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# 31

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# Mechanics of Applying Nitrogen Fertilizer

Of the three major plant foods—N, P, and K—N is required in the largest quantities. Countries that have increased fertility of their soils to a relatively high level will continue to increase consumption of N while use of P and K will increase less rapidly (Achorn, 1981). In the United States, 75% of the energy consumed in manufacturing all fertilizers is used to produce N products (Achorn, 1980). The rising cost of energy mandates efficient use of N through uniform and accurate application. Energy is also conserved by combining fertilizer with herbicides to eliminate a trip across the field. The means for reducing energy consumption in application are dictated by the form of N used.

There are four basic forms of N: pressure liquid, nonpressure solutions, suspensions, and granular. The latter three forms include mixed fertilizers containing N; the application method is the same as N alone.

## I. RECENT DEVELOPMENTS IN APPLICATION EQUIPMENT

### A. High-Pressure Liquids

#### 1. ANHYDROUS $NH_3$

The most common form of directly applied N is anhydrous $NH_3$ (AA). It comprises about 50% of all directly applied N. Popularity of AA results from its low cost, which is largely the result of excellent facilities for transporting and storing liquid $NH_3$.

Direct application of $NH_3$ was begun in the early 1940's, using a horse-drawn applicator with a small laboratory gas cylinder. As the agronomic ef-


*Nitrogen in Crop Production.*

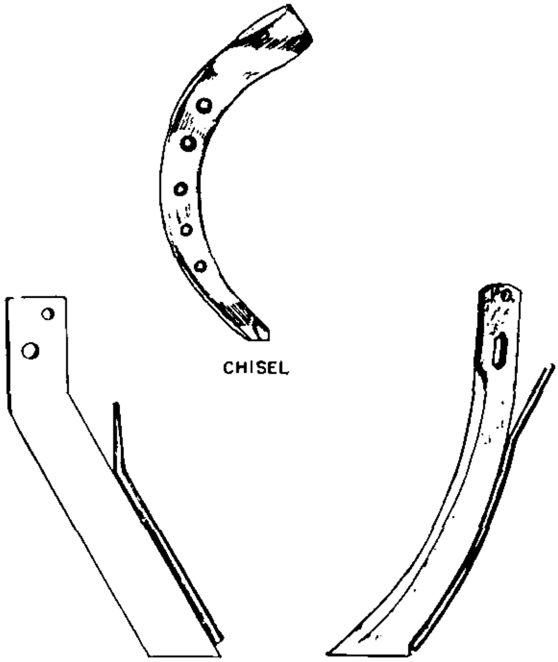


Fig. 1—Application knives.

fectiveness of $NH_3$ was proven, more sophisticated equipment was developed. Because it is applied as a volatile liquid, $NH_3$ must be injected 12 to 24 cm below the surface of the soil. 4-8" This usually is accomplished by application knives such as those in Fig. 1. In sandy, loose soil, $NH_3$ often is applied by an $NH_3$ chisel, also shown in Fig. 1. Anhydrous $NH_3$ usually is metered by a variable-orifice meter or by a piston pump. Rate of application using the orifice meter is determined by applicator speed, swath width, and orifice opening. Piston pumps usually are actuated by a chain driven by a sprocket attached to a wheel of the applicator. Application rate is varied by changing length of stroke of the piston, the rate being independent of applicator speed.

Ammonia applicators range in size from small, 5-row rigs to large rigs with swath widths up to 20 m that are pulled by crawler tractors. Crawler tractors are being replaced by rubber-tired tractors because maintenance costs are much less.

The estimated cost of applying $NH_3$ is \$15/ha. This cost, however, varies widely throughout the country. Most companies report that the cost of applying $NH_3$ is usually about double that of applying nonpressure solutions.

Speeds of $NH_3$ application vary from 4 ha/h in the Midwest to 16 ha/h in the western United States. Application speeds are increasing, and a major reason is use of the large, rubber-tired tractors rated at over 300 kW to pull applicators. The large tractors have reduced energy consumption per hectare because of the wider swaths and more efficient engines.

The energy required to apply different types of fertilizers has been calculated by Achorn and Kimbrough (1978). Application of AA requires about 60% more energy than does application of nonpressure fluids and 40% more energy than application of solid fertilizers.

| | 1000 kcal/t | |
|---|---|---|
| | Product | Nutrient |
| Anhydrous $NH_3$ | 346 | 422 |
| Solids | 116 | 296 |
| Nonpressure fluids | 81 | 270 |

To help decrease energy consumption, some companies have introduced equipment for applying AA during other tilling operations, thereby avoiding one pass across the field. This concept has been used for many years in Kansas where AA is added during tillage following the wheat (*Triticum aestivum* L.) harvest. In Kansas and other sections of the Midwest, a triangular-shaped plow is passed about 7 to 10 cm beneath the soil. This helps destroy weed growth, tills the soil, and leaves a protective stubble mulch on the surface to prevent wind and water erosion. Figure 2 is a photograph of this tillage implement. Anhydrous $NH_3$ is released beneath the soil as the soil passes over the implement. Experience with this equipment has shown that 60 to 90 kg $NH_3$/ha can be applied without noticeable application losses. One dealer reported no noticeable losses with application rates as high as 225 kg/ha when the implement was used on irrigated land. About 40 ha/d can be tilled with one of these implements.

Fig. 2—Ammonia discharge from triangular tillage implement.

