

ganic matter. Acid soils sorbed better than alkaline soils, but a soil of pH 7.3 sorbed a large amount of ammonia, much of which was due to formation of organic nitrogen compounds. Work by ANDREWS (2) and by STANLEY and SMITH (26) showed that very little ammonia diffused more than 2 inches from the point of application when 100 pounds of nitrogen per acre was applied in 40-inch rows on normal soils. The movement was greater in sandy soils. ANDREWS (2) has pointed out that retention of injected ammonia is very difficult to measure with any accuracy, and that crop response may be the only practical way of measuring losses. The consensus seems to be that losses are not economically significant unless extreme conditions of soil type, soil moisture, soil subdivision, rate of application, and row spacing are involved.

The same factors apply to subsurface application of aqua ammonia and pressure-type solutions. However, the lower vapor pressure allows shallower injection. A depth of 2 inches is often used.

Nonpressure solutions usually are surface applied; subsurface application is used only to a minor extent, mainly in the western part of the country. For application before planting, tank trucks equipped with spray booms give a very rapid rate of application. For application during planting or for sidedressing, gravity flow is widely used. Practice in applying nonpressure solutions is similar to that in applying liquid mixed fertilizers, which is discussed in detail later.

The problem of metering liquid fertilizers during application is an important one. A major practice is to maintain constant pressure on a calibrated orifice and correlate this with the speed at which the applicator moves through the field. Anhydrous ammonia generates its own pressure; pumps or air pressure are used with other liquids. A more accurate method is to use a metering-type pump driven by a ground wheel, thereby making it unnecessary to maintain a constant applicator speed. For either method, care must be taken in applying anhydrous ammonia to prevent vaporization before the ammonia passes the metering point; this is accomplished by using a heat exchanger to cool the ammonia entering the metering device with gas evolved beyond the device.

Application of nitrogen liquid in irrigation water is practiced mainly in the western part of the United States, usually in ditch-type irrigation. Some spray irrigation is carried out in various parts of the country but it is not a major practice.

Anhydrous ammonia is metered from cylinders into irrigation water under its own pressure. Aqua ammonia and nitrogen solutions are usually applied by gravity flow. Losses from liquids containing free ammonia vary widely, running as high as 26% under conditions of high water temperature and low soil permeability (1). SOKOLOFF (25) found that losses can be minimized by (1) restricting addition of ammonia to cool, humid, nonwindy days, (2) keeping the ammonia concentration in the water below 110 p. p. m., and (3) keeping exposed surface of water to a minimum by using narrow ditches and avoiding turbulence.

Application of nitrogen liquids in sprinkler irrigation usually is restricted to nonpressure solutions. The solution is introduced into the water either by gravity or by differential pressure. The latter is accomplished by fitting an orifice into the water line. The pressure built up at this orifice is transmitted to the liquid fertilizer tank, thereby forcing the fertilizer solution into the water line downstream from the orifice.

Application of nitrogen liquids in sprinkler irrigation involves spraying the fertilizer directly onto foliage. Care must be taken to dilute the fertilizer sufficiently to avoid burning of the plants.

#### Behavior in the soil

The main differences between behavior of nitrogen liquids and nitrogen solids in the soil is associated with those liquids containing free ammonia. Those containing only ammonium

nitrate or urea should have an effect no different from that of solid ammonium nitrate or urea, since it has been demonstrated that the latter dissolve in a matter of minutes in moist soil and thereby become, in effect, nitrogen solutions. Free ammonia, however, has some specific effects that may or may not be found in use of solids. The closest parallel in the solids group is use of urea, which hydrolyzes to ammonia in the soil at a fairly rapid rate.

**Effect on soil properties and population:** One of the main effects of ammonia on soil is increase in pH to a relatively high level in the zone of application. BURGESS and HAWKINS (4) found that the initial pH resulting from anhydrous ammonia application might be as high as 9.5. This high level does not remain very long; as nitrification proceeds the pH drops and eventually an over-all decrease in soil pH results. However, the latter is no different from that resulting from use of equivalent quantities of materials such as ammonium nitrate and urea.

The temporary high pH level is claimed to make heavy clay soils stiffer and more compact in the zone of application. However, this effect would not seem to be very serious since only a relatively small volume of soil is affected (2).

The high pH also promotes nitrification as compared with fertilizers that do not increase pH. ENO and BLUE (7) compared nitrification rates for anhydrous ammonia and ammonium sulfate in a soil of 5.1 pH at 28° C. The ammonia raised the pH initially to 9.1 (for a 380 p. p. m. application) while the same amount of ammonium sulfate lowered the pH to 4.1. No nitrification occurred in the ammonium sulfate-treated soil in 63 days, whereas 25% of the ammonia nitrified in a similar period. Use of more ammonia (780 p. p. m.) to further increase the initial pH (to 9.6) reduced the degree of nitrification to 10%. Presumably the lower nitrification at the higher pH level was due to a toxic effect on nitrification bacteria. Ammonia is toxic to other members of the soil microbiological population also. Application of 100 pounds of nitrogen per acre in the form of anhydrous ammonia has been shown (6) to reduce the number of fungi, bacteria, and actinomycetes in soil. However, the toxic effect was limited to a zone of 3-inch radius (center at point of injection). In 3 days the number of bacteria and actinomycetes was back to normal, but the adverse effect on fungi persisted for at least 38 days.

