# FERTILIZER APPLICATION EQUIPMENT

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# FERTILIZER APPLICATION EQUIPMENT

## Ground Operated Dry Fertilizer Distributors

Most fertilizer is applied in dry form through ground operated equipment. There are many modifications of several types of fertilizer application systems. Some of the major types are discussed in this chapter.

### Broadcast Application Equipment

Equipment used to broadcast fertilizers may be classed as full-width and greater than machine width. Full-width machines distribute fertilizer in a swath only over the width of the applicator. Applicators which distribute fertilizer in excess of machine width in each pass are equipped with lateral conveyors or spinners. Slater (28) reported the full-width spreader with a plate-and-flicker type of mechanism was most used in England and Wales. On the other hand, trucks or trailers with spinners are probably the most popular type of broadcast equipment in the United States. However, much of this equipment is commercially owned.

Spinner and Boom Type Spreaders--Machines which broadcast fertilizers in a swath greater than applicator width are of two general types. The most popular type uses a spinner or spinners to distribute fertilizer which has been metered to the spinner(s). The spinner is also called spinning disc, fan-type or centrifugal distributor. The other type uses a boom extending on one side or both sides of the applicator to distribute fertilizer. These applicators may be of the truck or trailer type.

Smaller units may have a 3-point tractor hookup, using an adjustable gate and gravity feed. Some of these smaller units use an agitator above the gate.

Most truck and trailer applicators use a chain conveyor and an adjustable tail gate metering mechanism. An auger feed is used on a few applicators. Small trailer applicators use gravity flow through an adjustable gate for metering material. Chain conveyors are both the slatted drag-chain type and stainless steel belt type. Slatted drag-chain conveyors are not well suited for spreading low rates of fertilizers (12) but are more practical for applying soil amendments such as lime and gypsum. Now, most chain conveyors are made of stainless steel belts similar to that shown in Fig. 1. To reduce corrosion problems, many manufacturers are using stainless steel for other spreader components such as the metering gate, its guides and adjusting screw, drive chains, hopper and metering dials. Epoxy coatings on the inside of hoppers are also being used to minimize corrosion. Many truck spreaders use a supporting shield above the conveyor to reduce weight on the conveyor. An inverted V-shaped support is shown in Fig. 2.

Conveyor belts must be uniform in thickness to have a constant discharge of materials for a given gate setting. Also, belts with widely spaced slats give an uneven flow of material. For a constant application rate, the conveyor speed must be geared to the applicator's ground speed. Even with ground drive the application rate decreases when ground speed increases (13). The effect of ground speed upon rates of application for three types of feed mechanisms is shown in Fig. 3.

The rotary feed system consists of a fluted cylinder which displaces a given volume of material. Within the speed range tested, this system gave very good results while the drag-chain with an adjustable gate was intermediate and the gravity feed system with an agitator was least accurate. These data emphasize that greater accuracy is obtained where positive feed mechanisms are used. Even the rotary feed system is based on volumetric displacement and is inherently inaccurate because of varying densities of fertilizers.

Truck units drive the chain conveyor by a hydraulic pump operated from the truck power takeoff or in some cases from a wheel drive. The conveyor speed may be synchronized with the truck driveshaft rpm. Other truck units drive the conveyor from a drive wheel which contacts a ground wheel. A power booster is employed with some drive wheels to furnish more power for high rates of application. Also, a 2-speed gear box is used on some spreaders to give a wide range of application rates. Others use interchangeable chain sprockets to obtain this flexibility.

Trailer spreaders primarily use a drive wheel contacting one or two ground wheels for the conveyor drive. However, some units use a universal drive. Tractor-pulled trailer applicators and tractor-mounted applicators only spread materials. The capacity of trailers generally vary from 1 to 5 tons, but smaller trailers are available.

There are two types of truck spreaders: One spreads material only; the other blends and spreads. Truck spreaders range in capacity form 4 to 13 tons. Blender-spreaders use two or three hoppers. Several 2-hopper spreaders also have a tank and separate distribution system for nitrogen solutions as shown in Fig. 4. Also, liquid-dry trailer spreaders are widely used in Florida citrus groves. This unit is particularly suited to fertilizing citrus since many groves do not now require phosphate applications. Therefore, fertilization may be accomplished by using nitrogen solution and potash.

A typical spreader unit is shown in Fig. 5. The chain belt conveyor and liquid pumps are ground driven. Spinners are driven hydraulically. Thus, granular fertilizer is distributed conventionally. The solution is distributed through slits in rubber tubing supported by adjustable booms on each side of the trailer and a short fixed boom under the back of the spreader (33).

Blending in blender-spreaders is accomplished by continuously metering individual materials onto a common conveyor belt or into an auger conveyor or into a twin-auger mixer. Metering is usually done by conveyor belts and adjustable gates. However, some units meter individual materials to the common conveyor by the use of fluted cylinders and adjustable gates (Fig. 6). The mixing is accomplished during conveyance to the distributor (spinner or boom).

Another modification of the blender-spreader is the use of a chain conveyor in the bottom of both compartments to deliver a metered quantity of each material directly to a spinner. Rate of delivery is controlled by varying gate openings from each compartment. Mixing the materials is accomplished by a specially designed spinner. Unique characteristics of this type of blender-spreader are shown in Fig. 7.

As mentioned above, for applicators which spread material but do not blend fertilizers, conveyor speed of the blender-spreader should be geared to the ground speed of the equipment. Also, the metering mechanism should be geared to ground speed to obtain uniform rates of application and uniform blend ratios during changes in ground speed.

Spinner Distributors--Spinner distributors are used on 3-point hitch tractor, trailer, or truck mounted equipment. Both single and 2-spinner units are widely used on trucks and trailers. Spinners on truck spreaders are driven by hydraulic motors powered from the power takeoff or by an auxiliary engine. Most spinners on trailer spreaders are driven from the tractor power takeoff. However, some trailer units use a ground drive from the spreader wheel and others use an auxiliary engine to power the spinner. The speed of the spinner must be constant to obtain uniform swath width and distribution. The auxiliary engine is more accurate from this standpoint and the ground-driven spinner is least accurate. A fairly constant spinner speed can be maintained from the power takeoff drive when ground speed changes are made through gear shifting if the tractor does not have a ground-drive power takeoff.

The use of spinner distributors for blended fertilizers may result in segregation. When blending fertilizers, it is important to consider the distribution of particle sizes and particle density of each material (18). Larger particles tend to form wider patterns than smaller particles. Lower density particles tend to form narrower patterns than more dense particles.

The effect of particle size upon the distribution of granular fertilizer by a single spinner is shown in Fig. 8. The blended fertilizer consisted of 50 percent by weight of minus 10 to plus 14 mesh particles and 50 percent minus 6 to plus 8 mesh particles. Using a 30-foot spacing, the rate of application of minus 10 to plus 14 mesh material varied from about 50 pounds per acre to 250 pounds per acre. With the same spacing the rate of application of minus 6 to plus 8 mesh material ranged from 100 to 200 pounds per acre. This plotted distribution pattern shows the optimum spacing for the larger materials was too wide to give a good pattern for the smaller material.

A similar plot of fertilizer distribution from a 2-spinner blender-spreader across a 34-foot swath is shown in Fig. 9. The material larger than 9-mesh size was applied at rates ranging across the swath from 25 to 45 pounds per acre. The variation of application rate across a swath ranged from 30 to 130 pounds per acre for the material smaller than 9-mesh size. The 34-foot swath resulted in fairly uniform distribution for larger particles but was too wide for smaller particles. Two spinners may not necessarily give better distribution than one spinner (29).

Certain adjustments on the spreader may be made to improve the distribution pattern. An increase of the blade pitch or a decrease of spinner speed will delay departure of fertilizer from the spinner (12). The effect of spinner speed on distribution of particles is shown in Fig. 10. Placement of material on the spinner may be moved closer to the center or moved in the direction of spinner rotation to obtain later departure of material. Placement of fertilizer on spinners generally affect the distribution pattern as shown in Fig. 11.

Boom Distributors--When boom-type distributors are used, they are usually found on spreader trucks. These spreaders use a boom extending to one or both sides of the spreader. The booms are optional attachments on several blender-spreaders and general purpose spreaders. Metering of fertilizer to the booms may be accomplished by the same methods used for the spinner spreader. One type spreader directs the material to booms on each side of the truck via a flow divider and a pair of delivery chutes. Fertilizer is moved across adjustable openings located at 6-inch intervals in the booms by an auger inside each boom. Other boom-type spreaders use a drag-chain conveyor instead of an auger in each boom. Fertilizer is discharged through long tapered openings or through small adjustable openings in the bottom of the boom. The latter type sometimes return a portion of the fertilizer for a second pass along the boom.

Blended materials of unmatched particle size tend to segregate with boom distributors to about the same degree of nonuniformity as with spinner distributors (Fig. 12). There is little segregation due to particle size with the drag-chain type booms where small adjustable openings are in the boom. However, with a similar conveyance with tapered openings in the boom, the greater portion of large particles is deposited near the spreader. The auger boom conveyor carries a greater portion of large particles away from the spreader. This latter pattern is similar to that obtained with a spinner distributor.

Full-Width Distributors--Machines which broadcast material in an area approximately the width of the hopper can be classified by the method of controlling flow of materials. It is convenient to place these machines in three categories:

1) gravity flow through adjustable gates,

2) displacement feed mechanism, and

3) a combination of 1 and 2.

Spreaders of the gravity flow-type distribute fertilizer through adjustable openings spaced along the bottom of the hopper. Hebblethwaite and Pascal (14) reported the plate-and-flicker type of distributor is most common in Europe. A sketch of this type dirtributor is shown in Fig. 13. Material flow is controlled by an adjustable gate opening and is spread by rotating flickers throwing it from the revolving plates.

Probably the most popular full-width distributor in the United States is a gravity flow spreader with an agitator above the gate openings. This type of spreader is illustrated in Fig. 14. Several variations in the design of the agitator are used. Agitators crush lumps and assist in obtaining a uniform rate of feed with changing fertilizer level in hoppers (7). Agitators are commonly driven from a spreader wheel.

Broadcast distributors which meter fertilizer only by a displacement mechanism usually use an auger or a fluted rotor feed system. The important features of an auger type spreader are shown in Fig. 15. This spreader is available in widths from 10 to 34 feet and has a hopper capacity of about 100 pounds per foot of hopper length.

Most broadcast spreaders which use both adjustable openings and a displacement mechanism to meter fertilizer use moving belts or star wheels for displacement. The star wheel feed mechanism illustrated in Fig. 16 is most commonly used. In this type of spreader, fertilizer is carried through gate openings on and between projection points of the wheel. The material carried through the gate on the wheel is scraped off as the projection points rotate back into the hopper. Rates of application are adjusted by varying the gate opening, the speed of rotation of the star wheel in relation to ground speed and/or changing the shape of the star wheel.

Southwell and Samuel (31) tested full-width spreaders of the gravity flow (with agitator), star-wheel and auger types for accuracy of application. Prilled urea (small, smooth spherical particles) with a bulk density of 45.8 pounds per cubic foot and a somewhat coarse granular 10-10-10 with a bulk density of 64.5 pounds per cubic foot were used in the studies. The rate of application varied considerably from the manufacturer's quoted rate for a given machine setting (Table 1). Also, as expected, the rate of application of each fertilizer was different for similar operating conditions. But, for the displacement feed spreaders, the ratio of application rate of 10-10-10 to urea was about the same as the ratio of their bulk densities. This again points to the inherent inaccuracy of volumetric feed mechanisms. These data indicate that information on bulk density of fertilizer would be useful in adjusting applicators for a nominal application rate. Also, the manufacturer's suggested adjustments should be based upon the density of fertilizers.

In the tests mentioned above, rates of delivery were determined at several time periods for pairs of openings across the spreader. The results could simulate expected variations down rows, between rows, and between swaths across a field. The estimated variability across a hypothetical field was ± 24 percent from the mean rate with the gravity flow machine, ± 12 percent for the displacement-feed applicator and ± 18 percent for the combination feed applicator (31).

Hepherd and Pascal (17) tested the performance of several distributors including the plate-and-flicker type. They found the variation in transverse distribution of material from the plate-and-flicker spreader to be about ± 50 percent of the mean application rate. However, any area receiving a low application rate was within 6 inches of an area receiving a high application rate. The separation between areas of high application rate corresponded to the distance between flickers. This type of distribution is well within acceptable limits. However, distribution along the path of this type of spreader may vary considerably especially on rough terrain (14). Bumping the spreader causes spillage of fertilizer from the plates and then there is a time lag (filling of plates) before normal distribution begins.

Row or Band Application Equipment

Most of the metering mechanisms previously discussed are also used on band application equipment. Augers, fluted rotors, belts (fabric and stainless steel) and star wheels are used. Auger and fluted rotor feed mechanisms are of positive displacement type. Rate of application with the auger system is controlled by varying the speed of rotation of the auger through changing sprockets on the auger shafts. One auger feed system is illustrated in Fig. 17. Some applicators use large hoppers and have reverse augers on a common shaft, which meter fertilizer from each end of the hopper. The application rate can be controlled in the fluted rotor system by varying the speed of rotor rotation. The main features of this system are shown in Fig. 18.

Both belt and star wheel feed mechanisms depend upon displacement and gate opening to meter fertilizer. These metering systems have been discussed in earlier sections of this chapter. Use of the belt feed systems is increasing in the United States.

The trend in band application equipment has been toward the use of larger hoppers to decrease the number of stops. However, bridging of the fertilizer has caused application problems in some equipment. Where planting is done on beds or ridges, there is increased use of band fertilizer applicators in conjunction with machines which prepare the ridges. Many band fertilizer applicators are now equipped with fiberglass hoppers. Some of the fluted roters are made of nylon and many of the gates, belts and other metalic parts are made of stainless steel.

## Fluid Fertilizer Application Equipment

The discussion of fluid fertilizer application equipment will include application of pressure and nonpressure solutions and suspensions. Pressure solutions include anhydrous ammonia and solutions containing free ammonia. The use of fluid fertilizers has increased rapidly in the last few years, especially in the United States and France. This rapid growth has brought about many changes in application equipment.

### Anhydrous Ammonia Equipment

Anhydrous ammonia is usually metered by one of two methods. In one method a variable orifice meter is used. Fig. 19 is a sketch of a typical orifice meter which has a calibrated plunger that moves in an orifice plate. A V-type groove is machined into the plunger so that a larger opening is exposed between the orifice and the groove as the plunger moves out from the orifice plate. Constant pressure is maintained on the orifice plate by means of a diaphragm and spring device. This diaphragm makes it possible to maintain a constant pressure that is not affected by changes of pressure in the applicator tank or by back pressure from the application knives on the orifice plate. Liquid from the orifice meter is directed by tubes to application knives. These knives are usually shaped in the form of curved swords which inject the ammonia 6 to 12 inches beneath the soil surface. Two paddle-shaped blades on the applicator cover the groove in the soil made by the knives. This type of metering system is dependent upon speed of the tractor. If the application rate is to be uniform, a constant tractor speed must be maintained.

One manufacturer fabricates a variable orifice meter which has a governor device attached to the diaphragm. He reports that this orifice is not dependent upon tractor speed. As tractor speed is varied the governor device varies the spring tension on the diaphragm. The result is a compensation in the ammonia flow proportional to the change in tractor speed.

Fig. 20 is a sketch of a piston-type metering pump--another type of metering device used to control the flow of liquid anhydrous ammonia to the applicator knives. Ground-driven through a system of sprockets, it has a double-acting variable stroke piston. The application rate is determined by varying the strokes of the piston. Incoming ammonia from the applicator tank is cooled in a heat exchanger consisting of pipes within a pipe. Liquid from the heat exchanger enters the piston through the inlet port. The cylinder in which the piston moves is divided into two compartments. There is an inlet and a discharge valve in each compartment. One section of the cylinder discharges while the other is filling. Therefore, there is a delivery stroke for each stroke of the piston. As the piston moves to the left, the righthand section of the cylinder fills. The inlet valve opens, and liquid ammonia flows from the liquid header into this section of the cylinder. The movement of the piston to the left causes the lefthand side of the cylinder to discharge through the outlet valve which in this instance is open. Liquid discharged from the outlet valve expands and passes through the vapor side of the heat exchanger.

This vapor cools the incoming liquid from the applicator tank and insures that liquid ammonia is delivered to the header. As the stroke changes to the right the inlet valve closes, and this section of the cylinder discharges into the outlet header. As the stroke continues to the right, the inlet valve in the lefthand section of the cylinder opens and the inlet valve closes. Liquid ammonia is then drawn into the lefthand section of the cylinder. The back and forth movement of the piston in the cylinder creates a constant metered flow of ammonia to the applicator knives.

Broadcast Applicators

Nonpressure solutions (no free ammonia) and suspensions are commonly broadcast applied. Fig. 21 is a sketch of a truck equipped for broadcasting fluid fertilizers. This truck has a single flooding-type nozzle. Pressure on the nozzle is maintained by pressure in the applicator tank. Air from a compressor enters the applicator tank through a sparger mounted inside and near the bottom of the tank. This sparger agitates suspension-type fluid fertilizers. The sparger is not necessary for clear liquids. Application rates are varied by changing the size of the nozzle, speed of the truck or height of nozzle from the ground. If a pressure of 20 - 30 pounds per square inch is maintained in the tank, the pounds per acre applied remains relatively constant. This is because the increase flow, due to increase pressure, is compensated by wider swath width.

Fig. 22 shows another type of broadcast application truck for fluid fertilizers. This truck varies the pressure on the nozzles by varying the amount of liquid recirculated to the applicator tank. Liquid is pumped to the nozzles and recirculated by a centrifugal pump. The truck uses more than one nozzle. TVA tests indicate that when multinozzles are used, it is difficult to control overlapping of application by individual nozzles. When overlapping occurs, the rate of application is not uniform. These tests also show a more uniform application of fluid fertilizer can be obtained by using a single flooding nozzle.

Fig. 23 is a cut-away sketch of a slinger-type applicator recently developed for the application of suspensions. An agitator in the shape of a sweeping baffle agitates the liquid in the applicator tank. The slinger mechanism causes the material to be pumped from the applicator tank as it rotates. The applicator has been tested with many types of suspensions and has been satisfactory for applying even the most difficult to handle.

Row or Band Applicators

Most liquids applied in the row are handled by some kind of gravity-flow system as shown in Fig. 24. This type of applicator has an airtight tank with a vent pipe. A constant pressure is maintained at the orifice plate independently of the height of the liquid in the tank. The orifice disk metering head is composed of an orifice disk and holding device. The orifice disk usually has six graduated holes. The rate of liquid being metered is controlled by the speed of the tractor and the size of the hole in the orifice plate. Many farmers find they can convert a 55-gallon drum to a constant head metering system instead of purchasing prefabricated equipment of this type. Fig. 25 is a sketch of a drum that has been converted to a metering system. The breather pipe is usually installed in the filling hole of the tank. It is important that the drum be airtight so a constant pressure can be maintained on the orifice plate. The orifice assembly is usually fabricated from a standard machine pipe union and has a flat disk-type orifice plate. The union must be opened and the orifice plate changed each time the application rate is changed to a degree where it cannot be varied with tractor speed.

Positive Displacement Pumps

Fig. 26 is a sketch of a typical piston-type metering pump for liquid fertilizers. Details of the operation of this pump are similar to those of the anhydrous ammonia metering pump, but this pump for liquid fertilizers does not require a heat exchanger. Liquids that have a slight vapor pressure--such as aqua ammonia--also have been satisfactorily applied with pumps of this type.

Fig. 27 is a sketch of a squeeze pump used for row application of liquid fertilizers. As liquid is squeezed from the rubber tubes, more liquid is drawn into them from the applicator tank. The quantity of liquid delivered by the pump is varied by changes in the speed of the rollers as they pass over the tubes. The roller speed is changed by varying the ground-driven sprockets of the drive to the pump.

Fig. 28 is a sketch of an internal gear pump--another type positive displacement pump used to apply liquids, either in the row or broadcast. This pump consists of a gear which revolves inside another gear. The motion of the gears provides positive pumping of liquid from the applicator tank to the application knives. The pump is usually ground-driven. Quantity of liquid delivered to the application knives is dependent upon the shaft speed of the internal gears.

Another pump of this type has a roller-impeller. Fig. 29 is a cut-away sketch of this pump. As the roller-impeller passes over the eccentric housing, it draws liquid from the applicator tank and delivers it to the application knives. The quantity of liquid delivered by the pump is dependent upon the shaft speed of the roller impellers. These shafts can be either ground-driven or driven by a power takeoff.

### Applicators for Multiple Fluids

Application systems where two or more fluid fertilizers are applied simultaneously are used to a great extent in the United States. Usually one of the fluids is anhydrous ammonia and the other is a neutral ammonium phosphate solution. In some instances phosphoric acid is applied.

One dual applicator used to apply fluid mixed fertilizer and anhydrous ammonia is shown in Fig. 30. Both fertilizers are injected into soil immediately behind the furrow cutter. The sweeps are used to cut roots of old stubble and prepare seedbed. Planting can then be done with a minimum of tillage.

## Aerial Application

Use of airplanes in agriculture increased greatly after World War II (16). Aerial application of fertilizer is mostly limited to crops or areas where ground-operated equipment is not well adapted. In 1960, about 180,000 tons of fertilizer were applied by aircraft in the United States (4).

In 1961, over 560,000 tons of superphosphate were applied by air to about 5.25 million acres in New Zealand (25). Mechanization of handling bulk fertilizer for aerial application and large field sizes has resulted in application costs as low as 0.45 cents per 100 pounds per acre.

Cost of applying fertilizer to rice with aircraft in the United States is about 0.8 to 1 cent per pound where relatively large volumes are concerned (1). Aerial application charges for fertilizing mountainous pastures where smaller fields and lower concentration of workloads exist are from 1.2 to 1.4 cents per pound when applying about 300 pounds per acre (8, 32). Johnson (19) reported a cost of about 2 cents per pound for applying nitrogen solution at a rate of 140 pounds per acre on 700 acres of runway shoulders at an airport.

The distribution of materials by aircraft is affected by airflow resulting from the propeller slipstream and vortical airstreams around each wing tip (35). The propeller slipstream carries material from right to left of the aircrafts' flight path because of counterclockwise rotation of the propeller. The wing-tip vortices tend to carry material away from the flight path (Fig. 31).

Other major factors influencing the distribution pattern of materials are the size and design of the distributor and the feed mechanism. A positive feed mechanism from the hopper is extremely important for certain materials. Roberts and Smith (24) found large variations in rate of flow with changes in hopper load as shown in Fig. 32 when a gate opening gravity feed system was used.

New Fixed Wing Agricultural Aircraft and Distribution Systems

Some planes recently introduced for agricultural work are the L-60 Brigadyr from Omnipol, the Agricola from Auster Aircraft, Ltd., and the Distributor Wing Agricultural Airplanes from Aerial Distributors, Inc. The Brigadyr is equipped with full-span interconnected slots on the leading edge of the wings (3). This airplane has a minimum true air speed of 40 miles per hour. The Agricola is the first aircraft specifically designed for spraying (3). The Distributor Wing Airplane is discussed in more detail below.

Venturi Systems--Most aircraft distributors use a venturi system. In these systems air is forced into a scoop and through a restricted section to increase the velocity of flow. Materials to be spread are injected into the duct at the point of maximum air velocity and forced through ducts which guide the particles in the proper direction and to the desired point of injection into the airstream. A pictorial view of a typical single venturi distributor is shown in Fig. 33.