## 2. COLD $NH_3$

Some applicators keep $NH_3$ in the liquid state for a prolonged period so that the liquid can be applied and covered with soil during conventional tilling operations, such as disking. Figure 3 is a curve depicting the effect of liquid $NH_3$ temperature on vapor pressure. The vapor pressure of $NH_3$ is equal to atmospheric pressure at $-34°C$. At this temperature, liquid $NH_3$ does not have to be injected deep into the soil to avoid $NH_3$ loss.

Cold $NH_3$ equipment is shown in Fig. 4. This equipment has one evaporator for several application knives. In the evaporator, $NH_3$ is allowed to expand, which cools the liquid from $-32$ to $-34°C$. Cold liquid from the evaporator is added to each applicator knife and gaseous $NH_3$ is added to alternate knives. Some operators report that with this equipment it is possible to apply $NH_3$ during tillage operations and thus avoid one pass across the field. One operator reported that with this equipment and a tractor speed of 8.0 km/h it was possible to apply 140 to 180 kg N/ha. Others report that $NH_3$ can be injected to a shallow depth (10–15 cm), resulting in some energy saving as compared with the conventional applicator, which uses deep injection (20–30 cm). Others report high $NH_3$ losses when this equipment is used to inject $NH_3$ to the side of a cultivating disk. This equipment is still being tested to prove its usefulness and value.

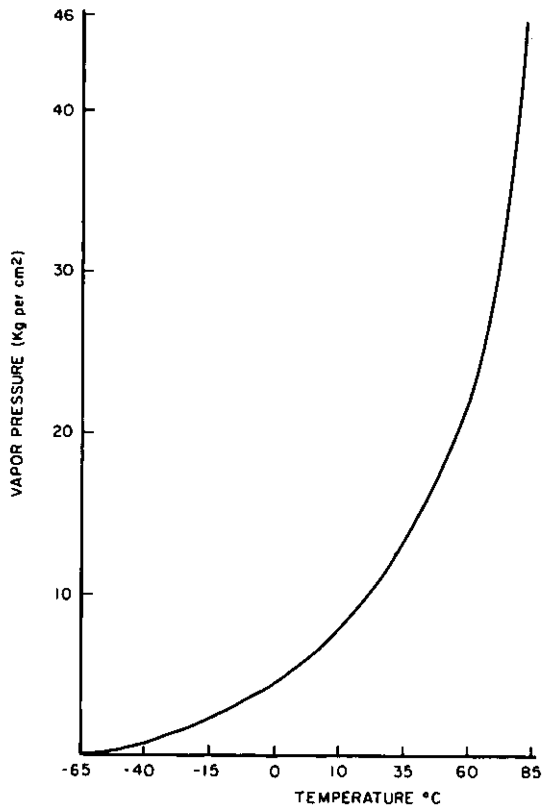


Fig. 3—Effect of temperature on vapor pressure of anhydrous $NH_3$.

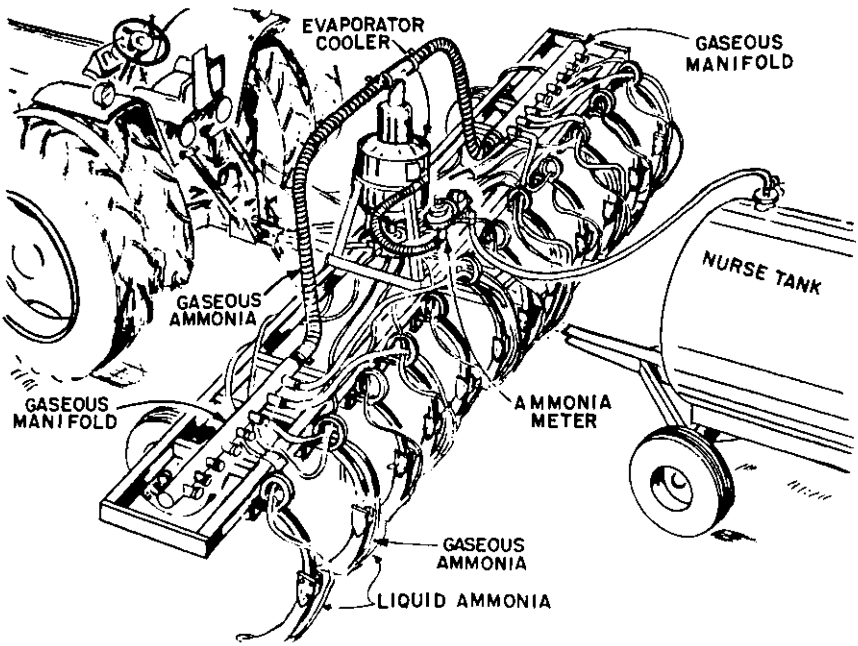


Fig. 4—Cooled $NH_3$ applicator.

