimental plots. This was done to avoid trampling on the experimental plots. The amount of seed actually present on the field prior to harvest was determined by the quadrat system of sampling and the results converted into pounds of seed per acre. Hereafter, the yield determined by this method will be referred to as the "actual yield."

The white heads, the ripe heads standing, and the ripe heads bent on the ground were counted and then the whole clover inside the frame was cut and put in paper bags. Eleven random samples were taken. The green clover in the bag was weighed immediately and put in the drier of 100° F maximum temperature. After two days drying, the clover was weighed and the moisture content determined. Furthermore, each sample was put through the threshing machine four times and the remaining chaff was rubbed out by hand to get any seeds still remaining.

In addition, one hundred heads of white clover were picked from the field, dried in the oven, threshed and cleaned. It was found that these heads contained no mature seeds.

From the results shown in Table I, the average moisture content of the clover was 73.60 percent at the time it was cut.

The number of Ladino clover heads were determined to be as follows:

25.58% of white or immature heads.

40.90% of ripe standing heads.

33.52% of ripe heads bent to the ground.

From the total number of ripe or mature heads, 45 percent were bending on the ground, which meant that, if the mower cutter bar missed all the bent heads, only as high as 55 percent of the mature seed could be harvested.

The calculated total yield per acre was 155.25 pounds and the total weight of green clover was 5.54 tons per acre.

TABLE I

FIELD I

Sample Area 2' x 2'

SAMPLE	1	2	3	4	5	6	7	8	9	10	11	AVERAGE
White heads	63	22	88	63	48	66	67	52	13	58	59	54.4
Ripe standing	114	83	109	65	105	63	85	97	77	100	59	87.0
Ripe on ground	72	31	76	69	95	78	100	47	47	108	61	71.3
Total number of ripe heads	186	114	185	134	200	141	185	144	124	208	120	157
Total number of heads	249	136	273	197	248	207	252	196	137	266	179	212.7
Weight of green clover in grams	444	333	367	403	538	608	464	406	398	576	541	
Weight of dry clover in grams	126	80	95	85	154	147	143	116	105	142	149	
Moisture content, percent	71.62	75.97	74.11	78.90	71.37	75.82	69.18	71.42	73.61	75.34	72.45	73.60
Weight of seed, grams per four square feet	7.12	5.61	6.07	4.44	10.55	4.55	8.09	5.30	6.84	8.63	3.90	6.463
Weight in grams per 100 ripe heads	3.83	4.82	3.38	3.30	5.28	3.23	4.36	3.68	5.50	4.15	3.25	4.07
Actual yield per acre; weight of seed in pounds per acre	171	135	146	106.8	253	109.5	194	127.5	164	207	94	155.25

Field No. 2

Field No. 2 was also located on the college farm at East Lansing. It was seeded in the spring of 1949 but not clipped. The field layout followed the same pattern as field No. 1, with 16 experimental plots instead of 8.

Each plot was 5 feet wide and 174.24 feet long, each equivalent to an area of 1/50 acre.

The same four harvesting methods as used in Field No. 1 were distributed at random among the 16 plots, as shown in the field layout, Figure 34.

After harvesting the experimental field by different methods, a 2' x 2' frame was thrown 5 times at random on every 1/50 acre plot, and the clover inside the frame was gathered, dried, and threshed 5 times.

The picking efficiency was determined by the amount of seed recovered from first threshing, the efficiency of the threshing machine, and the amount left in the field.

Field No. 3

Experiments were conducted near Middleville, Michigan, on a field of Ladino clover seeded in the spring of 1949. Red

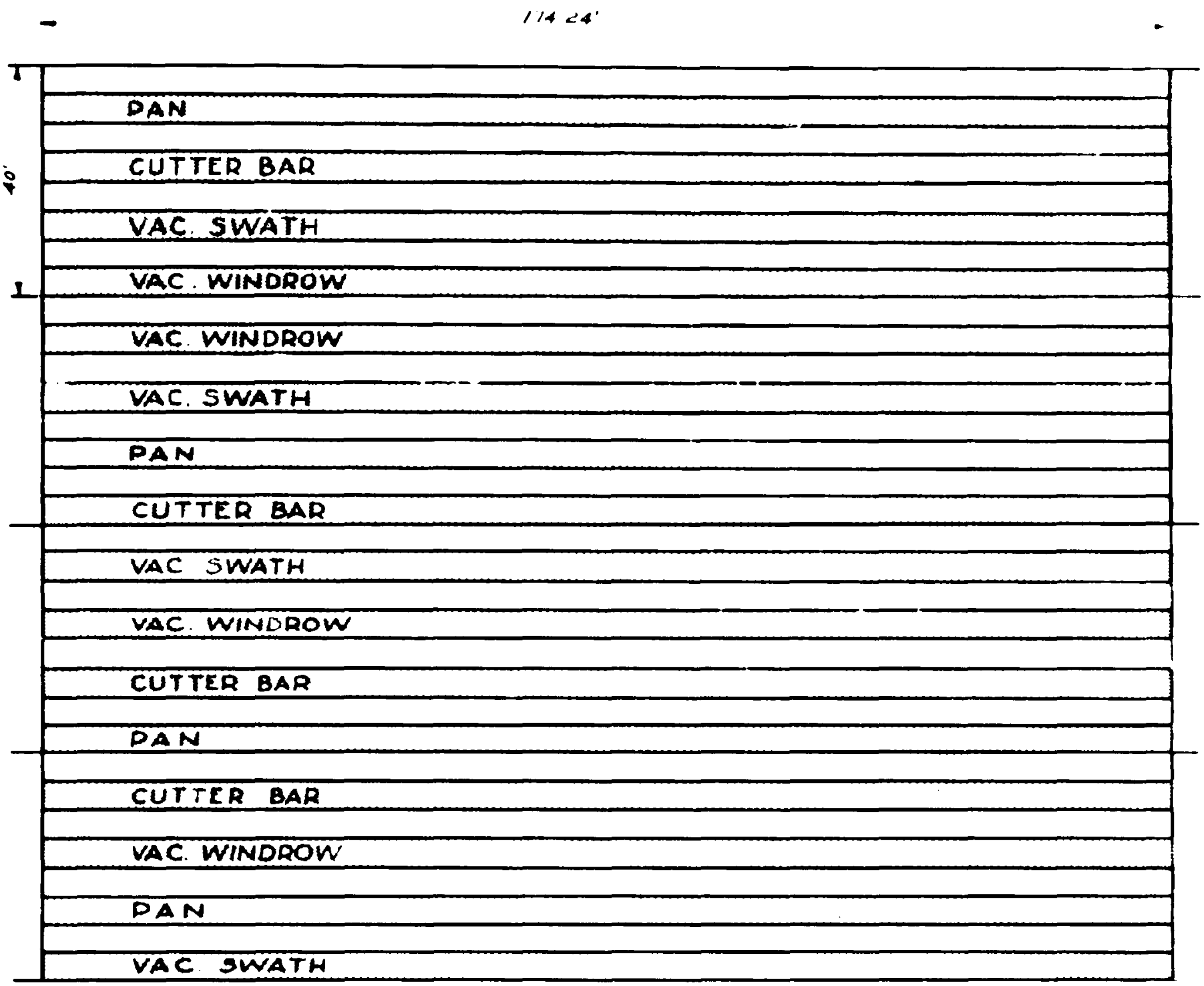


Figure 34. LAYOUT OF FIELD NO 2

COLLEGE EXPERIMENTAL FARM

E LANSING

clover and alsike clover had grown with the Ladino. It was clipped on June 13, 1950, and put up for grass silage. The field had a very heavy growth—6 to 10 inches tall—but was not regularly leveled.

The general purpose of the experiments conducted in field No. 3 was:

To compare the harvesting efficiency of the following four methods:

(1) The pan method of harvesting.

(2) The windrow method of vacuum harvesting.

(3) The windrow method of combine harvesting.

(4) The swath method of combine harvesting.

The layout of field No. 3 in Middleville (Figure 35) had a different pattern from the one used on the college farm. Between every two adjacent experimental plots there was a strip of land 10 feet wide, which allowed sufficient room for the equipment to work in without damaging the clover in the experimental plots. The width of every two adjacent experimental plots, instead of being only 10 feet wide, was made 15 feet wide to insure a mower cut width of 5 feet for every plot in case the tractor deviated from its path.

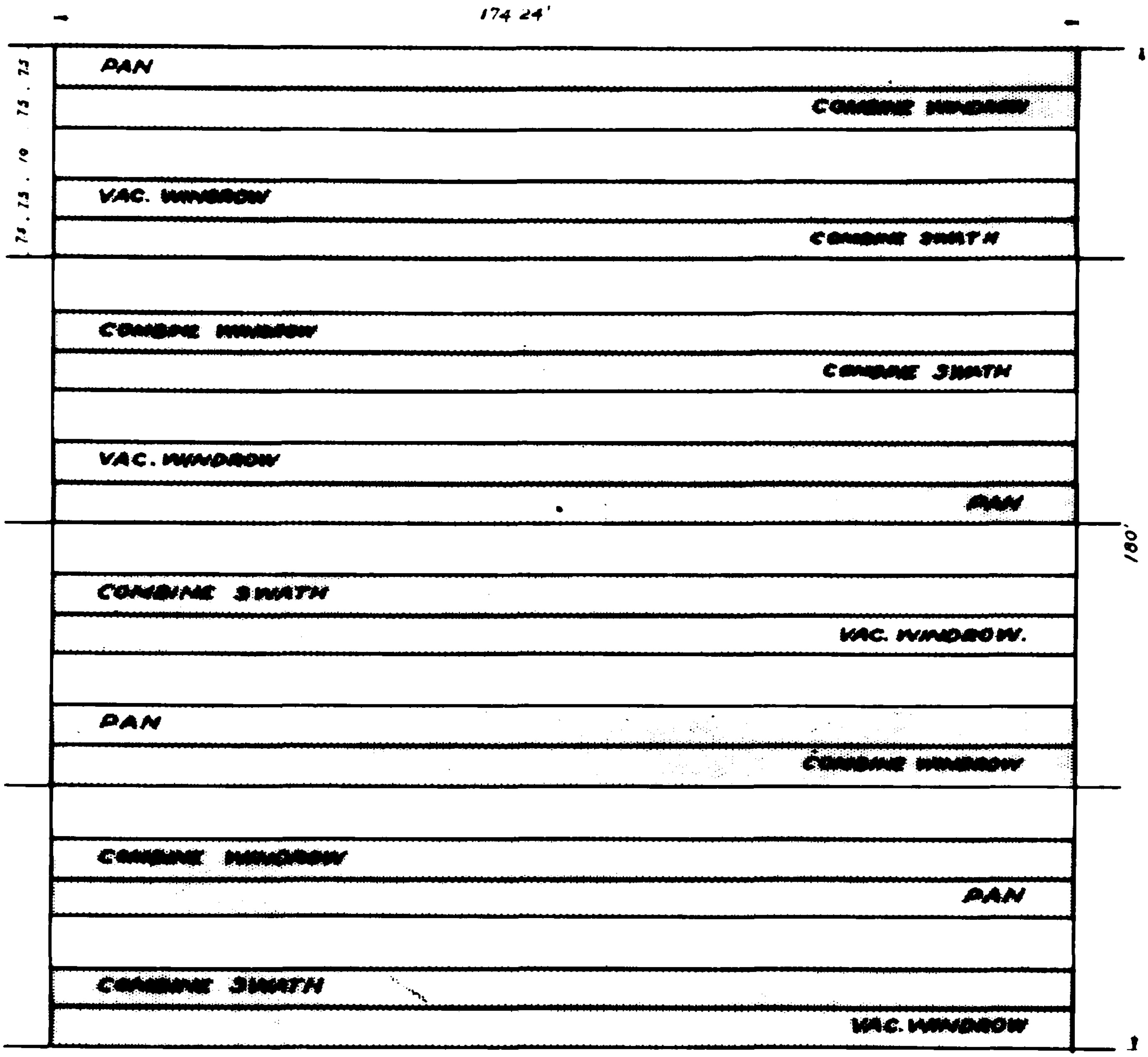


Figure 35. LAYOUT OF FIELD NO. 3
MIDDLEVILLE, MICHIGAN

After the four harvesting methods had been tried, a 2' x 2' frame was thrown five times at random in every experimental plot and the clover inside was gathered, dried, and threshed five times. This represented the amount of seed left by each harvesting method. The picking efficiency was determined by the amount of seed recovered from the first threshing, the efficiency of the threshing machine, and the amount left in the field.