Modifications of the single venturi system include the double venturi, Swathmaster and Roth distributors. The Swathmaster is essentially a venturi distributor designed as an airfoil. The airfoil has slots on the top surface through which materials are distributed into the airstream (23). The discharge end of this type spreader usually measures about 16 feet across. The Roth distributor has air vents on the bottom which act as scoops for additional ram air entry. It was especially designed to apply 500 to 700 pounds of fertilizer per acre on cane fields in Hawaii (26). Distribution patterns developed from data of Nelson (23) with single venturi and Swathmaster distributors are shown in Figs. 34 and 35, respectively.

Positive Energy Systems--The Agricultural Engineering Department at Mississippi State University designed an aerial distribution system with an engine driven blower to give increase lateral velocity to the fertilizer materials (24). The greatest velocity is at the throat--where materials are usually injected--in the venturi system and at the distributor outlet in the positive energy system. The velocity imparted by the blower somewhat overcomes the adverse effects of propeller slipstream and ejects material into the vortical airstreams of the wingtips. The results are better distribution and wider swaths. In tests with powdered material, effective swath widths or flagging interval up to 120 feet are obtained (24). Vortical airflow has less effect on granular particles than dust particles. However, effective swath widths up to 60 feet were obtained with granular fertilizer from this positive energy distributor (30).

The University of California, University of Wichita, and Aerial Distributors, Inc., built and tested a plane which uses the positive energy approach and distributes material through the aircraft wing (5). The main engine is 290 horsepower rated. An auxilary engine (160 horsepower) drives a fan which forces air through the distribution system. Fertilizer is metered from the bottom of the hopper by a hydraulic motor driven rotary metering gate into the high velocity airstream. Guide vanes distribute material along the full lenth of the flaps where it is discharged through a slot over the trailing edge of the flaps (Fig.36). A portion of the air for the distribution system is directed over the ailerons to increase their effectiveness (6).

Helicopter Distributors

The high initial cost, high maintenance cost, and small payloads have limited the use of helicopters in applying fertilizers. In countries where field size is relatively small, helicopters are accomplishing a greater portion of aerial application work than in the U. S. For example, practically all aerial application work in Japan is done by helicopters (20) and the helicopter is the most popular type aircraft used in the British Isles (3).

Gravity Feed Systems--A standard distribution system to spread granular fertilizer by helicopter is shown in Fig. 37. Fertilizer flows by gravity feed from the saddle hoppers through adjustable gates in each duct onto a spinning disc driven by an electric motor.

Another type distributor uses a spillplate under each hopper in place of a spinner or rotating disc. The spillplates are curved similar to a moldboard plow. Particles dropped on the plates are dispersed. The dispersal is also aided by additional airflow directed from the cooling shroud of the helicopter to the spillplate.

Positive Feed System--One positive feed distributor uses the saddle-type hoppers with an auger to transfer and meter material from the bottom of hoppers to a spinner. The auger and spinner may be driven by a common motor or separate motors. Hydraulic motors are more satisfactory than gasoline engines or electric motors. It seems to be more desirable to drive the auger and spinner from separate power sources.

A distributor operating on the same principle of delivery is shown in Fig. 38. This type system was started by a firm in Sweden but is being developed by a flying service firm in the northwestern United States. The entire distributor is hung from the hoist hook on the helicopter to get dust well below the helicopter to reduce corrosion. A 6-inch auger (driven by a hydraulic motor) deposits material on a spinner. Since the spinner and auger are driven by separate motors, the speed of each may be varied depending upon the rate of application, swath width desired, and material used.

Hydraulic lines from the helicopter to the distributor contain quick disconnect couplings for fast changing. By using two of these distributors, one hopper is filled while the other is in use. A helicopter can almost continuously spread fertilizer with this system. Representatives of the firm developing this distributor hope to be able to apply fertilizer for about 1.5 cents per pound.

## Application Through Irrigation Systems

Most fluid and water soluble dry fertilizers are suitable for application through irrigation systems. Ammonia solutions are applied in flooding or furrow systems. However, excessive ammonia volatilization occurs from ammonia solutions when applied through sprinkler systems (15,21). Urea-ammonium nitrate and ammonium phosphate solutions may be applied satisfactorily through either irrigation system.

Uniform distribution of fertilizer over the soil surface when applied in irrigation systems is determined by water distribution and adequate mixing. The first factor is influenced by the design of the system, the rate of water application _versus_ the infiltration rate into soil and in the case of sprinkler systems, wind velocity and direction. The second factor is influenced by the method or point of injection of fertilizer solution into the irrigation system.

To ensure proper mixing in an open ditch system, the solution may be metered into the water at the end of the discharge pipe where churning action in the stilling basin will cause proper mixing. With an enclosed system, injection of the solution into the pump suction line or into the discharge line ahead of pipe elbows or tees will provide thorough mixing.

Injection Systems

Anhydrous ammonia and other fluid fertilizers may be metered from a nurse or applicator tank. Ammonia metering is accomplished through systems discussed in the section on ammonia application equipment. Injection of ammonia solutions is made through a sparger positioned in the ditch water. Other commercial fluid fertilizers or dissolved dry materials are metered into ditch water by a constant-head supply tank and orifice similar to that described in the section on fluid application equipment. Another constant pressure system uses a pressure regulator and high pressure cylinders of gaseous nitrogen to maintain a constant pressure on the solution supply tank.

Injecting solutions into sprinkler systems requires a positive pressure differential between the solution and water in the sprinkler line. Booher (9) reported that at least 23 companies manufacture equipment for injecting fertilizers into sprinkler pipes. Injection systems may be classified into four types: 1) injection into pump suction line, 2) injection into discharge line through an auxiliary pump, 3) injection into the discharge line from a closed tank by maintaining a pressure differential, and 4) an aspirator used to suck the fertilizer solution into the pipeline.

A system for injection into the suction line of a turbine pump is illustrated in Fig. 39. This system uses a shutoff valve between the fertilizer supply tank and the suction pipe to control the rate of fertilizer solution flow. A line from the discharge pipe may be used to supply water to the mixing tank to dissolve solid fertilizers. A similar system may be used to supply solution to the suction pipe of a centrifugal pump (34).

One method of injecting fertilizer solution into the discharge line of an irrigation pump is to use a small high pressure pump to obtain the pressure gradient necessary for injection. The principles of operation of this unit are shown in Fig. 40. A positive displacement pump operated by a self-contained water motor is usually used. An extra power source is sometimes used but units may be operated from the drive shaft of the irrigation engine. Disadvantages include the requirement of components with moving parts and the contact of corrosive concentrated solution with moving parts. Martin (22) reported one case of pump stoppage after 12 hours of pumping ammonium nitrate solution. Relative corrosion of solutions to certain metals is shown in Table 2.

A closed tank may be used for the fertilizer solution container when metering solution into the discharge line is accomplished by creating a pressure differential across the supply tank. Allred and Pomroy (2) discussed the method shown in Fig. 41. Shearer and Jackson (27) illustrated the use of a shutoff valve in the main line between the intake and outlet points of the solution tank to gain a pressure differential across the tank. Other devices used to create a pressure differential between points in the irrigation pipe are coupler, elbow, gate or butterfly valve, venturi-section, or a pipe enlargement. These systems meter a measured amount of fertilizer when the supply tank is emptied and the total amount of fertilizer applied per unit area can be accurately controlled. However, the concentration of fertilizer in the irrigation water varies during the period of application because of the continual dilution of fertilizer solution in the supply tank. Advantages of the closed tank system are the simplicity and freedom from moving parts.

Cook, et. al. (11) described an injection system which depends upon a pressure reduction in the irrigation line but does not use a closed tank. A portion of the water from the irrigation pipe is bypassed through an aspirator, creating suction that draws fertilizer solution into the bypass line (Fig. 42). A pressure reducing device located in the irrigation pipe between the two points of connection gives a pressure differential and causes injection of solution into the irrigation line.

Bryan and Thomas (10) studied the effectiveness of an auxiliary pump and a closed tank system for introducing fertilizer solutions in irrigation water applied with a sprinkler system. They concluded that reasonably uniform concentration of fertilizer was distributed through the systems and that fertilizers were applied to soil as uniformly as the irrigation water.

## References

1. Akesson, N. B., and Yates, W. E. 1962. Airplane Distribution Systems Cost Study on Dry, Bulk Fertilizer Applications. Council on Fertilizer Application, Proc. National Plant Food Institute, Washington, D. C.

2. Allred, E. R., and Pomroy, J. H. 1954. Introducing Fertilizer Solutions into High-Pressure Irrigation Systems. Agr. Eng. 35:171, 172, and 178.

3. Anonymous. 1960. Aerial Lime Spreading Techniques Demonstrated in Great Britain. Pit and Quarry. 52:152, 156, and 159.

4. Anonymous. 1962. Aircraft in Agriculture. 1960. Federal Aviation Agency.

5. Anonymous. 1965. Distributor Wing Plane Enters Test Stage. Agr. Chem. 20:66 and 68.

6. Anonymous. 1965. Introducing the Distributor Wing Airplane. Farm Chem. 128:44.

7. Bainer, R., Kepner, R. A., and Barger, E. L. 1955. Principles of Farm Machinery. John Wiley and Sons, Inc., New York. Ch. 13, p. 283-303.

8. Bond, B. J., and Russel, D. A. 1965. Insuring Economical Operation in Aerial Application of Fertilizers. Agr. Chem. 20:53-54 and 56.

9. Booher, L. J. 1965. How to Spread Fertilizer through Irrigation Sprinklers. Crops and Soils. 18:10-11.

10. Bryan, B. B., and Thomas, E. L., Jr. 1958. Distribution of Fertilizer Materials Applied through Sprinkler Irrigation Systems. Arkansas Agr. Exp. Sta. Bull. 598.

11. Cook, R. L., Davis, J. R., and Kidder, E. H. 1956. Fertilizing through Irrigation Water. Michigan Coop. Ext. Bull. 324.

12. Cunningham, F. M. 1963. Distribution Equipment, Southern Bulk Blending Fertilizer Conf., Proc. Tennessee Valley Authority, Knoxville, Tennessee. p.85-92.

13. Cunningham, F. M. 1963. Performance Characteristics of Bulk Spreaders for Granular Fertilizer. ASAE, Trans. 6:108-114.

14. Hebblethwaite, P., and Pascal, J. A. 1960. Current Agricultural Techniques for the Broadcast Application of Fertilizers. Fert. Soc. (London), Proc. No. 60.

15. Henderson, D. W., Bianchi, W. C., and Doneen, L. D. 1955. Ammonia Loss from Sprinkler Jets. Agr. Eng. 36:398-399.

16. Henry, J. E. 1962. Study of Distributors for Applying Dry Materials by Airplane. Ohio Agr. Exp. Sta. Res. Bull. 906.

17. Hepherd, R. G., and Pascal, J. A. 1958. The Transverse Distribution of Fertilizer by Conventional Types of Distributor. Agr. Eng. Res. 3:95-107.

18. Hoffmeister, G., Watkins, S. C., and Silverberg, J. 1964. Bulk Blending of Fertilizer Material: Effect of Size, Shape, and Density on Segregation. J. Agr. Food Chem. 12:64-69.

19. Johnson, E. G. 1961. Aerial Application of Fertilizer. Public Works. 92:100.

20. Jose, D. K. 1963. The Helicopter: Out of Its Infancy and Emerging as A Major Factor in the Aerial Application Business. Texas Agr. Aviation Conf. and Short Course on Pest Control, Proc.

21. Koch, K. A. 1958. Nitrogen Vaporization Loss in Sprinkler Irrigation. ASAE Paper No. 58-511.

22. Martin, W. E. 1954. Do Fertilizers Ruin Sprinkler Systems? Presented at Sprinkler Irrigation Conference, Jan. 30.

23. Nelson, G. S. 1965. Aerial Application of Granular Fertilizer and Rice and Lespedeza Seed. Council on Fertilizer Application, Proc. National Plant Food Institute, Washington, D. C.

24. Roberts, S. C., and Smith, M. R. 1963. The Evaluation of A Positive Energy Distribution System for the Aerial Application of Solid Materials. Mississippi State Univ., Dept. Aerophysics. Res. Note No. 20.

25. Robertson, G. M. 1962. Aerial Topdressing: Past, Present, and Future. New Zealand Fert. J. 9:3-4.

26. Roth, G. A. 1961. Aerial Fertilization Equipment in Hawaii. Agr. Aviation (Magazine). Int. Agr. Aviation Center. le.v d. Bochstraat 4, Hague, Netherlands, 3:no. 3.

27. Shearer, M. N., and Jackson, T. L. 1958. Applying Fertilizer through Sprinkler Systems. Oregon Coop. Ext. Bull. 774.

28. Slater, J. K. W. 1957. A Survey of Fertilizer Distributors and Combine Drills. J. Agr. Eng. Res. 2:293-298.

29. Smith, G. E. 1961. Bulk Blended Fertilizers. Fert. Ind. Round Table, Proc. 11th. p. 90-97.

30. Smith, M. R. and Anderson, J. H. 1964. Development of Equipment and Techniques for the Aerial Application of Agricultural Materials. ASAE Paper No. 64-606.

31. Southwell, P. H., and Samuel, J. 1965. The Accuracy of Fertilizer Metering by Full-Width Machines. ASAE Paper No. 65-606.

32. Stangel, P. J. 1964. Aerial Fertilization in the Appalachian Region of the United States. Council on Fertilizer Application, Proc. National Plant Food Institute, Washington, D. C.

33. Wander, I. W., and Shores, B. E. 1962. Liquid-Dry Spreading and Hauling Equipment Developed for Florida Grove and Pasture Fertilization. Council on Fertilizer Application, Proc. National Plant Food Institute, Washington, D. C.

34. Woodward, G. O. 1959. Sprinkler Irrigation. Sprinkler Irrigation Association, Washington, D. C. Ed. 2, 377.

35. Young, V. D., Winterfield, R. G., Deonier, C. E. and Getzendaner, C. W. 1961. Factors Influencing the Deposit Position of Granular Materials Applied by Aircraft at Low Flight Levels with Fixed-Wing Aircraft. ASAE Paper No. 61-614.

Table 1. Variation in Application Rate for Two Fertilizers with Three Types of Spreaders (31).

| Type of Distributor 1/ | Nominal Rate Setting | Actual Rate | |
|---|---|---|---|
| | | Urea | 10-10-10 |
| | Lbs./A. | Lbs./A. | |
| Gravity flow | 112 | 336 | 218 |
| Displacement | 137 | 114 | 176 |
| Combination | 136 | 136 | 197 |

1/ Gravity flow type machine controlled flow rate by adjustable openings in bottom of spreader, displacement type spreader used an auger feed mechanism, and combination used a star wheel displacement mechanism with adjustable gates.

Table 2. Relative Corrosion of Various Metal Sheets after 4 Days of Immersion in Solutions of Commercial Fertilizers (22).

| Fertilizer Solutions | Solution pH | Corrosion Ratings1/ Galvanized Iron | Sheet Aluminum | Stainless Steel | Phospho-Bronze | Yellow Brass |
|---|---|---|---|---|---|---|
| Calcium Nitrate | 5.6 | 2 | No | No | 1 | 1 |
| Sodium Nitrate | 8.6 | 1 | 2 | No | No | No |
| Ammonium Nitrate | 5.9 | 4 | 1 | No | 3 | 3 |
| Ammonium Sulfate | 5.0 | 3 | 1 | No | 3 | 2 |
| Urea Nu-Green | 7.6 | 1 | No | No | No | No |
| Phosphoric Acid | 0.4 | 4 | 2 | 1 | 2 | 2 |
| Diammonium Phosphate | 8.0 | 1 | 2 | No | 4 | 4 |
| Liquid (17-17-10)2/ | 7.3 | 2 | 1 | No | 4 | 4 |

1/ Corrosion ratings are: No - none, 1 - slight, 2 - moderate, 3 - considerable and 4 - severe.

2/ A commercial mixture of ammonium sulfate, diammonium phosphate, and potassium sulfate.

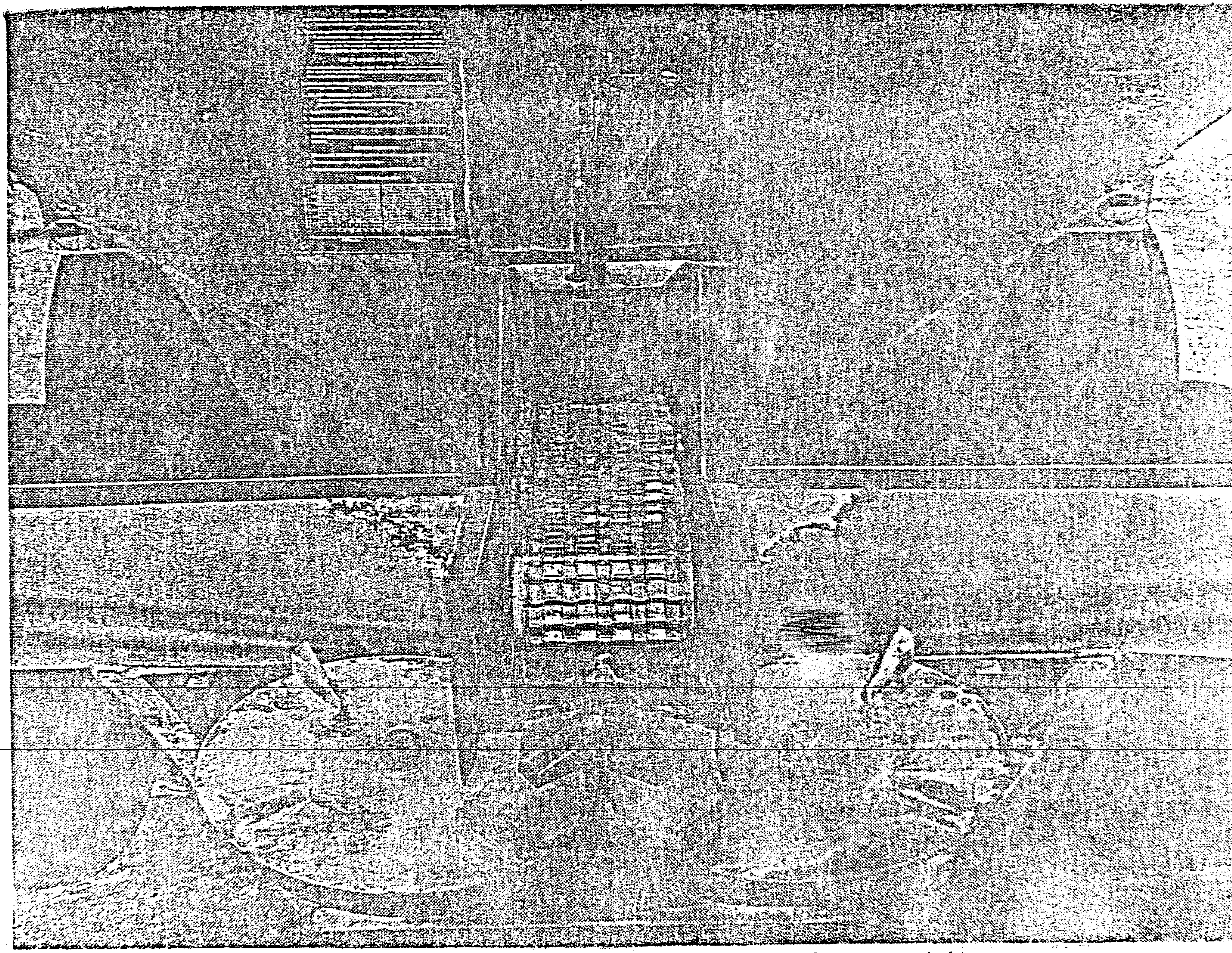

Fig. 1. Spinner-type trailer spreader showing stainless steel conveyor belt.

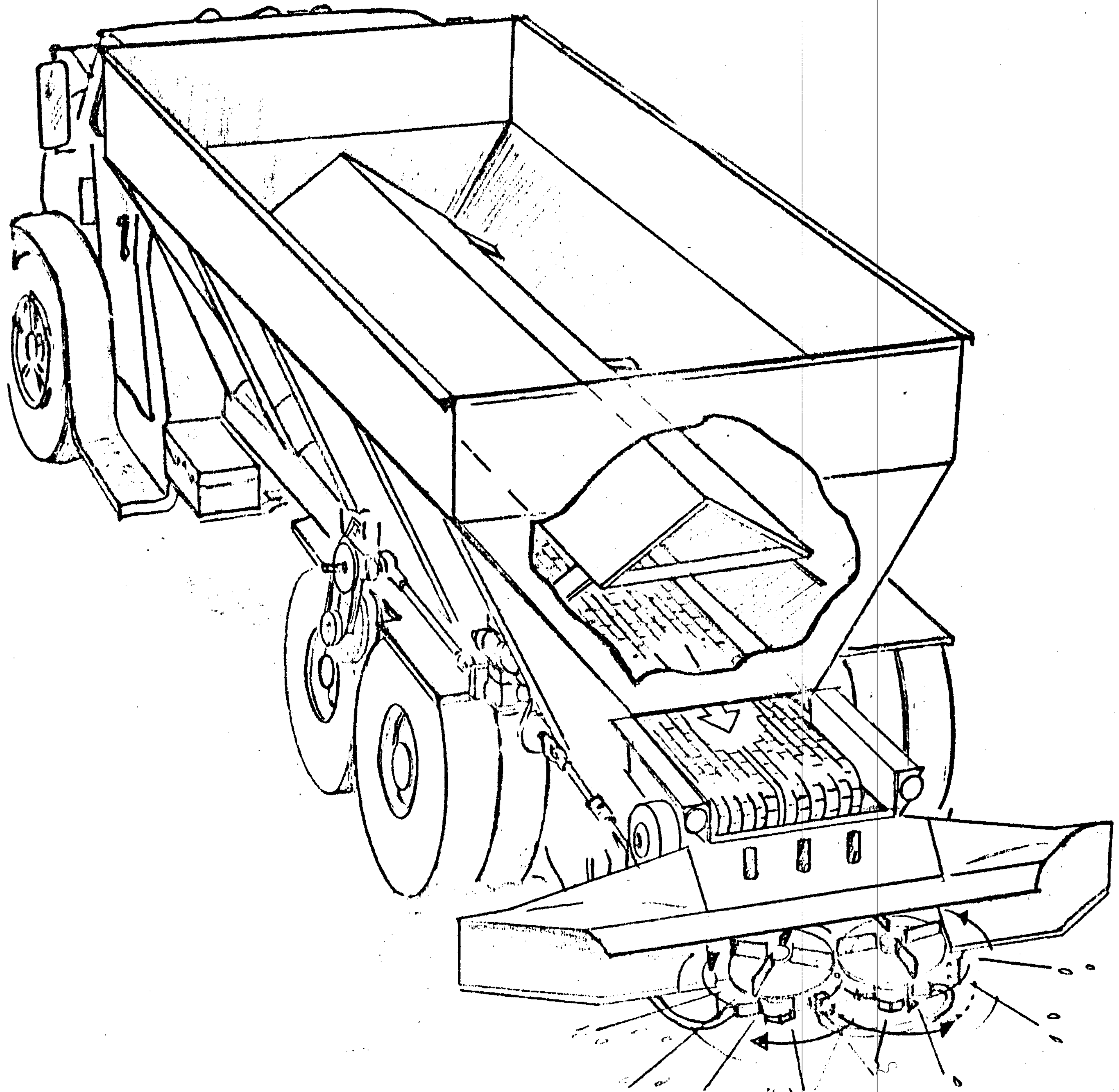

Fig. 2.
Spreader truck with twin spinners showing inverted V-shaped support to ease load on conveyor belt.