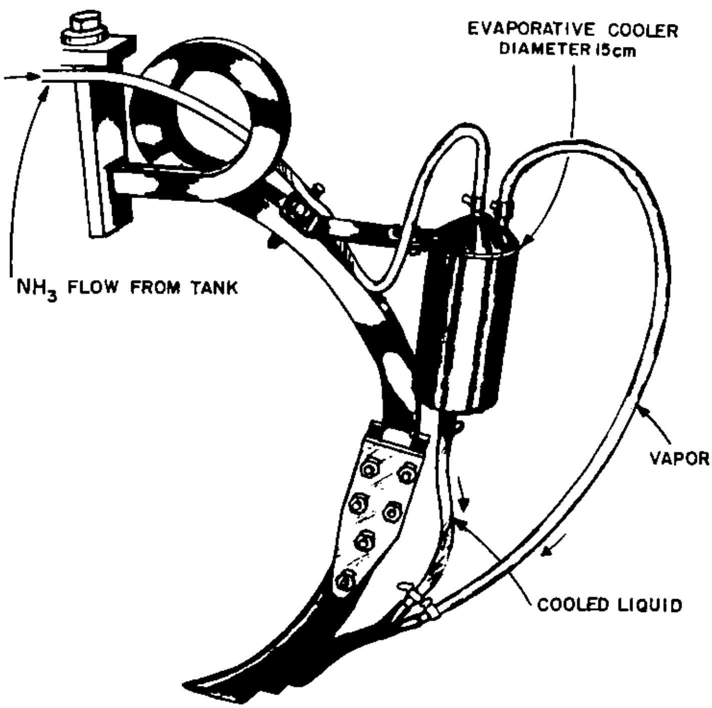


Fig. 5—Small $NH_3$ evaporator-cooled for each $NH_3$ tine.

Another equipment manufacturer using the principle of applying cold $NH_3$ to avoid deep placement uses an evaporative cooler much smaller than the cooler just discussed. This applicator has a cooler on each $NH_3$ tine, as shown in Fig. 5. These coolers are small, baffled cylindrical pressure vessels having a diameter of about 15 cm and a height of about 25 cm. Cold liquid flows from the bottom of the cylinder to the tine through plastic tubing, and vapor flows from the top of the cylinder through a separate tube to the same tine used to apply the cold liquid. The manufacturer has not reported its experience with this equipment. There is some disagreement among engineers, physical chemists, applicator operators, and equipment manufacturers about the value of this type of $NH_3$ cooling and application equipment. Therefore, tests are needed to determine its relative merits compared with conventional equipment.

## 3. HIGH-PRESSURE $NH_3$

Another procedure used to ensure that a larger percentage of $NH_3$ is delivered to the soil is that of increasing $NH_3$ pressure so that nearly all of the $NH_3$ is liquid before it is forced into the soil. The $NH_3$ can be kept in liquid form until it is injected into the soil if the pump pressure exceeds the vapor pressure in the delivery tubes. This can be accomplished by using a positive displacement pump, such as a piston pump, and restricting the hole size at the outlet end of the injection tine or injection tube. This outlet hole is drilled at an angle so that the high-pressure stream of $NH_3$ is forced down into the soil. This equipment, of course, requires delivery tubing and hose capable of withstanding higher pressures than are used for conventional or the new cold $NH_3$ equipment. A typical piston metering pump for this purpose is shown in Fig. 6.

This pump also has a heat exchanger that uses partially expanded $NH_3$ from the pump to cool $NH_3$ entering the pump. Pump capacity is varied by changing the length of the stroke. The pump must be able to deliver liquid $NH_3$ at pressures as high as 10 kg/cm$^2$.

## 4. DUAL APPLICATION

The observed agronomic benefit from placement of fertilizer near the roots of plants has led to development of equipment that also conserves energy. A trip over the field is eliminated by dual application because other plant nutrients, such as those in a liquid mixture, are knifed into the soil directly behind the $NH_3$. Figure 7 is a sketch of a research applicator used in Kansas to study the agronomic benefit of injecting $P_2O_5$ fertilizer. The applicator shown in Fig. 7. is equipped for injecting granular fertilizer with $NH_3$. The vertical cylindrical tank in the figure is for a liquid source, such as ammonium polyphosphate solution of 10-14.8-0 (10-34-0) grade. When applying 10-14.8-0, either a ground driven squeeze pump or piston pump injects the 10-14.8-0 through tubes that are welded "piggyback" to the $NH_3$ injection tubes.

In spite of the increased energy required to inject fertilizers, farmers in wheat-producing areas in the United States are adopting dual application. An active program for improving application equipment for subsurface

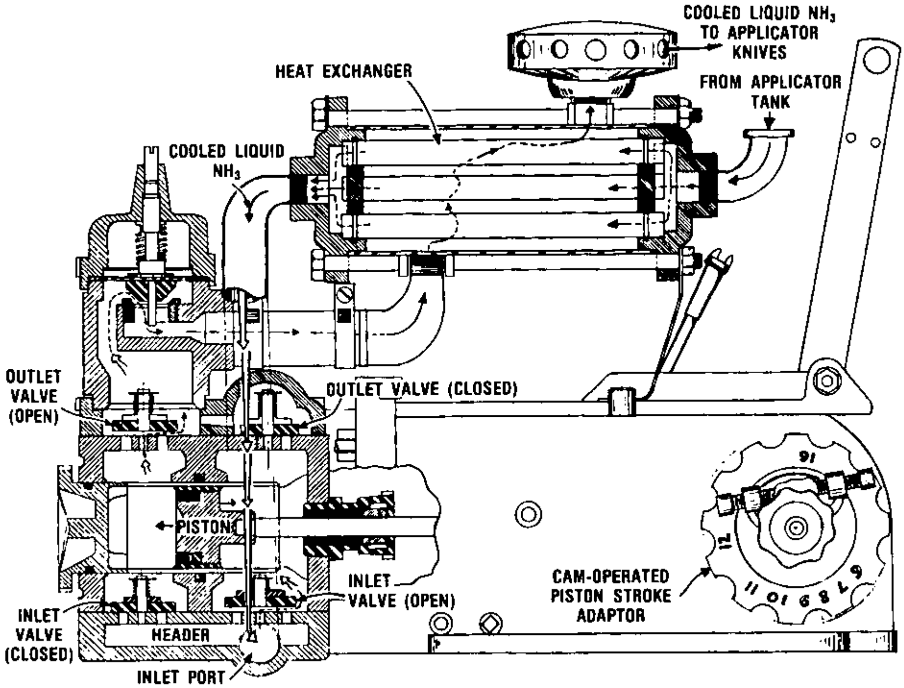


Fig. 6—Anhydrous $NH_3$ metering pump with heat exchanger.