Field No. 4

This field (eight acres area) was also located near Middleville. The Ladino clover was seeded in the spring of 1949 and clipped on June 13, 1950.

The experiments on Field No. 4 were conducted to test the performance of the Brillion vacuum harvester after the clover had been picked by a hay loader.

The clover was mowed and left to dry in the windrow. It was collected afterward by a hay loader and the clover was threshed by a stationary combine. The field was then swept by the Brillion vacuum harvester.

Observations on Different Phases of Harvesting Procedure

Mowing

When cut for seed, the vegetation was from four to ten inches tall with many of the seed heads bent over almost to the ground.

In the preliminary survey of field No. 1, it was found that the total yield was:

25.58% of white or immature heads.

40.90% of ripe standing heads.

33.52% of ripe heads bent to the ground.

Only ripe heads would produce seed and the above figures indicate that 45 percent of the mature heads were bending over to the ground. This shows that mowing was an important factor affecting the harvesting of the Ladino clover. A vegetation of that nature required a mower that would cut the clover stems as close as possible to the ground. The length of the cutter bar for an irregular field should be rather short to fit the contour of the land.

In field No. 1 a five-foot lespedeza cutter bar was used to cut the clover previous to the actual harvesting. This cutter bar was provided with special narrow guards and with the inner shoe removed, it cut the clover from 1 and 1/2 inches to 2 inches above the ground.

Preliminary cuttings with the lespedeza cutter bar were made around the edge of the experimental field No. 2. Because of the heavier growth of this field compared to the field No. 1 the narrow guards of the cutter bar got clogged up by the excess clover and the cutting was not properly done. The lespedeza cutter bar was then replaced by a five-foot Ford mower with the inner shoe removed. This mower was used in both fields No. 2 and No. 3 and it did a satisfactory job.

In addition, a seven-foot mower was tried on an 8-acre field with the inner shoe removed but due to the irregularity of the field level this long mower bar was inferior in performance to the five-foot bar.

In mowing Ladino clover it was noticed that the mower would generally go over, without cutting, any patch of clover that was recently trampled by a tractor wheel.

<u>Windrowing</u>

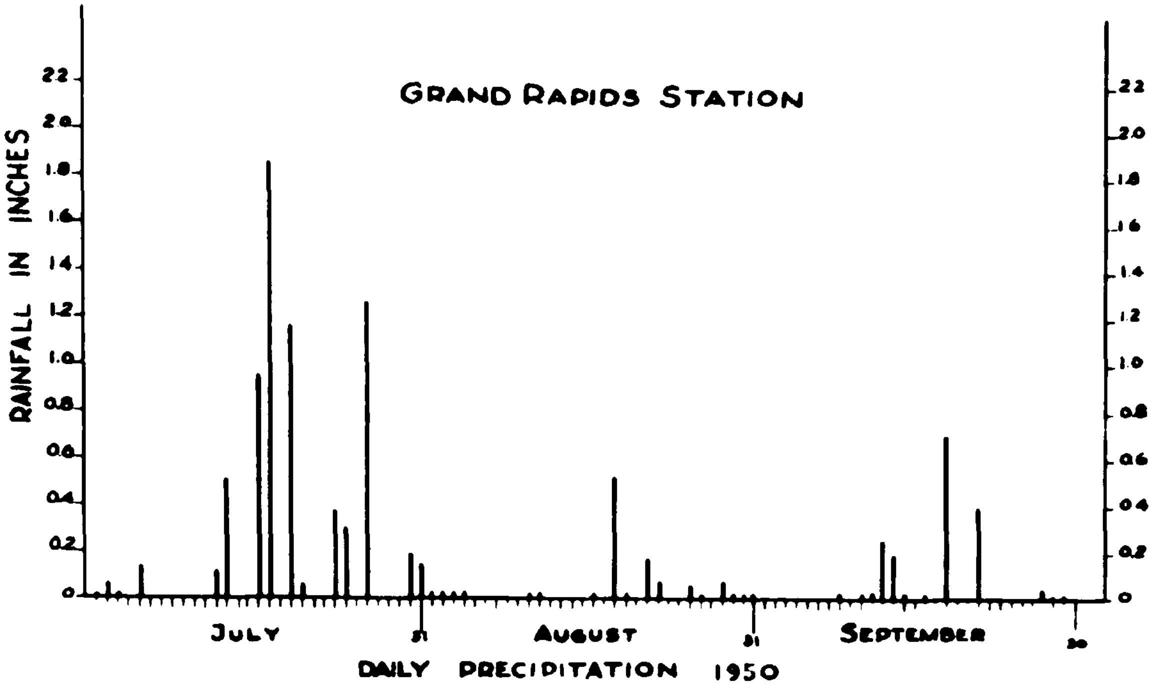
In harvesting Ladino clover, windrowing is done after mowing in order to harvest it either by the vacuum harvester or by the combine with a pick-up attachment.

The ordinary side delivery rake was used in the summer of 1949 in the preliminary trial of the windrow vacuum harvester, and in the summer of 1950 in field No. 4. It was noticed that, due to the short stem of the clover, there was definitely part of the clover dropping from in between the fingers of the windrower.

To minimize the loss of seed in windrowing, a special metal sheet-covered side delivery windrower was fastened to the mower cutter bar. This setup, used in field No. 1, required someone to rake it over as the clover on the covered windrower lacked the drag of the soil.

In field No. 2 a center delivery windrower was used. This consisted of two metal pans with guide walls and fastened to the cutter bar. The clover when cut was directed by the side pans toward the center as the mower moved along.

The 1950 summer season was a very wet one, as shown in the rainfall intensity chart (Figure 36), and it rained every



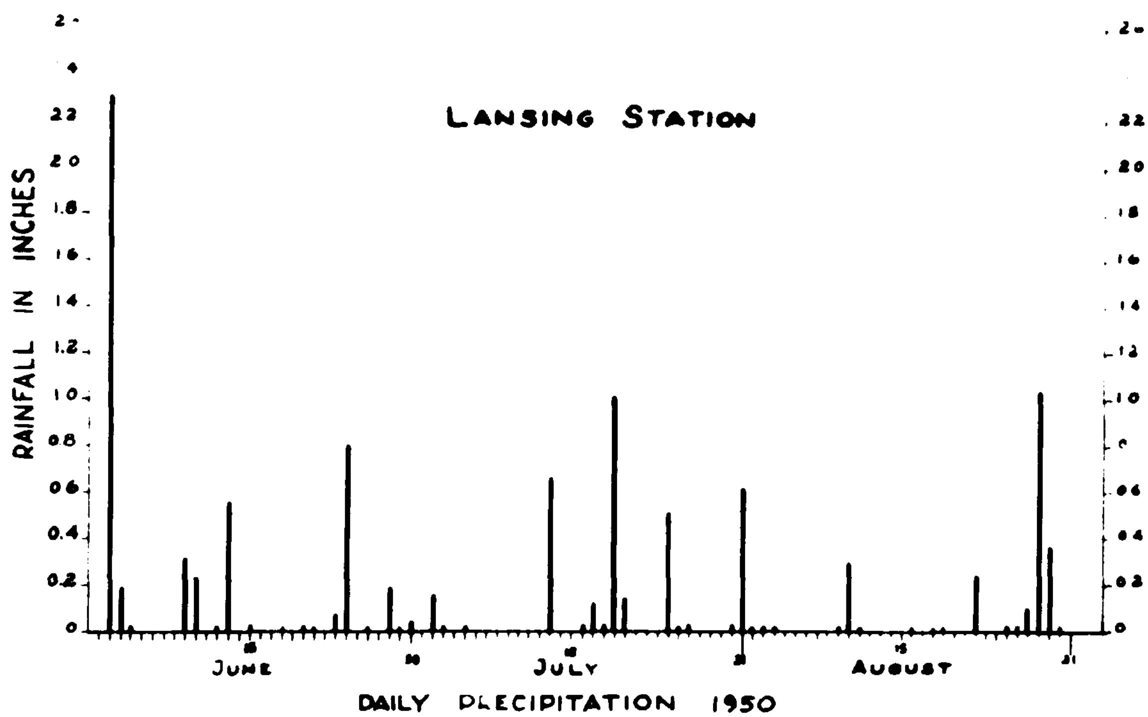


Figure 36. Rainfall intensity chart.

time after the clover was windrowed. The windrows were turned over the next day very early in the morning when the clover was wet to prevent shattering.

Drying

The moisture content of the Ladino clover when cut for seed ranged from 70 to 75 percent.

The clover had to dry in order to be threshed. The method of drying the clover depended to a great extent on the way it was harvested.

For the pan method, the clover was spread over silo paper to dry. The main purpose of the silo paper was to protect the clover from the moisture of the soil, as the Ladino clover has a great affinity to absorb the moisture either from the atmosphere or from the soil.

While the clover was still on silo paper, heavy rain fell and the water was held from infiltrating into the soil and was kept under the clover. The practice of using silo paper on a wet summer was undependable and did more harm than good to the clover.

For the cutter bar method, an artificial drier with mechanical raking was essential. Assuming six tons of green clover with 70 percent moisture content were to be handled per acre, the amount of water to be extracted to reduce the moisture content to 12 percent in order to be easily threshed is calculated as follows:

At 70 percent moisture content,

weight of dry matter =

$6 \times 2000 \times (30/100) = 3600$ pounds,

weight of water =

$6 \times 2000 \times (70/100) = 8400$ pounds.