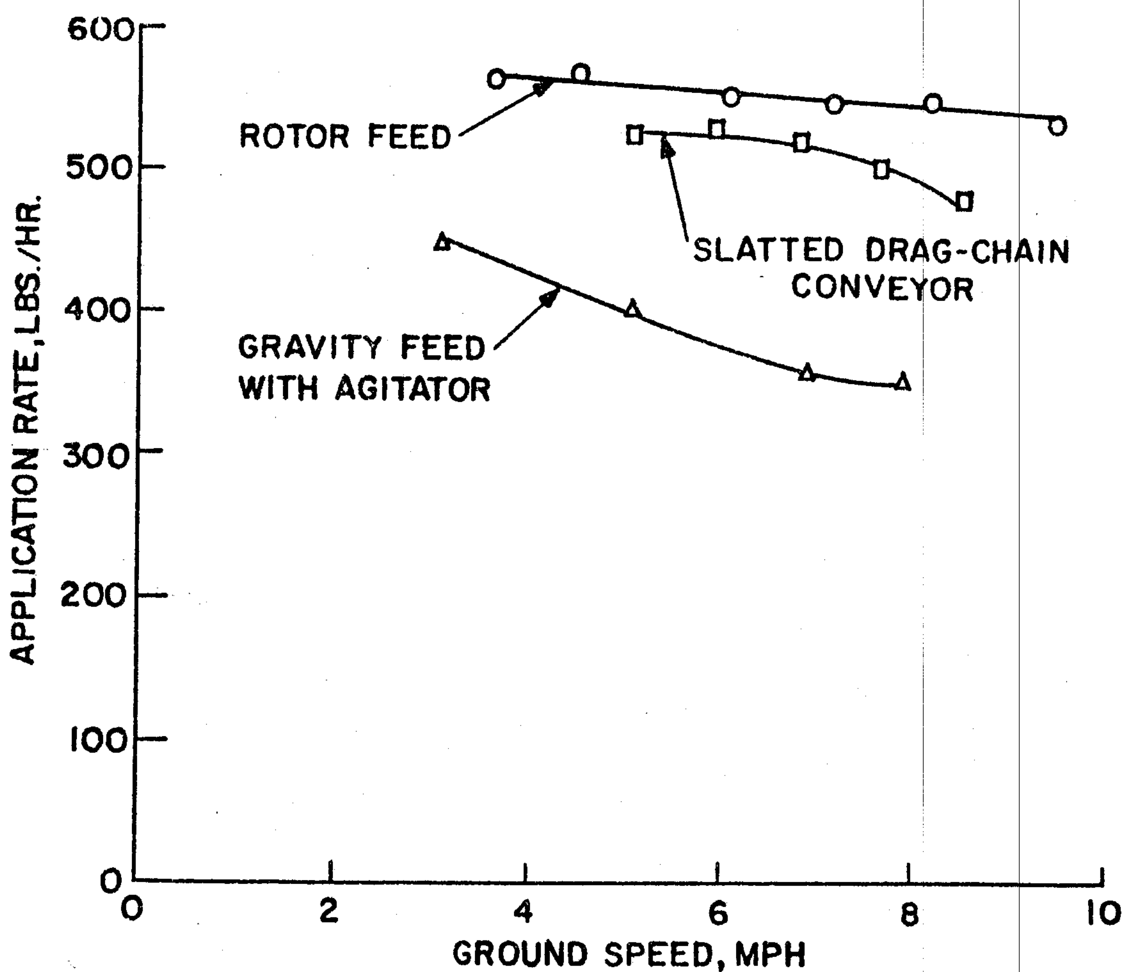


Fig. 3
Effect of ground speed on application rate for three feed mechanisms (13).

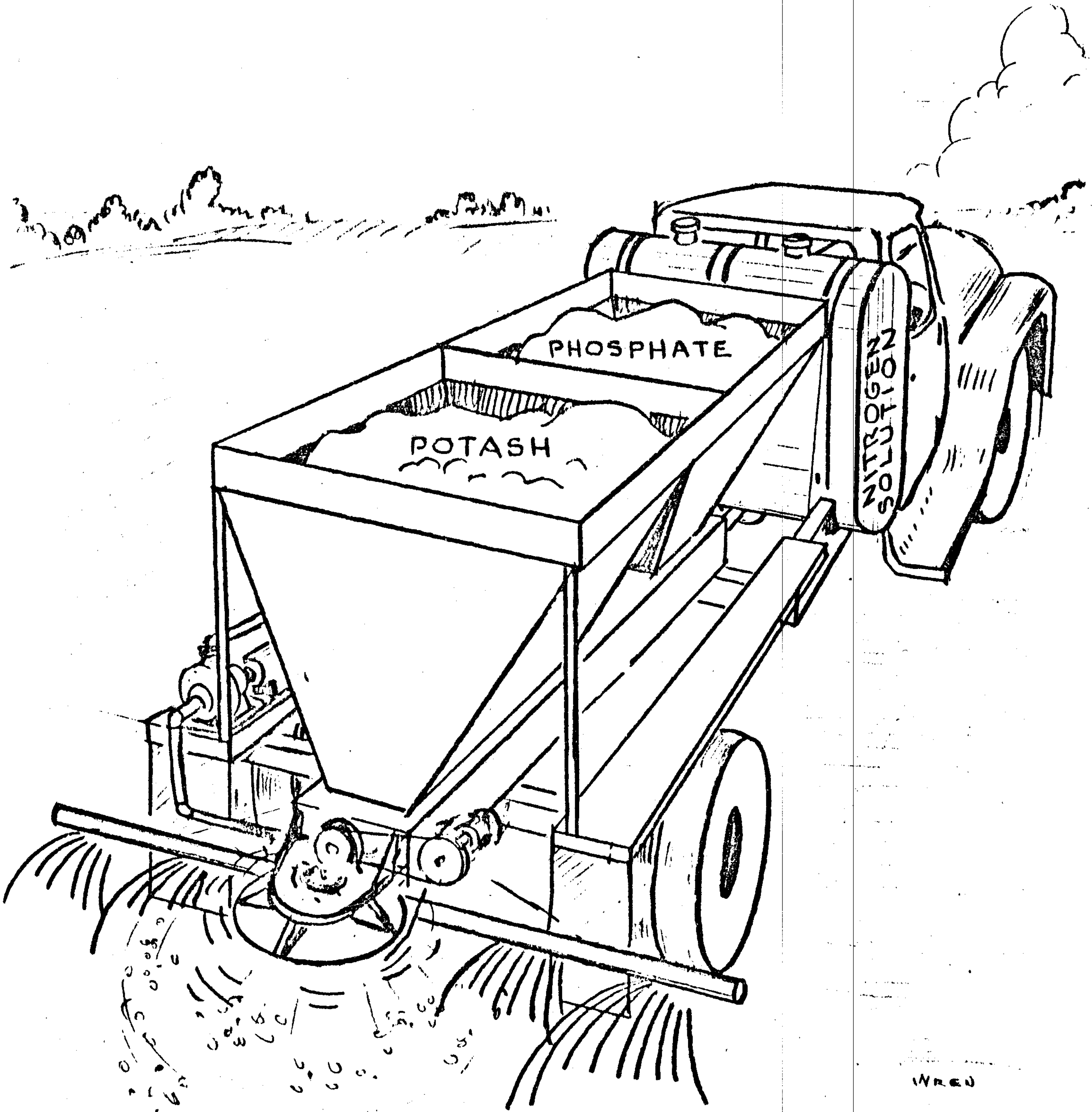


Fig. 4
Two hopper blender-spreader truck equipped to apply nitrogen solutions.

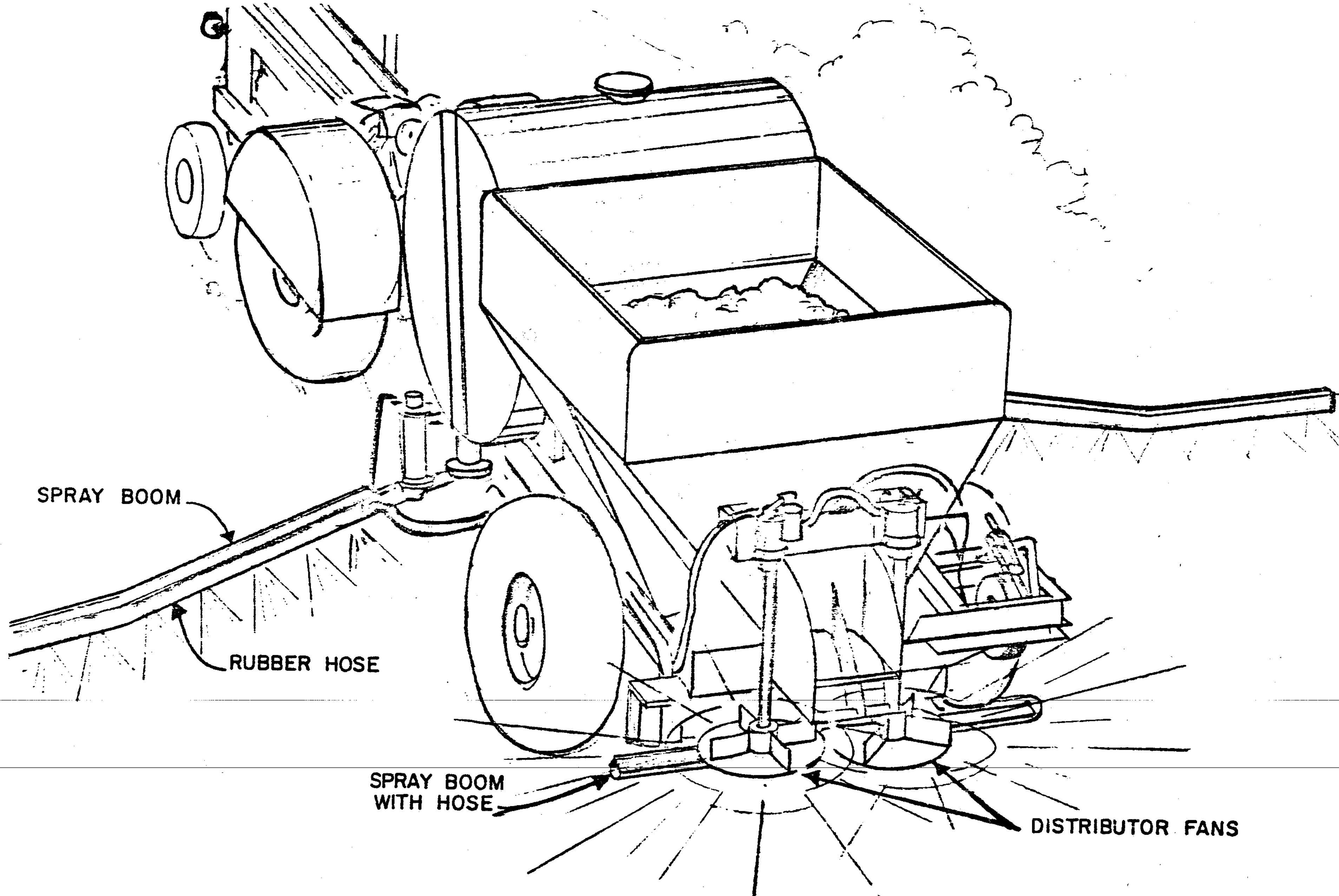


Fig. 5. Liquid-dry trailer spreader commonly used for Florida citrus.

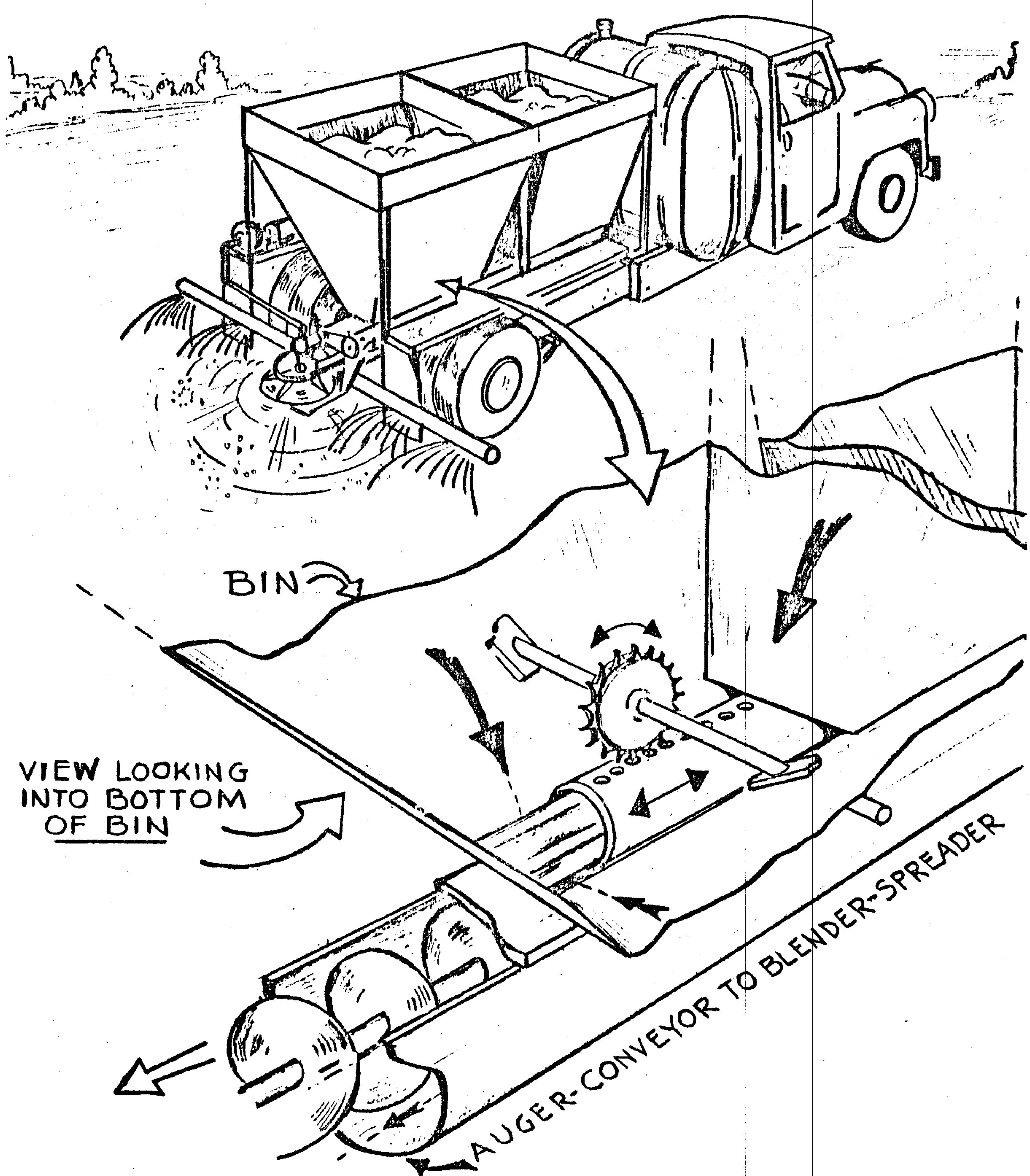


Fig. 6. Fluted cylinder feed and auger conveyor on a blender-spreader.

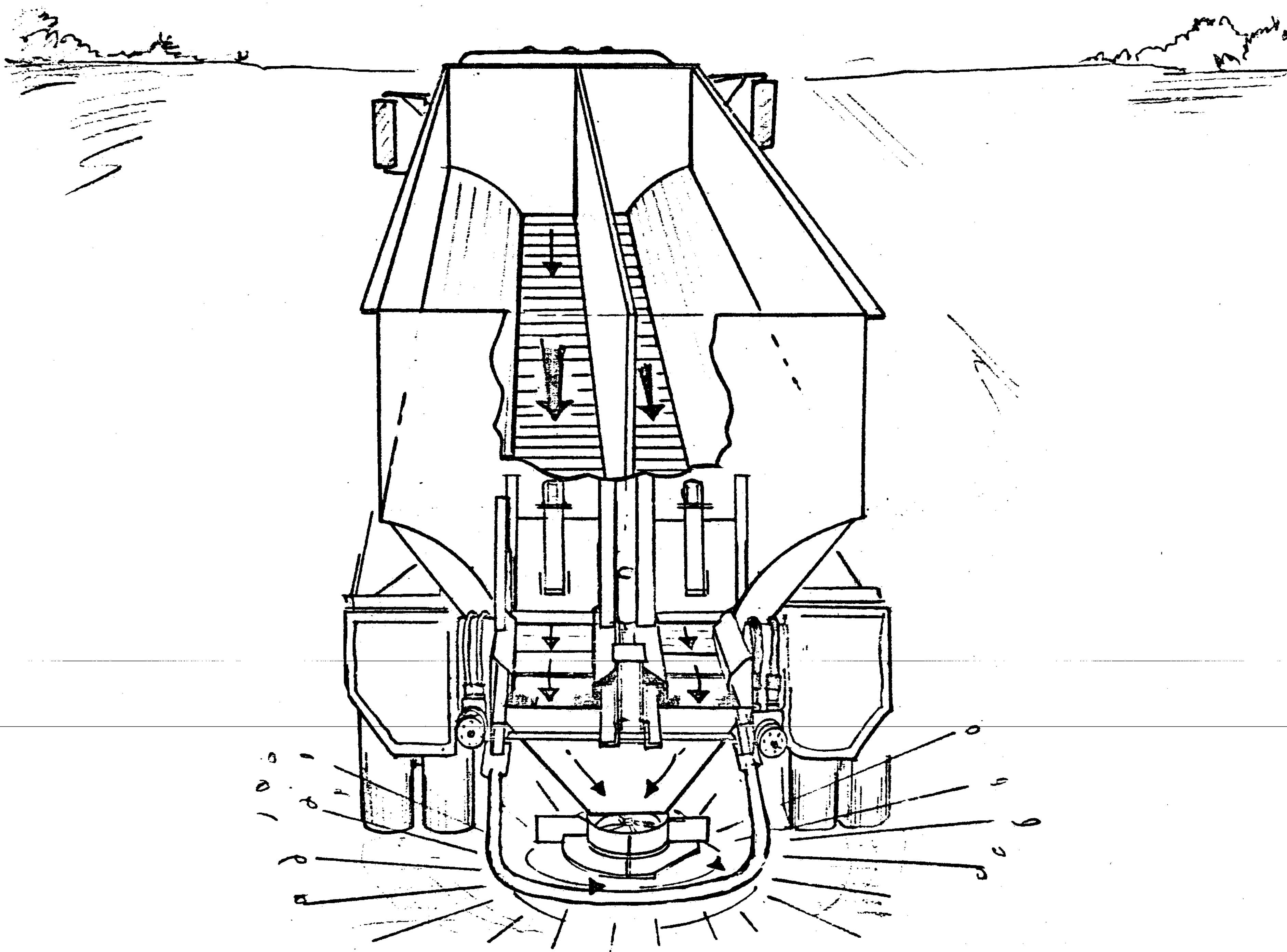

Fig. 7. Blender-spreader which blends with a specially designed spinner.

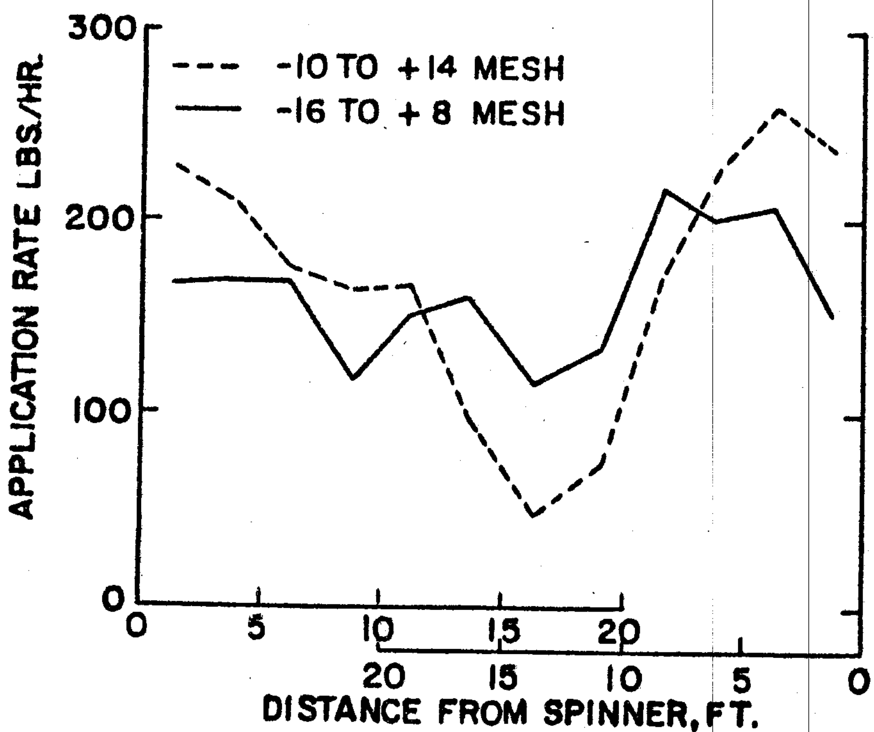


Fig. 8.
Effect of particle size on distribution of fertilizer by a single spinner spreader (18).

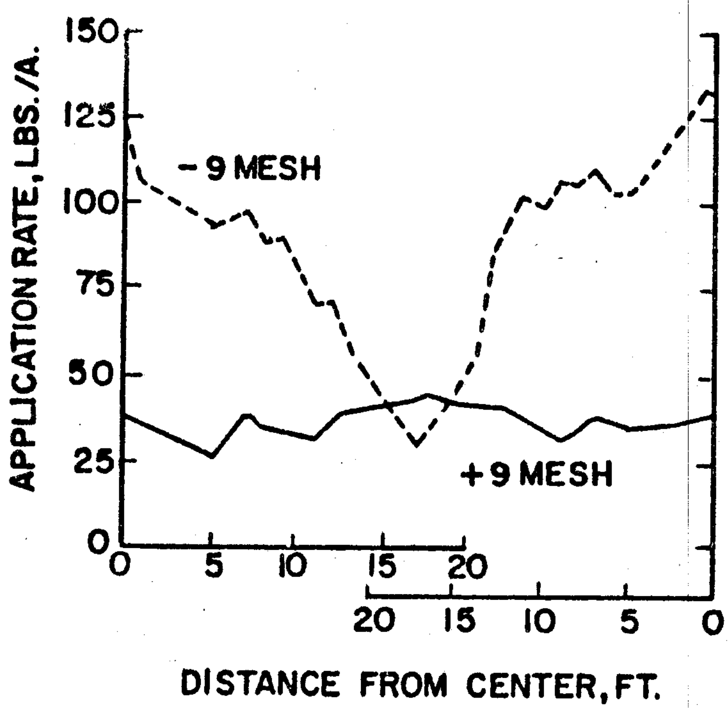


Fig. 9.
Effect of particle size on distribution of
fertilizer by a two-spinner spreader (12).