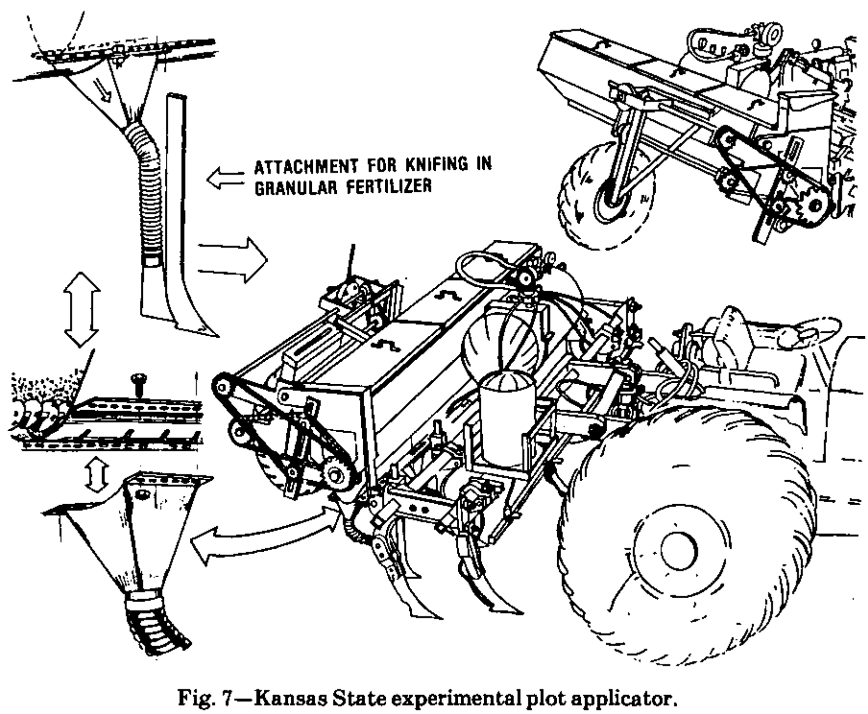


Fig. 7—Kansas State experimental plot applicator.

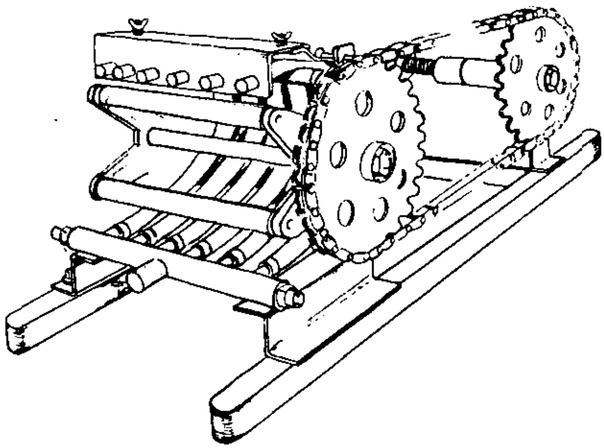

Fig. 8—Squeeze pump with round hoses and back plate.

injection of fertilizers is carried on by TVA. This work has shown that gravity-flow systems for application of solutions cannot be readily adapted for application of suspensions. If suspension is to be injected, it should be pumped to the injection knife.

TVA tests show that squeeze pumps are most reliable for metering and pumping suspensions to the applicator knives. Figure 8 is a sketch of a typical squeeze pump for this purpose. Material is pushed through the hose by rollers as they press over the hose. The spring-loaded back-up plate provides a surface onto which the round hose can be pressed. One equipment company has found that flatter hoses without a pressure plate work better in their squeeze pumps.

### B. Low-Pressure Liquids

Use of low-strength aqua $NH_3$ (AQA) has declined in recent years because of this product's low N content (20% N); however, use of high-strength AQA as a way to reduce application time has been discussed. High-strength AQA (50% N) retains some of the inherent advantages of low-strength AQA—particularly low vapor pressure.

Figure 9 shows the vapor pressure of high-strength AQA. Pressures shown are about half those for AA at normal operating temperatures (see Fig. 3). This low pressure means that high-strength AQA can be applied at shallower soil depths and at higher application speed with lower energy consumption than can AA. These factors contribute to lower unit costs than might be expected because of the high specific gravity of AQA. Only 13% less N can be stored as high-strength AQA than as AA. A 4000-L tank filled to 85% capacity with AA contains 1728 kg N and a 4000-L tank filled to 95% capacity with high-strength AQA contains 1500 kg N. The lower pressures encountered with AQA permit use of a thinner tank wall. This results in lower unit cost for AQA storage that more than offsets the extra volume required.