At 12 percent moisture content, weight of dry matter will be 88% of the total weight.

Weight of water =

$3600 \times (12/88) = 490$ pounds.

Weight of water to be extracted =

$8400 - 490 = 7910$ pounds.

B. T. U. of furnace fuel per gallon = 130,000 B. T. U./gal.

Latent heat of evaporation of water = 966.6 B. T. U./lb.

Gallons of fuel needed per acre, assuming a 30% drier efficiency =

$$[7910(212 - 80) + (7910 \times 966.6)] \div [0.30 \times 130,000]$$

$$= 223 \text{ gallons.}$$

Due to the limited available equipment for artificially drying Ladino clover, the clover, harvested by the cutter bar method in field No. 1, was spread thin on silo paper. The green material, after it was sucked by the blower, became pasty and compact. A sample was dried in the artificial drier. It was noticed that the outer part became crusty while the inside was still pasty. The hot air could not get into the inside of the sample.

In field No. 2 the green clover sucked from the cutter bar was again spread over silo paper to dry, but due to the rain, it molded and heated, therefore, the seed was useless to thresh. Drying green clover that has been mashed by the blower presented a big difficulty, even with the artificial drier and, consequently, it is not to be recommended.

The clover, after being cut, had to be dried in the windrow for the windrow method of combining or vacuum harvesting. In dry weather the windrow would take about two days to dry, but in case of rain, the windrow would pack and need to be turned again to dry.

The Ladino clover, when cut and left in swath, took the least time to dry. In case of rain, not only most of the seed would be buried on the surface of the ground, but also the new growth would decrease the picking efficiency of the harvesting machine. Figure 37 shows how the intermittent rains induced new growth through the clover previously cut and left to dry in the swath. The 1950 summer was so wet that some seeds sprouted in the heads left on the ground as shown in Figure 38.

Field Observations of the Different Harvesting Methods

The pan method. This method was tried on experimental plots in the three fields, 1, 2, and 3. A 5' x 4' pan was fastened behind the mower cutter bar (Figure 39) and the clover was raked and collected on the pan as the mower moved along. The tractor speed could not exceed two miles per hour, as two men had to walk behind the pan and rake the clover. When the pan was full, the tractor stopped and the clover was removed from the pan and put on silo paper. The pan was emptied every 50 to 60 feet and it took an average of two minutes to empty the pan when full, thus taking about six hours to harvest one acre.

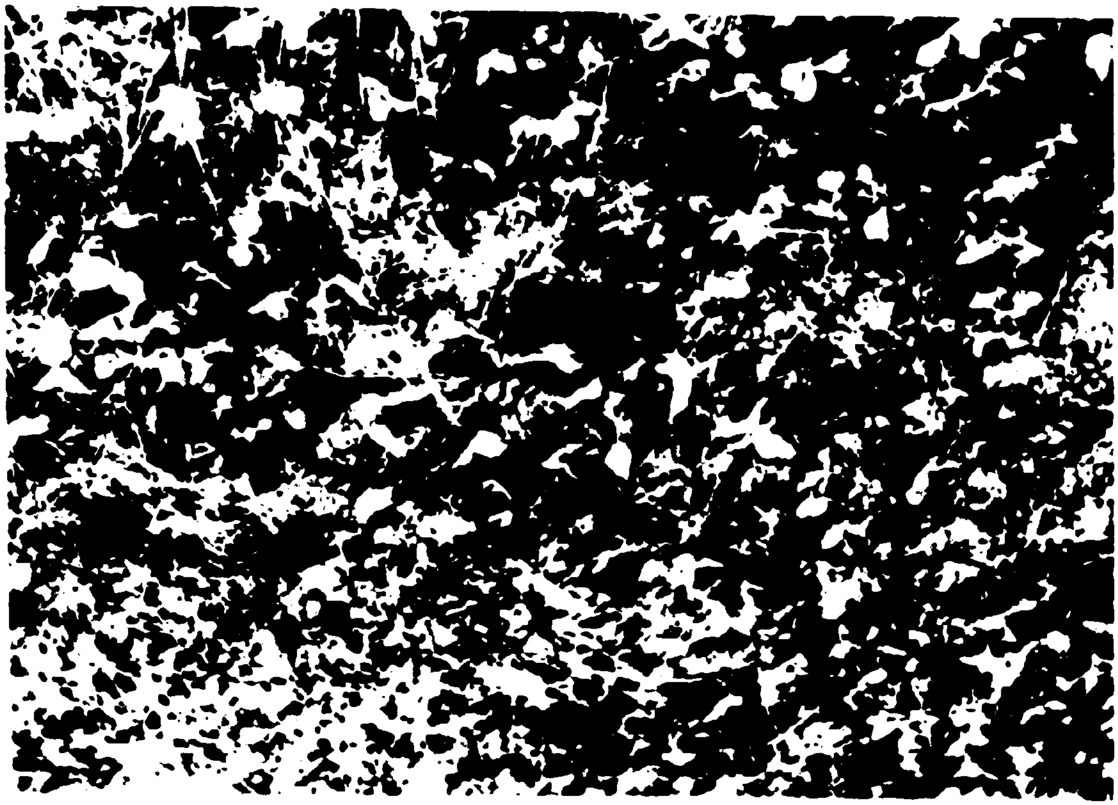


Figure 37. Intermittent rains induced new growth through the clover previously cut and left to dry in the swath.

Figure 38. Some seeds sprouted in the heads left on the wet ground.

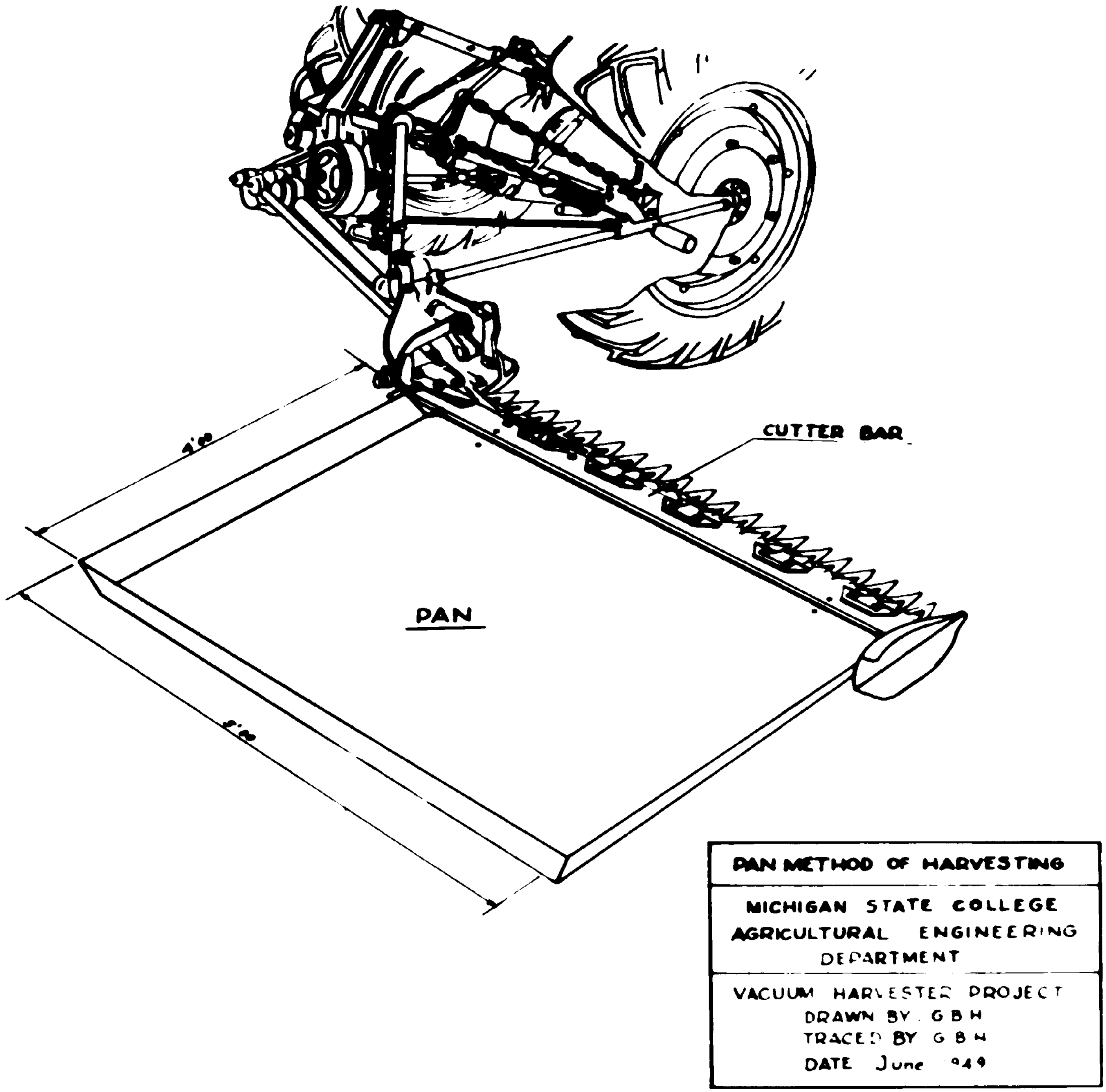


Figure 39. The Pan Method of harvesting clover seed.

Three men were needed for this method—one for driving the tractor and two for raking and emptying the pan.

The clover was then removed from the silo paper and spread over burlap. Two days later, the clover was put in bags and dried in the hay drier.

The windrow method of vacuum harvesting. This method was tried with the developed vacuum harvester in the three different fields. The tractor speed was four miles per hour. The method consisted of sucking the clover after it had been mowed, windrowed, and dried. The clover, after passing through the blower, was collected in a canvas-lined wagon with a burlap top.

It was noticed that the side delivery windrower laid part of the cut clover over the standing clover in the neighboring strip. The clover intertwined with the standing windrowed clover, and thus decreased the picking ability of the vacuum harvester. It was decided, therefore, to replace the side delivery windrower by the center delivery one in the field trial No. 2.

The wagon was emptied at the end of each experimental plot and because the clover was not dry enough to thresh, the clover was spread on silo paper. While the clover was still on silo paper to dry, rain fell on July 30, 31, August 1, 2, and 3.

The cutter bar method. This method consists of sucking the green clover immediately after it is cut by the mower up through the blower into a canvas-lined wagon with a burlap top. It was tried in field No. 1 on July 27, 1950. The speed of the tractor was three miles per hour. Figure 40 shows the cutter bar method of harvesting while Figure 41 shows the nozzle sucking the green clover from the collecting pan. At the end of the plot the wagon was emptied and the clover was spread over silo paper to dry. Two men were required, one for driving the tractor, and the other for emptying the full wagon.

Due to the bulk of green clover sucked, the blower pipe at the inlet side became jammed once during the trial of the two plots of field No. 1. The green clover, when passed through the blower, became pasty and compact, and, therefore, was spread thin over the silo paper to dry.