The toxic effect increases rapidly with concentration. ENO et al. (8) showed that application of enough ammonia to give a pH higher than 9 had a drastic effect on the population of fungi and nematodes. At 608 p. p. m. and a pH of 9.4, very few of the organisms survived. Concentrations of this order are attained in anhydrous ammonia application zones; however, the volume of soil that reaches this level is relatively small. There appears to be no evidence that the toxicity to microorganisms has any effect on crop growth.

A further effect demonstrated for the temporary high pH is an increase in availability of other plant nutrients present in the soil. STANLEY and SMITH (26, 27) found that application of 100 pounds of nitrogen per acre as ammonia increased availability of soil phosphate and potash compounds and reduced the amount of readily available calcium. Again, the proportion of soil involved is a limiting factor in profiting from this effect.

**Leaching and time of application:** Ammonia sorbed on soil particles is quite resistant to leaching, whereas most other types of nitrogen compounds do not sorb and therefore may be lost by dissolution in water passing through the soil. By taking advantage of this characteristic of ammonia, the possibility is presented of applying nitrogen fertilizer in the fall or winter for use by crops the following spring. This would give a major advantage of avoiding the congestion at all points in the production-use pattern when the major portion of the fertilizer used is applied in a few weeks in the spring season. Use of the method, however, requires that the temperature be low throughout the winter period. Nitrification



ten, dass sie gewöhnliche Eisenmetalle nicht angreifen. Man kann also Ammoniakwasser in Behältern transportieren und lagern, wie sie zum Transport von flüssigen Brennstoffen benutzt werden. Bei Verwendung von Ammoniakwasser braucht man nur etwa 1/3 der sonst üblichen Arbeitskräfte und spart 30-40% der sonst üblichen Kosten für Kauf, Lagerung, Transport und Verteilung der üblichen stickstoffhaltigen billigeren Düngemittel, wie Ammonsalpeter. Im Jahre 1956 wurde ein Versuch mit Ammoniakwasser auf einer Gesamtfläche von nur 30 ha gemacht. Im Jahre 1961 wurde bereits eine Fläche von 530 000 ha mit Hilfe von Ammoniakwasser gedüngt, und zwar vor allem in der Umgebung von Düngerefabriken, die den gewöhnlichen stickstoffhaltigen Dünger herstellen und bei denen nach der Synthese ein Ueberschuss an Ammoniak anfiel. Zurzeit wird eine ganze Reihe von Fabriken nach vereinfachten Gesichtspunkten aufgebaut, die nur Ammoniak produzieren sollen. Die Folge wird ein vermehrter Absatz sein. Er findet jedoch nicht nur in der praktischen Landwirtschaft immer mehr Eingang, sondern wird auch in zunehmendem Masse in wissenschaftlichen Versuchen verwendet.

Es zeigte sich bisher, dass der Dünger tief in den Boden eingebracht werden muss, um Stickstoffverluste zu vermeiden.

Der Ammoniak wird mit Hilfe einer Reihe von Scharen, die in bestimmten Abständen stehen, in den Boden eingebracht und kann sich nur verhältnismässig wenig nach den Seiten ausbreiten. Aus diesem Grunde dürfen bei der Anwendung des Düngers zu Getreide die Scharen nicht weiter als 25 cm voneinander entfernt sein.

Die Anwendung der gesamten Menge auf einmal hat dieselbe Wirkung wie das Verteilen auf mehrere Gaben. Wird der Dünger vor der Aussaat oder dem Auspendeln der Hack-

früchte eingebracht, so ist die Wirkung besser, als wenn er während des Wachstums der Pflanzen zwischen den Pflanzenreihen eingebracht wird. Die Wirkung des Stickstoffs zeigt sich stark auch in dem nachfolgenden Jahr. Man kann manchmal im Getreide, das auf Hackfrüchte folgt, wenn zuvor zwischen den Reihen gedüngt wurde, im nachfolgenden Jahr eine Art Zebrastreifen beobachten.

Vor allem wurde auch die Möglichkeit untersucht, den Dünger bereits im Herbst auszubringen. Diese Möglichkeit böte zweifellos grosse Vorteile.

Die Produktion von Ammoniak statt der bisher üblichen stickstoffhaltigen Düngemittel würden in der Stickstoffindustrie erhebliche Kosten für Investitionen für Fabrikanlagen einsparen. In der Landwirtschaft jedoch entstehen bei der Düngung mit Ammoniak erhebliche Kosten für Lagern, Transport und Verteilen einschliesslich der Ausgaben für Behälter für ein eventuelles Lagern des Düngers in flüssiger Form.

Könnte dagegen der Dünger bereits im Herbst auf die Felder gebracht werden, ohne dass sich seine Wirkung im Vergleich zum Ausbringen im Frühjahr verringern würde, dann wären die grossen Behälter für die Lagerung der Düngemittel überflüssig. Aus Versuchen in Gebieten mit besonders ausgeprägtem Kontinentalklima, wie z. B. Sibirien, ging hervor, dass die Wirkung des Düngers, wenn er im Herbst zur Sommerung auf die Felder gebracht wird, viel grösser ist, als wenn er erst im Frühjahr gestreut worden wäre. Und selbst in Zentralrussland (in der Gegend von Moskau und den angrenzenden Gebieten) sowie in den westlichen Gebieten auf lehmigen Podsol-Böden und in den Tschernozemen hatte Ammoniak, der im Herbst ausgebracht wurde, die gleiche und manchmal sogar eine bessere Wirkung als bei der Düngergabe im Frühjahr.