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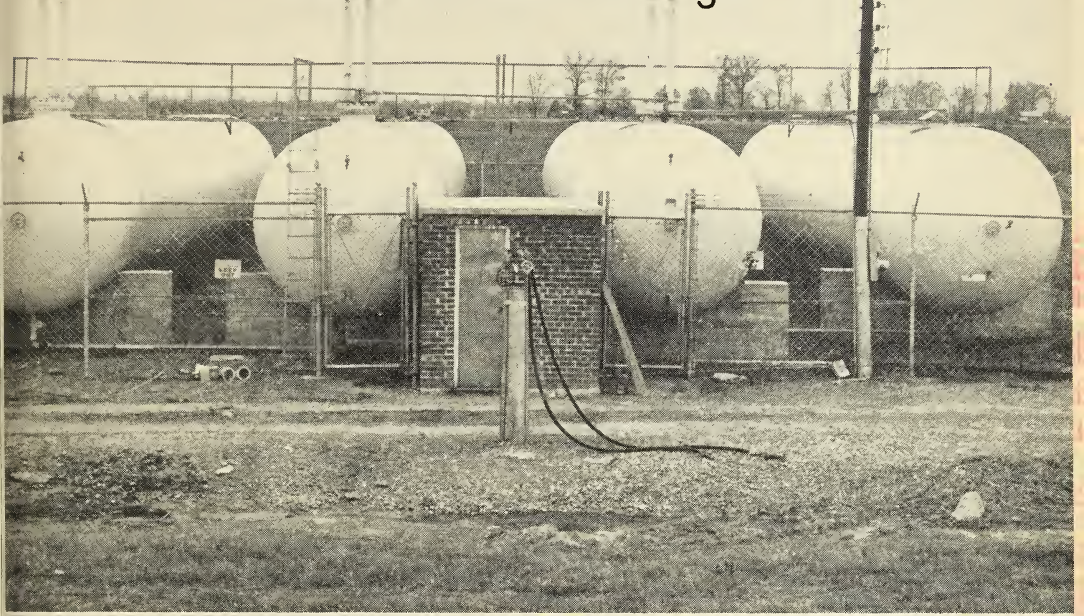
As A Source Of Nitrogen



MISSISSIPPI STATE COLLEGE
AGRICULTURAL EXPERIMENT STATION
FRANK J. WELCH, Director

STATE COLLEGE MISSISSIPPI

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Anhydrous Ammonia as a Source of Nitrogen

By W. B. ANDREWS, J. A. NEELY, and F. E. EDWARDS[1]

Prior to 1850 nitrogen was obtained from animal manures, green manure crops, and legumes grown in rotation. During the last one hundred years nitrogenous fertilizers have come into general use for crop production. In some sections nitrogenous fertilizers supply most of the nitrogen applied to crops; in others, organic materials are still the primary source of nitrogen.

The population of the United States increased about nineteen million from 1940 to 1950 and the indications are that it will continue to increase. The increasing population, combined with the prospective continued decrease in the relative number of farm workers, will increase the intensiveness of farming and, no doubt, the total amount of nitrogen, as well as other fertilizers, used.

The primary sources of nitrogen used directly by farmers are nitrate of soda, ammonium nitrate, or a mixture of ammonium nitrate and limestone. Ammonium nitrate, urea, and sulphate of ammonia are used in mixed fertilizers.

About one hundred years ago attempts were made to use a solution of ammonia and water (aqua ammonia) as a source of nitrogen in Europe. Since this practice did not develop, it is reasonable to assume that the equipment for handling and applying aqua ammonia was not suitable at that time.

In 1930, J. O. Smith, who was a member of the staff of the Mississippi Delta Branch Experiment Station at Stoneville, applied anhydrous ammonia in the field. He mounted a small anhydrous ammonia cylinder on a mule-drawn plow in such a manner that the ammonia was released in the soil.

The Shell Development Company started using anhydrous ammonia in irrigation water in California in the early thirties. The company recognized the possibility of applying it directly to the soil in the late thirties and patented (Patent No. 2,285,932, June 9, 1942) its use for this purpose; however, so far as the authors know, no one is paying a license fee.

In 1943, the Mississippi Agricultural Experiment Station started work on the application of aqua ammonia to field crops. In 1944, work, in cooperation with the Tennessee Valley Authority, was started on the use of anhydrous ammonia for crop production. After data had been obtained on the value of anhydrous ammonia for crop production and equipment had been developed for its application, the information was released to farmers the first of March, 1947. The anhydrous ammonia used by Mississippi farmers has been as follows:

1947 (Spring)	2,253 tons
1947-1948	12,873 tons
1948-1949	27,433 tons
1949-1950	29,862 tons.

Anhydrous ammonia used in the 1949-1950 fertilizer year was sufficient to fertilize one million acres at 49 pounds of nitrogen per acre. In addition, 1,094 tons of aqua ammonia was used.

After the use of anhydrous ammonia was started by Mississippi farmers, its use moved quickly into other states. By early 1951 there were bulk stations in Alabama, Arizona, Arkansas, Colorado, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Nebras-

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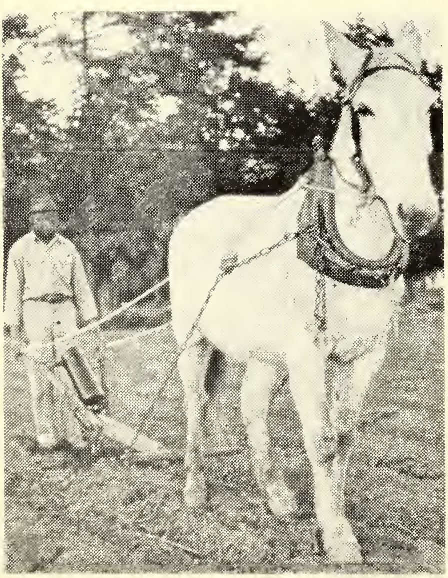
[1]Agronomist, assistant agronomist, and associate agricultural engineer, respectively. J. G. Hammons, J. Clyde Edwards, C. M. Baker, I. E. Stokes, E. L. Moore, P. H. Grissom, J. A. Campbell, S. P. Crockett, B. C. Hurt, B. L. Arnold, John Gill, C. L. Blount, Louie Walton, John Pitner, and Ralph Dickerson contributed much to the investigations during the course of the experiments.

ka, New Mexico, North Carolina, Ohio, Oklahoma, Oregon, South Carolina, Tennessee, Texas, Washington, and Cuba. In these states the ammonia is handled according to methods worked out by the Mississippi Experiment Station and there were indications that other states would also use anhydrous ammonia in the near future.

Nitrate of soda from Chile, ammonia from coking coal, and ammonia made in synthetic nitrogen plants supply most of the nitrogen used in this country. Ammonia derived from coal is usually converted into sulphate of ammonia. That produced synthetically is used largely for making ammonium nitrate and urea, in solutions of ammonia and ammonium nitrate and urea in mixed fertilizers, for direct application, and in making a small amount of other sources of nitrogen. Since anhydrous ammonia is used to make other sources of nitrogen, it is apparent that its direct use would be economical.



This photo shows how anhydrous ammonia was first used at the Mississippi Delta Branch Experiment Station in 1930.

The rapid expansion of the use of anhydrous ammonia was due in a large measure to its low cost. The 1950 retail price of anhydrous ammonia was usually \$110 to \$150 per ton, with \$130 being a common price in established territories. With a price of \$130 per ton of anhydrous ammonia, one pound of nitrogen costs 8 cents as compared to 12 cents in ammonium nitrate at \$79.20 per ton, and a considerably higher cost in other sources of nitrogen.

In practice anhydrous ammonia is applied to row crops with considerably less labor and often more rapidly than solid sources of nitrogen.

Properties of Anhydrous Ammonia

Anhydrous ammonia contains 82 percent nitrogen. It weighs 5 pounds and contains 4.1 pounds of nitrogen per gallon at 80 degrees F. At lower temperatures it weighs slightly more and at higher temperatures slightly less. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. At –28 degress F. and lower and at atmospheric pressure it is a liquid. Anhydrous ammonia has a gauge pressure of 75 pounds per square inch at a temperature of 50 degrees F., and 197 pounds at 100 degrees.

Anhydrous ammonia is handled as a liquid under pressure. It is stored in tanks which have a working pressure of 250 pounds per square inch, except where they are underground or refrigerated. The information now available suggests that the atmospheric temperature may not get high enough for 30,000-gallon tanks to pop-off provided the pop valve begins to operate at about 240 pounds of pressure per square inch.

Mississippi "House Bill No. 91, Regular Legislative Session Laws of 1948," authorizes the Motor Vehicle Comptroller (Jackson, Mississippi) to establish and enforce reasonable rules and regulations for the purpose of carrying out the provisions of the "Liquefied Compressed Gas Equipment Inspection Act."

"These rules and regulations shall be complied with by all persons, firms, or corporations engaged in the use, installation, manufacture, or sale of equipment and containers in the utilization, transportation and storage of anhydrous ammonia, when used as a source of nitrogen in the State of Mississippi." All fittings are made of steel and, in the case of hose, materials which are not attacked by ammonia.

Anhydrous ammonia is not considered an explosive; however, when air contains 16 to 25 percent anhydrous ammonia it may be ignited by a spark, causing an explosion. Openings in tanks which contain a mixture of air and ammonia should not be welded, because of explosion hazards. Anhydrous ammonia is much lighter than air and rises quickly except where brought down by wind. In agricultural use, it is handled outside of buildings making unlikely the combination of circumstances required for an explosion.

In low concentrations ammonia is very irritating to the nose, eyes, mouth, throat and lungs. It will blister the skin. Water should always be available for washing off any ammonia which comes in contact with the body.

Anhydrous ammonia should contain over 99 percent ammonia. Insofar as the authors know inspectors have not found ammonia which had been diluted. A general idea of the purity may be obtained by collecting a quart jar full of ammonia and permitting it to evaporate. It is desirable to cover the jar with a top, which has several holes in it, to prevent a little water in the air from accumulating in the jar. Evaporation can be speeded up by setting the jar of ammonia in a shallow pan of water. When the ammonia stops boiling, water containing 25 to 30 percent ammonia should be present only in the depressions in the bottom of the jar. If any significant amount of water is present, dilution is indicated and the inspector may be contacted.

Properties of Aqua Ammonia

Anhydrous ammonia may be diluted with water to make a solution containing 25 to 30 percent ammonia at ordinary temperatures; however, high pressure tanks are required and considerable heat is given off in the process. Even though it is possible to dilute anhydrous ammonia on the farm or at the local bulk station, special equipment is required, except where dilution is made over a period of a day or two and time is allowed for it to cool to atmospheric temperature. Cooling and dilution may be speeded up by running water over the dilution tank and by the use of special equipment.

Aqua ammonia containing 30 percent ammonia exerts no pressure below 70 degrees F., and 10 pounds per square inch at 110 degrees F. A 30 percent ammonia solution contains 24.6 percent nitrogen. One gallon weighs 7.4 pounds and contains 1.85 pounds of nitrogen.

Choice Between Anhydrous and Aqua Ammonia

When applied to the soil, anhydrous and aqua ammonia behave alike. Either form must be covered at the time of application. Since the products formed in the soil are identical, when they are properly applied there is no difference in the response of crops to them.

Anhydrous ammonia tanks are less than one-half as large as aqua ammonia tanks for a given amount of nitrogen, but are much heavier. With the same total load, at least two trips are required for aqua ammonia to move the same number of pounds of nitrogen as would be moved in one trip with anhydrous ammonia. For this reason anhydrous ammonia is less expensive to transport and apply.

Where anhydrous ammonia is exposed to the air it boils vigorously. The serious loss of ammonia is clearly evident, and the operator tries to prevent it. Where aqua ammonia is exposed to the air it does not boil; however, it does lose ammonia rapidly. Since the loss of ammonia from aqua ammonia is not easily estimated, farmers sometimes transport it in open tanks and apply it on the surface of the land to be covered later, both of which result in large losses of ammonia.

On the basis of the authors' experience, a good job of handling and applying anhydrous ammonia is done, but aqua ammonia is often handled and applied inefficiently. Even though aqua ammonia can be handled and applied efficiently, it appears doubtful that it will be so used by the average farmer.

Acidity of Sources of Nitrogen

Most of the sources of nitrogen used in mixed fertilizers and as materials are acid forming, which means that they leach lime out of the soil; however, a few sources increase the lime content of the soil. In mixed fertilizers, the acidity of the nitrogen sources is often neutralized with dolomitic lime. The amount of 90 percent lime gained or lost from the soil by the use of different sources of nitrogen is shown in Table 1.

Anhydrous ammonia, ammonium nitrate, and uramon have a slightly acid effect on the soil. In order to maintain the lime content of the soil where these sources of nitrogen are used it is necessary to apply some lime to the soil periodically. The cost of the lime needed is relatively low. Lime may be used at 10-year intervals to maintain the lime content of the soil where these sources of nitrogen are used. Sulphate of ammonia is about three times as acid forming as anhydrous ammonia, ammonium nitrate and uramon. Nitrate of soda and cyanamid increase the lime content of the soil slightly; however, the increase is not sufficient to markedly increase the lime.

One should become lime conscious and take care of the lime needs of the soil where acid-forming sources of nitrogen are used; however, there is no need to be alarmed about the immediate effect of anhydrous ammonia and ammonium nitrate on the acidity of the soil.