While the clover was still on silo paper to dry, rain fell for five consecutive days from July 30 to August 3. On

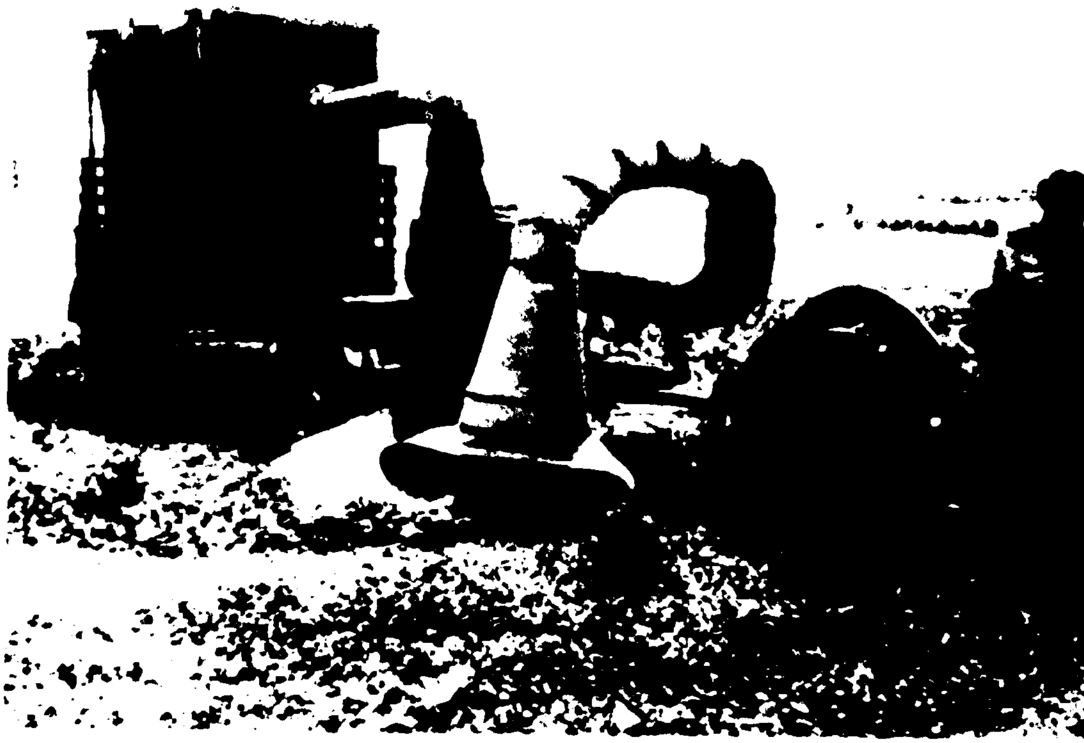


Figure 40. The cutter bar method of harvesting clover seed.

Figure 41. Green clover sucked by the nozzle from the collecting pan.

August 6 the clover was put in bags and dried in a mechanical drier.

It was noticed that the clover harvested by the cutter bar method took the longest time to dry even with frequent raking, as the material was too compact for the air to flow through it.

In field No. 2, this method was tried again on August 15 on four plots at random but, due to the excessive rain, the condition of the harvested clover by the cutter bar method was hopeless. Even in the artificial drier the outer part of the clover was dry and crusty while the inside was molded and pasty because of lack of air infiltration. It was thrown away and that method was rejected.

The swath method of vacuum harvesting (the Brillion Harvester performance). The Brillion harvester (shown in Figures 42 and 43) was designed to pick the seeds left in the field after the clover has been harvested by the combine. Due to the light stand of the clover in the college fields, No. 1 and 2, and because a combine was not available at the harvesting time, the Brillion machine was used to pick the clover directly from the swath after it had been cut and left to dry.

Figure 42. The Brillion vacuum harvester.

Figure 43. The Brillion vacuum harvester during operation

Figure 44. The vacuum harvester brush throwing back the picked clover.

In field No. 1, in spite of the light clover stand, the nozzle entry, although adjusted to maximum opening, became clogged about every 50 feet of travel. The brush would pick the clover from the ground and throw it back to the field as shown in Figure 44.

In field No. 2, after the clover was mowed, the intermittent rains induced new growth through the clover previously cut and left to dry in the swath. The Brillion machine was not effective in such conditions and its use was eliminated from field No. 2.

The Brillion harvester was further tried in Middleville on an 8-acre field seeded in the spring of 1949 and clipped in June, 1950. The field was not regularly leveled. The clover was mowed and put in windrows to dry. A raker-bar loader, Figure 45, with its reciprocating bars of flexible teeth raked the clover up the sloping deck and dropped it on the rack. A McCormick-Deering combine Model 52R with a mounted engine was used as a stationary thresher for all hay picked up by the raker-bar loader, Figure 46.

The Brillion was then used to sweep the field after all the hay had been picked. Again, due to the rain that fell after

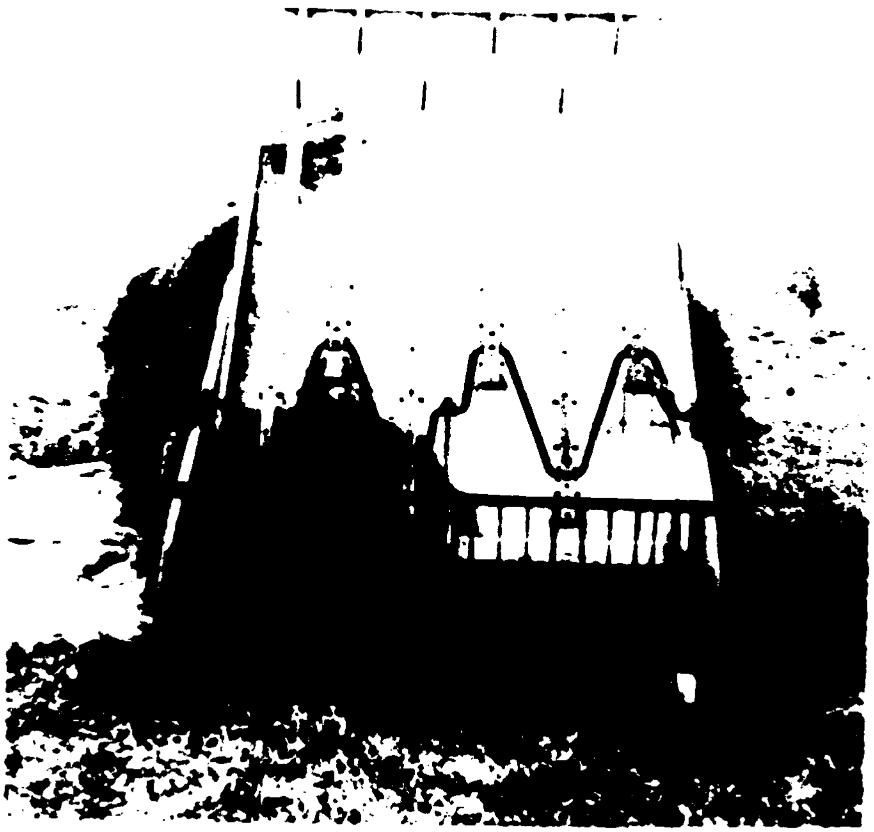


Figure 45. The raker-bar loader used in field No. 4.

Figure 46. The clover threshed by the McCormick-Deering combine.

the hay had been picked, the seed left was difficult to pick from the soil that was muddy and then dried. In addition, the new growth of clover contributed more to the inferior performance of the Brillion harvester. The brush always had to be watched; throwing back the picked clover was an indication of a clogged nozzle.

Windrow method of combine harvesting. This method was used in field No. 3 on four experimental plots 1/50 acre each. A power take-off driven Allis Chalmers combine (Figure 47) with a special pick-up attachment was used in the field to pick up windrows (Figure 45). The harvested seed was collected in a bag and the blown chaff on a canvas sheet while the combine was moving along. This was done to find the threshing efficiency of the combine when harvesting from the windrow. The speed of the combine was 3 m.p.m.

Swath method of combine harvesting. Again this method was used in field No. 3 on four experimental plots, 1/50 acre each. The same combine with the same speed was used to pick the Ladino clover that was mowed and left to dry in swath (Figure 48). The chaff from the combine was collected and threshed to find the threshing efficiency of the combine (Figure 49).

Figure 47. Combining from the windrow.

Figure 48. Combining from the swath.

Figure 49. Collecting tailings from the combine
to determine its threshing efficiency.

Threshing

Threshing of the harvested clover was either done by the clover threshing machine located in the college laboratory or by the combine in the field.

To find the threshing efficiency of the clover threshing machine, 16 samples of clover were threshed and cleaned 6 times and the average percent of seed recovered in each successive threshing was recorded in Table II.

The threshing efficiency of the combine was found by collecting simultaneously the clean seed and the tailings while the combine was harvesting. Three trials were made: when harvesting from the swath; when harvesting from the windrow; and when harvesting from a windrow that was turned over in order to dry. The results are shown in Table III.

TABLE II

PERCENTAGE OF LADINO SEED RECOVERED FROM SUCCESSIVE THRESHING AND CLEANING
(using the clover huller and the clipper seed cleaner)

Threshing No.	Percentage of Ladino Seed Recovered
1	50.30
2	31.74
3	9.61
4	4.43
5	2.82
6	1.10
Total	100.00

TABLE III

PERCENT OF SEED THRESHED BY THE ALLIS-CHALMERS COMBINE USED IN FIELD NO. 3

No. of Threshing	Lb. of Seed Recovered	% of Seed Recovered
	Combining from a Windrow Replicate 4 Field No. 3	
Combine threshing	1.170	59.51
2nd threshing	0.755	38.40
3rd threshing	0.041	2.09
Total	1.966	100.00
	Combining from a Turned Windrow Outside of Experimental Field	
1st threshing	0.665	69.63
2nd threshing	0.275	28.80
3rd threshing	0.015	1.57
Total	0.955	100.00
	Combining from Swath Replicate 1 Field No. 3	
1st threshing	0.965	71.21
2nd threshing	0.370	27.31
3rd threshing	0.020	1.48
Total	1.355	100.00

EFFICIENCY OF DIFFERENT HARVESTING PROCEDURES

Analysis of Data

<u>Field No. 1</u>

From Table I the estimated average yield per acre was 155.25 pounds of Ladino seed. Based on that yield, the efficiencies of the four different methods were calculated as shown in Table IV.

It was previously estimated that 45 percent of the mature heads were bending to the ground. The pan method efficiency, found to be 65.5 percent, indicated that in addition to the standing heads some of the bending heads were also collected by the pan.