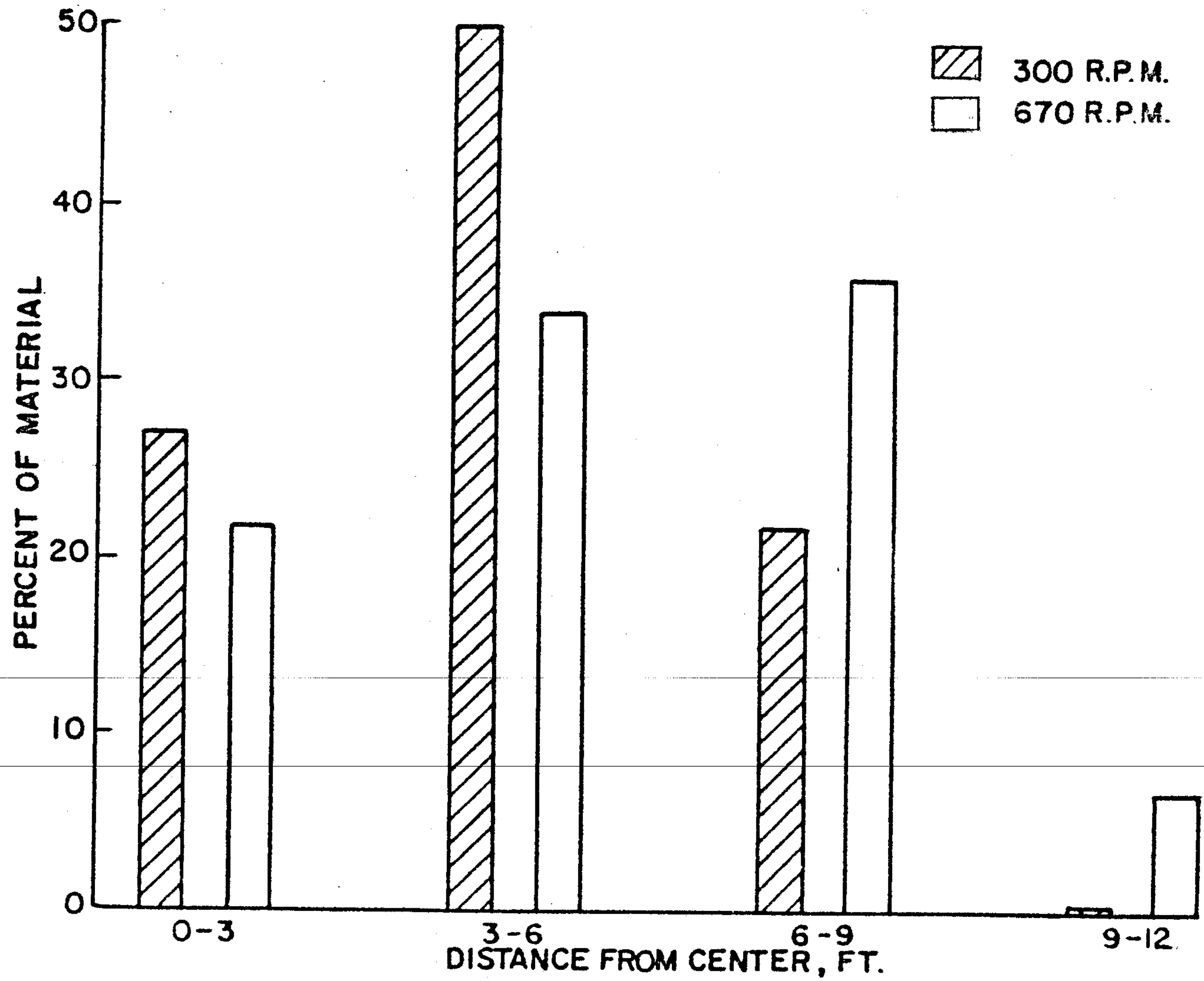


Fig. 10. Effect of spinner speed on distribution of -10+32 mesh limestone particles (29).

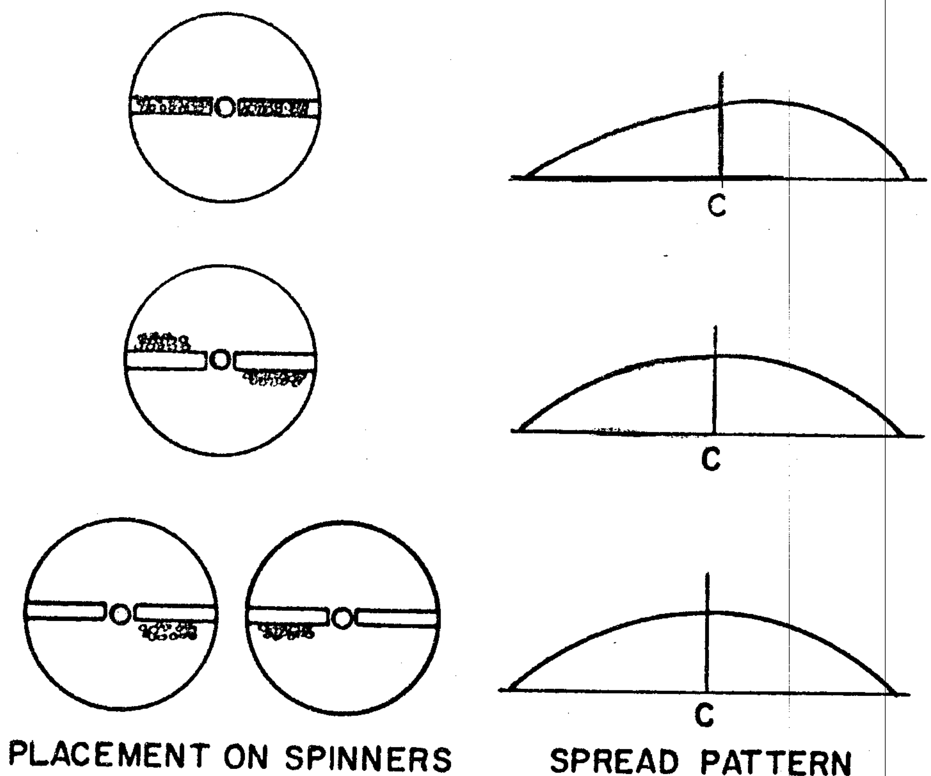


Fig. 11.
Spread pattern of fertilizer as influenced by placement on spinners (29).

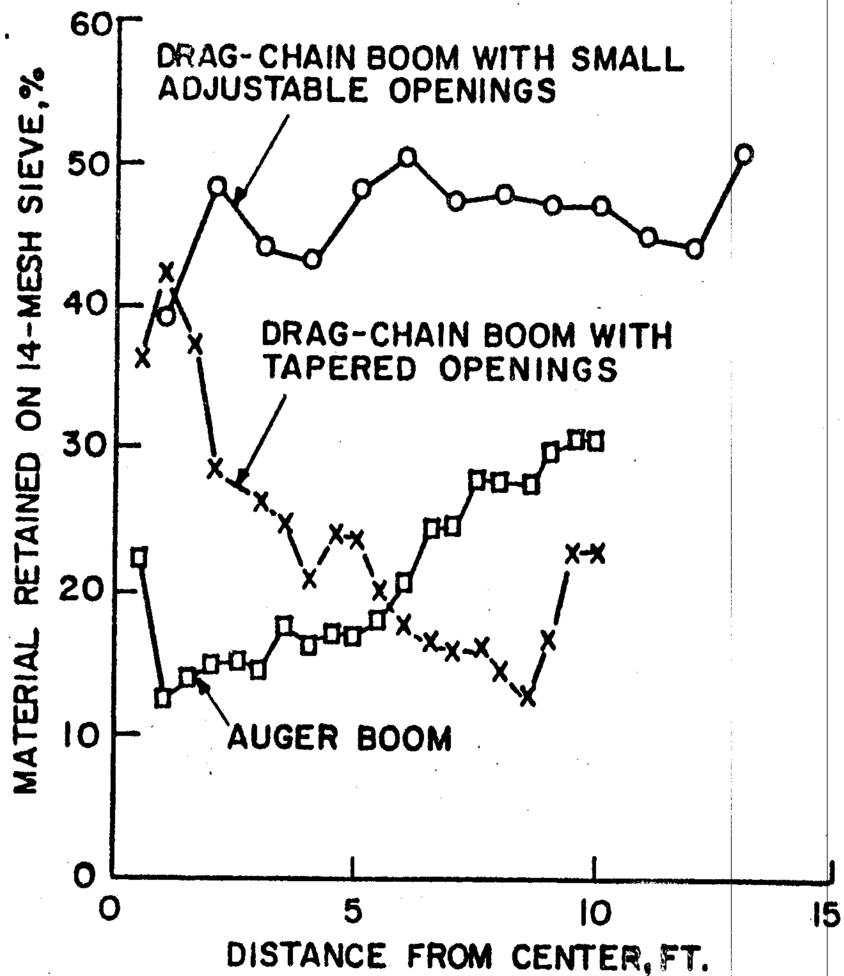


Fig. 12. Fertilizer particle size segregation from boom-type spreaders.

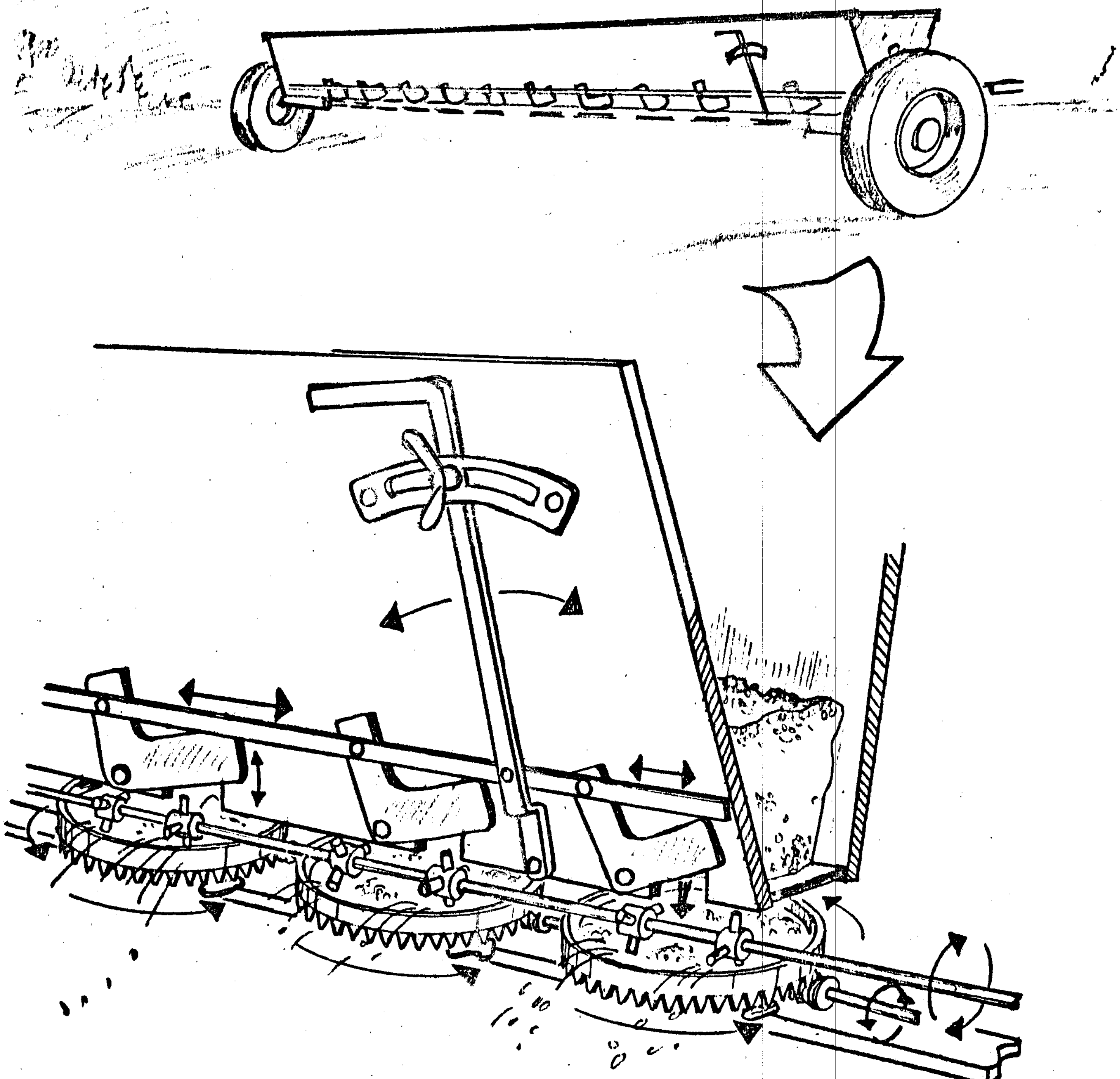

Fig. 13.
Plate-and-flicker spreader.

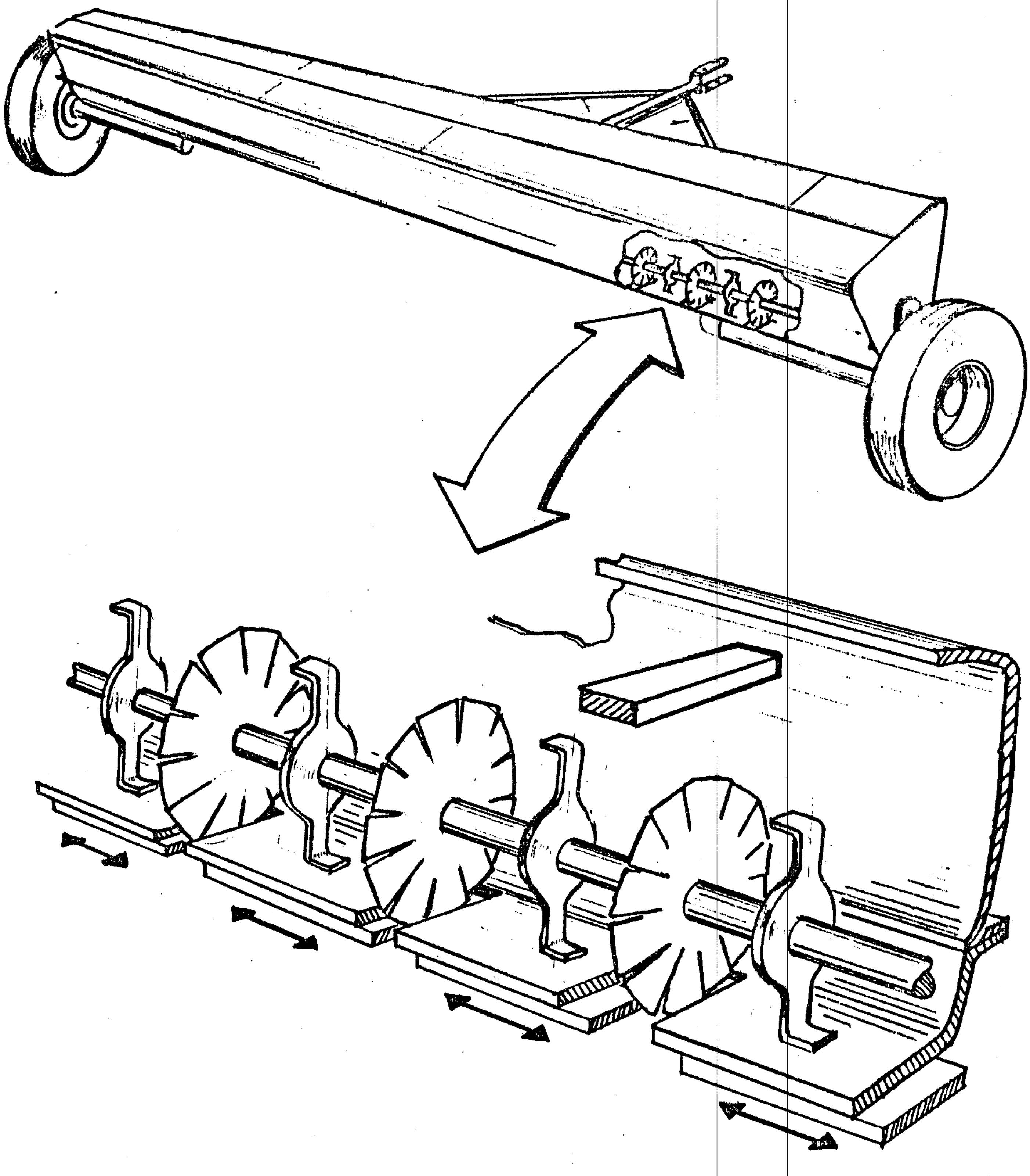

Fig. 14.
Gravity flow spreader with an agitator.

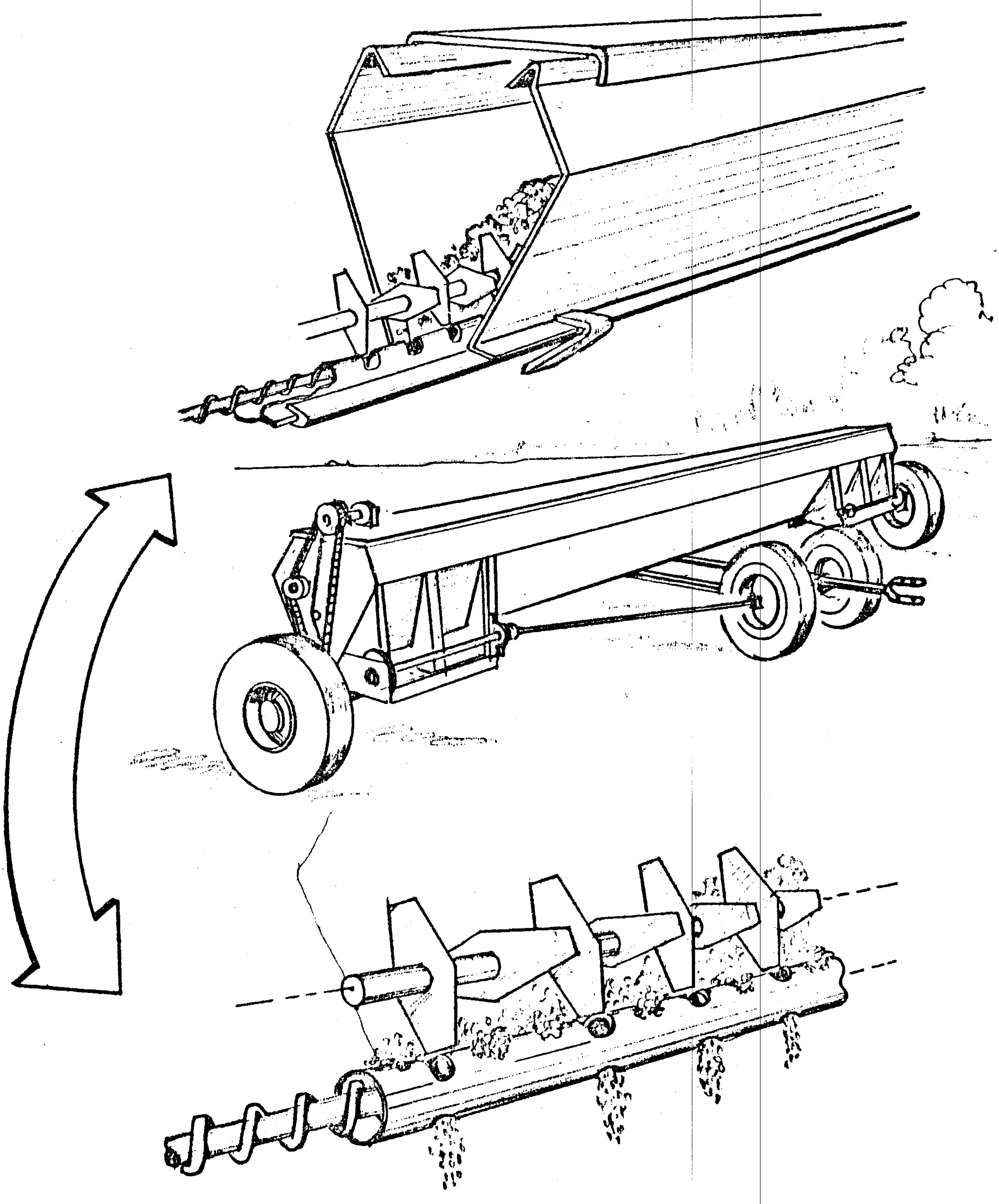

Fig. 15. Auger feed broadcast spreader.

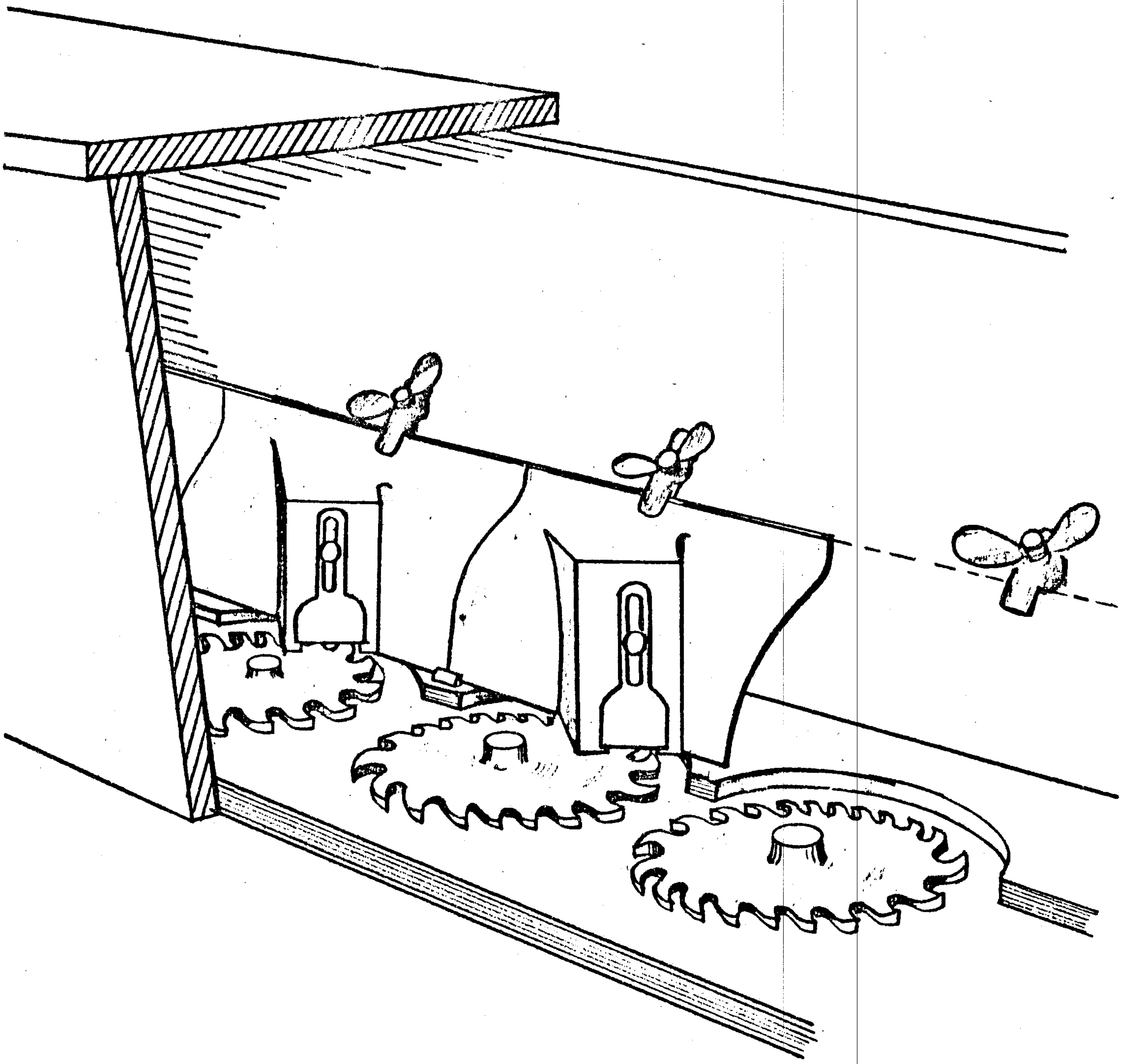

Fig. 16.
Star wheel feed type broadcast spreader.