Factors Affecting Crop Response To Ammonia

When anhydrous ammonia is applied to the soil it goes into solution in the soil water (aqua ammonia is in solution), and moves only until it comes in contact with enough clay and organic matter to hold it, after which it does not move. In tests, nitrogen applied at rates of 100 pounds per acre as anhydrous ammonia has come in contact with a cross section of about 16 square inches in a sandy loam soil when the applicators were spaced 42 inches apart. The area covered is larger in more sandy soils and smaller in soils containing more clay. In order for plants to use ammonia they must grow roots to where it is applied.

Since plants must grow roots to where ammonia is applied, it is necessary that it be applied relatively close to small slow-growing plants, like cotton, in order for them to get it while they are young. Anhydrous ammonia applied half way be-

Table 1. The effect of sources of nitrogen on the lime content of the soil.

Source of nitrogen	Pounds of 90 percent lime gained or lost	
	1 lb. of nitrogen	320 lbs. of nitrogen
Anhydrous ammonia	2.0 lost	640 lost
Ammonium nitrate	2.0 lost	640 lost
Cyanamid	3.17 gain	1014 gain
Nitrate of soda	2.0 gain	640 gain
Sulphate of ammonia	6.0 lost	1920 lost
Uramon	2.0 lost	640 lost

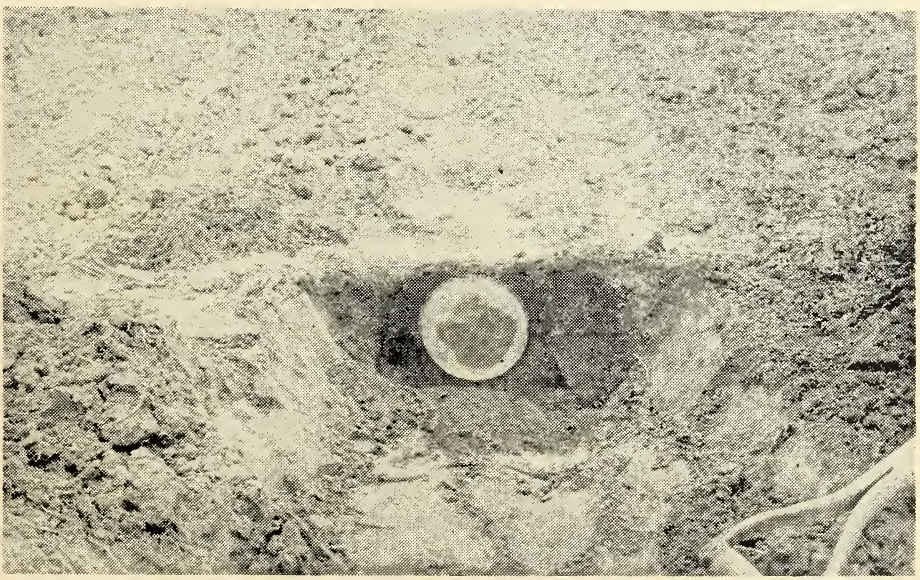
tween the rows of cotton would have about the same effect as a very late side dressing. Under boll weevil conditions, the necessity for rapid development of the young cotton plant requires applying the nitrogen relatively close to the plant. This would not necessarily hold true where soils are naturally very high in nitrogen. Crops like corn which grow rapidly and send their roots out quickly are able to utilize ammonia applied in the middles at the time of sidedressing; however, with small corn some time is required for the roots to reach it.

When ammonia is applied to the soil it readily goes on the clay and organic matter. When applied well below the surface of soils containing free lime it is also held by the soil. The authors have applied 200 pounds of nitrogen per acre as anhydrous ammonia with one applicator in rows 40 inches apart at a depth of 5 to 6 inches without any noticeable loss of ammonia. On extremely sandy soils it should be applied deeper or more than one applicator per 40-inch row should be used where a very high rate of application is made.

Ammonia is a gas at ordinary temperatures and atmospheric pressure. In order that it not be lost, it is necessary that either anhydrous or aqua ammonia be applied 4 or more inches deep and covered simultaneously. If exposed to the air ammonia from both anhydrous and aqua ammonia is lost.

Ammonia may be applied in surface irrigation water as used for rice; however, the soil where the water first comes into the field absorbs more ammonia than that farther away. The different rates of nitrogen obtained in this manner may result in uneven maturity and ripening, which in turn may cause harvesting problems. Ammonia cannot be applied in sprinkling systems without very large losses.

Ammonia which is on clay and organic matter in the soil does not leach out. It is held in the soil even though excessive



When released in the soil anhydrous ammonia does not move far. Filter paper containing a dye was used in this test to show that 100 pounds of nitrogen per acre in 42-inch rows covered about 16 square inches in a sandy loam soil.

rains come. Leaching of nitrogen applied as ammonia does not take place until after it is converted into nitrate nitrogen; only nitrate nitrogen leaches.

During warm weather most ammonia is changed into nitrate nitrogens in about 6 weeks in soils which have a good supply of lime, and which are well drained. The rate of conversion of ammonia into nitrates is slow during cold weather, in excessively wet soils, and in soils which are low in lime.

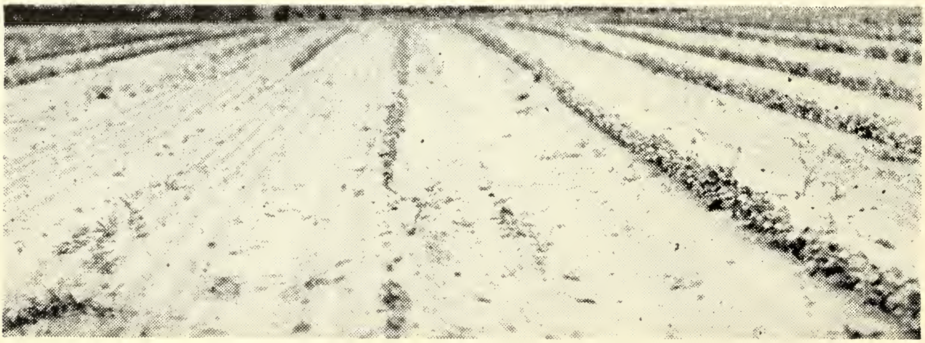
Data presented below show that in soils with a good supply of lime, anhydrous ammonia applied to oats from October to December was largely lost before spring; where the soils were low in lime the ammonia was retained by the soil through the winter and was present for use in the spring. These differences are attributed to differences in the rate of nitrification.

Young cotton and corn plants grow off more rapidly when ammonia is the source of nitrogen as compared to nitrate nitrogen. Since young corn grows off much more rapidly than young cotton, the advantage of ammonium nitrogen is much more noticeable with corn than with cotton. Young oats, and probably other young small grains, apparently use ammonium and nitrate nitrogen equally well; however, fall-planted oats apparently make little use of ammonia in the spring and it must be converted into nitrates before it is utilized efficiently. Most plants in an advanced stage of growth show better response to nitrates than to ammonia; however, in our experiments corn has utilized ammonia as well as nitrates, even though they were applied late in the season.

For side dressing, ammonium nitrate has been superior to anhydrous ammonia for cotton where both were applied four to six inches deep.

Where the ammonium form of nitrogen is to be used to give young plants a quick start, it is necessary that it be applied immediately before planting or while the plants are very small. If ammonia is applied to fertile soils several weeks in advance of planting it is converted into the nitrate form before the young plants use it.

When crops are exposed to the fumes of ammonia the leaves are killed; however, the buds are usually not killed and growth is resumed. Very young cotton plants may be completely killed by ammonia fumes. In side dressing, it is therefore, doubly important that either anhydrous or aqua ammonia be applied properly, for in addition to injuring the plants, noticeable ammonia fumes mean also that nitrogen is being lost.



Anhydrous ammonia and other fertilizers kill cotton and other seedlings when placed too close to the seed.

Ammonia kills seed when it is placed in contact with or just below them. It is important that ammonia be placed so that it will be at least 3 inches below or to the side of the seed. If there is any doubt about whether or not seed may come in contact with ammonia if put in the center of the bed, the ammonia should be put in the side of the bed. In order to avoid possible injury to the seed and young plants, it is recommended that the ammonia be applied about 4 inches to the side of where the seed are to be placed and 4 to 6 inches below the seed level.

When no odor can be detected at the point where the ammonia was applied, the soil may be plowed up without loss of nitrogen. In most cases, the odor of ammonia disappears within 24 hours after application.

Ammonia and Fuels Form Poison

Experiments at State College show that when a mixture of anhydrous ammonia and butane or propane is burned, hydrocyanic acid, which is very poisonous, is formed. Propane or butane, which is to be used for household purposes, should not be put into tanks which have been previously used for anhydrous ammonia unless the ammonia is completely removed.

Ammonia may be completely removed from tanks by first draining the liquid ammonia and then blowing the fumes out or filling the tanks with water, which will absorb the ammonia, and draining. No odor of ammonia should remain in tanks which are to receive household butane or propane.

Marvin Gieger, Chemist.

Response of Crops to Anhydrous Ammonia

Anhydrous ammonia has been compared to ammonium nitrate in numerous tests, and in a few cases other sources of nitrogen have been included. Time, depth and rate of application have been variables. Usually, there were six replications of the treatments in each corn and cotton test, except those reported from Stoneville where there were four. In tests other than corn and cotton there were four replications. In most tests the treatments were randomized or were in randomized blocks. A blanket application of superphosphate and potash in amounts considered adequate was made on all tests conducted outside of the Delta.

Both anhydrous ammonia and ammonium nitrate are slightly acid forming, sulphate of ammonia is strongly acid forming, and nitrate of soda and cyanamid increase the lime in the soil slightly. However, the tests have been conducted for too short a period for the effect of the sources of nitrogen to exert a noticeable effect on the lime content of the soils.

Even though young plants grow off more rapidly where the source of nitrogen is ammonia than where it is nitrate, there is probably no difference in yield due to the form of nitrogen utilized by the plant. Where differences in yield were obtained from the use of anhydrous ammonia in comparison with other sources of nitrogen, the difference is probably due to differences in the amount of nitrogen which was actually used by the plant.

Since all of the nitrogen in anhydrous ammonia is in the ammonium form, and that in ammonium nitrate is half nitrate and half ammonium nitrogen, less leaching of nitrogen from anhydrous ammonia would be anticipated before the ammonia is converted into nitrate. The nitrogen in nitrate of soda is in the nitrate form which is subject to leaching; however, on some soils the sodium in nitrate of soda increases the yield of cotton, sugar beets, and some other crops. The nitrogen in uramon and cyanamid has to be changed to the ammonium form before plants can use it.

Cotton

Anhydrous ammonia was first compared to ammonium nitrate in side dressing tests conducted in 1944. The fertilizers were applied in June; the weather was

Table 2. The response of cotton to side dressing with anhydrous ammonia and ammonium nitrate on a dry year.

Location	Source of nitrogen	
	Anhydrous ammonia 5 inches deep	Ammonium nitrate surface
	Increase in yield, pounds seed cotton per acre	
Eupora	193	175
Marks	242 (305)[1]	92 (180)[1]
Shuqualak	258	104
Heathman	98	48
Stoneville	305	159
Stoneville	105	125
Yazoo City	207	225
Valley Hill	263	215

[1]The first figures are for the first picking. The second picking was lost. The figures in parenthesis are based upon the first picking and boll counts.

Table 3. The response of cotton to anhydrous ammonia and ammonium nitrate at several locations in 1945, 1946 and 1947.

Location	Source of nitrogen, pounds per acre, depth of application, and time of application								
	Ammonium nitrate 32 lbs. N 4" deep preplant	Anhydrous ammonia 32 lbs. N 4" deep preplant	Anhydrous ammonia 32 lbs. N 6" deep preplant	Anhydrous ammonia 32 lbs. N 4" deep side dress	Ammonium nitrate 4" deep 32 lbs. N side dress	Ammonium nitrate 32 lbs. N surface side dress	Check no nitrogen	Anhydrous ammonia 64 lbs. N 4" deep preplant	Anhydrous ammonia 64 lbs. N 6" deep preplant
	Yield in pounds seed cotton per acre								
Greenwood[1]	1310	1175	1432	1338	1433	1410	1013	1240	1303
Lambert	2160	2130	2443	2375	2370	2297	2013	2660	2607
Columbus	953	1150	1072	1100	1177	1143	703	1343	1180
Holly Springs	1907	1942	1923	1860	1875	2002	1433	2237	2240
Tomnolen	1485	1710	1720	1350	1470	1510	1130	1440	1380
Columbus	1263	1352	1507	1458	1302	1423	1120	1320	1453
Indianola	1593	1723	1707	1563	1503	1583	1523	1633	1663
Indianola	1785	1710	1690	1630	1725	1720	1205	1945	1860
Holly Springs	1270	1274	1412	1308	1264	1258	756	1362	1520
Lambert	2127	2353	2183	2190	2177	2073	1983	2313	2290
Starkville	1473	1568	1487	1487	1565	1472	1148	1455	1373
Tomnolen	1215	1265	1408	1228	1353	1188	755	1310	1323
Aberdeen	430	453	527	407	417	503	217	563	643
Clarksdale	2750	2888	2944	2514	2824	2620	2402	3024	3094
Roundaway	1426	1396	1572	1542	1264	1274	1216	1462	1538
Lambert	1130	1094	1102	1124	1068	1090	998	1144	1100
Morgan City	1352	1404	1478	1402	1460	1356	1100	1672	1718
Holly Springs	1023	1122	1080	947	1014	1048	863	1048	1076
Columbus	890	1080	1036	1082	1048	996	682	1052	944
Average 18 tests	1457	1534	1572	1476	1493	1475	1180	1610	1611
Average increase	277	354	392	296	313	295	-------	430	431

[1]Omitted from average due to loss of ammonia in application at the 4-inch depth of application.

dry at the time of application and continued dry in most places where the tests were conducted. The ammonium nitrate was applied on the surface of the soil. The anhydrous ammonia was applied about 5 inches deep. The rate of nitrogen was 32 pounds per acre.