The efficiency of the vacuum harvesting method in that field was only 56.0 percent. This was due mainly to the fact that the clover was put in the windrow by a side delivery windrower which deposited the mowed clover over onto the green uncut clover of the neighboring strip. The rain packed the windrow of the cut clover over the standing green clover,

TABLE IV

A COMPARISON BETWEEN SEED ACTUALLY PRODUCED AND THAT HARVESTED BY VARIOUS HARVESTING METHODS FROM FIELD NO. 1
(area of plot = 1/50 acre)

Method of Harvest	Pounds of Seed Harvested per Plot		Average Pounds Seed Harvested per Plot	Pounds Seed Harvested per Acre	Efficiency Based on 155.25 Pounds Yield per Acre
	Replicate 1	Replicate 2			
Pan	2.140	1.930	2.035	101.75	65.4%
Cutter Bar	1.500	1.830	1.665	83.25	53.6%
Vacuum Windrow	1.905	1.575	1.740	87.0	56.0%
Brillion Swath	1.300	1.266	1.283	64.75	41.3%

resulting in an intertwining of the two. This made the vacuum harvesting less efficient than it normally would be.

The cutter bar method proved to be very impractical for harvesting the clover. After the clover had passed through the blower, it was very difficult to dry, even in an artificial drier.

The efficiency of the Brillion harvester in this field was definitely low due to the fact that it was used on a plot not previously harvested by the combine.

The statistical analysis of the data in Table IV shows that there were no significant differences in the amounts of seed harvested by the four different methods.

Field No. 2

The amount of seed harvested added to the amount of seed left in the field does not give the actual yield of the field unless the clover has been threshed 100 percent.

Knowing the percent of seed recovered from the first threshing,

The amount of seed picked

= [amount of seed recovered from first threshing]

÷ [percent seed recovered from first threshing]

Actual yield

= [amount of seed picked]

+ [amount of seed left in the field]

Picking efficiency

= [amount of seed picked] ÷ [actual yield]

Over-all efficiency

= [amount of seed recovered from first threshing]

÷ [actual yield]

Tables V and VI show that there is no significant difference between the yield estimated from the pan method and that estimated from the vacuum harvesting method.

The difference between the efficiencies of the two methods of harvesting was significant in favor of the vacuum harvesting from windrow. The difference was more pronounced in the over-all efficiencies because of the greater recovery of seed from the first threshing in the vacuum harvesting method due to the additional threshing effect of the blower.

Field No. 3

In this field four harvesting methods were tried and compared with each other. Table XI and Figure 50 show the summary of the results obtained.

The windrow method of vacuum harvesting had the highest picking efficiency and the highest over-all efficiency. Combining from the swath had the lowest picking efficiency while the pan method had the lowest over-all efficiency. Combining

TABLE V

PAN METHOD - FIELD NO. 2
(% of seed recovered from first threshing = 50.3%)

	Pounds of Seed per 1/50 Acre Replicate 1	2	3	4	Average
Amount of seed recovered from first threshing	1.150	0.890	1.080	1.120	1.060
Amount of seed picked	2.290	1.790	2.150	2.230	2.110
Amount of seed left	1.023	0.785	0.800	1.040	0.912
Actual yield	3.313	2.575	2.950	3.270	3.022
Picking efficiency	69.20%	69.60%	72.90%	68.20%	69.97%
Over-all efficiency	34.80%	34.60%	36.60%	34.30%	35.07%

TABLE VI

WINDROW VACUUM METHOD - FIELD NO. 2
(% of seed recovered from first threshing = 70.0%)

	Pounds of Seed per 1/50 Acre Replicate 1	2	3	4	Average
Amount of seed recovered from first threshing	1.500	1.630	1.367	1.350	1.462
Amount of seed picked	2.145	2.330	1.950	1.930	2.090
Amount of seed left	0.892	0.790	0.736	0.882	0.825
Actual yield	3.037	3.120	2.680	2.812	2.915
Picking efficiency	70.80%	74.80%	72.50%	68.80%	71.72%
Over-all efficiency	49.40%	52.30%	50.80%	48.10%	50.15%

TABLE VII

PAN METHOD - FIELD NO. 3
(% of seed recovered from first threshing = 50.3%)

	Pounds of Seed per 1/50 Acre Replicate 1	2	3	4	Average
Amount of seed recovered from first threshing	1.575	1.175	1.337	1.200	1.322
Amount of seed picked	3.130	2.340	2.665	2.390	2.632
Amount of seed left	1.355	1.260	1.030	1.090	1.186
Actual yield	4.485	3.600	3.695	3.480	3.818
Picking efficiency	69.80%	65.00%	72.20%	68.60%	68.90%
Over-all efficiency	35.20%	32.60%	36.10%	34.50%	34.60%

TABLE VIII

VACUUM WINDROW METHOD - FIELD NO. 3
(% of seed recovered from first threshing = 74.6%)

	Pounds of Seed per 1/50 Acre Replicate 1	2	3	4	Average
Amount of seed recovered from first threshing	2.490	1.970	2.360	2.130	2.2375
Amount of seed picked	3.340	2.640	3.165	2.860	3.000
Amount of seed left	1.035	0.766	0.840	1.000	0.910
Actual yield	4.375	3.406	4.005	3.86	3.910
Picking efficiency	76.50%	77.70%	79.20%	74.20%	76.90%
Over-all efficiency	57.00%	58.00%	59.00%	55.20%	57.30%

TABLE IX

COMBINE WINDROW METHOD - FIELD NO. 3
(% of seed recovered from first threshing = 59.51%)

	Pounds of Seed per 1/50 Acre				Aver-age
	Replicate				
	1	2	3	4	
Amount of seed recovered from first threshing	1.770	2.340	0.670	1.170	1.487
Amount of seed picked	2.975	3.930	1.125	1.965	2.497
Amount of seed left	1.930	1.015	2.040	0.532	1.380
Actual yield	4.905	4.945	3.165	2.497	3.877
Picking efficiency	60.70%	79.50%	35.60%	79.00%	63.70%
Over-all efficiency	36.20%	47.30%	21.15%	46.80%	37.61%

TABLE X

COMBINE SWATH METHOD - FIELD NO. 3
(% of seed recovered from first threshing = 71.21%)

	Pounds of Seed per 1/50 Acre				Aver-age
	Replicate				
	1	2	3	4	
Amount of seed recovered from first threshing	0.965	2.50	1.350	1.385	1.550
Amount of seed picked	1.355	3.515	1.900	1.945	2.180
Amount of seed left	1.425	2.120	1.470	1.940	1.738
Actual yield	2.780	5.035	3.370	3.885	3.918
Picking efficiency	48.75%	62.4%	56.4%	50,0%	54.39%
Over-all efficiency	34.75%	44.50%	40.20%	35.70%	38.80%

TABLE XI

SUMMARY OF DATA - FIELD NO. 3

Method of Harvesting	Percent Seed Recovered From Threshing	Picking Efficiency %	Over-all Efficiency %
Pan	50.3	68.90	34.60
Vacuum harvesting from windrow	74.60	76.90	57.30
Combine from windrow	59.51	63.70	37.61
Combine from swath	71.20	54.39	38.80

from the windrow had a greater picking efficiency than combining from the swath. However, due to the fact that the clover in the swath dries quicker than when laid in windrow, the threshing efficiency of combining from the windrow was inferior to that from the swath.

It was noticed that the picking efficiency in the combine methods had a greater variation from the mean than the other two methods, and that is due to the fact that the picking efficiency of the combine depends on the amount of the vegetation

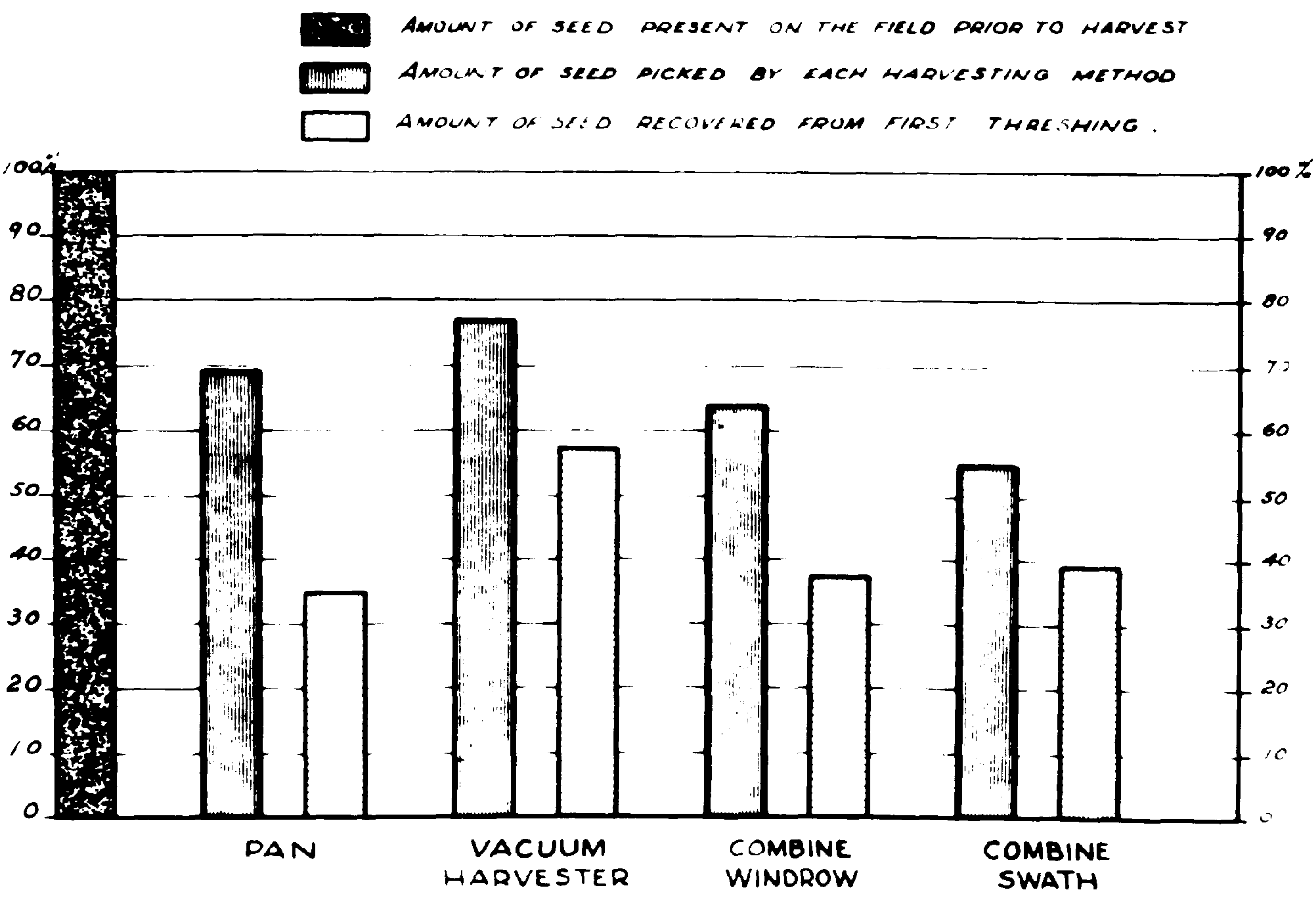


Figure 50. Comparative analysis of the picking and over-all efficiencies of the four harvesting methods on field No. 3.

growth; the heavier the growth, the better the picking ability of the combine.