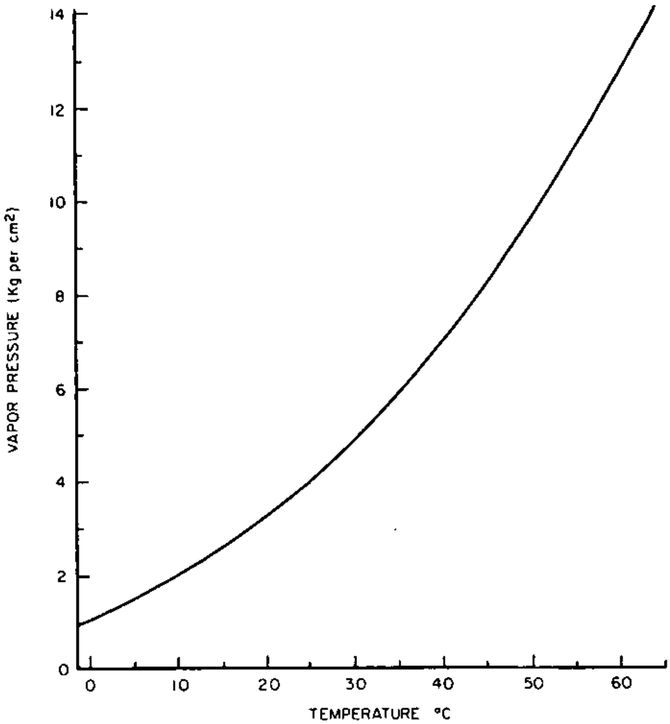


Fig. 9—Vapor pressure of high-strength AQA (50% N).

Another advantage of producing and applying AQA is that the chemical heat of dilution of the $NH_3$ in water can be used to convert ammonium nitrate and urea to an N solution that can be used in irrigation units. Figure 10 shows a plant for using this chemical heat to produce a nonpressure solution containing 18% N. This solution is added through an irrigation system throughout the growing season for efficient use of N.

## C. Nonpressure Solution

### 1. N SOLUTIONS AND CLEAR LIQUIDS

Most solutions are used for direct application; however, some are used to produce fluid mixtures. Most are applied by broadcasting using various types of nozzles. Figure 11 shows common spray nozzles. The nozzle on the right is a fan-type that emits fine droplets. Some applicator operators like fan-type nozzles to apply mixtures of N solution with herbicides. They report uniform response from the N and uniform kill of weeds. Other operators report that with moderate wind, there is too much fertilizer drift with these nozzles; they prefer to apply solutions through flooding nozzles such as shown on the left side of Fig. 11. Flooding nozzles emit drops of about the same size as average rain drops; there is little or no drift. They

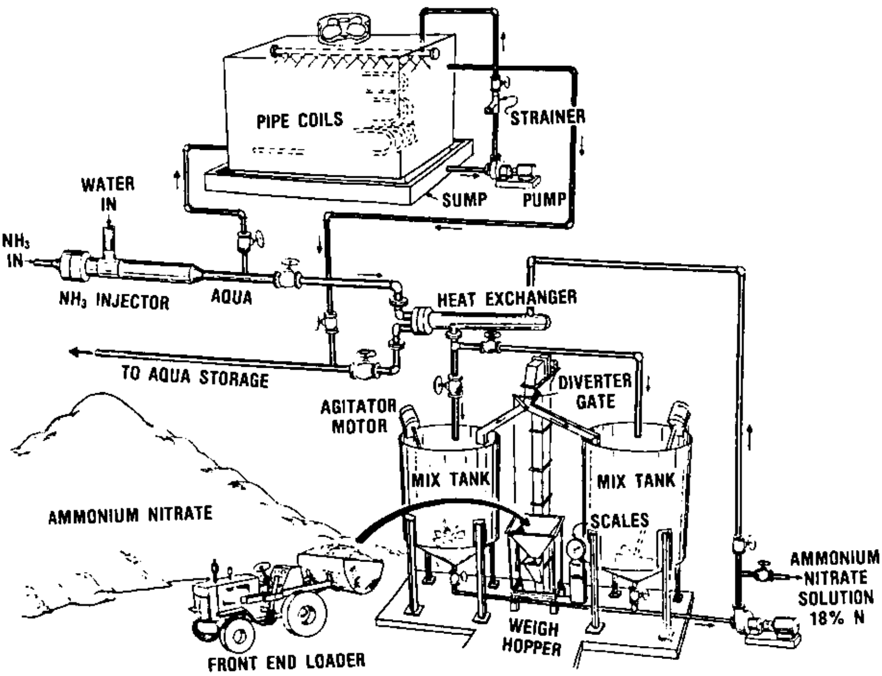


Fig. 10—Aqua converter ammonium nitrate dissolver.

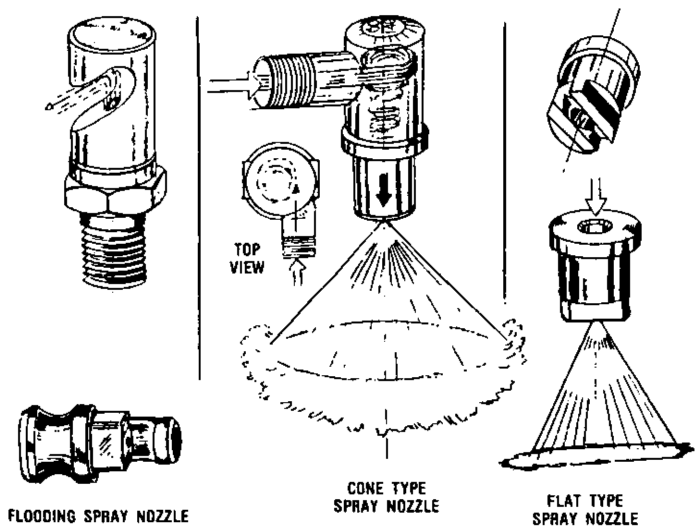


Fig. 11—Nozzles used to broadcast and apply fluid fertilizers.