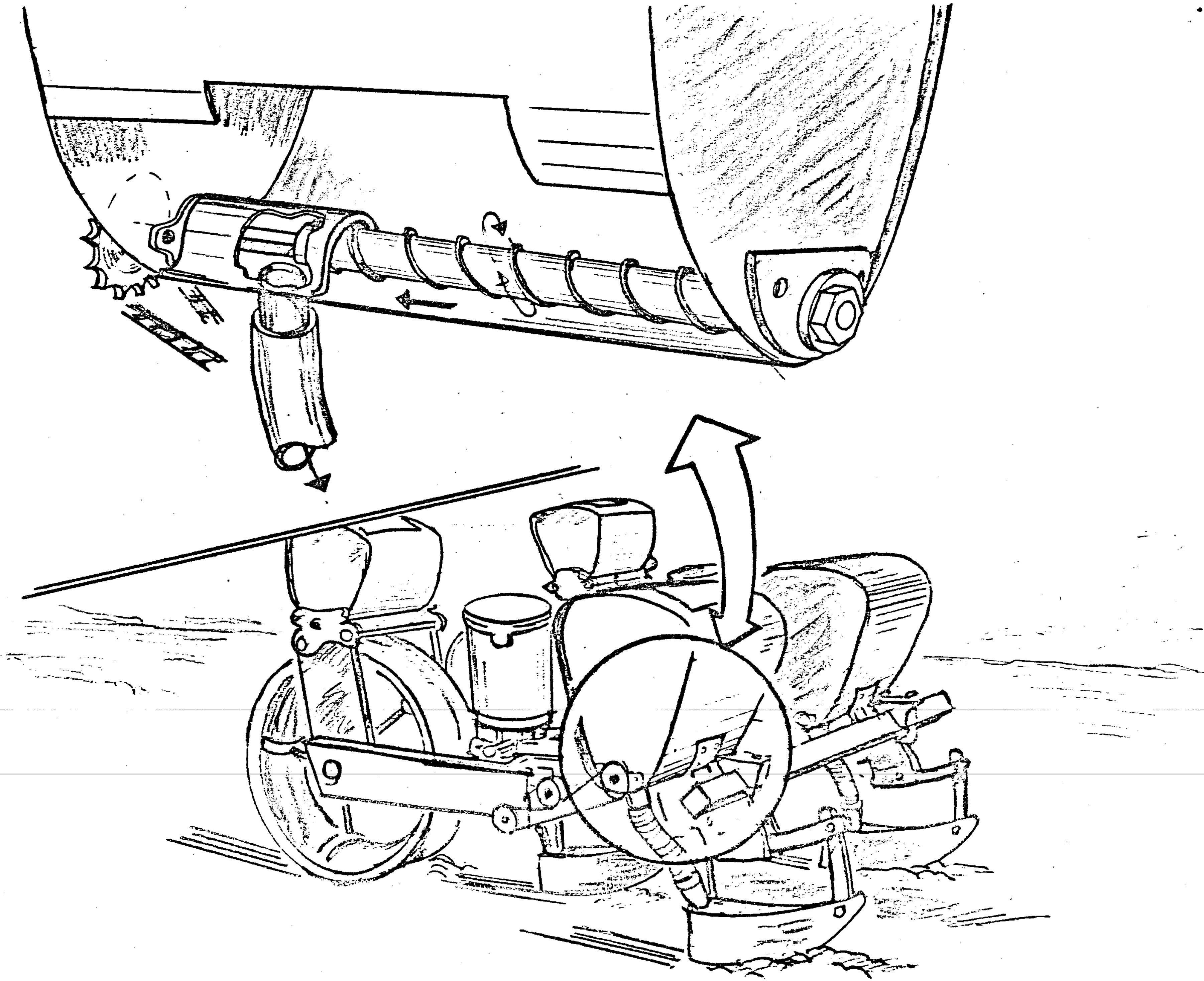

Fig. 17. Auger feed type of band applicator.

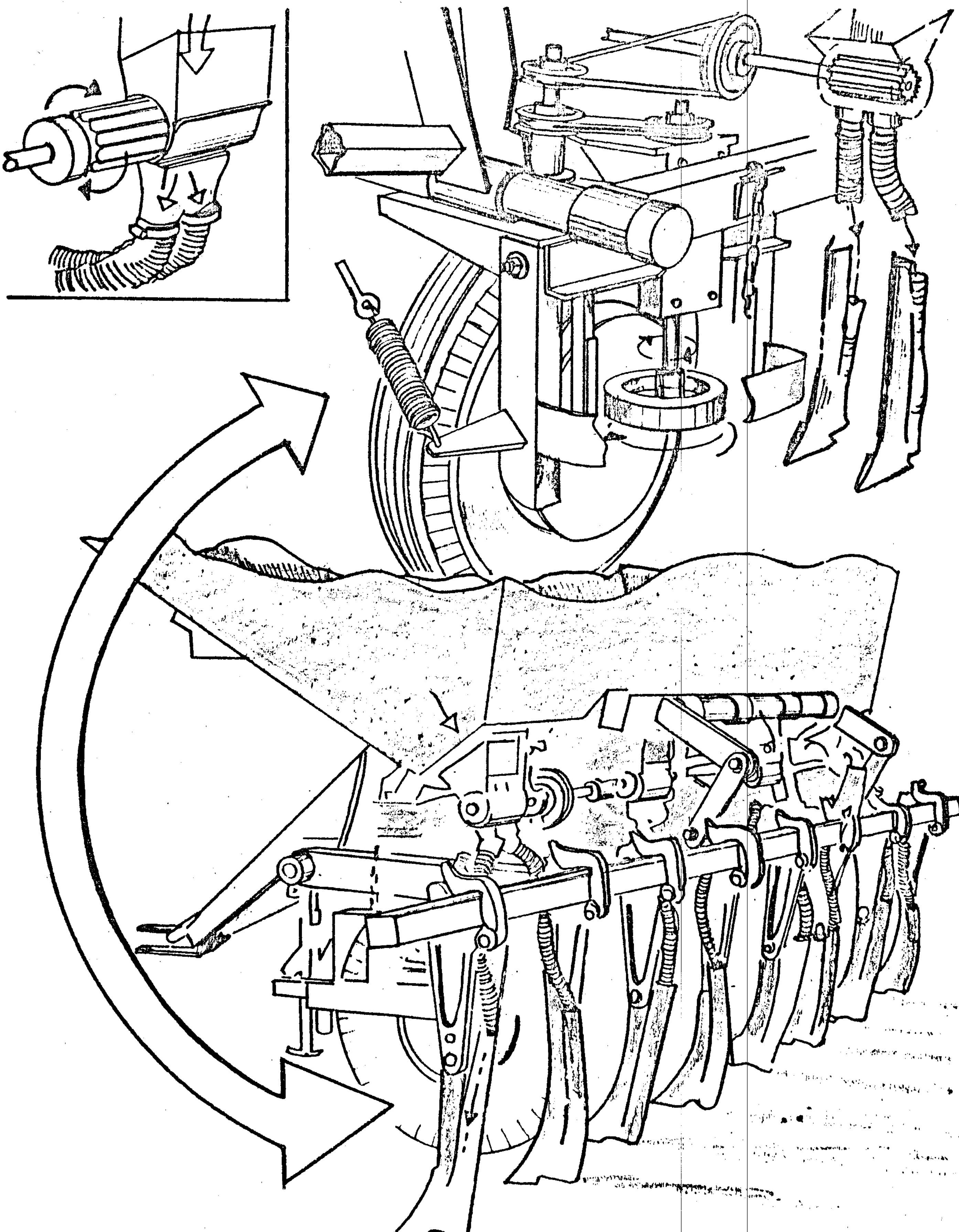

Fig. 18. Fluted rotor feed type of band applicator.

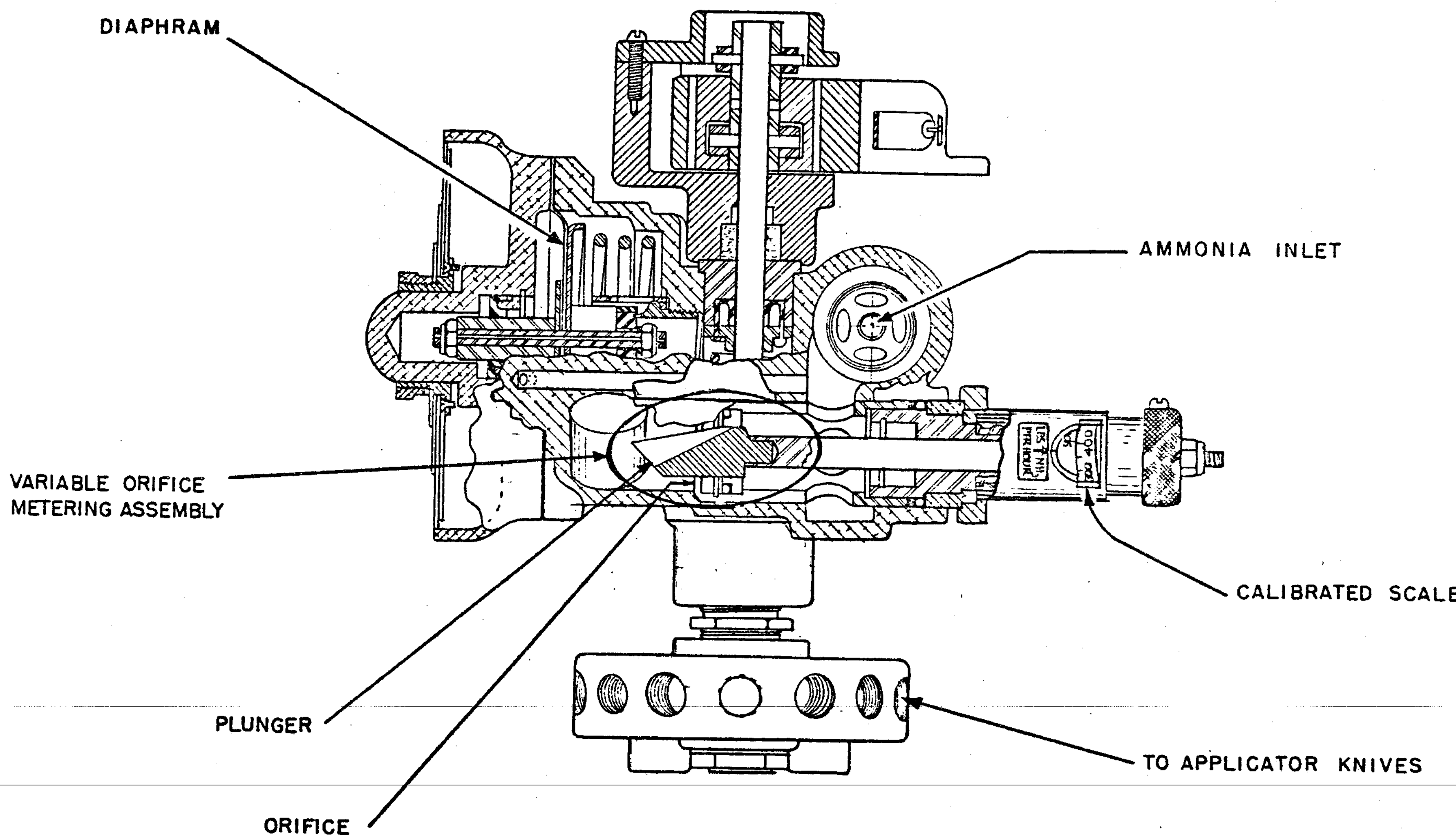


Fig. 19.
Variable orifice meter for anhydrous ammonia applicator.

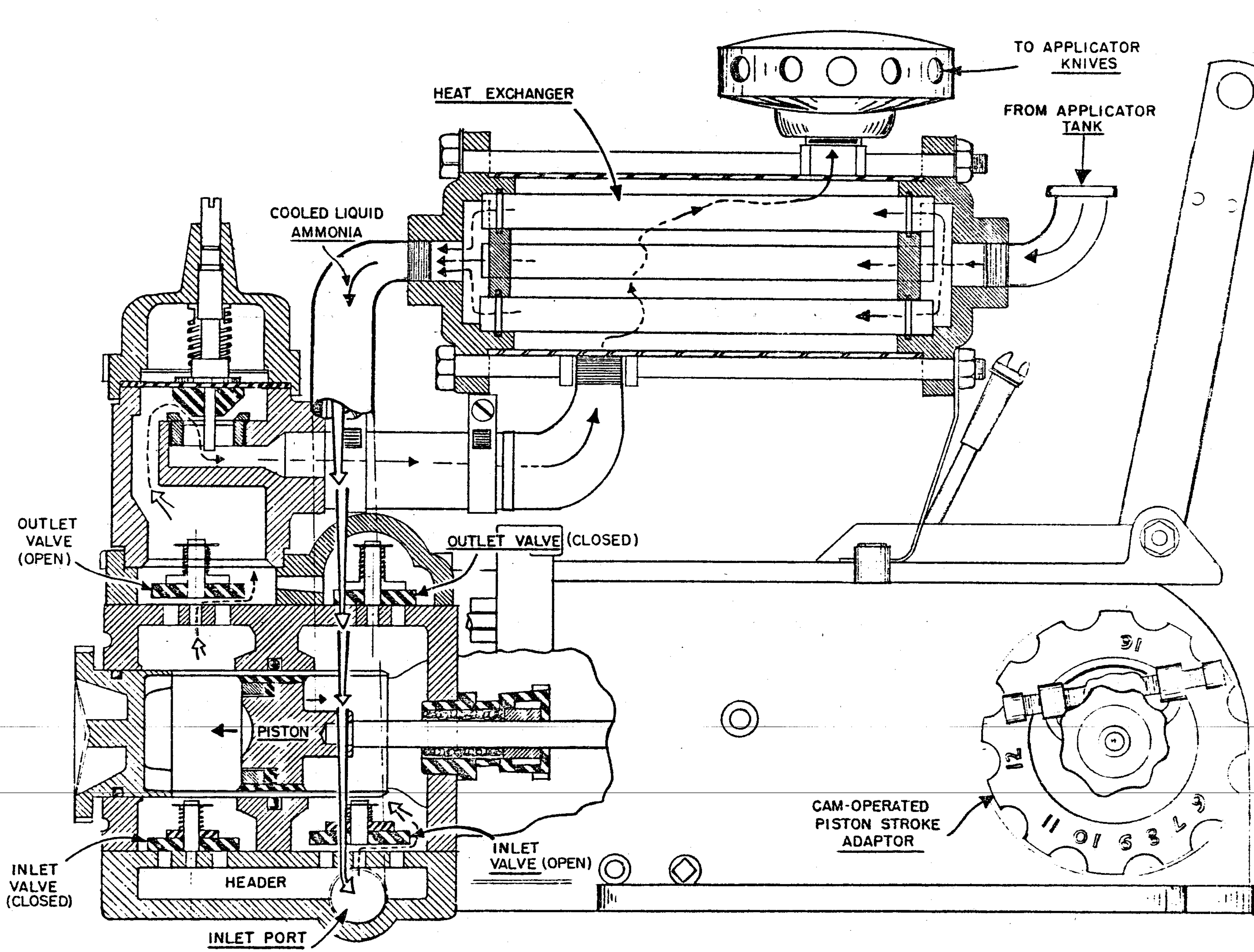


Fig. 20.
Anhydrous ammonia metering pump.

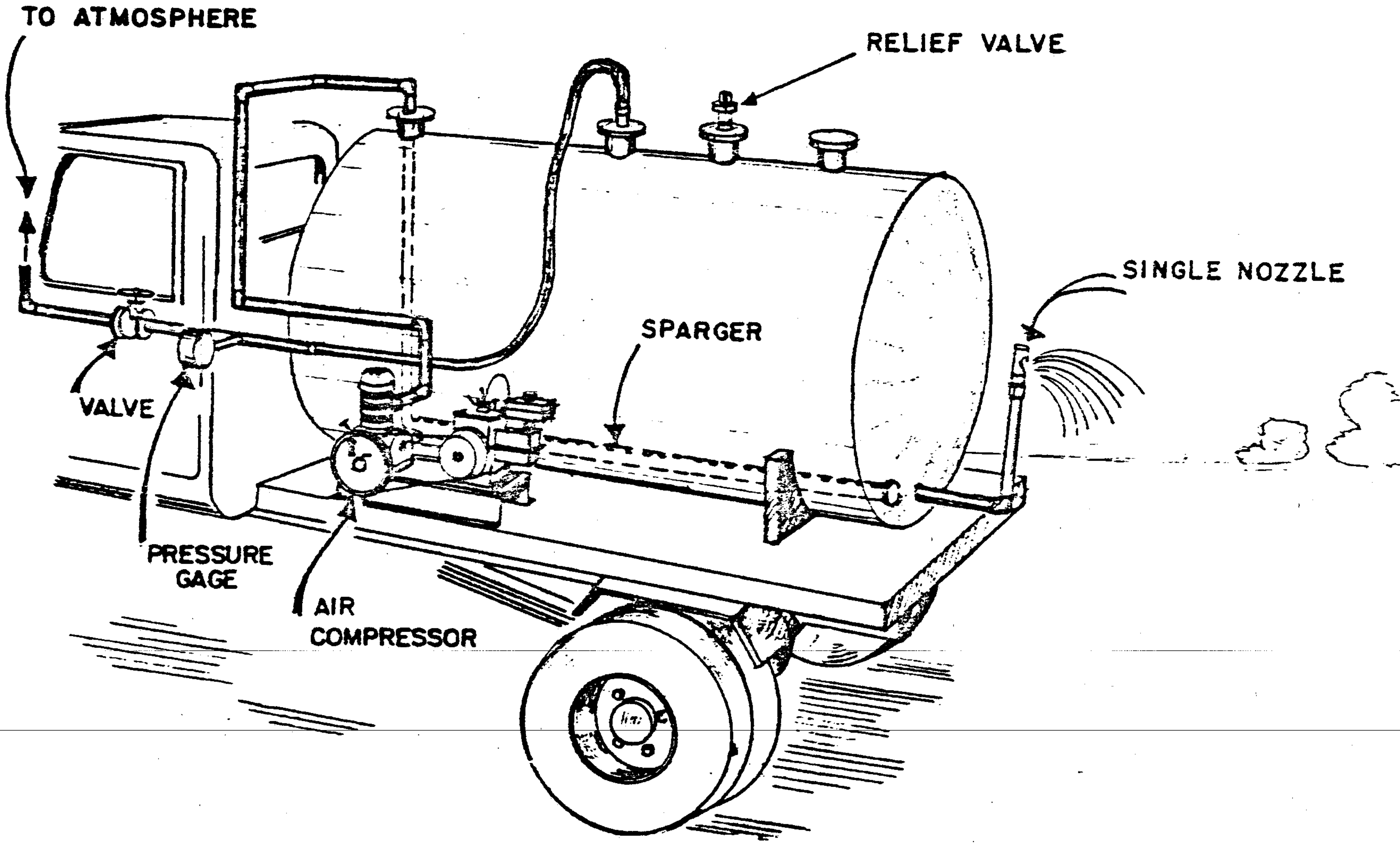


Fig. 21. Truck mounted pneumatic operated broadcast applicator for fluid fertilizers.

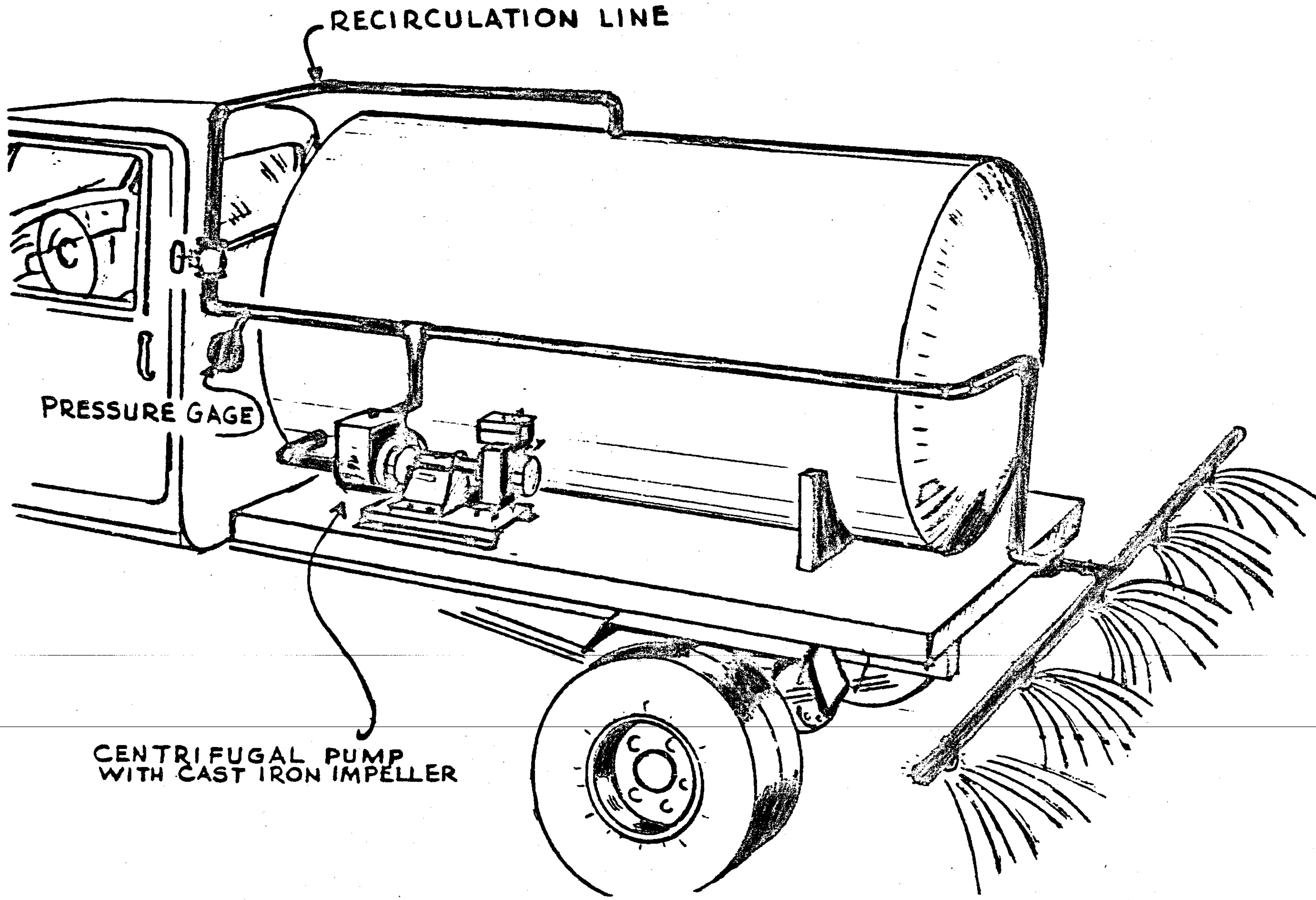


Fig. 22. Truck mounted hydraulic operated broadcast applicator for fluid fertilizers.

