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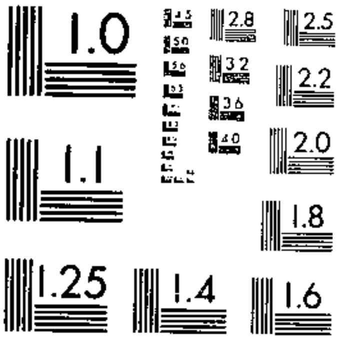

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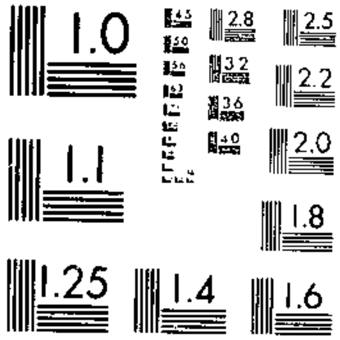

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RESIDUAL EFFECTS OF FALL- AND SPRING-APPLIED NITROGEN FERTILIZERS ON CROP YIELDS IN THE SOUTHEASTERN UNITED STATES

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CONTENTS

Growth Through Agricultural Progress

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Residual Effects of Fall- and Spring-Applied Nitrogen Fertilizers on Crop Yields in the Southeastern United States

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Farmers in the humid region of the United States are spending more than one-third of a billion dollars for nitrogen fertilizer each year. Yet available data indicate poor recovery of this nitrogen by the crops, probably no more than 50 percent on an average. What happens to the remainder and how to improve its utilization by subsequent crops are questions of tremendous economic importance to the farmers in this region.

It has generally been assumed, particularly in the Southeastern United States, that the bulk of the nitrogen fertilizer not used by the crop is lost by leaching. For this reason little or no consideration has been given to residual nitrogen in making fertilizer recommendations. However, field observations and limited experimental data suggest that with increasing use of high rates of nitrogen fertilizer this assumption needs to be reexamined.

Another phase of the problem has to do with offseason applications of nitrogen. Certain segments of the fertilizer industry urge fall application of ammonium sources of nitrogen on the assumption that overwinter leaching losses would be tolerable, even in the South. If losses are sufficiently low, such offseason application would be advantageous to both farmer and fertilizer distributor through better distribution of labor, storage facilities, and sales effort. The actual effectiveness of fall-applied nitrogen is, of course, the key to rationally solving the problem.

Research workers have long been puzzled by what has been aptly termed by Allison (*1*)[2] "the enigma of soil nitrogen balance sheets." Lysimeter experiments have generally shown a large nitrogen deficit, which cannot be accounted for after consideration of crop removal and leaching losses. Based on these experiments, there is strong evidence that volatilization accounts for a considerable fraction of this deficit.

The ammonium forms of nitrogen so extensively used require microbial conversion to nitrate before appreciable movement can occur in any but coarse-textured soils. Although urea itself is readily mobile in soils (*17*, *20*), it is quickly converted to ammonium form by

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[1] Soil scientists, Soil and Water Conservation Research Division, Agricultural Research Service, except C. E. Scarsbrook, soil chemist, Alabama Agricultural Experiment Station.

[2] Italic numbers in parentheses refer to Literature Cited, p. 18.

enzymatic hydrolysis (*5, 6, 7, 8, 11*) and is then subject to the same restrictions of movement as are the common ammonium fertilizers.

The rate of this conversion, as of the subsequent steps to nitrate, is governed by the temperature, pH, initial urea concentration, and moisture level of the soil. Although the optimum pH and temperature have been reported to be 6.2 and 30° C., respectively, the reaction does proceed at an appreciable rate, even at extremely low pH values and under relatively cold conditions (*10*). Thus, in general, urea should behave in essentially the same manner as applied ammonium salts with regard to its movement in the soil by percolating water. In turn, any difference in susceptibility to leaching between applied ammonium salts and nitrates would be the result of time lag in nitrification, with allowance for increased plant uptake, microbial immobilization, and ammonium ion fixation.