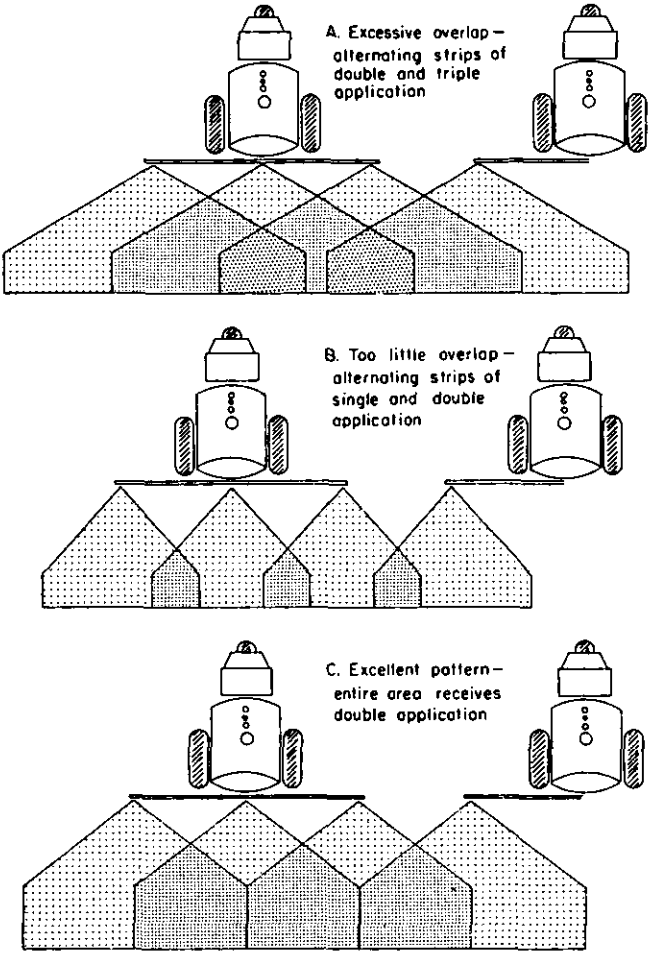


Fig. 12—Spray patterns.

also give uniform application across the swath if proper overlap of adjacent nozzle sprays is maintained. Figure 12 shows how to obtain uniform application by proper adjustment of overlap.

A nozzle designed to reduce drift and produce larger droplets than flood nozzles is rapidly being adopted. This nozzle produces a hollow cone pattern and is shown in the center of Fig. 11. The large droplets are produced in a swirl chamber, which also decreases fluid velocity. The orifices in these hollow cone nozzles are, therefore, slightly larger than orifices in flood nozzles of similar capacity.

Since nozzle pressure is generally used to control application rate, nozzle flow rates for particular pressures must be available. This information is determined by a nozzle calibration. Equipment fabricators usually calibrate nozzles with water; a more effective calibration is obtained with the N solution to be applied (Broder et al., 1980). Also, nozzles wear, resulting in changes in flow characteristics of the nozzles. For this reason, it is recommended that nozzles be calibrated with the fluid to be applied. The following formula is used to calculate application rate:

$$R = 600\,FN/SW,$$

where $R$ = application rate in kilograms per hectare; $F$ = single nozzle output in kilograms per minute; $N$ = number of nozzles on applicator; $S$ = applicator speed in kilometers per hour; and $W$ = swath width in meters. This formula can be adapted to English units. Usually the nozzle is calibrated at several pressures. These pressures and flow rates and the above formula can be used to plot a system of curves for the applicator from which the operator can choose a particular applicator speed for a desirable nozzle pressure and application rate.

In most liquid applicators, solution is pumped to the nozzles by a centrifugal pump driven by a power takeoff of the applicator engine. Figure 13 shows the flow diagram of solution in the truck. Usually, a 15.24-m boom with several equally spaced nozzles if used instead of the single nozzle shown in the figure. Note that pressure at the nozzle is usually controlled by the amount of material bypassed to the applicator tank. The regulating valve and the pressure gauge are usually located in the truck cab. Sometimes a spring-loaded pressure regulator is used instead of the control valve.

A few companies use air-pressure applicators. Pressure required to spray solution from the nozzle is supplied by a small air compressor driven by a power takeoff from the truck engine. Air is added to the applicator tank through an air sparger, a pipe with holes oriented to spray air tangentially around the applicator tank. This helps keep herbicides mixed into the solution as it is applied. Air pressure applicators are often equipped

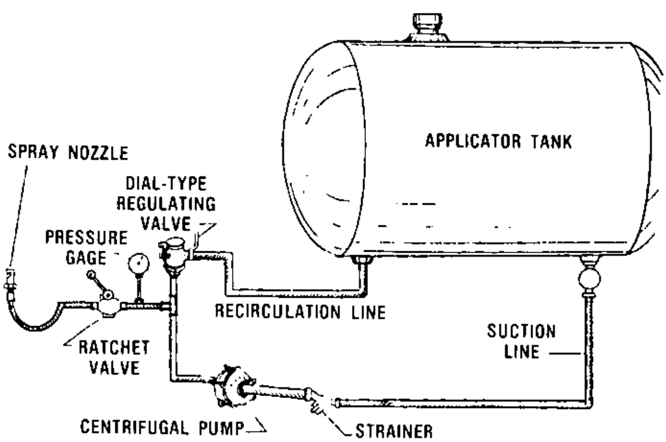


Fig. 13—Flow diagram for N solution applicator that uses pump bypass to control pressure at nozzle.