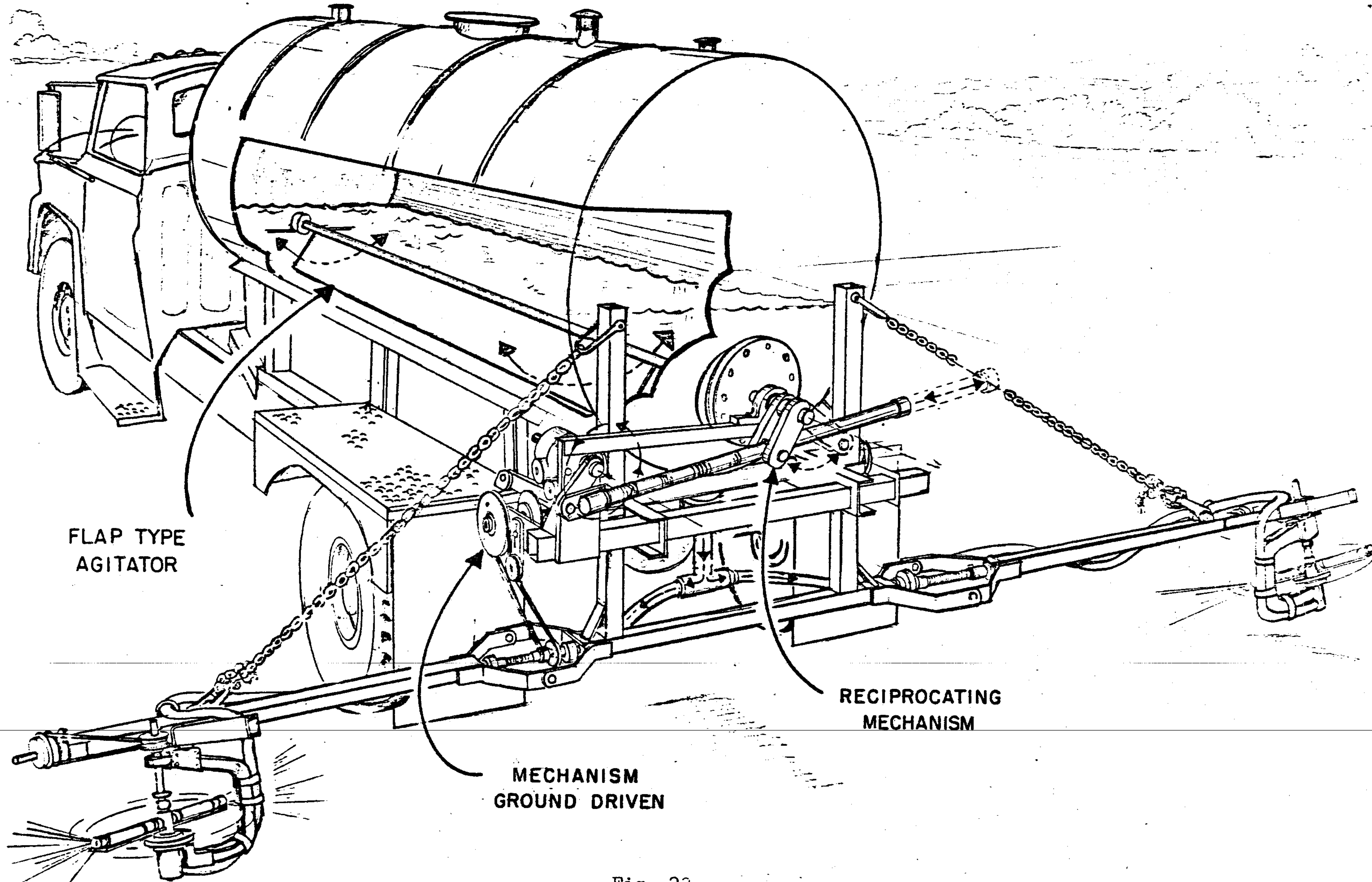


Fig. 23.
Truck mounted slinger type applicator for suspensions.

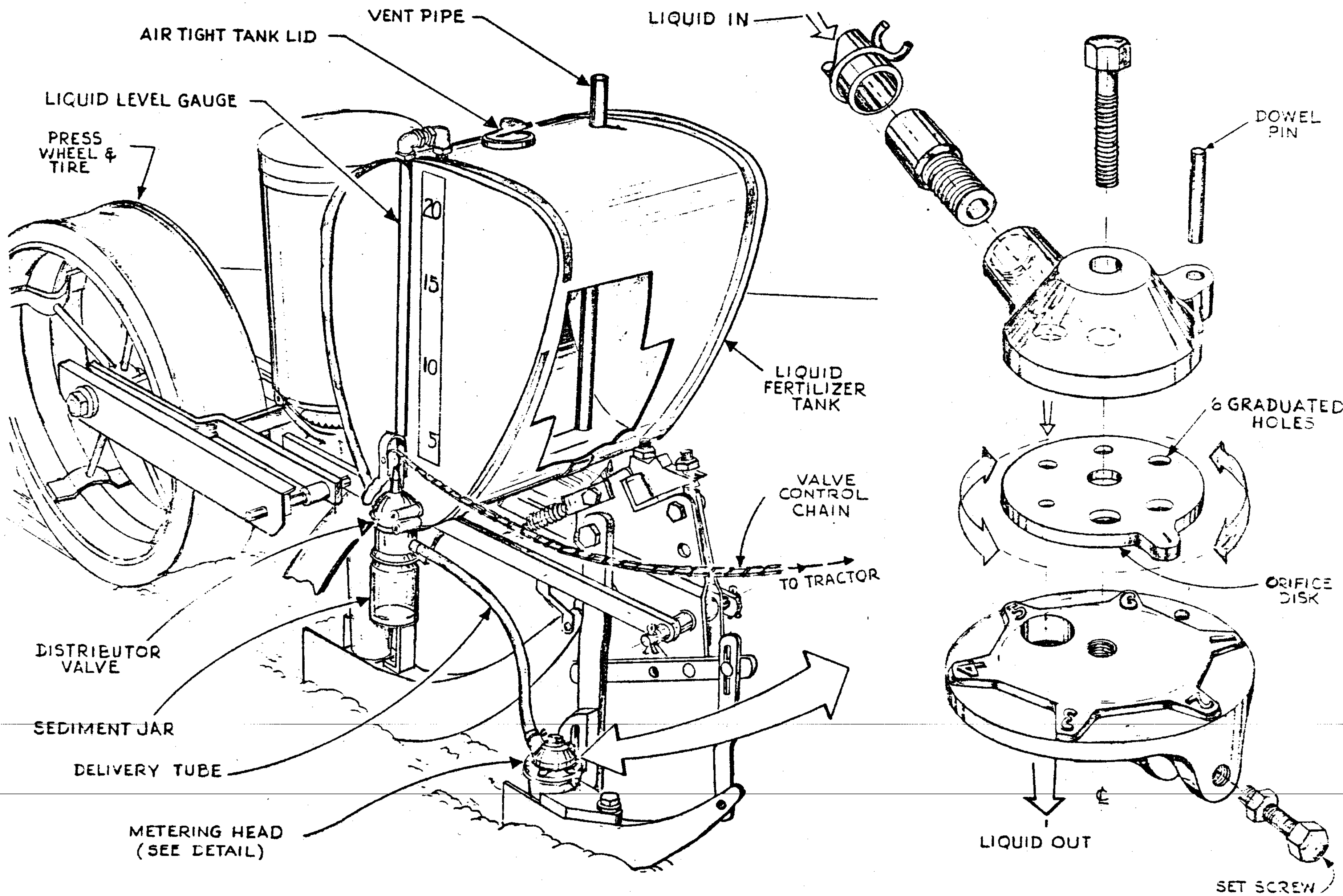


Fig. 24. Constant-head gravity-flow fluid fertilizer applicator and orifice plates.

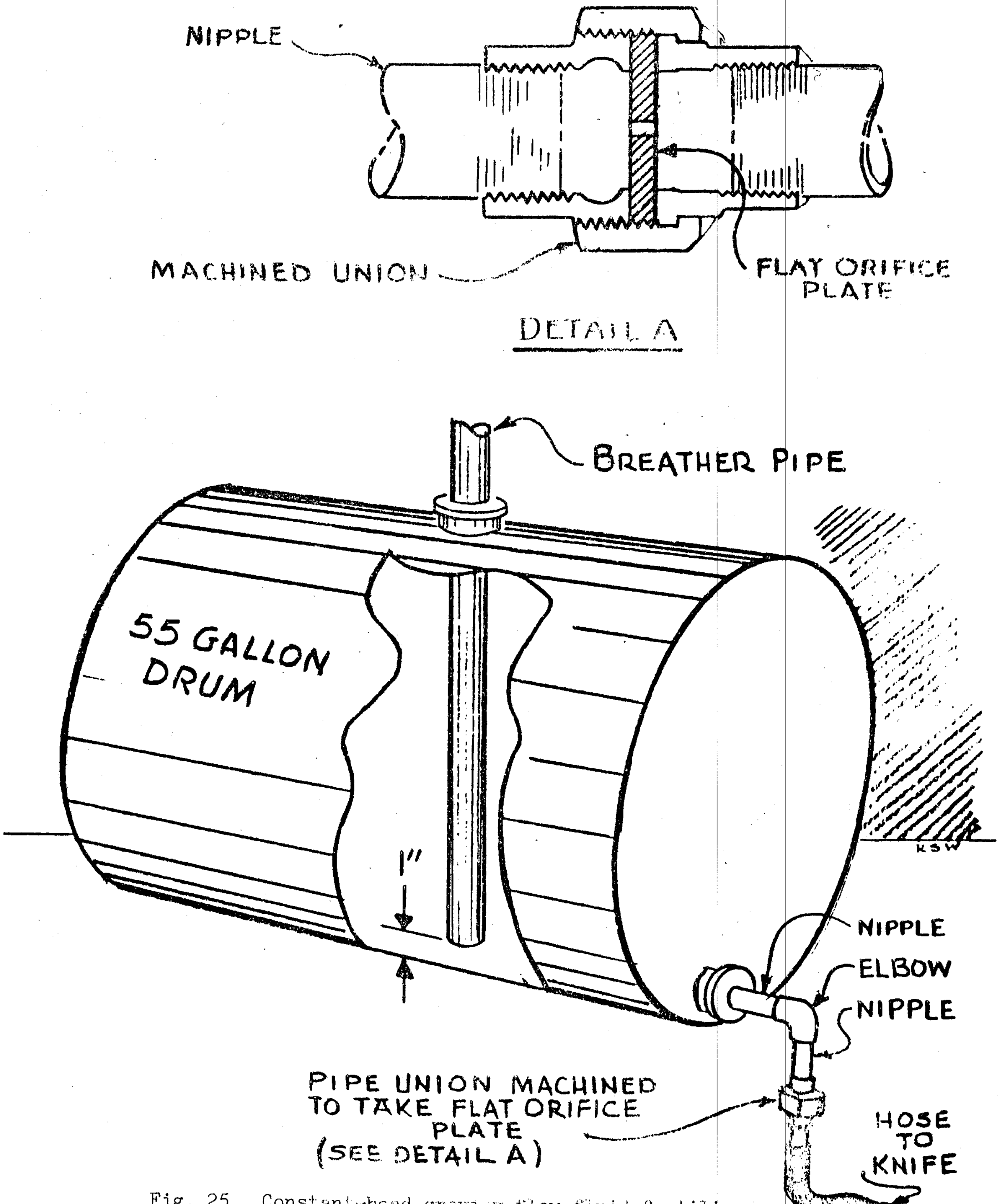


Fig. 25. Constant-head gravity-flow fluid fertilizer applicator constructed from 55-gallon drum.

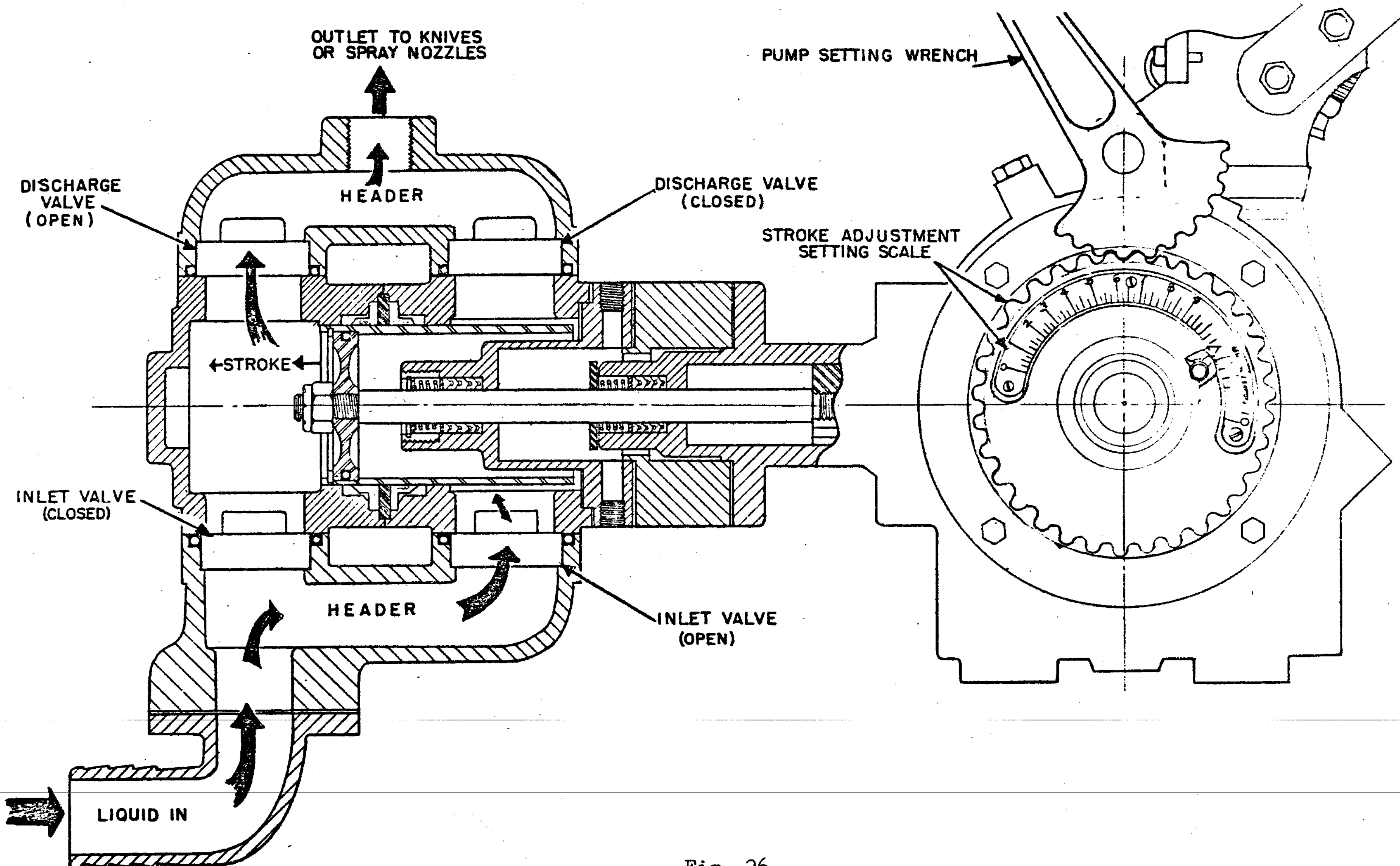


Fig. 26.
Fluid fertilizer piston-type metering pump.

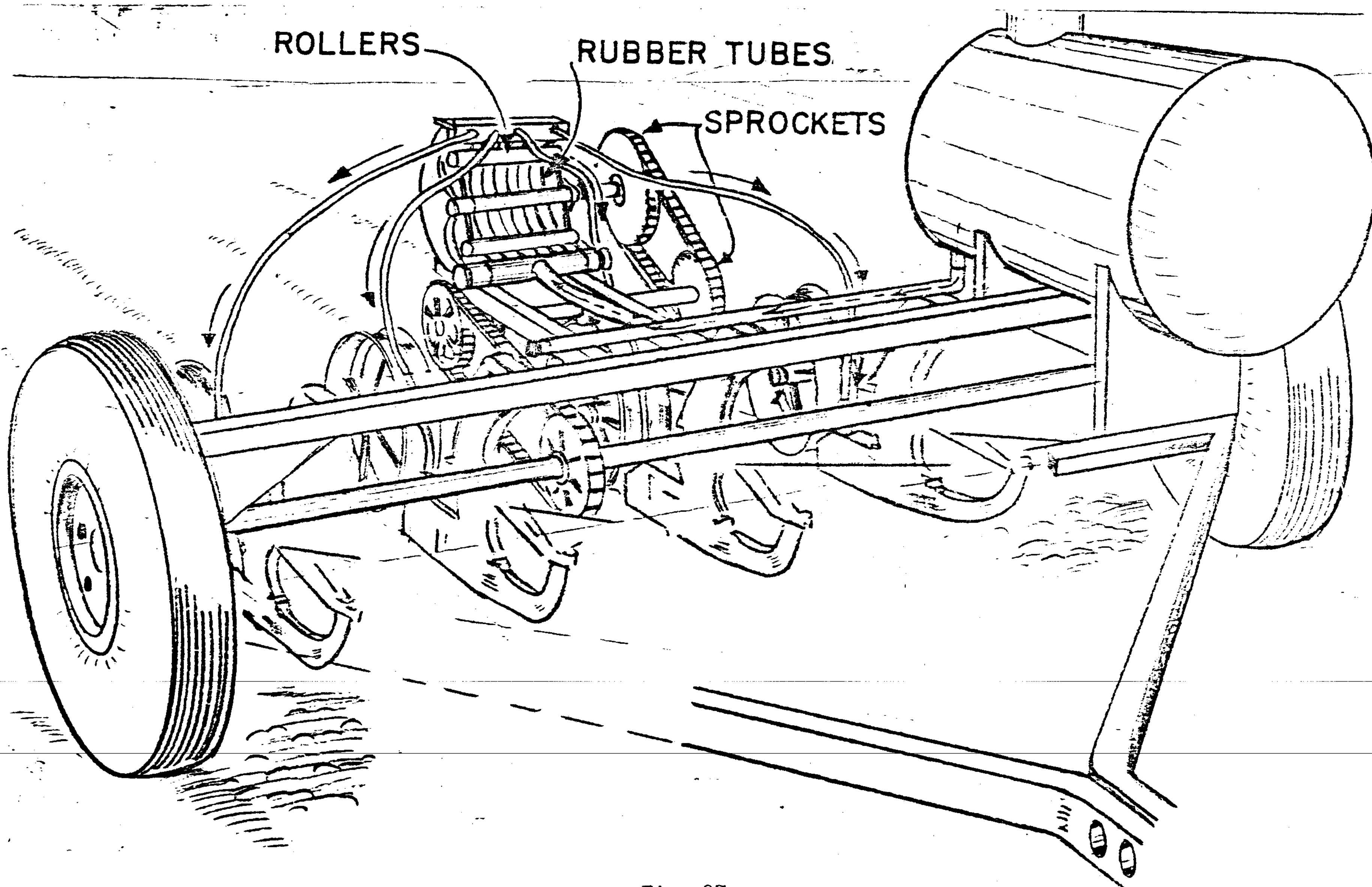


Fig. 27.
Fluid fertilizer applicator equipped with squeeze pump.

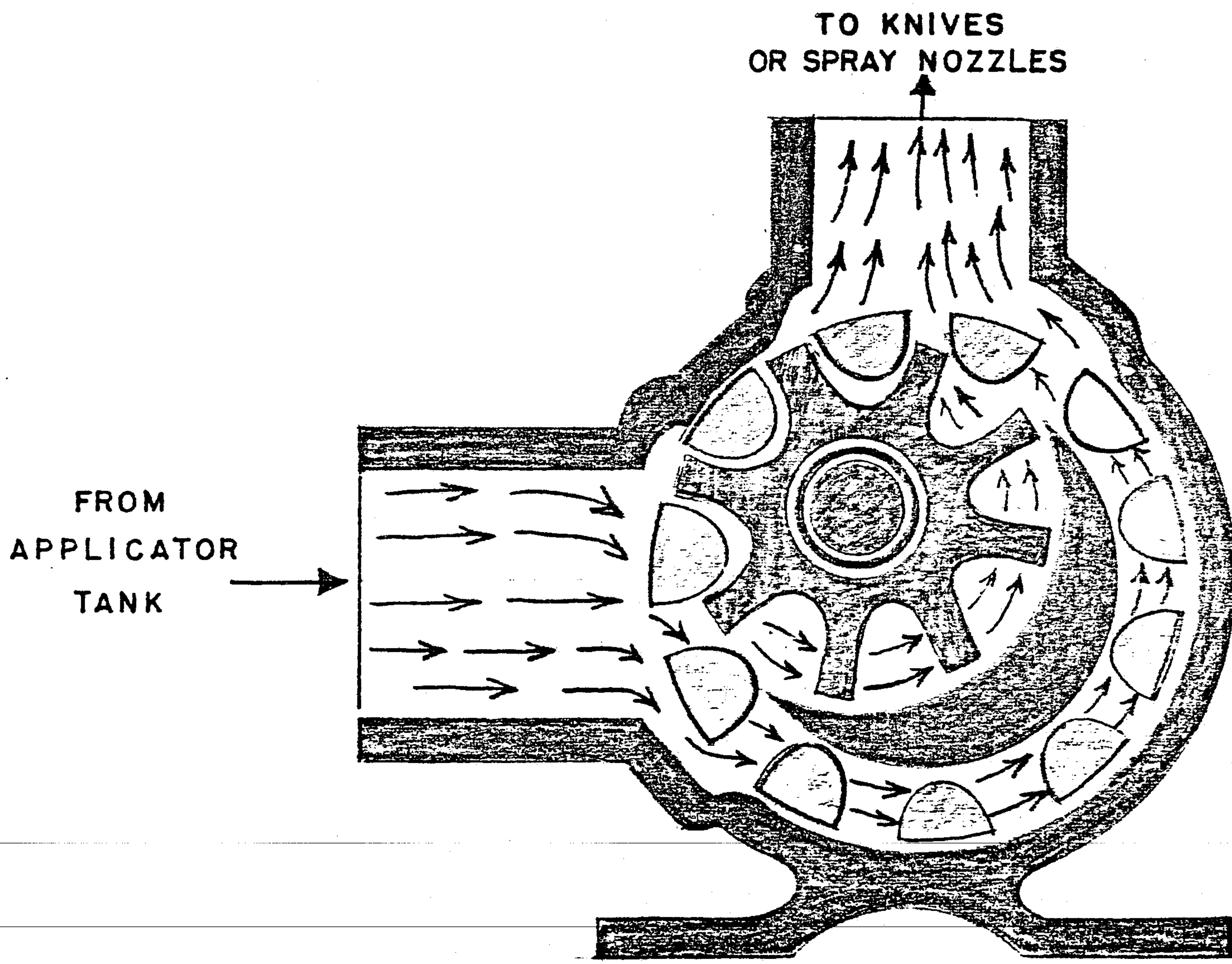


Fig 28.
Internal idle gear pump for fluid fertilizers.