The difference in efficiencies between the vacuum method and any other method was statistically significant.

An attempt was made to estimate the total income in dollars versus the number of acres harvested by the four different methods. This was based on a yield of 200 pounds of seed per acre; the over-all efficiency of each method being shown in Table XI. The retail price of the Ladino seed was assumed to be $1.75 per pound. Figure 51 shows the graphical representation of the relative merit of each harvesting method. It shows the definite economical advantage of using the vacuum harvesting method when the acreage exceeds 15 acres.

<u>Field No. 4</u>

The experiment on field No. 4 were conducted in order to test the performance of the Brillion vacuum harvester after the clover had been picked by the hay loader.

Area covered = 8 acres

Amount of clean seed recovered from the hay loader and threshed by the combine = 389 pounds

Pounds of seed per acre = 48.62

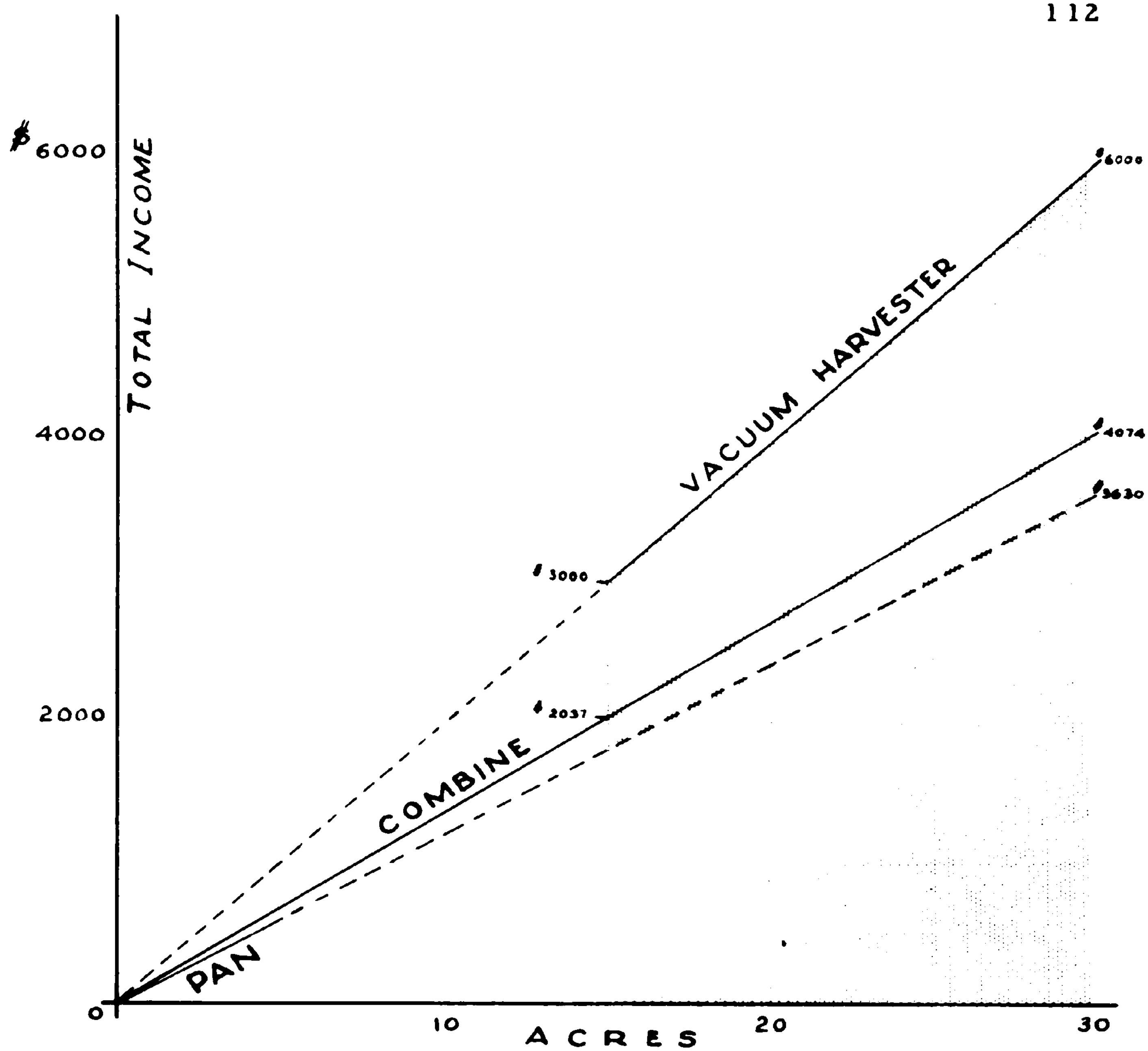


Figure 51. Estimated total income versus number of acres using different harvesting methods.

Performance of the Brillion Harvester

Weight of clover collected by Brillion harvester

= 3093 pounds

Weight of unclean clover seed picked by the Brillion

and threshed in the combine = 1050 pounds

This seed was further cleaned in the Clipper seed cleaner with the following results:

Weight of seed =	575 pounds
Weight of dirt collected =	378 pounds
Weight of scalping =	65 pounds
Weight of dirt blown =	32 pounds
Total =	1050 pounds

The seeds were still far from clean and were mixed with stones and sand of the same size as that of the Ladino seed.

After a further cleaning in a commercial seed cleaner:

Weight of uncleaned seed = 575 pounds

Weight of dirt = 383 pounds

Weight of dirt blown = 68 pounds

Weight of clean seed = 124 pounds

Pounds of clean seed per acre = 124/8 = 15.5 pounds

TABLE XII

PERFORMANCE OF HAY LOADER AND THE BULLION VACUUM HARVESTER
Field 4

	Pounds of Clean Seed per Acre	Percent
Estimated yield	156.54	100.00
Amount of seed recovered by hay loader	48.62	31.10
Amount of seed recovered by Brillion harvester	15.50	9.92
Total recovery	64.12	41.02

THE DESIGN OF A SWATH VACUUM HARVESTER

The 1950 summer experiments established the following facts:

(1) Harvesting Ladino clover from the swath gave a higher threshing efficiency than windrow harvesting.

(2) Windrowing was a difficult operation when the vegetative growth was less than 6 inches tall.

(3) Loose seed heads between the windrows were missed by the vacuum windrow harvester.

For these reasons a swath vacuum harvester will be more desirable than the windrow vacuum harvester, especially when harvesting a large acreage. An attempt was made to design a swath vacuum harvester, shown in Figure 52, that included most of the desirable features.

General Description of the Designed Vacuum Harvester

The Frame

The harvester is of the trailer-type unit to be driven behind a tractor while the clover collecting wagon will be hitched

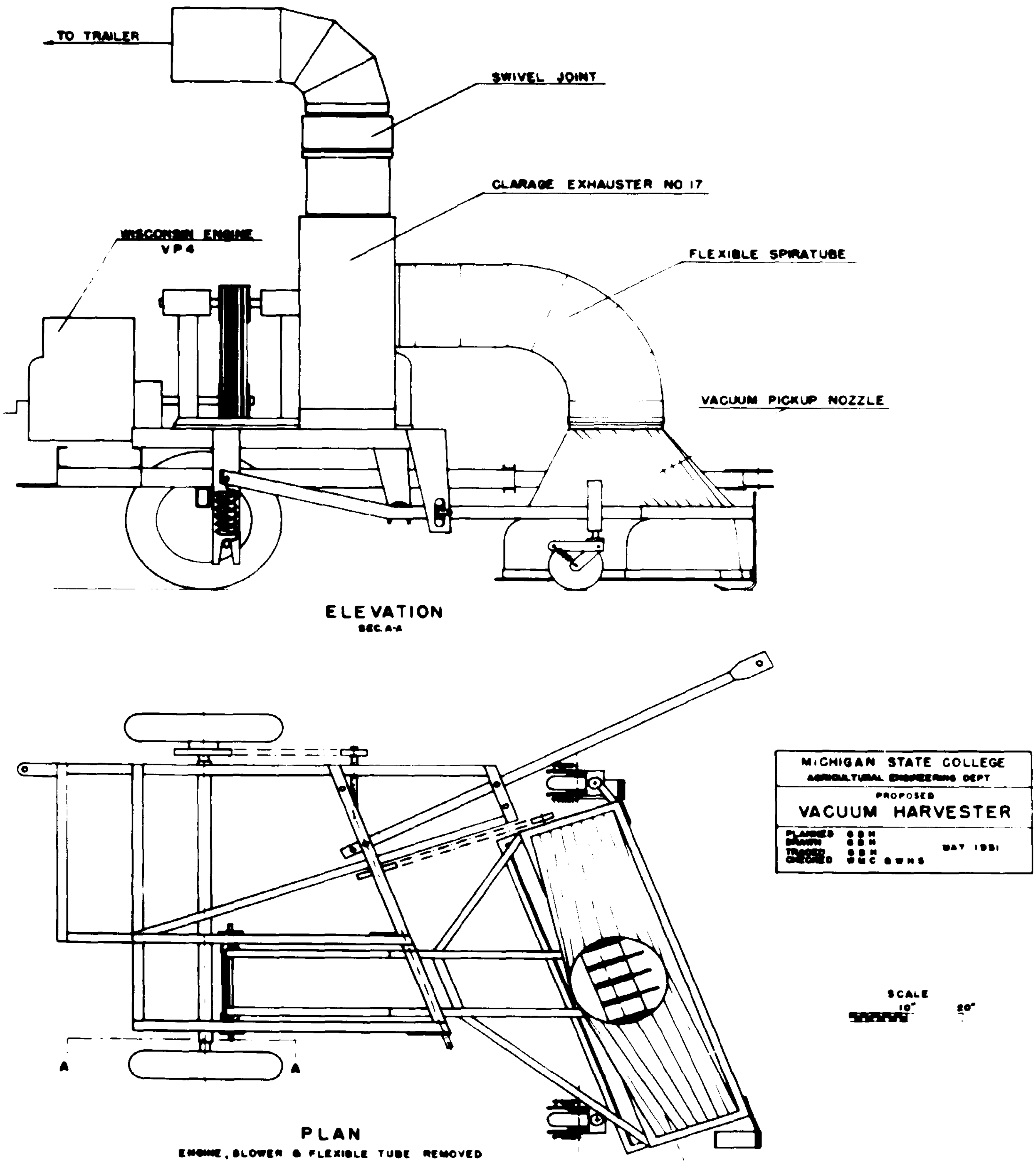


Figure 52. Proposed vacuum harvester - assembly drawing.