Anhydrous ammonia was much superior to ammonium nitrate in most of the tests (Table 2), which is attributed to the anhydrous ammonia being placed in the root zone where it was available to the plants even though little rainfall followed application. The ammonium nitrate was placed on the surface where much of it remained because there was insufficient rain to completely carry it into the root zone.

The differences in the efficiency of anhydrous ammonia and ammonium nitrate in these tests were due to positional availability. In order to seal anhydrous ammonia it is necessary to apply it 4 or more inches deep, while ammonium nitrate may be, and is commonly, applied on the surface of the soil in side dressing. These data emphasize, primarly, the desirability of applying solid sources of nitrogen in the root zone when dry weather is likely to follow, rather than a difference in the potential efficiency of these sources of nitrogen when used as a side dressing.

Anhydrous ammonia and ammonium nitrate were compared in 18 tests during 1945-1947 and 12 tests in 1948-1950. Time, rate, and depth of application of nitrogen were variables in the tests, as shown in Tables 3 and 4. Boll weevils limited yields markedly in some tests. The individual tests may be studied; however, there are no differences which can be accounted for on the basis of soil differences.

Where anhydrous ammonia and ammonium nitrate were applied at the rate of 32 pounds of nitrogen per acre before planting, the following increases in yield were obtained:

Source of nitrogen 32 lbs. per acre	Depth of application inches	Increase in yield per acre pounds seed cotton		
		1945-47	1948-50	Average
Ammonium nitrate	4	277	329*	298
Anhydrous ammonia	4	354	324*	342
Anhydrous ammonia	6	392	......	......
Number of tests	....	18	12	30

*Applied five inches deep.

Anhydrous ammonia increased the yield 342 pounds of seed cotton per acre as compared to 298 pounds for ammonium nitrate at the 4- and 5-inch depth of application. The superiority of the anhydrous ammonia of 44 pounds of seed cotton is attributed to less leaching of nitrogen during the first 8 weeks after application because all of its nitrogen was in the ammonium form which is not subject to leaching, while only half of that in ammonium nitrate is in the non-leaching ammonium form. After 8 weeks all of the nitrogen from both sources should be in the nitrate form on most soils, after which there would be no difference in the leaching.

At the 64-pound rate of application anhydrous ammonia and ammonium nitrate produced the same yields in 18 experiments in 1945-47; in the 12 1948-50 experiments anhydrous ammonia produced 71 pounds more seed cotton than ammonium nitrate at this rate of application.

Broadcast application of ammonium nitrate before planting was almost as efficient as drill application.

The 6-inch depth of application of anhydrous ammonia produced an average

Table 4. The response of cotton to anhydrous ammonia and ammonium nitrate at several locations in 1948, 1949, and 1950. Source of nitrogen, pounds of actual nitrogen per acre, depth of application in inches, and time of application.

Location of test***	Ammonium nitrate, 64 lbs. 5" preplant	Anhydrous ammonia, 64 lbs. 5" preplant	Anhydrous ammonia, 32 lbs. 5" preplant	Ammonium nitrate, 32 lbs. 5" preplant	Ammonium nitrate, 32 lbs., B'd c't. preplant	Ammonium nitrate, 32 lbs. surface, early side-dress	Ammonium nitrate, 32 lbs., 5" early side-dress	Anhydrous ammonia, 32 lbs., 5" early side-dress	Ammonium nitrate, 32 lbs. surface, late side-dress	Ammonium nitrate, 32 lbs., 5" late side-dress	Anhydrous ammonia, 32 lbs. 5" late side-dress	Check no nitrogen
	Yield in pounds of seed cotton per acre.											
(1948)												
Holly Springs	1582	1667	1348	1400	1332	1308	1365	1447	1468	1603	1247	1007
Newton	1437	1380	1319	1303	1301	1275	1237	1101	1288	1328	1323	926
Clarksdale	2442	2648	2390	2490	2277	2052	2340	2047	2250	2505	2233	1807
Roundaway	2366	2636	2038	2138	2350	1996	2312	1978	2434	2346	2188	1888
(1949)												
Parchman	1980	2094	1968	1798	1838	1921	1978	1888	1625	1878	1880	1591
Brooksville	1328	1292	1068	1128	1096	996	1180	1044	1020	1032	880	816
Newton	422	391	321	303	262	282	299	315	235	260	255	120
Holly Springs**	1121	1163	987	936	985	830	920	930	No Late	side-dressing	applied	585
(1950)												
Parchman	700	718	654	650	656	617	656	636	580	584	606	452
Morgan City	1510	1618	1496	1518	1436	1514	1486	1464	1286	1450	1344	1352
Brooksville	1132	1084	844	936	980	860	1016	920	980	964	952	756
Holly Springs	785	1058	972	928	840	950	925	830	840	955	930	695
Newton	1782	1734	1442	1329	1368	1320	1294	1433	1298	1289	1446	562
Average	1456	1527	1322	1327	1311	1258	1341	1259	1275	1350	1274	998
Average increase	458	529	324	329	313	260	343	261	277	352	276	

**Omitted from average.

***Tests at Holly Springs, Brooksville and Newton, were on the same site each year.

of 38 pounds of seed cotton per acre more than the 4-inch depth. The superiority of the 6-inch depth of application is attributed to this depth being slightly more favorable for cotton, or possibly to a slower rate of nitrification which would result in less leaching of nitrogen.

Results reported in Table 3 show that the 6-inch depth of application of anhydrous ammonia was considerably superior to the 4-inch depth in a few tests, was inferior in a very few tests, and there was little difference in many tests. In one two-year test at Stoneville a 6-inch depth of application of both anhydrous ammonia and ammonium nitrate made about 100 pounds more seed cotton than the 4-inch depth and the 8-inch depth made about 100 pounds more than the 6-inch depth. The advantage for deeper application of anhydrous ammonia is usually greater when extremely dry weather follows.

From a practical standpoint anhydrous ammonia is more easily sealed in the soil when applied 6 inches deep than when applied 4 inches deep. Deeper applications are more expensive. Taking everything into consideration, it appears that the most reasonable depth of application is 6 inches.

In side dressing young cotton, the distance away from the young plants is important on poor soils. Young cotton grows off slowly and extends its roots out slowly. If the ammonia is applied 5 to 6 inches from small cotton the roots begin to take it up in a short time. If it is applied farther away it has the effect of a delayed side dressing which is undesirable with cotton. Where soils have sufficient nitrogen for cotton to grow off rapidly the distance of side dressing from the plant is less important.

When anhydrous ammonia and ammonium nitrate were used as an early side dressing for cotton the following results were obtained.

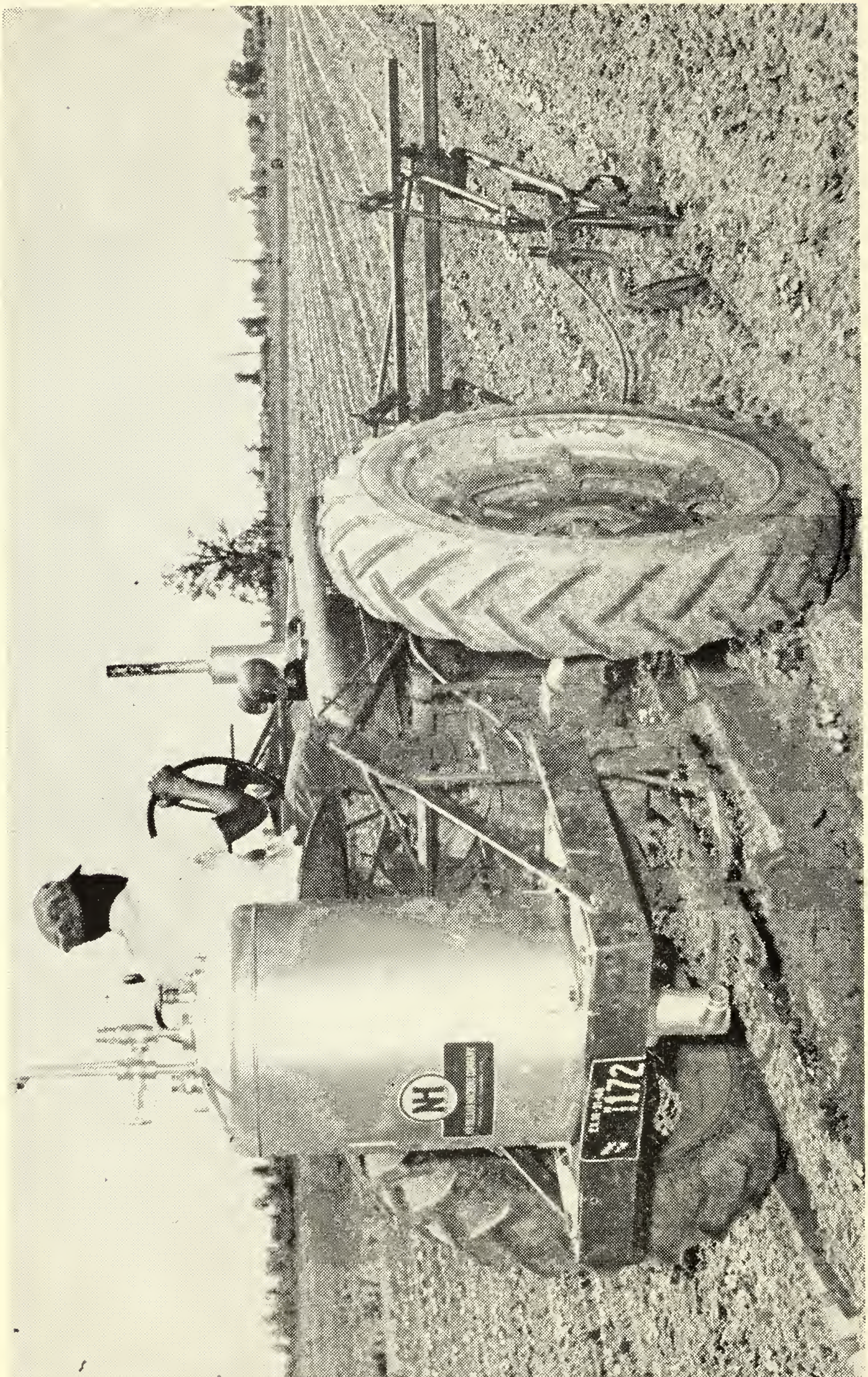
Source of nitrogen 32 lbs. per acre	Depth of application inches	Increase in yield per acre, pounds seed cotton 1945-47	1948-50	Average
Anhydrous ammonia	4	296	261*	282
Ammonium nitrate	4	313	343*	325
Ammonium nitrate	Surface	295	260	281
Number of experiments	----	18	12	30

*Applied 5 inches deep.

Anhydrous ammonia applied 4 or 5 inches deep and ammonium nitrate applied on the surface made the same increase in yield of cotton. Ammonium nitrate applied at the same depth as anhydrous ammonia made 43 pounds more seed cotton than anhydrous ammonia in an average of 30 tests, which suggests that ammonium nitrate is slightly superior to anhydrous ammonia for side dressing provided both are placed 4 or 5 inches deep.

The late side dressings were applied in June in the 12 tests (Table 4), and in these tests, in which 32 pounds of nitrogen was applied, the June side dressings produced almost exactly the same increase in yield as the May side dressings. In one test at Stoneville side dressing and preplanting application of 30 pounds of nitrogen per acre produced the same increase in yield; however, where 45, 60 and 75 pounds of nitrogen was applied per acre side dressing was considerably inferior to preplanting or split application.

It should also be pointed out that ammonium nitrate at 32 pounds of nitrogen per acre, 4 and 5 inches deep, produced an average of 27 pounds more seed cot-



Anhydrous ammonia is applied before planting cotton or as a side dressing.

ton when applied as an early side dressing than when applied just before planting. However, anhydrous ammonia applied just before planting produced 60 pounds more seed cotton than when used as a side dressing.

In using anhydrous ammonia the normal anticipated needs of cotton for nitrogen should be applied just before planting, and side dressing with additional nitrogen should be applied in June where cotton appears to need more nitrogen.

As has been pointed out, the 64-pound rate of nitrogen was only slightly superior to the 32-pound rate, on the average which no doubt is associated with the severity of boll weevil damage. However, there were some good increases due to the higher rate of nitrogen. Some of the larger increases for the higher rate of nitrogen were obtained where 1900 to 2400 pounds of seed cotton was obtained with the lower rate. It appears that the yield per acre on low-producing soils which are capable of high yields might be increased to a very high level by the use of high amounts of nitrogen and other fertilizers. Where soils are well drained and no serious disease exists it appears that yields equal to the highest reported are possible where sufficient fertilizer is used and insects are controlled.

Large amounts of nitrogen increase stalk growth and reduce yields where insects are not controlled. However, early fruiting, which is obtained with early insect control, tends to prevent excessive stalk growth.

The response of cotton to five sources of nitrogen in the Mississippi Delta is shown in Table 5. The data are 6-year averages for 30, 45 and 60 pounds of nitrogen per acre at four locations. There was little difference between the yields produced with anhydrous ammonia and ammonium nitrate; however, these two sources of nitrogen produced some higher yields than nitrate of soda, sulphate of ammonia and cyanamid.

The effects of time of application of anhydrous ammonia and ammonium nitrate are variable. Results reported below show that anhydrous ammonia applied to oats produced excellent increases in yield when applied in October or December to soils of pH 5.0 or lower, and poor results when applied to soils of pH 5.45 or higher. The poor results for fall application on the latter soils were, no doubt, due to the conversion of the ammonia to nitrate nitrogen and subsequent leaching out before spring. On soils of pH 5.0 or lower the change of ammonia into nitrate nitrogen was much slower, as shown by laboratory tests.