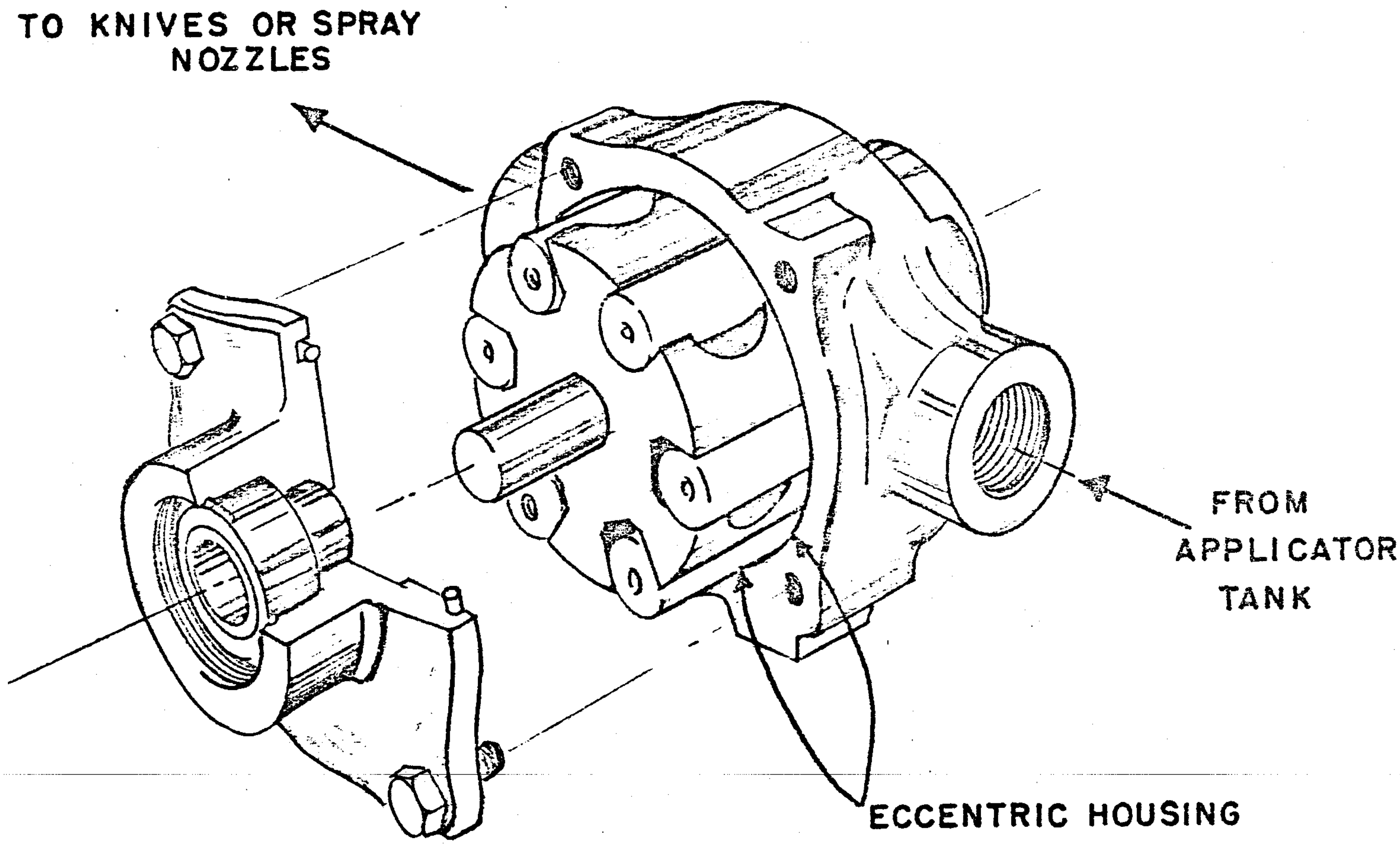


Fig. 29.
Roller impeller pump for fluid fertilizers.

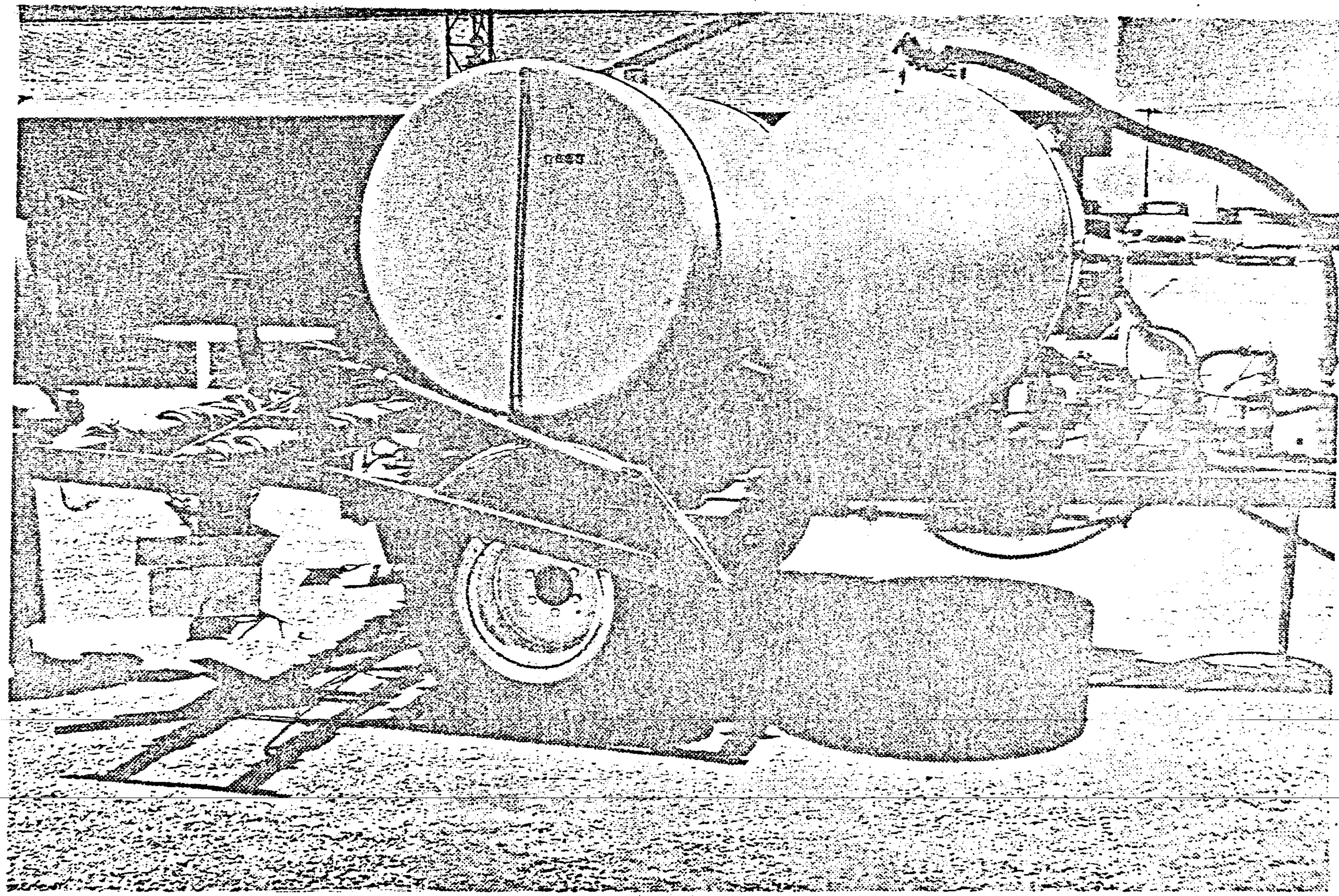

Fig. 30.
Applicator used to simultaneously apply anhydrous ammonia and fluid mixed fertilizer.

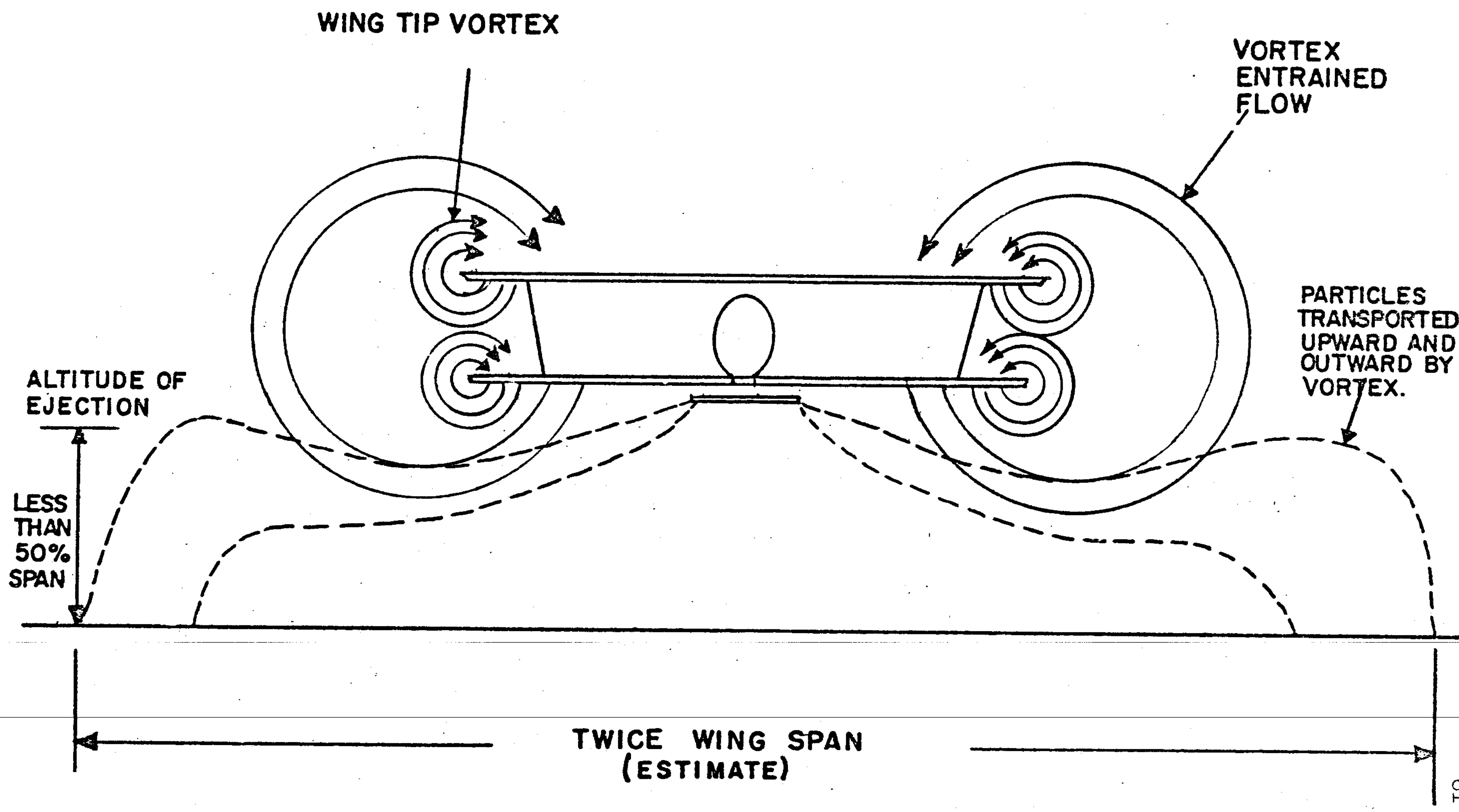


Fig. 31.
Entraining materials in wing-tip vortices (24).

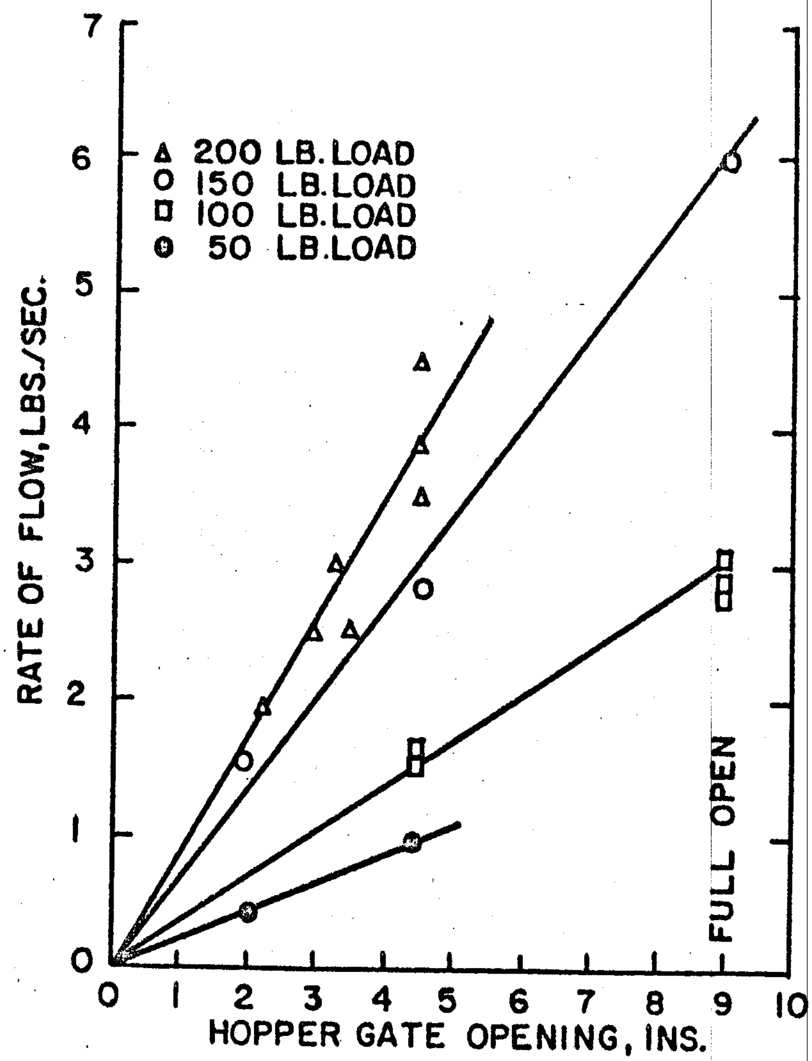


Fig. 32.
Rate of flow from a gravity feed hopper as influenced by hopper loads (24).

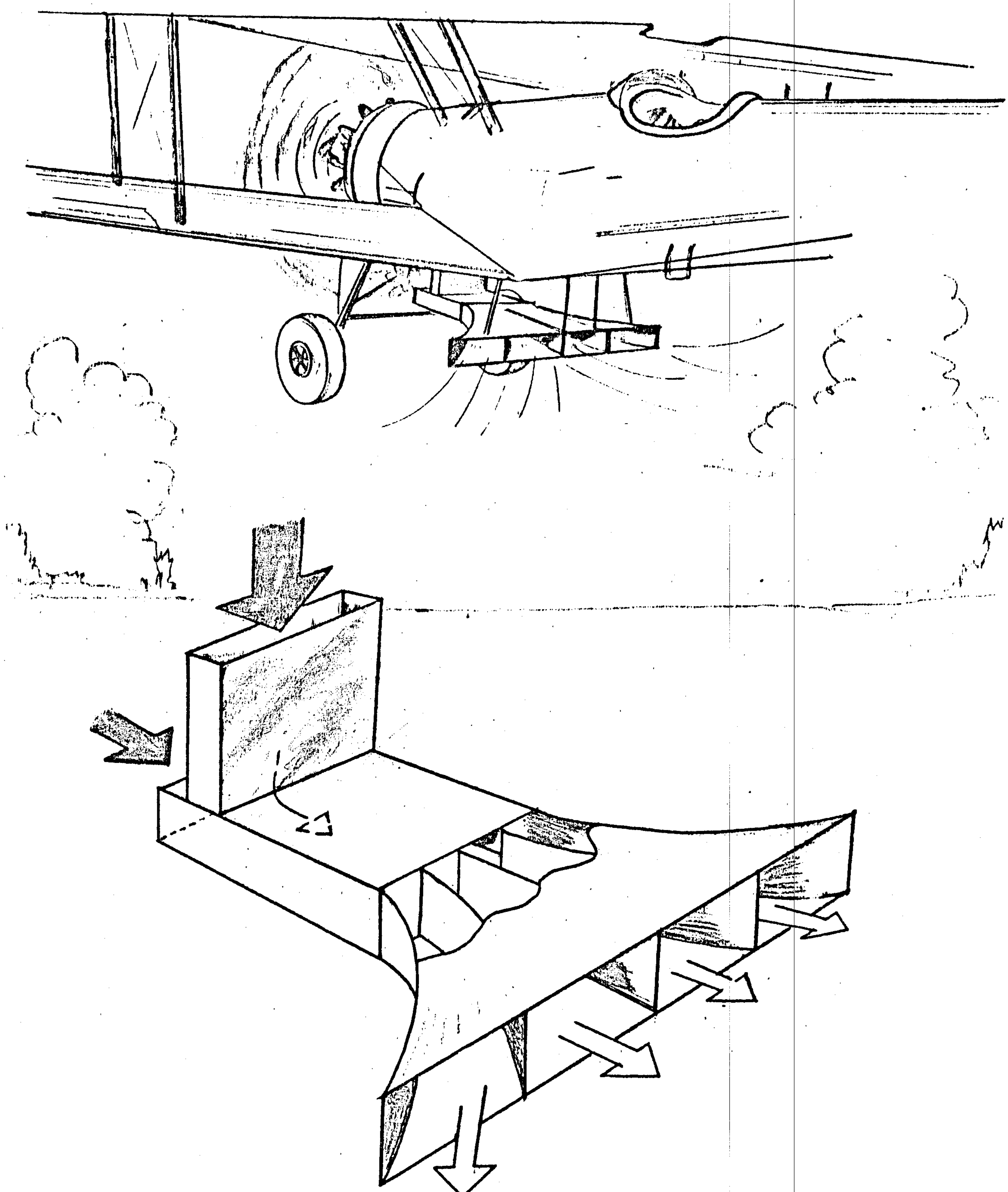

Fig. 33. Single-venturi type aircraft distributor.

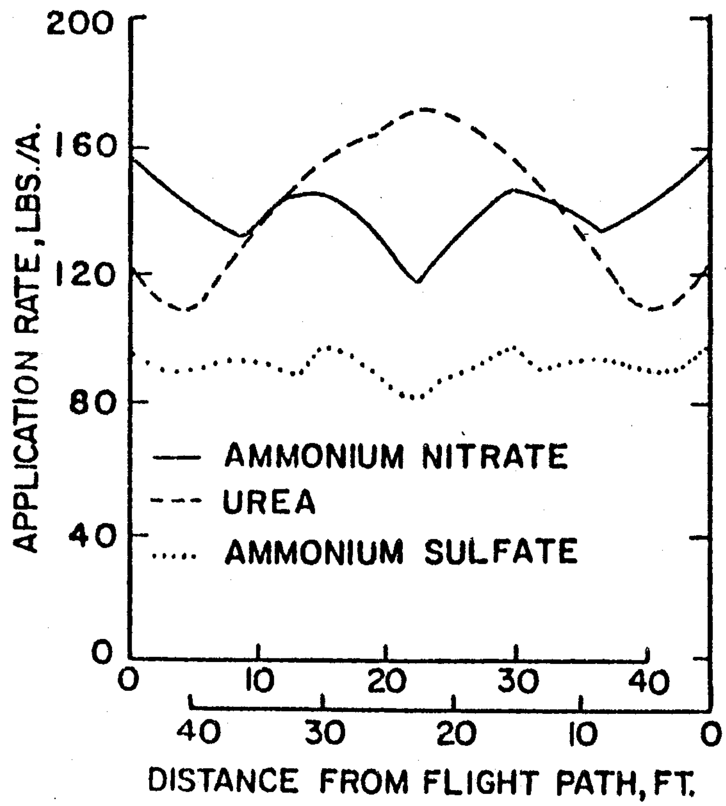


Fig. 34.
Distribution pattern of fertilizer from a single-venturi aircraft distributor (23).

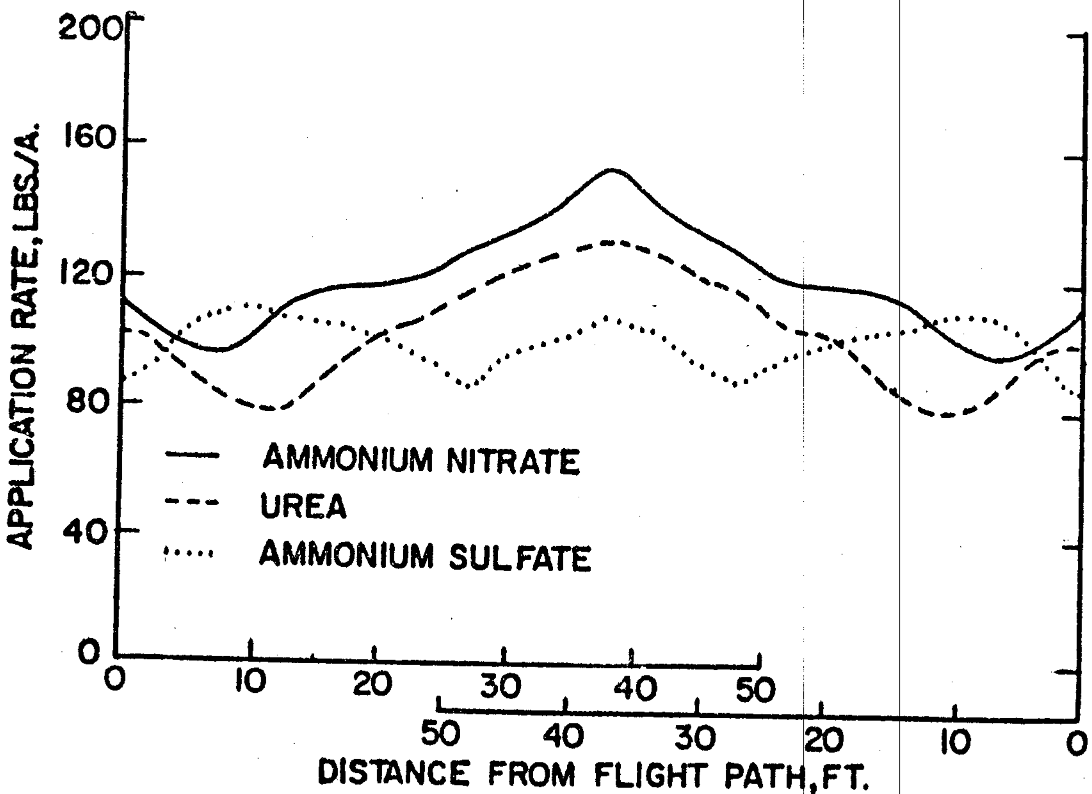


Fig. 35
Distribution pattern of fertilizers from a Swathmater aircraft distributor (23).