Since all nitrates are water soluble and are very weakly adsorbed by soil colloids, they are more susceptible to leaching than other nitrogen fertilizers (*4, 5*). Of course, under conditions of incomplete profile leaching, nitrates may simply migrate within the zone of maximum water movement and can remain within the root zone for relatively long periods (*22*). However, evidence is accumulating that applied nitrates can be reduced to intermediate states of oxidation within a relatively short time (*3, 9, 21*), followed by considerable losses by volatilization of both molecular nitrogen and nitrous oxides. This reaction appears to be a microbial process, since it does not occur in sterilized soil; but its counterpart, volatilization losses of molecular nitrogen and nitrous oxides during nitrification, has been shown to be essentially a chemical process (*2, 9*).

It is noteworthy that such losses of nitrogen have been shown to take place under soil conditions that could occur in the field and regardless of the form of nitrogen applied (*3, 21*). For example, they are not limited to conditions of poor aeration, although reduced oxygen supply accentuates them. However, of real value to the practical aspects of the problem is the fact that these reactions are apparently controllable largely through soil characteristics, such as pH and internal drainage, which can be modified through management.

In addition to the losses of molecular nitrogen and nitrous oxides, it appears certain that rapid volatilization of anhydrous ammonia can occur under certain conditions when urea is used as a top dressing either on bare soil or on sod (*19*). This type of loss from sod has been attributed to the action in the plant of urease, which forms ammonium carbonate on the plant-material surfaces, where low retentive forces prevent immediate volatilization of anhydrous ammonia.

Convincing evidence has been reported (*6*) that, although urease activity is inherently present in variable degrees in plant material, it also originates with bacterial activity. Thus, highest soil urease activities seem to occur in the soil zone of maximum microbial activity. It could be rationalized, then, that ammonia volatilization losses would vary considerably with the type of sod to which urea is applied and with the nature of the soil.

The fact that ammonia loss from bare soil apparently does vary tremendously from soil to soil (*19, 21*) raises several questions regarding urease activity in soils, as well as the possibility of inorganic catalysts or other factors taking part in the reaction. The magnitude of the loss, once the conversion of surface-applied urea to ammonium carbonate is underway, seems to be strongly affected by the cation exchange capacity of the soil. In Volk's (*19*) experiments little loss occurred in soils having cation exchange capacities above 7–8 milliequivalents per 100 grams.

In addition to leaching and volatilization, applied nitrogen can be lost by solution in runoff water and by erosion in organic form after microbial immobilization. The former is likely to be of real importance only in fine-textured, relatively impermeable or crusted soils, but the latter mode of loss is an ever-present hazard.

The residual value of applied nitrogen fertilizer, then, will certainly be affected by several factors, some controllable by the farmer and others not. Among these are the chemical characteristics of the nitrogen carrier, the chemical and physical nature of the soil, climatic conditions, method of application, and crop-residue management.

Marked carryover effects from one season to another have been observed under widely different soil and climatic conditions (*12*, *13*, *p. 62*, *14*, *15*, *16*, *22*), and probably these effects can be greatly improved in many instances by a judicious combination of management practices. However, before satisfactory predictions can be made of expected levels of residual nitrogen under conditions in any given region, the relative effectiveness of the various factors and their interaction must be clarified.

In this study a series of field experiments were undertaken during 1955–59 to determine the residual effects on crop yields of nitrogen applied from various sources to widely different soils under the range of climatic conditions found in the Southeastern United States.

PROCEDURE

Field experiments following the same general plan were undertaken in 1955 at three locations in Alabama, one in Georgia, and two in Mississippi and in 1957 at one location in Georgia. The soils ranged in texture from clay to sandy loam, and the annual rainfall varied from 47 to 62 inches, as shown in table 1.

Nitrogen from various sources was applied at uniform rates to a series of plots in November or December. It was broadcast on land with cornstalk residues left on the surface. In the spring, ammonium nitrate was applied to another series of plots in a conventional manner to supply increments of nitrogen adjusted to define a yield curve. Corn was planted on both series of plots. The effectiveness of fall-applied nitrogen was compared with the yield curve obtained from spring-applied nitrogen.