December application of ammonium nitrate was considerably inferior to May preplanting application on both the sandy and the heavy soil (Table 6). December application of anhydrous ammonia was as good as May application in two sandy land tests. On the heavy soil both the December and the May applications of anhydrous ammonia were less than half as efficient as ammonium nitrate applied in May. The poor results from anhydrous ammonia applied in December on the heavy soil are attributed to the growth of weeds which consumed a large part of

Table 5. The response of cotton to sources of nitrogen, 1945-50.

Source of nitrogen[1]	Stoneville	Yazoo City	Money	Onward	Average	Increase
			Yield in pounds seed cotton per acre			
Anhydrous ammonia	2247	1997	1783	1872	1975	542
Ammonium nitrate	2286	1953	1828	1786	1963	530
Cyanamid	2212	1902	1796	1779	1922	489
Sulphate of ammonia	2254	1930	1787	1760	1933	500
Nitrate of soda	2190	2021	1811	1780	1951	518
No nitrogen	1807	1496	1440	990	1433	-----

[1]Average of 30, 45 and 60 pounds of nitrogen per acre for each location.

the anhydrous ammonia. The poor results from the May application of anhydrous ammonia are attributed to the loss of ammonia in application because of the poor physical condition of the soil.

It appears that application of anhydrous ammonia earlier than December results in more leaching and a greater growth of weeds, which further reduces the efficiency of fall-applied ammonia.

The uncertainties in the efficiency of anhydrous ammonia applied in the fall and early winter apparently justify a general conclusion that it is uneconomical to apply anhydrous ammonia to row crops before early spring.

Corn

In 1944 seven side-dressing tests and one preplanting test were conducted with corn. In 1945, 1946, and 1947 five tests were conducted in which both preplanting and side-dressing applications were made, and in thirteen tests side dressing applications only were made. The stands of corn were usually considered adequate; however, the stands were not adjusted to the rate of nitrogen. In tests conducted since 1947 arbitrary stands were used for the different nitrogen levels.

The first use of anhydrous ammonia on corn was in 1944 when seven side-dressings tests were put out in June, and very dry weather followed (Table 7). The rate of application was 32 pounds of nitrogen per acre. Anhydrous ammonia was applied 5 inches deep and the ammonium nitrate was applied on the surface. Response to anhydrous ammonia was almost normal in three of the tests, low in two, and very low in three tests. Response to ammonium nitrate was about normal in one test, and very low in seven tests. Anhydrous ammonia was superior to ammonium nitrate in all but one of these tests and much superior in most of them. The inferiority of the ammonium nitrate is attributed to the lack of sufficient rain to carry it into the root zone. The results emphasize the desirability of applying solid sources of nitrogen in the root zone when rain may be insufficient to carry the nitrogen into the root zone.

Preplanting and side dressing applications at 32 pounds of nitrogen per acre were about equally effective for producing corn (Table 8). The average data for the side dressing treatments for the 18 tests (Table 9) are as follows:

Source of nitrogen, 32 lbs per acre	Depth of application inches	Increase in yield per acre corn, bushels
Anhydrous ammonia	4	16.2
Ammonium nitrate	4	14.3
Ammonium nitrate	surface	13.1

Anhydrous ammonia produced 1.9 bushels more corn on the average than ammonium nitrate. Ammonium nitrate applied 4 inches deep produced only 1.2 bushels more than when applied on the surface, which contrasts sharply with the data above where the differences were much greater. In the latter tests the side-dressing applications were usually made during May and there was more time for the rain to carry the nitrogen into the soil; while in the former experiments the

Table 6. The influence of time of application of anhydrous ammonia and ammonium nitrate, applied at the rate of 60 pounds of nitrogen per acre, on the yield of cotton.

Time of application	Sandy loam soil. 1949-1950			Clay (buckshot) soil, 1950	
	Test 1	Test 2		Test 3	
	Anhydrous ammonia	Anhydrous ammonia	Ammonium nitrate	Anhydrous ammonia	Ammonium nitrate
	Increase in yield, pounds seed cotton per acre				
December (preplant)	752	568	462	315	372
May (preplant)	716	585	624	319	727
June (side dress)	626	------	------	------	-- ---
July (side dress)	485	------	------	------	------

Table 7. The response of corn to side dressing with anhydrous ammonia and ammonium nitrate on a dry year.

Location	Anhydrous ammonia 5 inches deep	Ammonium nitrate surface
	Increase in yield, bushels corn per acre	
Eupora	10.8	8.2
Marks	5.6	2.2
State College	12.5	8.6
State College	13.8	4.5
Tomnolen	13.4	13.0
Shuqualak	6.2	3.4
Valley Hill	10.0	7.2

Table 8.The response of corn to anhydrous ammonia and ammonium nitrate, 1945 and 1946.

Location	Source of nitrogen, rate per acre, and depth of application								
	Ammonium nitrate 32 lbs. N 4" deep preplant	Anhydrous ammonia 32 lbs. N 4" deep preplant	Anhydrous ammonia 32 lbs. N. 6" deep preplant	Anhydrous ammonia 32 lbs. N 4" deep side dress	Ammonium nitrate 32 lbs. N 4" deep side dress	Ammonium nitrate 32 lbs. N surface side dress	Check no nitrogen	Anhydrous ammonia 64 lbs. N 4" deep preplant	Anhydrous ammonia 64 lbs. N 6" deep preplant
	Yield in bushels per acre								
Columbus	24.2	28.3	27.8	27.4	27.8	28.5	12.1	38.9	37.7
Starkville	21.8	26.0	29.1	34.6	28.7	26.2	12.4	38.4	40.2
Tomnolen	55.3	56.1	55.9	57.8	55.3	54.6	42.8	60.6	61.8
Holly Springs	82.8	84.6	82.5	79.1	79.5	80.6	69.9	84.8	77.8
Holly Springs	66.3	60.5	66.7	69.5	62.3	63.7	56.0	72.8	69.8
Average	50.1	51.1	52.4	53.7	50.7	50.7	38.6	59.1	57.5
Average increase	11.5	12.5	13.8	15.1	12.1	12.1		20.5	18.9

Table 9. The response of corn to anhydrous ammonia and ammonium nitrate applied as a side dressing: 1945, 1946, and 1947.

Location	Source of nitrogen, rate per acre, and depth of application						
	Check no nitrogen	Anhydrous ammmonia 32 lbs. N 6" deep	Anhydrous ammmonia 32 lbs. N 4" deep	Ammonium nitrate 32 lbs. N 4" deep	Ammonium nitrate 32 lbs. N surface	Anhydrous ammmonia 64 lbs. N 4" deep	Anhydrous ammmonia 64 lbs. N 6" deep
	Yield in bushels per acre						
West Point	54.1	59.2	60.3	58.2	59.6	68.3	65.4
State College	61.8	75.9	73.2	73.8	68.6	79.8	84.8
State College	33.8	41.4	37.3	40.8	35.2	43.5	47.2
Starkville	11.7	34.6	33.8	28.1	27.4	39.4	40.1
Columbus	13.6	37.1	36.1	34.2	35.1	46.2	49.9
Aberdeen	19.3	44.1	42.3	40.6	35.2	54.0	51.4
Columbus	5.6	34.3	34.7	33.0	33.9	48.4	47.6
Starkville	40.3	46.2	47.0	48.8	50.9	56.3	57.4
Columbus	22.2	42.9	44.4	46.3	39.3	50.5	53.9
Sessums	37.0	47.7	46.5	40.5	43.1	60.7	58.1
New Hope	31.2	51.6	52.3	50.2	46.9	54.7	59.0
Columbus	18.6	46.7	45.6	43.7	44.1	56.9	57.9
Columbus	11.0	22.7	22.8	17.7	16.6	19.4	19.8
Average increase		17.3	16.6	15.1	13.5	24.5	25.6

Table 10. The response of corn to anhydrous ammonia and ammonium nitrate at several locations in 1948, 1949, and 1950.

Location of test****	Anhydrous ammonia, 100 lbs. preplant, 200 lbs. early side-dress 5", 16,000	Anhydrous ammonia, 100 lbs. preplant, 100 lbs. early side-dress 5", 12,000	Ammonium nitrate 100 lbs. preplant 100 lbs. early side-dress 5" 12,000	Ammonium nitrate 100 lbs. late side-dress surface, 8,000	Ammonium nitrate 100 lbs. late side-dress 5", 8,000	Anhydrous ammonia 100 lbs. late side-dress 5", 8,000	Ammonium nitrate 100 lbs. early side-dress surface, 8,000	Ammonium nitrate 100 lbs. early side-dress 5", 8,000	Anhydrous ammonia, 100 lbs. early side-dress 5", 8,000	Anhydrous ammonia, 100 lbs. pre-plant 5", 8,000	Ammonium nitrate 100 lbs. pre-plant 5", 8,000	Check no nitrogen
	Source of nitrogen, pounds of actual nitrogen per acre, depth of application in inches, time of application and plants per acre.											
(1948)	Yield in bushels of corn per acre											
Holly Springs	70.5**	95.0	87.0	74.5	76.9	73.9	74.9	76.6	75.4	71.4	69.2	34.3
Newton	21.3**	27.3**	26.7**	34.5	33.9	36.8	30.9	29.8	31.8	26.5	27.4	5.6
(1949)												
Brooksville	80.7	84.7	75.3	72.0	76.3	76.0	72.1	77.3	70.6	65.4	60.6	35.7
Parchman	77.7	79.2	76.2	72.0	76.6	77.5	76.3	71.8	65.2	75.4	69.5	53.7
Newton	85.6	91.0	80.3	69.8	67.6	70.6	64.2	71.9	72.3	63.4	64.4	9.7
Holly Springs	71.6	87.3	84.9	No late side-dress			73.1	70.7	62.2	79.1	72.7	23.6
Oakley	72.9	74.4	76.6	No late side-dress			53.2	48.6	49.3	66.0	55.7	21.8
(1950)												
Newton	63.2**	70.7	67.9	60.1	69.1	65.4	58.0	68.8	69.1	60.5	53.9	4.3
Morgan City	113.3	87.3	95.2	75.2	83.3	86.9	82.4	80.3	87.4	89.1	72.8	37.4
Holly Springs	118.9	118.5	126.8	92.6	91.5	86.6	102.0	98.9	106.1	103.9	94.1	39.2
Brooksville	58.0***	55.3***	58.7***	65.3	65.2	59.1	55.7	52.5	58.6	55.6	56.0	38.6
Average	75.8	79.2	77.8	68.4	71.2	70.3	67.5	67.9	68.0	68.8	63.3	27.6
Average increase	48.2	51.6	50.2	40.8	43.6	42.7	39.9	40.3	40.4	41.2	35.7	—

**The intended stand was not fully obtained.
***Disease damaged the high plant population plots.
****Tests at Holly Springs and Newton were on the same site each year.

applications were made later in the season and very dry weather followed.

Deep applications of nitrogen used as a side dressing becomes increasingly important as summer approaches, when prolonged dry periods are frequent, and as side dressing is delayed until crops are larger. Where crops are planted early and side dressed early, depth of application of solids is probably of little importance. Ammonia must be applied 4 to 6 inches deep in order for it to be covered and retained by the soil.

Where depth of application of nitrogenous fertilizers is a factor in crop production, and with conventional equipment for applying both liquid and solid sources of nitrogen, anhydrous ammonia may be applied at deeper depths more easily than solid sources of nitrogen.

Anhydrous ammonia and ammonium nitrate were compared for corn production in eleven tests with high rates of nitrogen (Table 10). With 100 pounds of nitrogen and 8,000 plants per acre anhydrous ammonia made 5.2 bushels more corn than ammonium nitrate when applied before planting. As an early side dressing there was no difference in the response to anhydrous ammonia and ammonium nitrate at the 5-inch depth of application, and ammonium nitrate applied on the surface. When side dressed late there was little difference between ammonium nitrate on the surface and 5 inches deep, and anhydrous ammonia 5 inches deep. In other experiments ammonium nitrate applied on the surface has given poor results when dry weather followed.

Application of 200 and 300 pounds of nitrogen with 12,000 and 16,000 plants per acre, respectively, produced about 10 bushels more corn on the average than 8,000 plants and 100 pounds of nitrogen.

In many tests the corn with the higher rates of nitrogen was affected more adversely by diseases, and there was much more lodging on these plots.

December application of both anhydrous ammonia and ammonium nitrate at the rate of 120 pounds of nitrogen resulted in a yield of eight bushels of corn less than April application in one test at Stoneville:

Time of application	Source of nitrogen: Anhydrous ammonia	Source of nitrogen: Ammonium nitrate
	Increase, bushels per acre	
December (preplant)	32.4	30.7
April (preplant)	40.3	38.6
June (side dress)	35.1	38.6

December application stimulated growth of weeds and grass which consumed part of the nitrogen. The efficiency of the nitrogen was low in these tests. If a higher efficiency had been obtained from the spring applications, superiority of the spring applications may have been still larger. Earlier application would, no doubt, stimulate the growth of weeds and grass more, and increase the time for leaching.

Side dressing stimulated the growth of grass in the corn, as compared to preplanting applications.

Oats for Grain

Oats for grain are commonly planted in October and early November. They usually make little growth before spring regardless of the fertility of the soil unless the winter is mild ,which means that little of the nitrogen is used in the fall and winter. In order for nitrogen to be available to oats for grain it must be present in the soil in early spring. The length of time nitrogen stays in the soil depends upon its form and upon the rainfall. Ammonia does not leach out of the soil; nitrogen leaches as the nitrate. The rate of change of ammonia to nitrate nitrogen is dependent upon the lime content of the soil, its temperature and the moisture content. In addition, young oats apparently use ammonia and nitrate nitrogen equally well, while fall planted oats apparently prefer nitrate nitrogen in the spring of the year.