with a single nozzle that has some advantages over an applicator equipped with a boom. The advantages are (i) fewer problems are encountered with boom carriage and breakage, (ii) a light truck can be used, and (iii) solution can be applied in restricted spaces. Application rate is controlled by pressure at the nozzle, height of nozzle, ground speed of the applicator, and size of nozzle. Pressure in the tank is controlled by the amount of air vented through the vent line. This truck works especially well on small farms. It usually is a small, inexpensive truck with a light, small tank. A similar unit is designed to fit into the bed of a pickup truck. This applicator with a single nozzle has some disadvantages. The swath width is more affected by pressure changes than is the swath width for booms with several nozzles. The swath width is also narrow, usually about 10 m; with booms, swath width is as great as 27 m.

### 2. INJECTION INTO IRRIGATION WATER

Nonpressure N solutions are added through various irrigation systems such as sprinkler, gated pipe, and drip. Solution is usually injected into the system by a positive displacement pump such as a piston or a diaphragm pump. It usually is added at a rate of one part solution per 1000 parts of irrigation water. Nitrogen is added several times through the growing season so it can be used efficiently—a practice sometimes designated as "spoon feeding." Probably the main advantage of adding N solution through the irrigation system is that it is applied at the time the crop needs it. Corn (*Zea mays* L.), for example, uses most of its N for rapid growth through the "milk" stage. Applying part of the N in irrigation water during this time assures the irrigator that adequate N will be available for crop use during critical stages of growth (Dennis, 1971).

## D. Suspensions

Most suspension fertilizers are broadcast with high flotation equipment. Manufacturers have modified conventional solution broadcast equipment, making applicators suitable for both suspensions and solutions. Suspensions require larger plumbing, more pumping capacity, and more recirculation. Main lines are 7.6 cm in diameter with 2.5- or 3.8-cm lines supplying each nozzle. Pumps are rated as high as 1300 L/min at 3.0 kg/cm$^2$ fluid pressure. Fertilizer flow path is the same as that shown in Fig. 13. Some applicators disperse recycled fertilizer in the tank by use of a sparger.

Nozzles suitable for suspensions are shown on the left and center of Fig. 11—flood nozzles and hollow cone nozzles. Flat fan nozzles have orifices that are too small to allow crystals in suspensions to pass.

A few dealers have successfully applied suspensions with a single nozzle applicator as shown in Fig. 13. These applicators are successful in areas where fields are small and terrain is hilly. Where land is suitable for large-scale farming, booms are preferred because they facilitate uniform application.

The science of suspension broadcasting is still developing. For years nozzle manufacturers have recommended flow correction factors to account for changes in solution density. Suspensions, however, vary considerably in such properties as viscosity, gel strength, solid fraction, and size and shape of suspended solids. Variations in these physical properties may lead to changes in flow properties and errors in suspension application. Research is needed to determine the effect that suspension properties have on nozzle flow.

### E. Granular N and Mixed Fertilizers

Broadcast application of granular fertilizer containing N has not increased as rapidly as has fluid application. One reason for this is that uniform application is more difficult to achieve with most dry broadcast equipment. Most dry broadcast equipment uses one or two spinning disks to broadcast fertilizer in 12- to 15-m swaths. Two factors are largely responsible for nonuniform application from spinner applicators, segregation of blends, and poor maintenance of equipment. *Segregation* is defined as the unmixing or separation of different components in a blend during handling, transport, or application.

problems

Size variation is the main cause of segregation. For example, if coarse KCl with many fines is blended with granular urea, the fines sift to the bottom of holding bins and applicator hoppers. When this same blend is poured into a pile, the larger urea will flow to the outside of the pile, while the fine KCl will remain in the center. This phenomenon, known as *coning*, can only be remedied by making several piles in storage or by installing partitions in bins and hoppers. Segregation is compounded by the spinner applicator, because fines will not travel as far from the spinners as will granular material. Segregation can also be minimized by proper sizing of blended components. According to TVA studies, shape and density variations contribute little to segregation. Therefore, uniform sizing of components will minimize segregation.

A spread pattern calibration is an essential part of applicator maintenance (Fig. 14). Adjustments are often required to obtain a desirable pattern. An area of concern is the point of delivery of fertilizer onto the spinner or

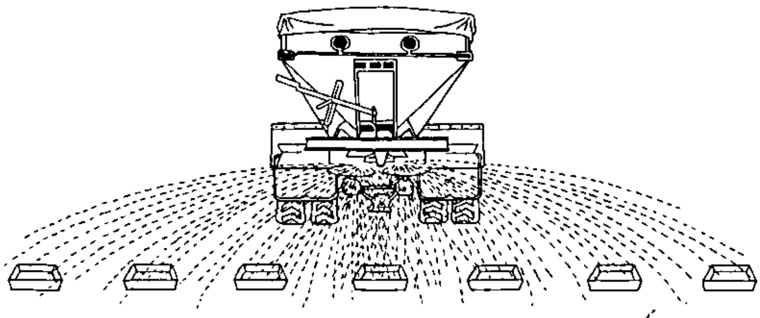

Fig. 14—Collecting samples across swath to determine patterns.