In experiments in Alabama and Mississippi, fall applications supplied nitrogen at 75 or 100 pounds per acre, and the yield curve was defined by spring applications of 0, 50, 100, 150, and 200 pounds per acre. In the Georgia experiments, fall applications supplied 90 or 120 pounds of nitrogen per acre, and rates of spring-applied nitrogen were 0, 30, 60, 90, 120, and, at one location, 240 pounds per acre.

There was some variation in the nitrogen sources used for fall application. Ammonium nitrate, sodium nitrate, and urea were used in all experiments; ammonium sulfate was used at all locations except Poplarville; and anhydrous ammonia was included at all locations except Brooksville and Tifton, where soil characteristics or lack of satisfactory metering equipment made its use inadvisable.

TABLE 1.—*Location of experiments and pertinent soil and climatic data*

Location of experiments [1]	Soil type	Soil reaction	Average annual rainfall	Days per year with 32° F. or less
Alabama:		*pH*	*Inches*	*Number*
Belle Mina, Tennessee Valley Substation.	Decatur clay loam.	5.7	52	69
Prattville, Prattville Experiment Field.	Greenville fine sandy loam.	5.8	52	43
Thorsby, Foundation Seed Stocks Farm.	Greenville sandy loam.	5.7	56	50
Georgia:				
Tifton, Coastal Plain Experiment Station.	Tifton sandy loam.	6.3	47	27
Watkinsville, Southern Piedmont Experiment Station.	Cecil sandy loam.	5.5	49	48
Mississippi:				
Brooksville, Black Belt Branch Station.	Houston clay	6.6	50	58
Poplarville, South Mississippi Branch Station.	Ruston sandy loam.	5.5	62	23

[1] All experiments were started in 1955, except those at Tifton, Ga., in 1957.

All plots received adequate phosphorus and potassium. They were arranged in randomized complete blocks with four to six replicates. In experiments at Thorsby, Tifton, and Watkinsville supplemental irrigation was provided.

Winter crops of wheat or oats for forage only were seeded after the first corn crop, and these were followed by the second corn crop. The small-grain and second corn crops did not receive any nitrogen fertilizer and were dependent on residual nitrogen from the first corn crop. Yields of corn grain and small-grain forage were measured, and nitrogen uptake was calculated by sampling and analyzing all three crops. Similarly, residual effects of the spring applications of ammonium nitrate were measured in the succeeding small-grain and corn crops over a period of about 16 months.

Some complementary measurements were made, although the records were not maintained uniformly at all locations. Rainfall records were kept at all locations, and evaporation from an open pan was measured at Thorsby. Runoff was measured at Thorsby, Tifton, Watkinsville, Brooksville, and Poplarville, and nitrogen in solution in the runoff water was measured at the last two locations.

Effectiveness of fall-applied nitrogen on the corn crop of the succeeding year was compared with the yield curve obtained from spring-applied nitrogen, as illustrated in figure 1. This method of interpretation is applicable only if yields from spring-applied nitrogen define a suitable yield curve. In some locations or years the data do not define such curves, often because corn yields are limited by dry weather. Such results are not subject to valid interpretation and account for deletion of some data from this bulletin.