During 1945-1946 ten tests were conducted with oats in which ammonium nitrate and anhydrous ammonia were applied in the fall; ammonium nitrate was applied in the spring, and anhydrous ammonia was applied in the winter or spring in three tests (Table 11). When applied in the fall the ammonium nitrate was a poor source of nitrogen in all tests as compared to anhydrous ammonia applied in the fall or to ammonium nitrate applied in the spring.

On four of the more acid soils anhydrous ammonia applied in the fall was superior to spring-applied ammonium nitrate. The soil in test number four had a pH of 4.95 on which aqua ammonia applied in January was as good as ammonium nitrate in March. The soil in test number 5 had a pH of 5.1; on this soil anhydrous ammonia applied in early March was inferior to ammonium nitrate at the same time. The rate of change of ammonia to nitrate nitrogen was slow on these soils, which enabled the fall- and winter-applied ammonia to be retained until spring and prevented the oats in test No. 5 from getting nitrate nitrogen in time for it to be fully effective.

On the soils which were above pH 5.45 anhydrous ammonia applied in the fall was not nearly as effective as ammonium nitrate applied in the spring. In test No. 10 (pH 7.8) anhydrous ammonia and ammonium nitrate applied in March were equally effective. The failure of anhydrous ammonia to go through the winter on these soils and its high efficiency when applied in March on one soil were due to the high rate of change of ammonia into nitrates. Ammonium nitrate applied in October gave poor results in all tests.

The data reported in Table 12 show that October application of anhydrous ammonia to oats was unsatisfactory in the first three tests which were high in lime; on the fourth soil, which was strongly acid, anhydrous ammonia was about equal to ammonium nitrate. Anhydrous ammonia applied the last of November on three soils which were high in lime was considerably inferior to a February application. When applied the last of February, anhydrous ammonia was superior to ammonium nitrate in all tests, and practically as good when applied during the first week in March.

The effect of anhydrous ammonia applicator spacing on the yield of oats for grain is reported in Table 13. The fertilizers were applied about the first of March, a little late for anhydrous ammonia on many soils, and the ammonium nitrate was a little superior to anhydrous ammonia. The data show that anhydrous

Table 11. The response of oats to fall-applied anhydrous ammonia and to fall and spring applied ammonium nitrate—32 pounds of nitrogen per acre.

Test No.	Ammonium nitrate		Anhydrous ammonia	
	Increase in yield—bushels oats per acre			
	Soils below pH 5.1			
	Fall	Spring	Fall	Spring
1	30	—	16	21
2	32	—	15	25
3	30	—	16	25
4	29	30*	20	27
5	19	10**	10	19
	Soils above pH 5.1			
6	25	—	15	30
7	12	—	8	19
8	15	—	8	22
9	14	—	10	24
10	4	25**	5	24

*Applied in January. **Applied in March.

ammonia may be applied with very satisfactory results with the applicators spaced up to 32 inches apart.

Observations have been made that when the anhydrous ammonia applicators are spaced farther apart than 16 inches many of the oats do not receive any benefit from the nitrogen. The failure of this to be reflected more definitely in the yield is not understood. Where soils are well drained the lateral spread of roots is greater; where they are poorly drained oats may not get nitrogen more than 6 inches from the point of application, which means that the applicators should be placed closer together on poorly drained soils.

In one test where anhydrous ammonia was applied to a sandy soil in October at the rate of 48 pounds of nitrogen per acre the yield of oats was 38, 37, and 33 bushels for 24, 18, and 12 inch spacings of the applicators, respectively.

As has been pointed out anhydrous ammonia moves only until it comes in contact with enough soil to hold it, which is a very short distance. In order for oats to get nitrogen applied as anhydrous ammonia it is necessary for them to grow roots to the point of application of the ammonia.

Oats are sometimes winter killed by being heaved out of the soil by ice because the root system is too small to hold them in the soil. The application of nitrogen to oats in the fall on soils which

Table 12. The response of oats to anhydrous ammonia and ammonium nitrate, 1946-1947.

Nitrogen treatment		Date of	Location and yield in bushels oats per acre							
Source	Lbs. N per acre	application	Lambert	Greenwood	Columbus	Shelby	Clarksdale	Columbus	Columbus	Holly Springs
None	----	------	36.9	50.0	34.9	25.8	23.1	26.3	14.6	5.0
Anhydrous ammonia	32	Oct.	45.1	53.9	39.7	------	------	------	------	16.5
Anhydrous ammonia	64	Oct.	41.9	58.0	50.6	------	------	------	------	24.9
Ammonium nitrate	32	Feb.	58.7	62.2	51.7	30.0	42.5	45.5*	40.4*	18.0
Anhydrous ammonia	32	Feb.	59.1	67.1	58.9	35.2	52.3	41.3*	35.9*	21.8
Anhydrous ammonia	64	Feb.	65.6	74.7	65.2	58.8	70.0	------	------	34.5
Ammonium nitrate	64	Feb.	69.8	62.7	------	43.3	58.2	------	------	30.0
Anhydrous ammonia	32	Nov.	55.2	53.0	50.8	------	------	------	------	------

*Applied the first week in March.

Table 13. The effect of spacing of applicators on the yield of oats for grain.

Nitrogen*		Applicator spacing inches	Yield—bushels per acre					
			Test number					
Source	Lbs. per acre		1	2	3	4	5	6
Check No nitrogen	----	----	38	5	11	11	18	14
Ammonium nitrate	32	Broadcast	58	31	51	----	----	----
Anhydrous ammonia	32	16	59	21	42	37	----	----
Anhydrous ammonia	32	24	59	23	43	37	----	----
Anhydrous ammonia	32	32	57	17	44	35	----	----
Anhydrous ammonia	48	16	----	----	----	----	42	31
Anhydrous ammonia	48	24	----	----	----	----	37	30
Anhydrous ammonia	48	32	----	----	----	----	38	29
Ammonium nitrate	64	Broadcast	71	32	62	----	----	----
Anhydrous ammonia	64	16	62	27	54	39	----	----
Anhydrous ammonia	64	24	66	23	47	39	----	----
Anhydrous ammonia	64	32	54	21	46	39	----	----
Anhydrous ammonia	96	16	----	----	----	----	49	31
Anhydrous ammonia	96	24	----	----	----	----	42	31
Anhydrous ammonia	96	32	----	----	----	----	37	34

*Time of application—first of March.

Table 14. The response of fall-planted oats to anhydrous ammonia and ammonium nitrate as measured by forage and grain yields.

Nitrogen treatment			Yield per acre test number				
	Time and rate		Air-dry forage			Grain	
Source	Fall	Spring	Test 1	Test 2	Test 3[1]	Test 1	Test 2
	Lb. N	Lb. N	Lb.	Lb.	Lb.	Bu.	Bu.
Anhydrous ammonia	32	----	1072	720	883	25	19
Ammonium nitrate	32	----	883	443	822	24	17
Ammonium nitrate	64	----	1892	817	1334	23	21
Anhydrous ammonia	64	----	1840	1251	1351	24	17
Anhydrous ammonia	32	32	1098	703	792	43	40
Ammonium nitrate	32	32	953	355	758	46	44
Ammonium nitrate	----	32	73	15	94	45	41
Anhydrous ammonia	----	32	60	16	--------	39	36
Anhydrous ammonia	----	32	--------	--------	--------	44	36
Ammonium nitrate	----	32	--------	--------	--------	50	41
No nitrogen	----	----	--------	--------	--------	26	15

[1]First week in December clipping only.

were very low in nitrogen prevented the heaving of oats in three of the tests conducted. Young oats are very responsive to phosphorus and lime. It is evident that the application of any element which is deficient in the soil would also prevent heaving of oats and other small grains.

Oats For Forage

The response of oats for forage and grain to sources of nitrogen is shown in Table 14. The three tests were put out the last week in September with the anhydrous ammonia being applied just before planting and the ammonium nitrate two weeks later after the oats were up. Anhydrous ammonia was considerably superior to ammonium nitrate for the production of forage in one test at the 32- and 64-pound rates. There was insufficient rainfall to carry the ammonium nitrate into the root zone soon after it was applied, and the superiority of the anhydrous ammonia was, no doubt, due to positional availability. Since dry weather in the fall is not uncommon the desirability of plowing solid sources of nitrogen into the soil before planting oats is suggested.

Data on the response of oats for forage and grain to anhydrous ammonia and ammonium nitrate are reported in Table 15. The time of application was September and December for forage, and March for grain. There was little difference between the yields where anhydrous ammonia and ammonium nitrate were applied, and 96 pounds of nitrogen in September was as effective as 48 pounds in September and December.

Where the yield of forage without nitrogen was 1,160 pounds per acre or more, 48 pounds of nitrogen per acre was apparently sufficient for most economical forage production; where the yield of forage without nitrogen was about 400 pounds per acre, 96 pounds of nitrogen was more economical except at Brooksville in 1950 where the yields were low because of poor drainage.

During 1948-1949 and 1949-1950, all of the tests produced at least one ton of air-dry forage per acre before March, where sufficient nitrogen had been applied. In some cases only one clipping was made.

It should be pointed out that from one to three clippings were made. Under these conditions oats make more total growth than where they are cut more frequently, and probably much more than

Table 15. The response of oats for forage and grain to anhydrous ammonia and ammonium nitrate—time and rate of application.

Source, rate, time of nitrogen	Brooksville		Holly Springs	Newton		Oakley		Poplar-ville, 1949
	1949	1950		1949	1950	1949	1950	
	(Pounds air-dry forage per acre)							
No nitrogen	1602	265	744	402	385	1270	1362	1160
Anhydrous ammonia 24 lbs. SDM*	2072	744	1686	1440	1668	2083	2001	1653
Anhydrous ammonia 48 lbs. SDM	2537	1135	1788	2036	2685	2066	2290	1915
Ammonium nitrate 48 lbs. SDM	2214	807	2349	2376	2445	2248	2574	1942
Anhydrous ammonia 48 lbs. SD	2651	984	1824	2528	2653	2292	2569	1806
Ammonium nitrate 48 lbs. SD	2291	691	2099	2324	2538	2322	2758	2035
Ammonium nitrate 96 lbs. S	2842	1052	2115	3340	2281	2302	2529	1850
Anhydrous amonia 96 lbs. S	2558	1097	1914	3092	2507	2190	2378	1998
Anhydrous ammonia 96 lbs. S, 48 D	2802	1326	2060	2930	2926	2124	2698	1950
Clipping date	12/9			12/2; 2/26		2/15		12/2; 1/26; 2/11
	Grain yield, bushels per acre where clipped.							
No nitrogen		7	25	2	4	Win-		Kill-
Anhydrous ammonia 24 lbs SDM		34	54	13	24	ter		ed
Anhydrous ammonia 48 lbs. SDM		50	56	16	30	Kill-		by
Ammonium nitrate 48 lbs. SDM		50	53	12	23	ed		rust
Anhydrous ammonia 48 lbs. SD		22	47	8	9			
Ammonium nitrate 48 lbs. SD		25	37	3	4			
Ammonium nitrate 96 lbs. S		11	38	3	4			
Anhydrous ammonia 96 lbs. S		8	46	2	3			
Anhydrous ammonia 96 lbs. S, 48 lbs. D		25	63	9	11			
	Grain yield, bushels per acre—not clipped							
No nitrogen		18	27	6	13			
Anhydrous ammonia 48 lbs. M		43	59	17	33			
Ammonium nitrate 48 lbs. M		45	73	25	38			
Anhydrous ammonia 96 lbs. M		50	74	18	40			
Ammonium nitrate 96 lbs. M		58	81	18	27			

*SDM—September, December or March.

Table 16. The response of oats for forage and grain to anhydrous ammonia and ammonium nitrate, 1949-1950.

Location			Holly Springs				Brooksville			Newton				Oakley		
Nitrogen treatment*			Clipping No. and date				Clipping No. and date			Clipping No. and date				Clipping No. and date		
Source	Lbs. per acre	Date of application**	1 11/8	2 12/23	3 3/7	Total	1 11/7	2 4/9	Total	1 11/2	2 12/24	3 3/3	Total	1 11/7	2 2/16	Total
			Pounds air-dry forage per acre													
No nitrogen	---	....	314	129	301	744	157	108	265	329	22	34	385	1141	221	1362
Anhydrous ammonia	24	SDM	608	401	677	1686	349	395	744	1183	145	361	1689	1443	558	2001
Anhydrous ammonia	48	SDM	431	468	890	1789	578	557	1135	1619	284	783	2686	1443	847	2290
Ammonium nitrate	48	SDM	615	718	1016	2349	355	452	807	1464	347	632	2443	1456	1119	2575
Anhydrous ammonia	48	SD	501	495	828	1824	462	522	984	1648	217	789	2654	1457	1112	2569
Ammonium nitrate	48	SD	558	657	884	2099	361	330	691	1620	302	616	2538	1564	1206	2760
Ammonium nitrate	96	S	626	647	843	2116	618	435	1053	1669	169	444	2282	1401	1128	2529
Anhydrous ammonia	96	S	398	723	793	1914	623	473	1096	1712	347	449	2508	1387	991	2378
(Anhydrous ammonia	96 48	S) M)	516	614	930	2060	665	661	1326	1674	291	962	2927	1504	1194	2698

*All plots received 80 pounds phosphate and 50 pounds potash.
**SDM=September, December and March.