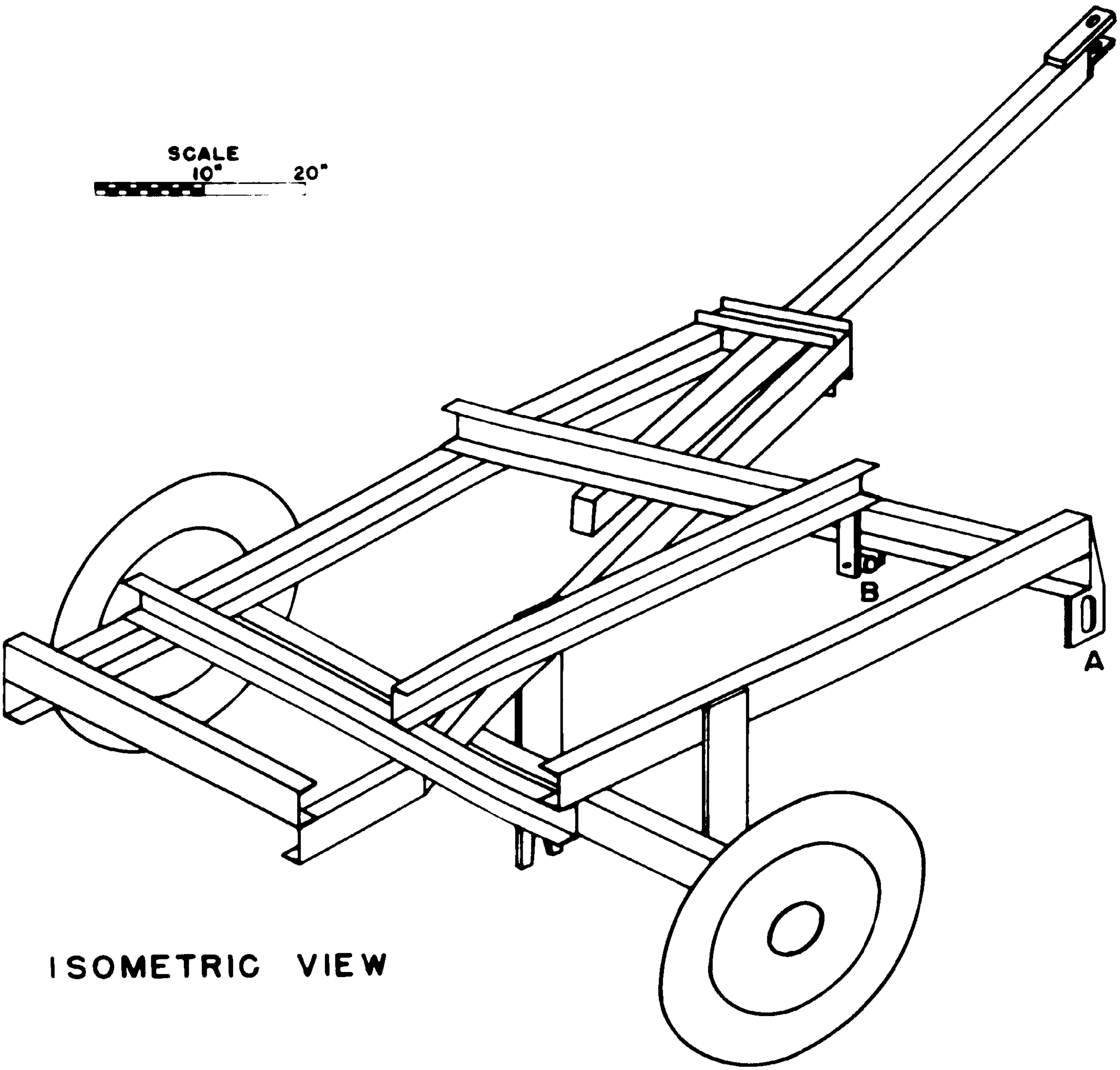
to its rear. The frame, shown in Figure 53, was designed to provide installation for a No. 17 Clarage exhauster, a VP 4-cylinder Wisconsin air cooled engine, the power transmission and the fuel tank.

The Nozzle

The nozzle, shown in Figure 54, is designed to be a separate unit. Therefore, when the nozzle is detached, the harvesting machine can easily be converted into a grain vacuum unloader.

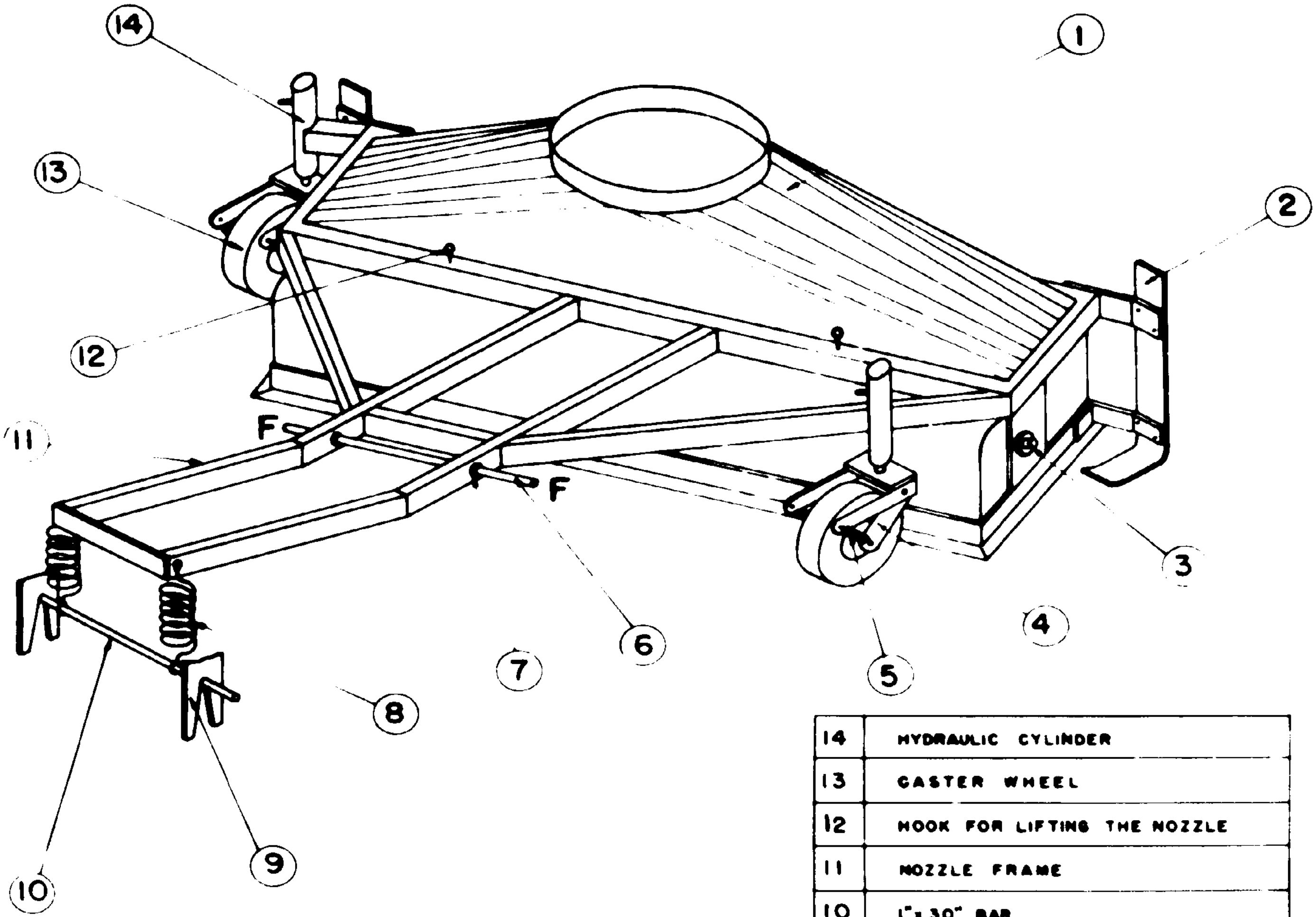
The nozzle is to be connected to the frame by means of a shaft that can be inserted into a slot A and a bearing B in the harvester frame as shown in Figure 53. The nozzle will swing around its fulcrum F-F (Figure 54) with a certain vertical allowance due to the slot A in the harvester frame. This arrangement will allow the nozzle pick-up to fit the irregularity of the ground.

Two heavy springs connecting the end of the nozzle frame with the harvester frame will partly balance the nozzle and make it respond readily to the contour of the field.



MICHIGAN STATE COLLEGE AGRICULTURAL ENGINEERING DEPT.
VACUUM HARVESTER FRAME
PLANNED G.B.H DRAWN G.B.H MAY 1951 TRACED G.B.H CHECKED W.M.C & W.H.S

Figure 53. Vacuum harvester frame.



ISOMETRIC VIEW

SCALE
10" 20"

PART NO.	DESCRIPTION
14	HYDRAULIC CYLINDER
13	CASTER WHEEL
12	HOOK FOR LIFTING THE NOZZLE
11	NOZZLE FRAME
10	1" x 30" BAR
9	HARVESTER FRAME
8	BALANCING SPRING
7	BEARING
6	1" x 30" SHAFT
5	SHOCK ABSORBER SPRING
4	CASTER WHEEL FRAME
3	PICKUP SHAFT
2	RUNNER
1	SUCTION NOZZLE

MICHIGAN STATE COLLEGE
AGRICULTURAL ENGINEERING DEPT.

VACUUM PICK UP ASSEMBLY

PLANNED G.B.H
DRAWN G.B.H MAY 1951
TRACED G.B.H
CHECKED W.M.C & W.H.S

Figure 54. Vacuum pick-up assembly.

Caster wheels will give maneuvering flexibility to the nozzle while the hydraulic cylinders located along the axes of the caster wheels will absorb the shocks.

The nozzle can be raised by means of a chain attached to the hooks (Figure 54, part 12) when the harvester is traveling on the highway.

The nozzle will be connected to the blower by means of a 17-inch diameter flexible spiratube manufactured by the Flexible Tubing Corporation (18).

The Pick-up

The pick-up nozzle assembly, designed to pick a 5-foot swath, is at a 20° angle to the axle of the harvester wheels. This will enable the pick-up fingers to cover more ground area than if the pick-up nozzle assembly were located parallel to the axle. The pick-up, shown in Figure 55, is the same as the one manufactured by the Innes Company (22), with the following modifications:

(1) Most of the pick-up fingers are made of 5/8" width flat springs designed to give a better disturbing action to the clover on the stubble.