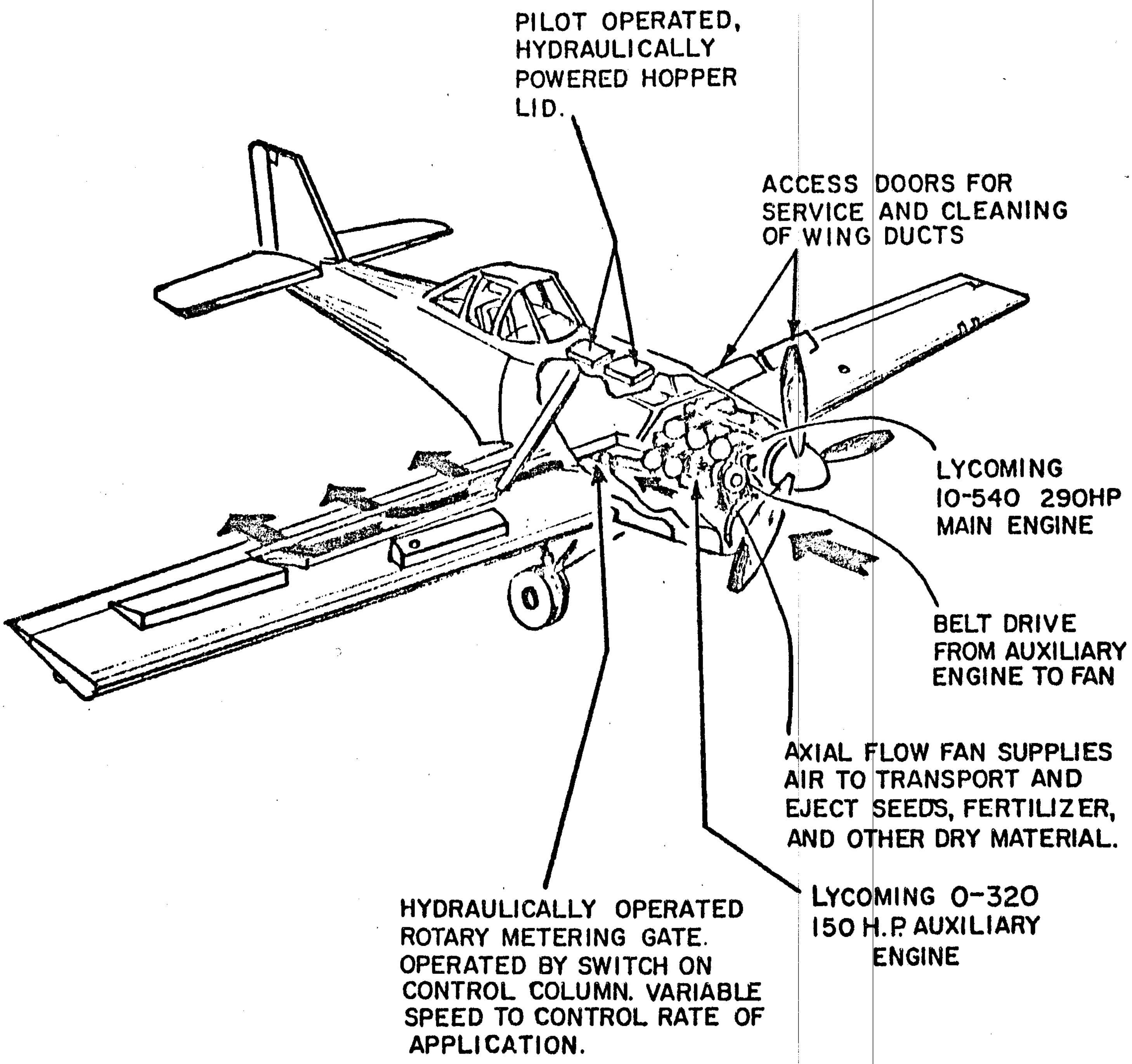


Fig. 36.
Distributor wing airplane (6)

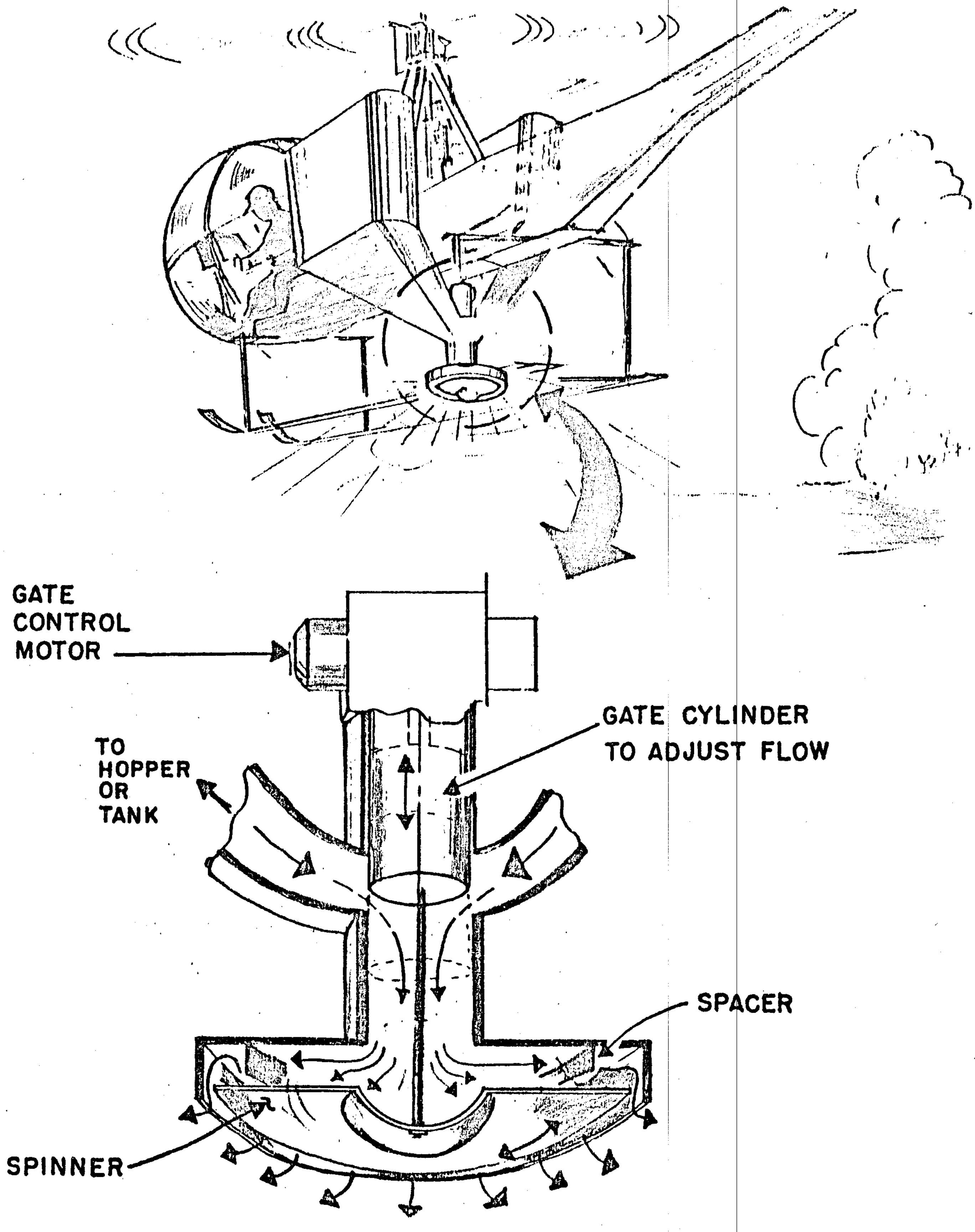


Fig. 37.
A standard distribution system for dry fertilizers from a helicopter.

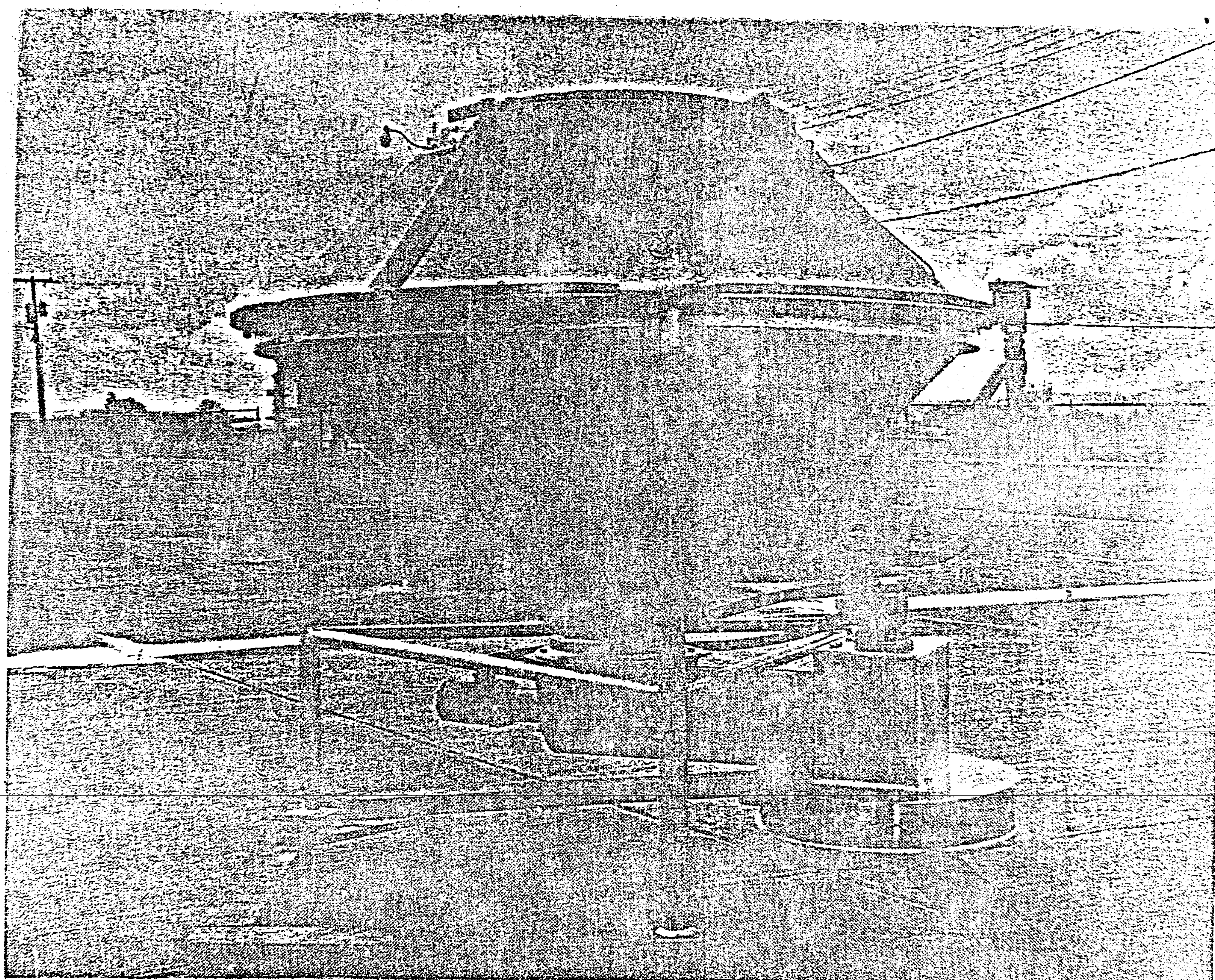

Fig. 38. Hoist suspended fertilizer spreader unit for a helicopter (Courtesy of Evergreen Helicopters, Inc.).

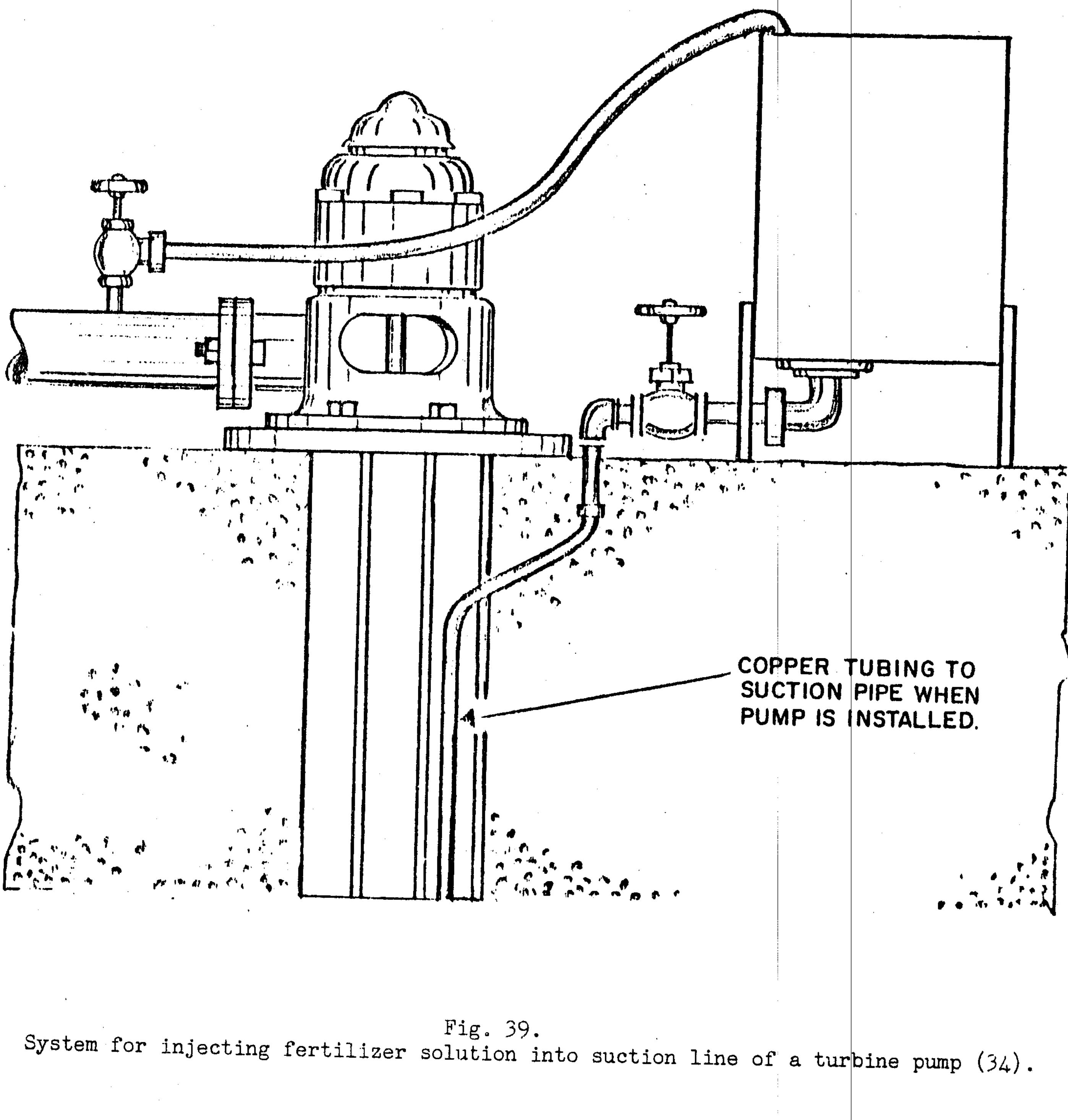


Fig. 39.
System for injecting fertilizer solution into suction line of a turbine pump (34).

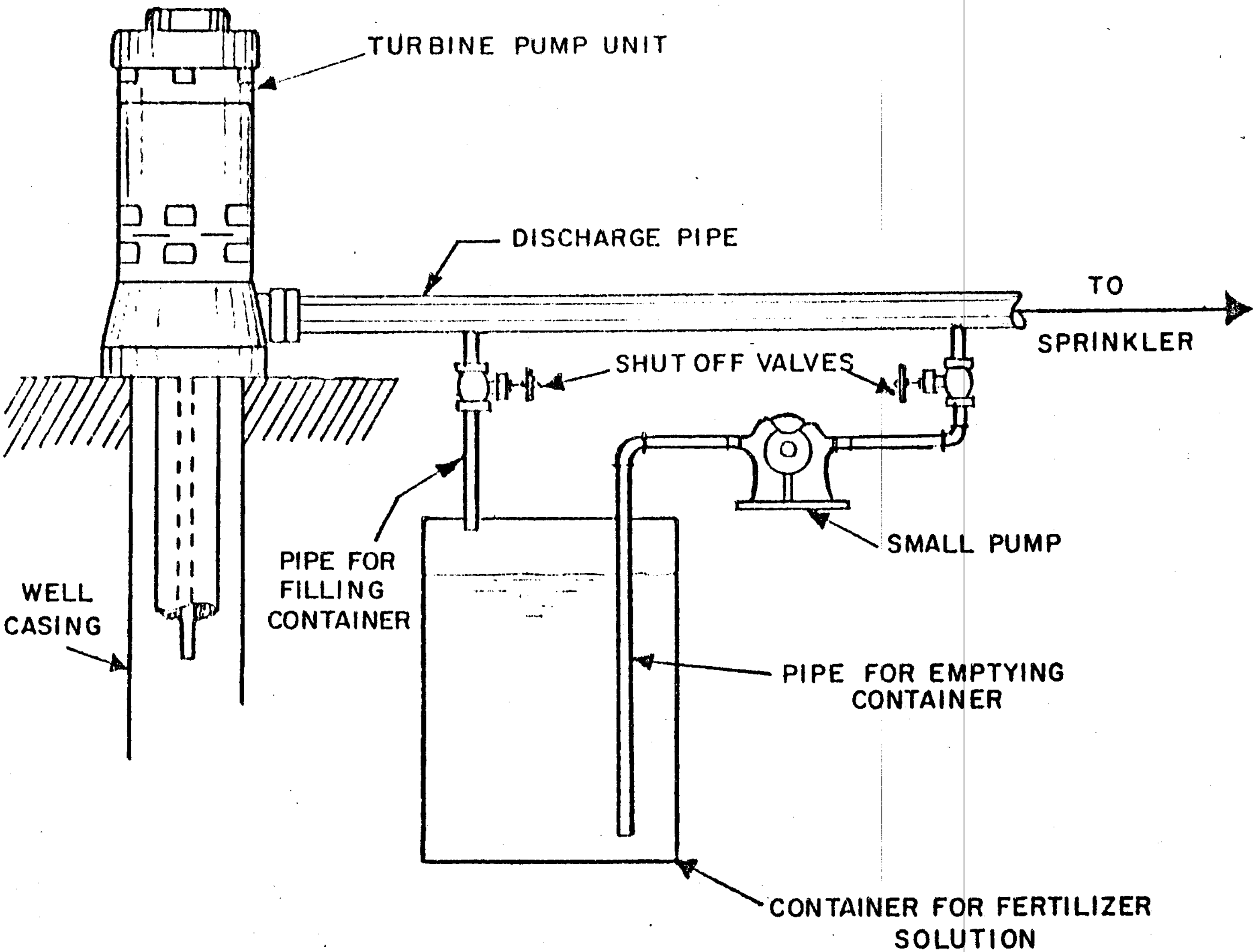


Fig. 40.
Using a pump to inject fertilizer solution into irrigation line (34).

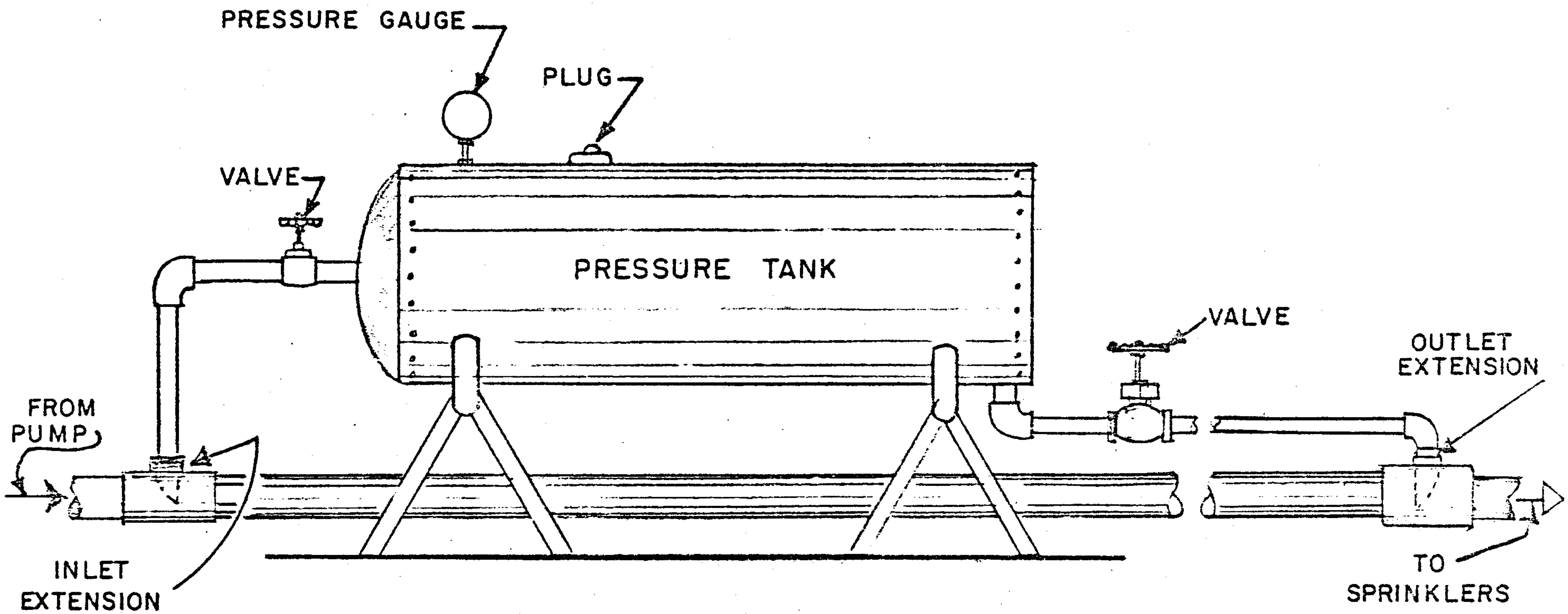


Fig. 41.
Closed tank system for injecting fertilizer solution into pump discharge irrigation line (2).

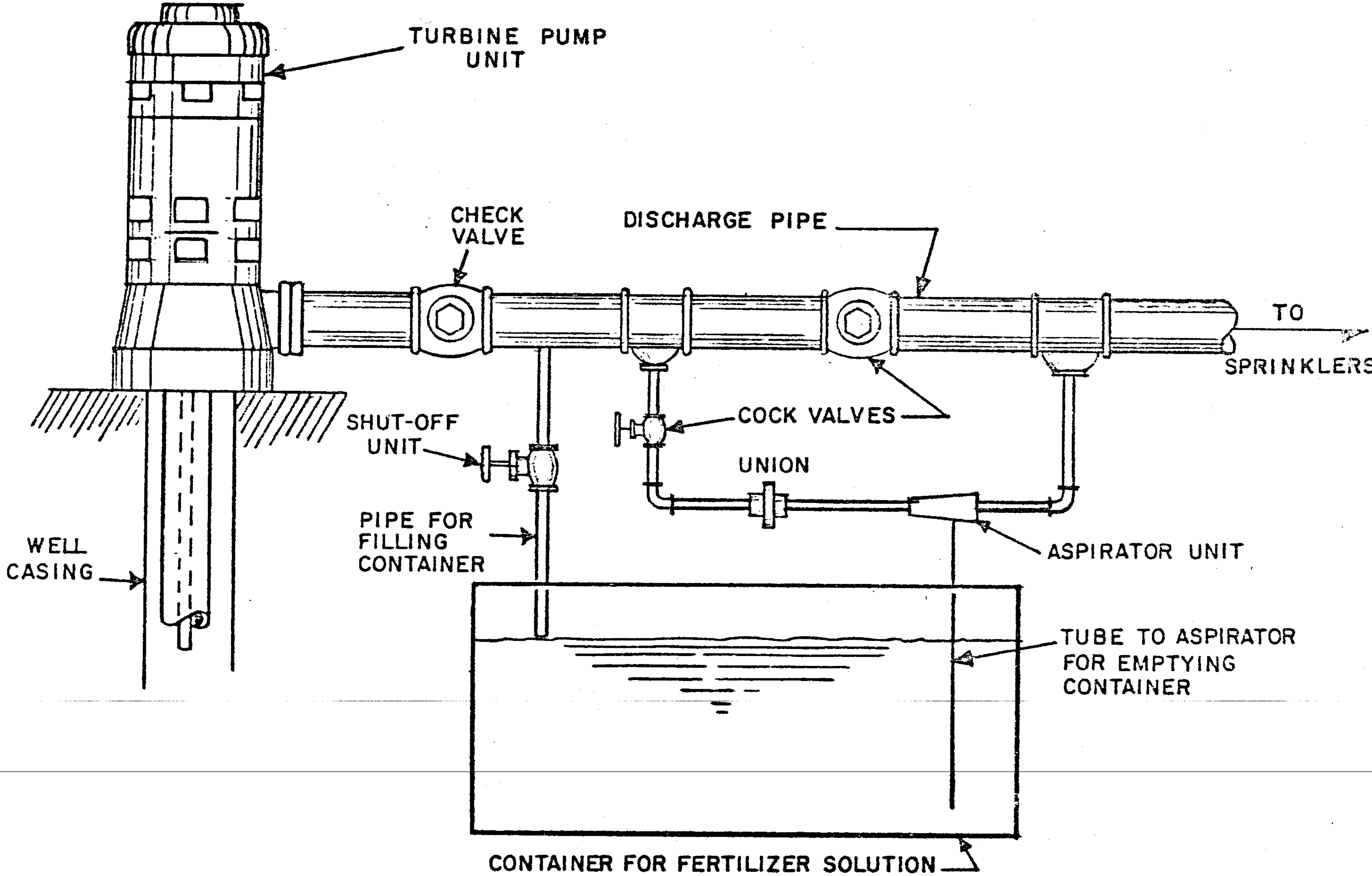


Fig. 42.
Aspirator system for injecting fertilizer solution into an irrigation line (11).