Table 18. The response of cabbage, tomatoes and beans to anhydrous ammonia, ammonium nitrate and nitrate of soda.

Source of nitrogen in 1200 lbs. 6-8-4, and 32 lbs. as side dressing	Depth of application	Cabbage			Tomatoes U.S. No. 1 & 2			Beans
	inches	1948 Lbs.	1949 Lbs.	Av. Lbs.	1948 Lbs.	1949 Lbs.	Av. Lbs.	1948 Bushels
1. Ammonium nitrate	4	18,077	14,946	16,512	8,730	11,276	10,003	184
2. Anhydrous ammonia	4	18,513	13,178*	15,846	8,040	8,501	8,272	180
3. Anhydrous ammonia	6	18,404	12,912*	15,658	9,120	10,831	9,976	171
4. Anhydrous ammonia All before planting	6	18,513	13,089	15,801	7,860	9,593	8,727	176
5. Nitrate of soda	4	18,186	13,973	16,080	9,270	10,256	9,763	152

*Applied about one month later than other sources.

where they are grazed closely. However, clipping more often or grazing should give forage of a higher protein content. The forage harvested usually had a protein content of 18 to 22 percent, which is higher than needed; however, it was as low as 6 percent during the coldest part of the winter. It appears that oat forage could be used more efficiently as only a part of the total feed rather than as the sole source of feed.

When top dressed with nitrogen the first of March, clipping the oats for forage reduced the yield of grain only slightly in two tests, had no effect in one test, increased the yield in one test, and reduced the yield in two tests. Clipping where the top growth is removed is, no doubt, a much more severe treatment than moderate grazing. Close grazing removes the leaf area and prevents large yields from being made. When oats are not grazed too closely, and grazing is stopped before March, and the oats are properly fertilized with nitrogen in February or March, fall and winter grazing do not reduce yield of grain markedly.

The response of oats for forage and grain to anhydrous ammonia and ammonium nitrate for 1949-50 is shown by data reported in Tables 15 and 16. Anhydrous ammonia was as effective as ammonium nitrate for the production of forage. A 96-pound application of nitrogen from ammonium nitrate and anhydrous ammonia was as effective as a 48-pound application in September and December, which means that one application is sufficient for forage production.

The data show that one to one and one-fourth tons of air-dry forage was made in three of the tests and about one-half ton in one test. This suggests that about 48 pounds of nitrogen is sufficient where there is a good supply of nitrogen in the soil, and that up to 96 pounds may be required for the most economical forage yields where soils are low in nitrogen.

Grain yields show that a March application of nitrogen is necessary to produce grain after grazing oats. The reduction in yield for grazing where the oats were re-fertilized with nitrogen in March averaged about 4 bushels, except for one test where the clipped oats were winter killed; however, in the latter case the yield without clipping was low.

Pasture Grasses

Five experiments were conducted in 1950 on pastures. The nitrogen treatments were started in July after the spring clover had disappeared. The weather was very dry at Poplarville where little response to nitrogen was obtained; the rainfall was good at all other locations. There are variations which cannot be accounted for. It will take several years' data to reach a reliable generalization concerning the value of top dressing pastures with nitrogen.

The good treatments (Table 17) produced 1200 to 1600 pounds of air-dry pasture clippings per acre at the four locations which had satisfactory rainfall. One hundred pounds of nitrogen cost about $11 as anhydrous ammonia and about $14 as ammonium nitrate, applied to the land. The value of the grass would be determined by whether or not it furnished normal grazing or prevented a shortage of grass during the summer months. It appears that these increases would be profitable only when they are used in the place of harvested or bought feed, or where they are used to prevent a loss in weight of cattle or a decrease in milk production.

The grasses responded to ammonium nitrate about two weeks earlier than to anhydrous ammonia; however, the reponse was more gradual where anhydrous ammonia was applied.

Even though the moisture was favorable little growth of grasses was made after September 15 with or without nitrogen. This suggests that if grass is to be used for grazing after this date it must be produced earlier.

There was little difference in the production of grass by anhydrous ammonia and ammonium nitrate, and between 16- and 32-inch spacings of the anhydrous ammonia.

Where nitrogen is to be used on summer pastures, observations suggest that it should be applied by the middle of June, rather than in July as was the case with the tests conducted.

Truck Crops

The response of cabbage, beans and tomatoes to anhydrous ammonia, ammonium nitrate and nitrate of soda is shown by the data reported in table 18. For cabbage, anhydrous ammonia was superior to the other two sources of nitrogen in 1948; in 1949 the side dressings of anhydrous ammonia were applied about one month later than the other sources of nitrogen and it was not quite as good as the other sources of nitrogen. Applying all of the nitrogen as anhydrous ammonia before planting cabbage was as effective as split applications of any source.

For tomatoes the 6-inch depth with two applications of anhydrous ammonia was equal to ammonium nitrate and nitrate of soda, and superior to the 4-inch depth of application and one application of anhydrous ammonia. Ammonium nitrate and anhydrous ammonia were superior (significantly) to nitrate of soda for beans. Ammonium nitrate was superior to the anhydrous ammonia treatments; however, the differences were not significant, statistically.

There are too few data to conclude whether or not there is any real difference between ammonium nitrate and anhydrous ammonia for truck crops; however, the data suggests that there is little difference between them for these crops.

Sweetpotatoes

Anhydrous ammonia was compared with nitrate of soda, ammonium sulphate and ammonium nitrate to determine their effects on the yield and quality of Unit I Porto Rico sweetpotatoes at the Coastal Plain Experiment Station at Newton. As may be seen in Table 19, in 1948, anhydrous was second in yield only to nitrate of soda. In 1949, it was second only to ammonium nitrate. In 1950 no response to nitrogen was obtained in the test which suggests that the 1948-1949 average should be given most consideration.

Table 17. Response of pasture grasses after clover to anhydrous ammonia and ammonium nitrate,1950.

Treatment	Lbs. N per A	Date of application	Spacing	Location of tests				
				State College[1]	Verona[2]	Holly Springs[3]	Oakley[3]	Poplarville[3]
				Yield—pounds of air-dry forage per acre				
Check—no nitrogen				3364	2061	2487	1119	902
Ammonium nitrate	33	July,Aug.,Sept.		5015	2815	3181	1827	1317
		July,Sept.	16″	4567	2857	3358	2173	1189
Anhydrous ammonia	45	July,Sept.	32″	4544	2935	3172	1967	1349
Anhydrous ammonia	45	July,Sept.		4815	3189	2936	2013	1502
Ammonium nitrate	45	July		4799	3329	3032	3361	2061
Ammonium nitrate	99	July	16″	4749	3300	3948	2940	1694
Anhydrous ammonia	99	July	32″	4642	3386	4087	2532	1354
Ammonium nitrate	99	Sept.		4162	2514	2255	1056	1187
Anhydrous ammonia	99	Sept.		3794	2123	2481	1121	1061

[1]Total of four clippings.

[2]Total of one clipping. No clipping was made after the September application of nitrogen.

[3]Total of two clippings. No clipping was made after the September application of nitrogen.

When the two- or three-year average yields are compared, the differences in yield between anhydrous ammonia, nitrate of soda and ammonium nitrate are not significant. The yields produced by either of these three nitrogen sources are significantly higher than the yield from sulphate of ammonia.

Sorghum

Anhydrous ammonia was used as a source of nitrogen along with several others for sorghum during the years 1945-1948. Experiments were conducted each year on an Ochlocknee silt loam near Starkville and on a Grenada silt loam near Holly Springs. The differences in yield among the five nitrogen carriers were small, as shown by the yields of sorghum and syrup reported in Table 20.

Sugarcane

The data reported in Table 21 show that, on the average, anhydrous ammonia was equal to or slightly superior to ammonium nitrate for the production of sugarcane. There was no advantage in making two applications of nitrogen instead of one. There was no difference in the quality of the syrup where the two sources of nitrogen were applied.

Table 19. The effect of nitrogen sources on the marketable yield of Unit I Porto Rico sweetpotatoes—Newton.

	Marketable yield in bushels per acre				
Source of nitrogen*	1948	1949	1950	3 year average	1948-49 average
No nitrogen	173	119	131	141	146
Nitrate of soda	203	164	114	160	184
Ammonium sulphate	163	136	114	138	150
Ammonium nitrate	187	186	132	168	186
Anhydrous ammonia	199	167	104	157	183

*Rate of nitrogen 48 lbs. per acre.

Table 20. The response of sorghum to sources of nitrogen.

	Yield	Gallons of syrup	
Source of nitrogen	Tons per acre	per ton	per acre
Sulphate of ammonia	15.45	19.9	310
Nitrate of soda	15.21	20.5	311
Ammonium nitrate	15.59	19.8	308
Anhydrous ammonia	16.31	19.6	318
Sulphate of ammonia neutralized with lime	16.05	20.1	322

Table 21. The response of sugarcane to anhydrous ammonia and ammonium nitrate, 1949-1950.

	Yield—gallons of syrup per acre						
Treatment	Test 1 1949	Test 2 1949	Test 3 1950	Test 4 1950	Test 5 1950	Test 6 1950	Average 6 tests
Anhydrous ammonia[1]	682	852	722	408	625	510	633
Ammonium nitrate[1]	673	773	682	406	630	460	604
Anhydrous ammonia[2]	684	862	711	421	678	449	634
Ammonium nitrate[1]	642	738	749	375	582	475	594
Anhydrous ammonia[3]	711	817	709	360	516	397	585
Ammonium nitrate[3]	681	869	670	352	600	411	597

[1] 60 pounds nitrogen, 80 pounds phosphate, and 40 pounds potash applied in March.

[2] 30 pounds nitrogen, 80 pounds phosphate, and 40 pounds potash applied in March, and 30 pounds of nitrogen in June.

[3] 60 pounds nitrogen only applied in March.

Equipment for Applying Anhydrous Ammonia

The retail cost of anhydrous ammonia in early 1951 varied from $110 to $150 per ton, the most common price in old territories being about $130 per ton or 8 cents per pound of nitrogen. At the same time the cost of nitrogen in ammonium nitrate was about 12 cents per pound.

Circular 152[2], Mississippi Agricultural Experiment Station, provides an appraisal of the use of 2800 pounds of nitrogen as anhydrous ammonia on 50 acres of farm land. Total cost of machinery and labor for applying anhydrous ammonia was 4.8 cents per pound of nitrogen and that for ammonium nitrate was 1.9 cents per pound. In very large operations these costs were reduced to 1.2 cents for ammonium nitrate and 1.4 cents per pound of nitrogen for anhydrous ammonia. It is evident that the savings in using anhydrous ammonia are much more on the larger operations, which in many cases are increased by maintaining farm storage.

The estimated costs of anhydrous ammonia equipment in Table 22 were taken from Circular 152. The prices are for 1949. Taxes were not included in the estimates. Prices vary considerably from area to area, and as economic conditions change. The estimates are based on purchase price, five percent interest, and a 20-year depreciation period.

[2]"An Economic Appraisal of Anhydrous Ammonia as a Nitrogenous Fertilizer," by James P. Gaines and Grady B. Crowe.

The annual storage cost per ton for the bulk station operator is cut in half when the tanks are filled twice during the year. Increasing the number of fillings per year beyond two reduces the cost per ton slightly; however, this reduction is small and might be uneconomical if it influenced the seasonal supply of ammonia markedly.

Where a farmer has a need for about 10 tons of anhydrous ammonia, it appears that a 2,500-gallon storage tank, which could be filled twice or more by the bulk storage operator, would be economical. The cost of this tank should be only a little more than that of a 1,000-gallon trailer tank and trailer. No doubt a reduced price of ammonia for filling farm tanks in off seasons can be obtained and the trailer tank may be eliminated.

Custom Application

With ammonium nitrate costing 12 cents per pound of nitrogen its cost applied to 50 acres of land is about 13.9 cents per pound of nitrogen. With anhydrous ammonia nitrogen costing 8 cents per pound its cost applied to the same area is about 12.8 cents per pound. At

Table 22. Cost of anhydrous ammonia equipment (1949)

Type of ammonia equipment	Capacity tons maximum	Total cost	Annual cost	Storage cost per annual ton of ammonia—No. fillings: 1	2	3	4
Tractor equipment, depending on number of rows and metering device		$ 300-500					
500-gallon transport tank	1	475	$60.22	-------	-------	-----	-----
1,000-gallon transport tank	2	585	67.97	-------	-------	-----	----
Heavy duty trailer	----	290	36.92[1]	--	----	-----	-----
6,000-gallon storage tank	12	2,500	283.25	$23.60	$11.80	$7.87	$5.90
18,000-gallon storage tank	36	8,500	739.30	20.54	10.27	6.85	5.13
30,000-gallon storage tank	60	11,500	959.30	15.97	7.99	5.32	4.00

Storage tank costs based on 5 percent interest, 20-year depreciation time and maintenance.

[1]One-half cost to ammonia.

this price ratio a farmer who had 50 acres to fertilize could afford to pay about 14 cents per pound of nitrogen for anhydrous ammonia applied to the soil and still do the job as cheaply as with ammonium nitrate.

There are a number of large farmers who prefer to hire a custom applicator to apply anhydrous ammonia even though the cost is more than if they applied it themselves. The difference is that the custom operator adds power and labor to that available on the farm at a time when power and labor are at a premium. There is one disadvantage— the custom applicator may not always be able to put out anhydrous ammonia at the time maximum response would be obtained. This may also be true where a farmer does his own work.

Custom application of solid fertilizers is increasing in many sections of the country. Economies which help to offset the cost of the service are bulk handling, with the elimination of bags and bagging costs, and a reduction in handling where the fertilizer goes directly from the plant to the farm.