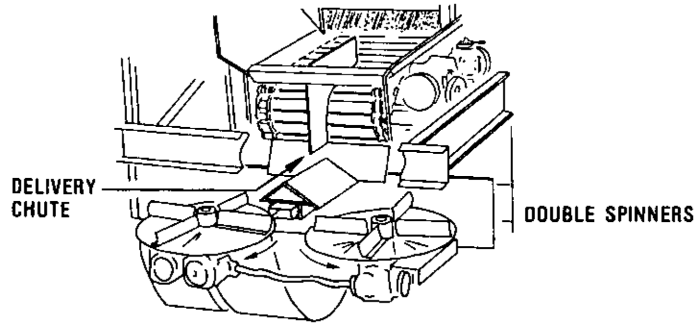


Fig. 15—Delivery chute on double spinner applicator.

spinners (Fig. 15). The most desirable patterns are shown in Fig. 16. A slight change in the location where fertilizer drops onto the spinners can considerably alter the distribution pattern. Location of the spinner blades on the disk also has an effect on the distribution pattern (Fig. 17). Caking of fertilizer on the spinner blades or delivery chute can alter distribution. Spinner speed or a change in particle size of the material applied will also alter distribution of fertilizer behind the applicator. Despite all the causes of

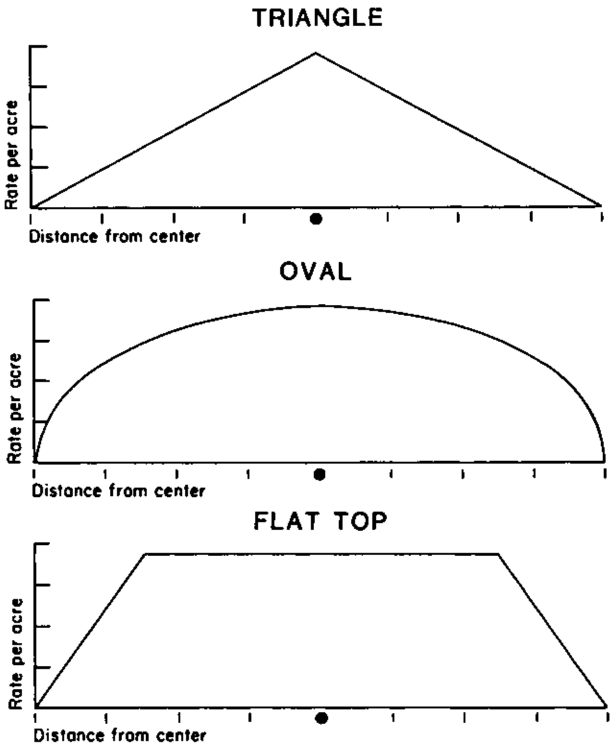


Fig. 16—Desirable application patterns.

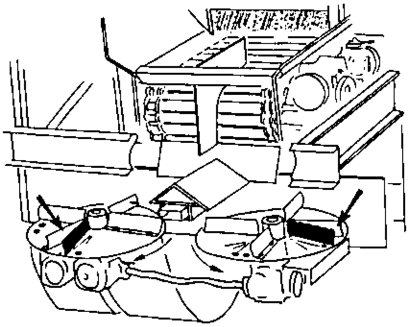


Fig. 17—Spinner blade adjustment on a double-spinner spreader.

nonuniform application, spinner applicators work well when they are well maintained and adjusted.

A few dry applicators use a boom. In one, fertilizer is moved by an auger across adjustable openings in a boom. Another uses high-velocity air to transport granules to as many as 20 nozzles. The nozzles have a deflector to distribute fertilizer. Both applicators give uniform application, but high maintenance and cost have impeded their adoption in the United States.

### F. Aerial Application

The use of aircraft in agriculture has increased greatly in the past few years. Most aerial application involves the use of herbicides and pesticides. Fertilizer, however, is applied extensively by aircraft on some crops. Rice (*Oryza sativa* L.) and citrus-producing areas in the southern region of the United States are often fertilized by aircraft. Forest producers use aircraft to apply N fertilizer.

Aerial application equipment is largely derived from ground equipment. Dry fertilizers are usually broadcast by electrically driven spinners. Fixed wing aircraft and helicopters are commonly fitted with booms and nozzles at close spacing. Flat fan nozzles are common; however, the problem of spray drift has turned interest to drift reduction (hollow cone) nozzles.

One broadcast method unique to airplanes is the venturi system. Air is forced into a scoop and through a restricted section to increase velocity. Fertilizer is injected into the venturi at the point of maximum air velocity and forced through ducts which direct fertilizer into the air stream.

Helicopters are becoming more popular for aerial application because they can reach areas inaccessible by plane and travel slow enough to apply fertilizer at high rates.

The main problem with aerial application is spray drift. A fine spray drifts 15 m in a 5 km/h wind while falling only 3 m. An aerosol droplet can travel 34 km under the same conditions (Anon., 1980). Similar results have been found in the aerial application of small and larger size solid materials. For example, much less drift occurs when large granules of urea (0.48–1.27

cm) are used in preference to standard size urea (0.1–0.33 cm). To reduce spray drift, one aerial sprayer manufacturer has placed extra nozzles on the right side of the fuselage to help compensate for prop wash, which moves spray from right to left. Other methods involve wing modifications on airplanes to modify their wake and nozzles that control droplet size.

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