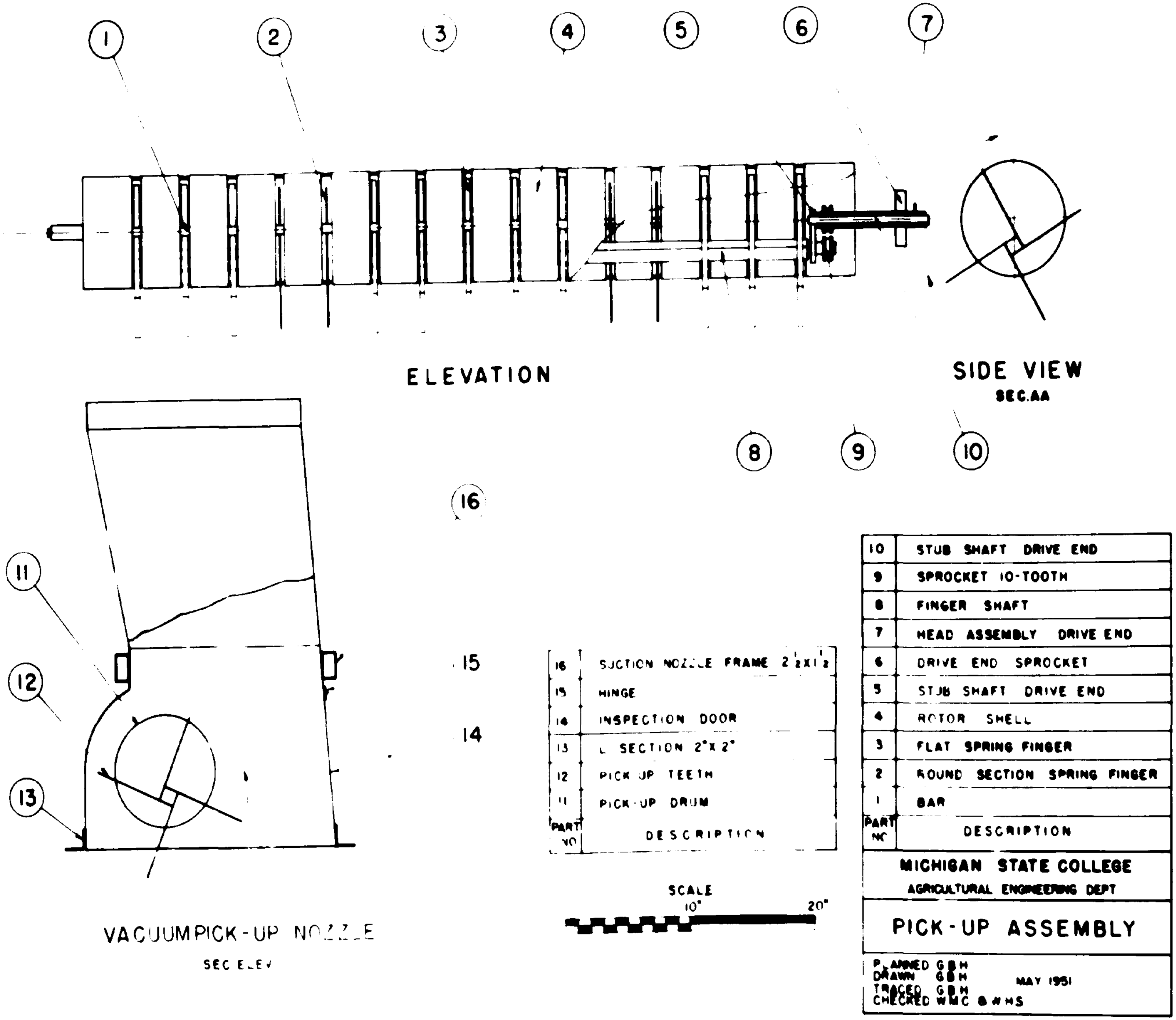


Figure 55. Pick-up assembly.

(2) Some round stiff fingers, one inch shorter than the flat springs, are included in order to lift the heavy material.

Therefore the round stiff springs will pick up the heavy material and the longer and more flexible flat springs will finish sweeping the field.

Steel fingers are spaced in staggered rows on rotor or pick-up drum, and revolve with it. The pick-up has a piston action that lifts all the material and then retracts. On the up-stroke they emerge again. All fingers are put to work with every turn of the cylinder, extending and retracting with a scooping and lifting motion from underneath, like a pitchfork. No wrapping or clogging will occur because fingers automatically strip themselves of entwined weeds and clover.

The Power Transmission

The engineering department of the Innes Company figured that the pick-up rotor should revolve approximately 30 to 35 r.p.m. for each one mile per hour forward travel of the field machine. This may be varied considerably depending on field conditions, but for gentle handling it should be as slow as possible without causing the windrow to "arc" up.

If the speed is faster than necessary, the windrow is pulled apart. As the forward travel of the vacuum harvester is intended to be from 2-1/2 to 3 miles per hour, the rotor speed will vary from 75 to 100 r.p.m.

The power required to drive the pick-up is small, and of course depends on the material being handled. It is figured that five horsepower would be the maximum and usually one to three would be sufficient.

DISCUSSION AND CONCLUSIONS

The actual harvesting of Ladino clover seed may be accomplished by any of several methods, or by a combination of methods. The arguments for and against each method of harvesting procedure are:

1. <u>Vacuum harvesting from swath when dry enough to thresh</u>

   Mowing is done when the clover is tough—7:00 p.m. to dark—and from daylight to 10:00 a.m.

   A. Argument for:

      (1) The clover can be threshed from the wagon or stored until convenient to thresh.

      (2) The weight of vegetative material to be hauled is greatly reduced by field drying.

      (3) The hay, after threshing, is dry enough to keep in a stack or mow.

      (4) The harvester should be able to travel at a higher speed than safe for mowing, and possibly cover two acres per hour.

   B. Argument against:

      (1) Mowing is very difficult when grass is tough.

      (2) If rained on in swath, the material, especially if short, is driven down into the stubble and new growth comes up through the swath.

(3) A mechanical pick-up was declared necessary by McKibben, Dexter and Sheldon after many trials with several sizes and shapes of pick-up nozzles.

(4) Dirt, stones, and dead material from previous growth add to the weight and bulk of material gathered and make the seed cleaning more difficult.

(5) Harvesting operations are limited to afternoons of good weather.

(6) The suction nozzle must be wide enough for desired width of swath and large enough to accommodate the mechanical pick-up device.

(7) Power required by the blower is proportional to size of suction nozzle.

2. <u>Vacuum harvesting from windrow</u>

The clover should be mowed when tough and put in windrow by means of a center-delivery windrow attachment.

A. Arguments for:

(1) Width of suction nozzle needed is reduced. Less dirt, stones, and material from previous growth will make easier the cleaning operation of the seed.

(2) More of the material is up where the air stream can get at it.

(3) A stronger suction can be produced with a given size of blower and engine.

(4) A mechanical pick-up is not necessary, and if it is needed, it will be shorter. The clearance between a short cylinder and the ground is less affected by an uneven ground surface.

(5) The rate of travel may be faster than a full swath.

B. Arguments against:

(1) The drying rate of the clover in a windrow is slower than when it is in a swath. The weather hazard is therefore increased and the material may mold if rained on.

(2) Loose seed heads between the windrows will certainly be missed.

(3) In a wet season windrows are less desirable when there is a heavy vegetative growth, unless a mechanical drier is used.

3. <u>Suction from the cutter bar</u>

This operation should be done during the heat of the day—12:00 noon to 6:00 p.m.

A. Arguments for:

(1) The whole harvesting procedure is reduced to one operation over the field and consequently, less man-hours are required in the field.

(2) The highest possible percent of the seed heads which are above the knife sections will be collected at the time of cutting.

(3) The minimum amount of dirt, stones, and dead material from previous growth will be picked up.

(4) Less suction and less power to lift the material for a given width of swath will be required.

(5) Uncut Ladino is less subject to damage by rain.

(6) No mechanical lifting device is needed in the suction nozzle.

B. Arguments against:

(1) Mechanical drying with heated air is necessary.

(2) Material after passing through the blower becomes pasty and too dense to dry easily.

(3) Harvesting operation is limited to about five or six hours per day of good weather. Cutting early in the day, or in unfavorable weather, would increase the load of water to be removed by mechanical drying. The average cut will be approximately one acre per hour with five-foot cutter bar and two miles per hour, rate of travel.

(4) Combination of the mowing and lifting operation usually reduces the over-all production below that of the slowest unit in the combination. A stoppage of any one stops all.

4. <u>The pan method</u>

This harvesting operation is done during forenoons and evenings. A large pan, attached to the cutter bar, collects the clover as the mower moves along. A second operator is needed to rake material back away from the cutter bar. The collected material is stacked in small cocks on wagon covers or large pieces of Sisalkraft paper. The clover is threshed from the cocks when dry.

A. Arguments for:

(1) Less extra or special equipment used.

(2) This method will save all the seed heads above the knife sections at the time of cutting.

(3) The material can be hauled into a mechanical drier at any convenient time after cutting.

B. Arguments against:

(1) More hand labor required.

(2) Limited to small acreage.

(3) Danger of molding in cocks.

(4) If the cocks are left more than a few days, the clover under them will be killed.

(5) Weather hazard.

5. <u>Combine harvesting from the swath</u>

A. Arguments for:

(1) Harvesting and threshing done in one operation.

(2) Reduced hazard of clover being heated and molded.

(3) The whole harvesting operation can be done by one man.

(4) Better threshing efficiency than when combining from windrow.

B. Arguments against:

(1) Ladino clover is usually too short to be picked efficiently by the combine pick-up.

(2) Although threshing efficiency is better than when combining from windrow, yet a high percentage of seed will be missed by the first threshing of the combine unless the tailings of the combine are collected and threshed again.

(3) If it has rained on the swath, the material especially when short, is driven down into the stubble and new growth comes up through the swath making it more difficult for the combine to pick it up.

6. <u>Combine harvesting from windrow</u>

A. Arguments for:

(1) Harvesting and threshing done in one operation.

(2) Better picking efficiency than when combining from swath.

(3) The whole operation can be done by one man.

B. Arguments against:

(1) Drying rate of the clover in a windrow is slower resulting in a lower threshing efficiency of the combine than when harvesting from the swath.

(2) Windrowing is added to the harvesting operation.

(3) Shattering of the seed may result when windrowing the clover.

(4) The hazard of clover being heated and molded is increased when laid in the windrow.

RECOMMENDATIONS ON HARVESTING PROCEDURE FOR DIFFERENT CONDITIONS OF VEGETATIVE GROWTH UNDER VARIABLE WEATHER CONDITIONS

Kind of Vegetation	Weather Condition	Recommended Harvesting Method
Tall vegetation (6" and up)	Dry season	(1) Combine from swath (2) Vacuum harvest from windrow
Tall vegetation (6" and up)	Wet season	(1) Load from swath or windrow and then sweep field with vacuum harvester (2) Vacuum harvest from swath
Short vegetation (Less than 6" tall)	Dry season	(1) Vacuum harvest from swath
Short vegetation	Wet season	(1) Vacuum harvest from swath
Mixed with other forage crop	Dry season	(1) Combine from swath (2) Vacuum harvest from windrow
Mixed with other forage crop	Wet season	(1) Load from swath or windrow and then sweep the field with vacuum harvester (2) Vacuum harvest from swath

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