Particularly where custom application is practiced, the application of phosphorus or potash, or a mixture of the two at the same time anhydrous ammonia is applied, offers an opportunity for considerable savings in the cost of fertilizers applied to the land. The greatest opportunity for the custom applicator is in areas where a variety of crops are planted, which gives a longer application period.

Where the fertilizer application period is short, it is more difficult to make a profitable business out of custom application.

Rental of Equipment

Since farmers first started using anhydrous ammonia in 1947, the practice is still in its infancy, and the possibilities of its use have not yet been fully realized. As has been pointed out, a farmer fertilizing 50 acres with 2800 pounds of nitrogen could afford to own anhydrous ammonia equipment. However, the field equipment (two-row) would not be used more than three days during the year. In most areas, the fertilizer application period should be 50 or more working days, which means that on a rental basis a farmer with 50 acres or less to fertilize could afford to pay several times the actual cost of the equipment for its use for the limited period. The availability of equipment for rental will, no doubt, increase.

The use of anhydrous ammonia equipment on a rental basis for small acreages on one farm will stimulate the production of equipment which may be changed from one tractor to another quickly. This may be approached from the standpoint of quick-changing tractor-mounted equipment, or trailing equipment may be used. Trailers may carry all of the equipment, or they may carry the tank and metering device with the applicators conventionally mounted on the tractor.

Where large applicator tanks are mounted on trailers to be used in the field they may be used for transporting the ammonia with the elimination of the conventional transport tank where small acreages are involved. A tank carrying 100 gallons of ammonia contains 410 pounds of nitrogen, enough for 10 acres at 41 pounds per acre.

The maximum size trailer tank which a tractor can pull through the field has not yet been established. A factor affecting the size of tank which may be used is whether or not the weight is all carried on the trailer or whether the tractor carries part of the weight. A factor affecting maneuverability is whether the wheels are swiveled or not.

In at least one case the anhydrous ammonia bulk plant operator rents a tractor and all equipment necessary for applying anhydrous ammonia at a very reasonable rate. For the immediate future, this appears to be one of the best means of bringing anhydrous ammonia to the small farms.

Combination of Operations

Anhydrous ammonia is normally applied as a single operation. However, it may be combined with other operations such as cultivating and various breaking operations. Combinations of this type increase the skill needed, but they reduce the total power and labor required.

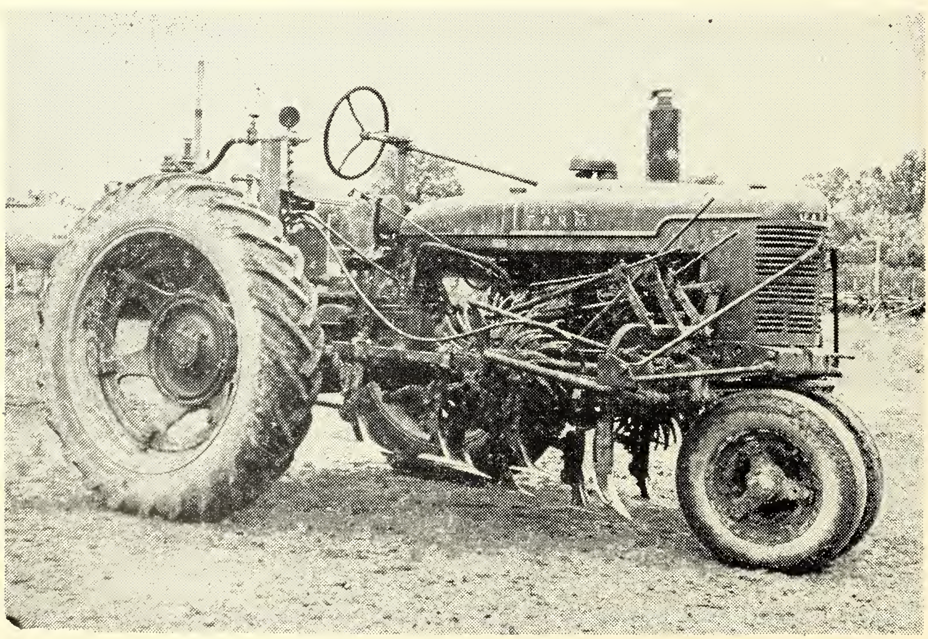
Anhydrous Ammonia Storage Equipment

Where the use of anhydrous ammonia is established in a state its storage and handling are controlled by regulations. In Mississippi these regulations are enforced by the State Motor Vehicle Comptroller. The requirements outlined below are for conditions as they exist in Mississippi, where the maximum day temperatures rarely exceed 100°F. The specifications would, of course, be different where the maximum temperatures are materially higher or lower than in Mississippi.

Anhydrous ammonia has a gauge pressure of 197 pounds per square inch at 100°F, and 215 pounds at 105°F. The maximum day temperatures never go as high as 105°F., and night temperatures are about 15°F. cooler. In 30,000 gallon tanks the temperature of the ammonia does not go as high as maximum day temperatures nor as low as the minimum night temperatures. It appears that the maximum pressure of anhydrous ammonia in 30,000 gallon tanks should never be as high as 215 pounds per square inch. Small tanks may reach a higher pressure. The recommendations are:

1. 250 pound working pressure A.S.M.E.—A.P.I. code tanks with the pop-off valve set to discharge between 237 and 250 pounds per square inch.

Popping off of anhydrous ammonia tanks is a loss. If popping off of a 30,000-



This tractor is equipped to apply anhydrous ammonia and cultivate at the same time.

gallon tank containing 60 tons of anhydrous ammonia lowers the pressure 10 pounds per square inch, over 300 pounds of ammonia is lost, which is a loss of about $20 each time the valve pops off and lowers the presure 10 pounds. Evidently, provisions must be made to avoid popping off of tanks. It has been reported that some pop-off valves go off at pressures which are much lower than the 237- to 250-pound setting; for this reason the Mississippi regulations require sheds, or provisions for sprinkling.

Bulk storage plant operators should keep a close account of the tanks if the pressure exceeds 200 pounds per square inch to determine whether or not the pop-off valves release at lower pressures than they are set for. If they do so, sheds or sprinkling systems should be provided to prevent the loss of ammonia.

The temperature (and pressure) of small tanks is more quickly changed by changes in the atmospheric temperature than that of larger tanks. They are, therefore, more likley to pop off than larger tanks.

2. Underground tanks for bulk storage of anhydrous ammonia. These tanks are used very little and there are depreciation hazards which are not common to other types of storage.

3. Refrigerated above-ground storage tanks which have a working pressure of less than 250 pounds per square inch. Refrigerated storage tanks are usually limited to Horton spheres which are insulated. However, it is possible that use could be made of some non-insulated lower working pressure tanks for storage of anhydrous ammonia during the winter months, where they are emptied as warmer weather approaches.

For specifications concerning storage tanks and other anhydrous ammonia equipment the reader is referred to:

This tractor is equipped to apply anhydrous ammonia, a mixture of superphosphate and potash, and plant seed in one operation.

1. Rules and Regulations, Liquified Compressed Gas Equipment and Containers, Office of the Motor Vehicle Comptroller, Jackson, Mississippi.

2. The regulations of other states.

3. Standards for the Storage and Handling of Anhydrous Ammonia and Ammonia Solutions, Compressed Gas Association, Inc., 11 West 42nd Street, New York, N. Y.

The size of high pressure anhydrous ammonia storage tanks usually varies from 6,000 to 30,000 gallons. Large tanks are used by dealers and large farmers. Smaller tanks are used by farmers. The Horton spheres usually have a total gallonage of about 210,000 gallons.

Anhydrous ammonia is usually transported in 26-ton tank cars to the local bulk storage plant, where it is transferred into storage. It is usually transported to the farm in 1000-gallon trailer tanks which are taken directly to the field. It is then transferred to tractor tanks holding from 60 to 100 gallons. From these tractor tanks, it is released through a metering device into the soil.

In the manufacture, transportation, and application of anhydrous ammonia to the soil, it is handled by pumps or compressors, or transferred by its own pressure by bleeding vapor from the tank being filled.

Tractor tanks are usually filled from 1000-gallon tanks by bleeding off a small amount of vapor from the tractor tank to lower the pressure. So long as the pressure in the tractor tank is maintained at a pressure no lower than 10 pounds per square inch less that in the 1000-gallon tank, the loss of ammonia is no more than one percent. The loss increases to three percent when the difference in pressure is 40 pounds per square inch. If a tank with a pressure of 232 pounds per square inch were bled to atmospheric pressure the loss would be 36 percent The accumulation of ice or sweating of the tractor tank indicates excessive loss of ammonia in bleeding.

Filling Tanks with Anhydrous Ammonia

Anhydrous ammonia is most frequently transferred to tractor tanks by bleeding gas off the tractor tank; however, pumps and compressors are also used.

Where bleeding is used to fill tractor tanks, after the liquid line has been connected between the tanks, the valves are opened in the following order: (1) Liquid valve on tractor tank (if this valve is not opened automatically), (2) liquid valve in line next to tractor tank (it should be open already), (3) valve on line at storage tank, and (4) vapor escape valve on the tractor tank which should be regulated to maintain 10 pounds less pressure in the tractor tank than in the storage tank. If this pressure is more than 10 pounds lower the loss of ammona is excessive.

When the tank is filled to 90 percent of capacity a white spray starts escaping from the vapor valve. At this time, the valves should be closed in the following order: (1) Valve in line next to storage tank, (2) hose valve next to the tractor tank, (3) vapor escape valve on the tractor tank, and (4) filling valve on the tractor tank. The hose connection is then loosened and the ammonia in the short nipple is drained, after which the connection is completely broken. The filling hose should be drained to prevent bursting, and unintentional release of ammonia on the operator or spectator. If the hose is not to be drained after each filling, it should be equipped with a safety valve; however, it is recommended that it be drained.

Where pumps are used to fill tanks with anhydrous ammonia (1) the vapor line is connected, (2) the vapor valves are opened, (3) the liquid line is connected, after which the order of opening the valves is (4) fill valve on tractor tank, (5) fill valve on hose next to tractor tank, (6) valve on line next to storage tank, and (7) depth fill gauge valve, and then (8) the pump is started.

As soon as the white spray starts to escape from the depth gauge valve the pump should be cut off, and the valves closed in the following order: (1) Valve on line next to storage tank, (2) depth gauge valve on tractor tank, (3) vapor valve on tractor tank, (4) vapor valve on storage tank. Then(5) disconnect vapor line, (6) close liquid valve on hose line next to tractor tank, (8) close fill valve on tractor tank, (9) loosen liquid line connection on tractor tank and let the ammonia in the short nipple drain out. The line is then completely disconnected and drained.

Where compressors are used to fill tanks with anhydrous ammonia, the operation of valves and connections is the same as in filling with the pump except the compressor is connected into the vapor line.

Tractor Equipment

The specifications for tractor tanks and fittings are prescribed in the rules of regulating agencies. There are a large number of manufacturers of anhydrous ammonia tractor equipment. For this reason most of the details of the equipment are omitted from this publication.

Essentially all of the tractor equipment except the devices to regulate the flow of ammonia and the applicators which go into the soil are the same. However, there are many differences in metering devices and applicators. The ammonia comes out of the tractor tank through a metering device, and is divided by means of orifices to the applicators.

Metering Anhydrous Ammonia on Tractor Equipment

The most widely used metering device for anhydrous ammonia is a needle valve and pressure gauge before the orifices. The rate of application of ammonia per acre through this equipment is dependent on:

1. Tank pressure
2. Orifice size
3. Orifice pressure
4. Back pressure in the lines which is determined in part by the line size and the size of the outlet in the applicator
5. Area covered per hour

With variations in orifice size, line size, and size of the outlet in the applicator it is evident that only identical machines would deliver the same quantities of ammonia. For this reason, detailed information on the calibration of one machine is not included in this bulletin. **It is therefore imperative that equipment manufacturers supply calibration data for their machines.**

If the calibration information on a machine in pounds of nitrogen (or ammonia) per hour were available the rate of application of ammonia per acre could be calculated very accurately; however, in actual practice the rate of application per acre is often determined on the basis of experience, rather than by making detailed calculations.

A regulating valve and pressure gauge before the orifices are also widely used for metering anhydrous ammonia. The regulating valve maintains a constant pressure on the orifices; however, since the vaporization of ammonia is related to changes in pressure, the regulating valve does not maintain a constant flow of ammonia. The same factors which affect the rate of flow with a needle valve and pressure gauge also affect the rate of flow through the regulating valve. The manufacturer of equipment using a regulating valve and gauge should supply calibration data with the machine. As is the case with a needle valve and pressure gauge regulator, operators often regulate the flow of ammonia with a regulating valve and gauge on the basis of experience.

A flowrator and cooler are used to regulate the flow of anhydrous ammonia. The flowrator is graduated in pounds of nitrogen per hour, and the rate of flow is indicated by a sight gauge. The error of this instrument has been estimated to be about five percent by the manufacturer. With a known area covered per hour the rate per acre may be calculated quickly. However, farmers may arrive at the rate per acre by experience.

In the cooler the incoming warm ammonia is cooled by the outgoing expanding ammonia. A cooler may be made by putting a coiled 3/4-inch pipe in a three inch pipe about 12 inches long. The expanding ammonia goes out through the coil, while the incoming ammonia comes through the larger pipe. Cooling prevents the ammonia from bubbling in the flowrator and pump. The size of the cooler depends upon the amount of cooling to be done.

The pump and cooler is another means of controlling the rate of application of ammonia to the soil. It is geared to the tractor and should maintain a constant rate of flow, regardless of changes in ammonia pressures.

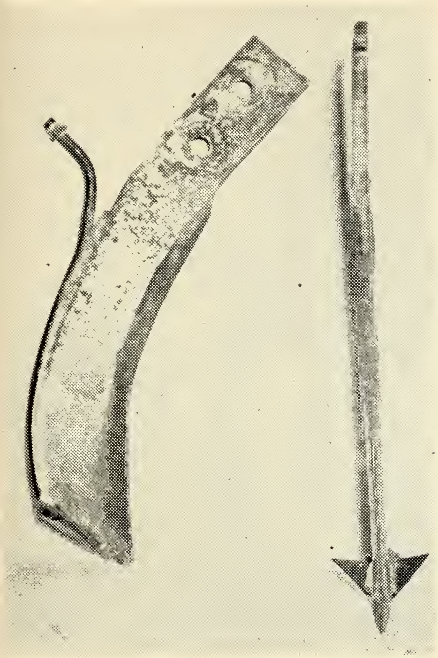
The order of increasing cost of devices for controlling the rate of flow of anhydrous ammonia is (1) needle valve and pressure gauge, (2) regulating valve and pressure gauge, (3) flowrator and cooler. and (4) pump and cooler. With numbers 1, 2 and 3 the setting of the needle valve is changed with changes in pressure to maintain a uniform rate of application; with number 4 no change in setting is required. All of the metering devices are very accurate with skilled operators; number 3 requires less operation skill than 1 and 2, number 4 still less when properly adjusted. Numbers 1 and 2 may find their greatest usefulness where farmers are doing their own work, while numbers 3 and 4 are probably more desirable for custom work; however, in skilled hands any of the metering devices is very accurate.

Even though very accurate metering may be obtained with metering systems 1 and 2, the rate of ammonia through them varies with the tank pressure and the valve gauge settings. For example, where it is desired to apply 300 pounds of anhydrous ammonia per hour through four 3/32-inch orifices, an orifice gauge pressure of 37 pounds per square inch is required with a tank pressure of 90 pounds per square inch, while an orifice gauge pressure of 52 pounds is required when the tank pressure goes up to 150 pounds per square inch. If a regulating valve maintained the orifice gauge pressure at 37 pounds, only 220 pounds of ammonia would be delivered as compared to the desired 300 pounds per hour when the tank pressure goes to 150 pounds per square inch.

Applicators

Anhydrous ammonia has proved to be slightly more efficient when applied 6 inches below where the seed are to be planted or 6 inches deep in side dressing than when the depth is 4 inches; however, good results are obtained at the 4-inch depth.

It should be borne in mind that anhydrous ammonia is a gas compressed to a liquid and handled under pressure. When the pressure is released it quickly evaporates into the air. When either anhydrous or aqua ammonia is applid to the soil it must be put into the soil and covered without exposure to the air to avoid the loss of ammonia. When ammonia is applied to the soil it moves until it comes in contact with sufficient clay and organic matter to take it up, and solids are formed which prevent its escape into the air. It is evident that if the ammonia comes in contact with a considerable volume of loose soil that it is



The addition of the point of a 12-inch sweep to an applicator increases the efficiency of the absorption of ammonia because more soil comes in contact with the ammonia.

more easily absorbed than if it is applied in a smooth narrow slit in compact soil.

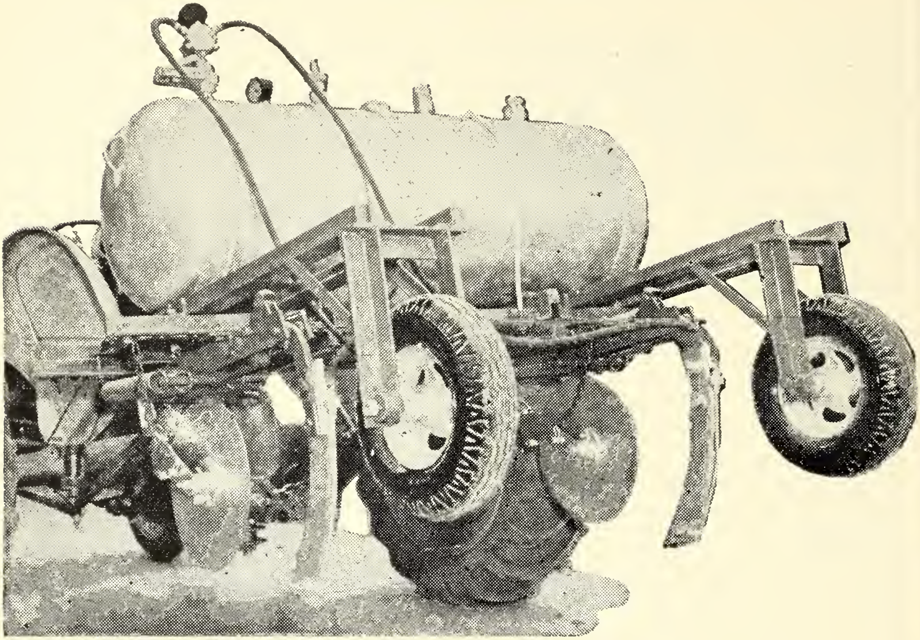
Almost any type of applicator is satisfactory for applying anhydrous ammonia in soils which have been broken, and which are friable and free of trash. The difficulty of applying ammonia increases as soils become less friable, more compact, and more trashy. The problem of sealing ammonia also increases as the rate of application per linear foot increases. The discussion of the applicators is made as if they were to be used under conditions where it is difficult to seal ammonia.

In most cases anhydrous ammonia applicators are put on cultivators instead of the feet. Some of the older cultivators are not strong enough to carry the applicators where the soil is extremely heavy and compact; however, it is reported that some of the newer models have sufficient strength. Where floating cultivators are used the applicator must have a point, or other additions, broad enough to enable it to take the ground. Where a machine is so constructed that weight or force can be applied to the applicator a broad piont is not needed to force it into the ground.

In order for an applicator to shed trash it must slope up and backward. If the point is too far forward, slipping in the holder, bending and breakage are increased. In practice ammonia leaves the applicator through small and large openings. The outlets may enter the opening made by the applicator or they may open against the unbroken soil as the applicator moves forward. In the latter case where the soil is extremely compact there is difficulty in getting sufficient ammonia through the openings. It appears that applicators will be more satisfactory when they open into the opening made in the soil, and there is no reason for the outlet being restricted or small.

In many cases the ammonia outlets in the applicators are not of uniform size. Where they are not of uniform size, the rate of application is different on each row. It is evident that if the rate of flow of water at a given head were determined for each applicator and stamped on the applicator that a farmer would be able to get applicators with uniform delivery of ammonia.

On soils which are not friable, the efficiency of the absorption and retention of ammonia by the soil is increased when an addition is put on the knife which opens a larger hole than where a straight knife is used. An illustration of an applicator foot which has worked very well is shown in this bulletin. The applicator wings on the bottom of the foot were made from the point of a 12-inch sweep. So far, the wings have been attached so that they come flush with the



This equipment was designed by engineers at the Mississippi Experiment Station for use in tung orchards. The curvature of the applicator facilitates shedding of trash; the broad point and the curvature enable it to take the ground.

rear of the applicator; however, it appears that attaching them so that they extend slightly to the rear of the applicator may be superior. The ammonia outlet may enter directly into the opening made by the applicator; however, opening to the side rather than straight down helps to prevent filling the outlet with soil on dropping it into the ground.

All applicators should be provided with a small break pin or a tripping device. Break pins are probably more satisfactory where there are few stumps, roots, or stones; where they are numerous spring trips are preferred. The number of springs required depends upon the size and length of the applicator as well as on the strength of the springs. In the tung area, where pine roots are numerous and the applicators used are relatively long, four Ford-cultivator trip springs are used on each applicator. There are, of course, other releasing devices.

Applicators should be hard-surfaced to reduce wear. The points of applicators depreciate due to wear much more rapidly than the rest of the applicator. The use of applicators with replaceable points could be more economical; these are not yet available.

Orifices

Orifices in the manifold are used to divide the ammonia for the different rows. For rates of application up to 100 pounds of ammonia per hour per orifice, 3/32-inch orifices give a uniform division of the ammonia; where higher rates are used larger orifices may be necessary. Where larger orifices are used than necessary, the flow to the individual applicators may be less uniform.

One anhydrous ammonia applicator is normally used per row, and there is no crop evidence to justify two applicators. In the case of listers and middle breakers, a number of whole rows and two or four half rows are formed, an applicator is necessary on each half row; the orifice for the half rows should have one-half the area of that for the full rows.

Difficulties in Cold Weather

With conventional equipment the rate of delivery of ammonia during cold weather is sometimes lower than desired. The rate of flow of anhydrous ammonia may be increased by:

1. Reducing constrictions in the line from the manifold to the outlet on the applicator.

2. Increasing the size of the hose to the applicator.

3. Increasing the size of the orifices.

4. Increasing the size of the hose and connections from the tank to the metering device.

The order of the importance of these changes in increasing the rate of flow of ammonia is probably the order in which they are listed.

Equipment for Applying Aqua Ammonia

Since the pressure exerted by a 30 percent solution of aqua ammonia should not exceed 10 pounds per square inch, the tanks for storing and applying it are made out of thin material. Even though the material from which gasoline tanks are made should be satisfactory, the heads should be convex so that they will withstand the pressure exerted. Flat-headed containers are unsatisfactory.

All tanks for handling aqua ammonia should have the following fittings:

1. Filling valve.

2. Pop-off valve set on 10 pounds pressure.

3. Bleeding valve.

4. Air inlet check valve.

5. Outlet valve and hose.

6. Glass indicator gauge.

All fittings should be made of iron or steel. Copper and brass fittings are not suitable because they are readily corroded by aqua ammonia.

A low pressure metering pump is the most satisfactory means of controlling the rate of application to the soil. The pump is driven from the axle of the equipment on which it is mounted, and a constant speed is not necessary. So far as the rate of application is concerned, when the pump is once calibrated correctly, it should operate accurately with little attention.

The pump recommended is a 20 DV Yale-Towne rotary-positive-displacement pump, with a variable-volume-manual control for quantities up to 1.5 gallons per hundred revolutions. The pump is driven from the axle of the machine on which it is mounted through a counter shaft which steps the speed up to 400 revolutions per minute. A 1 1/4-inch hose connects the pump to the supply tank. A fine screen should be placed over the hose outlet in the tank to keep trash out of the metering equipment. A 5- to 10-pound pressure-relief-discharge valve is put in the line after the pump to stop the flow of aqua ammonia through the pump when the equipment is not moving.

The manifold is connected to the pressure relief valve. The manifold, feed lines and applicators are the same as described above for anhydrous ammonia. The size of the orifices in the manifold for aqua ammonia may need to be increased where heavy rates of application are used.

A small air compressor may be used to build up pressure in the tractor tank if the tank has sufficient strength to withstand the pressure. A needle valve or regulating valve with orifices may be used to meter the aqua ammonia where compressors are used to build up the pressure in tractor tanks. Storage tanks are needed to withstand the pressure developed by compressors.

If aqua ammonia is exposed, ammonia is readily lost into the air. For this reason, the same care should be used in covering aqua ammonia as is necessary with anhydrous ammonia.

RECOMMENDATIONS

On the basis of experience with anhydrous ammonia the following recommendations are made. For preplanting application to row crops apply anhydrous ammonia 4 to 6 inches to the side of where the seed are to be placed. Up to 75 pounds of anhydrous ammonia (60 pounds nitrogen) per acre may be applied in the center of the bed if it is applied at least 4 inches below where the seed are to be placed. Higher rates should be applied to the side of seed on most soils.

Yields which reasonably may be expected without fertilizer and with the most profitable rate of fertilizer depend upon the soil. The amount of nitrogen (or other fertilizers) to be used should be based on the increase in yield expected above that which would be produced without fertilizer. In general, soils which are well drained 3 feet deep or deeper are capable of producing high yields. Those which are poorly drained often produce low yields.

1. **For cotton** apply anhydrous ammonia for normal needs within a month before and a month after planting. Pre-planting application is preferred. Make later applications where growth is unsatisfactory because of a lack of nitrogen. In side-dressing young cotton apply anhydrous ammonia 5 to 6 inches to the side of the plants; for larger plants apply at the edge of the root zone. On soils well adapted to cotton, apply one pound of anhydrous ammonia for each 8 pounds of increase in yield of seed cotton anticipated (one pound nitrogen for each 10 pounds of cotton). One pound of anhydrous ammonia may increase the yield 12 pounds of seed cotton under the best conditions or it may produce less than 8 pounds of seed cotton where soils and weather are unfavorable.

2. **For corn** apply anhydrous ammonia from one month before planting until the last cultivation. In side-dressing apply anhydrous ammonia 10 to 12 inches from young plants, and in the middles for larger plants. Apply 3 pounds of anhydrous ammonia (2½ pounds nitrogen) for each bushel increase anticipated. Leave a stand of 100 stalks of a good variety for each bushel of corn expected.

3. **For oats for forage** space applicators 18 inches apart. Apply anhydrous ammonia before planting. Apply 60 pounds of anhydrous ammonia (50 pounds nitrogen) per acre on soils which are high in nitrogen—those which produce 1200 pounds of dry forage per acre during the fall and winter months without nitrogen. Apply 120 pounds of anhydrous ammonia (100 pounds nitrogen) on those soils which are very low in nitrogen—soils producing less than 500 pounds of dry forage per acre during the fall and winter.

4. **For oats for grain** apply anhydrous ammonia in February on most soils. Space applicators 18 to 24 inches apart on heavy soils, and 24 to 32 inches apart on the lighter soils. Apply 1½ pounds of anhydrous ammonia (1 1/3 pounds nitrogen) for each bushel increase expected. Yields above 60 bushels per acre are not common.