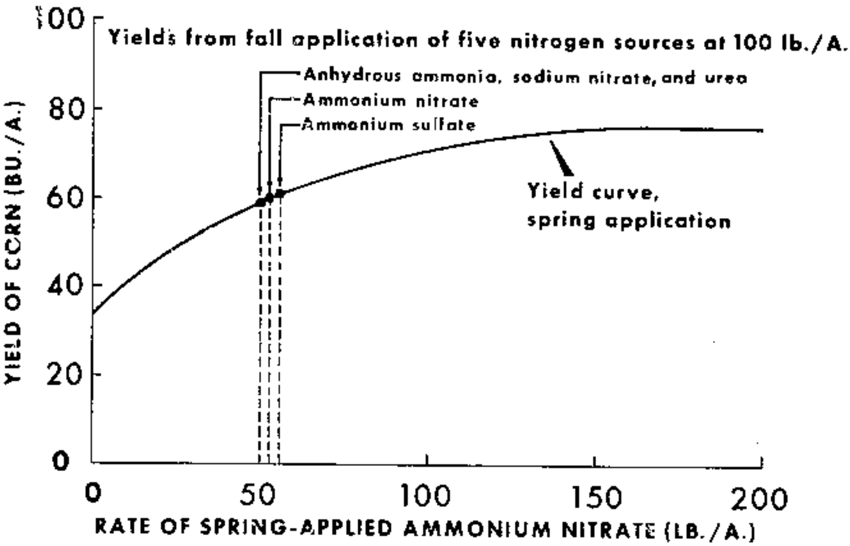

FIGURE 1.—Method used to compare the effectiveness of fall-applied nitrogen from various sources with that of spring-applied ammonium nitrate on corn yields in experiments conducted in Alabama and Mississippi during 1955–59. A yield curve is drawn based on the spring applications at different rates. Points representing yields from 100 pounds of nitrogen applied in the fall are marked on the curve. Dotted lines are extended from these points to the horizontal axis and indicate the amount of spring-applied nitrogen required to produce similar yields. For example, 60 bushels of corn could be produced with either 100 pounds of ammonium nitrate applied in the fall or 53 pounds applied in the spring.

RESULTS AND DISCUSSION

Yields

Yield Response of First Corn Crop to Fall and Spring Nitrogen Applications

Yield response of the first corn crop to both fall- and spring-applied nitrogen at all locations is presented in table 2. The relative effectiveness of the fall-applied nitrogen for each year and location was calculated to a common basis in terms of spring-applied nitrogen, by the procedure illustrated in figure 1, and is summarized as follows:

Nitrogen source	*Relative effectiveness of fall-applied nitrogen*[1] *in terms of spring-applied nitrogen on corn yields*
	Pounds per acre
Ammonium nitrate	53
Anhydrous ammonia	50
Urea	49
Sodium nitrate	47
Ammonium sulfate	46
Average	49

[1] 100 pounds per acre for each nitrogen source.

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TABLE 2.—*Yield response per acre of first corn crop to fall- and spring-applied nitrogen at various locations in Alabama, Mississippi, and Georgia, 1955–59*

Location and year	Fall-applied nitrogen from various sources at 100 pounds per acre						Spring-applied nitrogen as ammonium nitrate at pounds shown per acre					
	Ammonium nitrate	Ammonium sulfate	Anhydrous ammonia	Sodium nitrate	Urea	L.S.D. (0.05 percent)	0	50	100	150	200	
Alabama:												
Belle Mina:	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1955	78. 0	79. 0	74. 1	73. 5	80. 3	(1)	65. 6	83. 1	84. 3	--------	74. 2	--------
1957	82. 4	76. 9	64. 7	70. 2	78. 9	13. 8	49. 1	82. 4	83. 9	--------	74. 1	--------
1959	73. 9	70. 7	72. 3	65. 1	70. 1	(1)	25. 5	58. 5	74. 1	--------	76. 1	--------
Prattville:												
1955	73. 9	68. 4	73. 1	72. 7	76. 6	(1)	32. 3	69. 2	79. 2	--------	85. 4	--------
1957	43. 7	35. 3	39. 0	45. 2	47. 1	6. 2	18. 5	51. 5	56. 7	--------	57. 4	--------
1959	61. 6	60. 2	55. 1	55. 7	64. 7	4. 6	25. 0	50. 7	59. 6	--------	60. 9	--------
Thorsby:[2]												
1956	84. 5	79. 1	89. 7	88. 1	93. 4	6. 1	61. 5	83. 6	91. 4	96. 5	96. 4	--------
1958	96. 5	90. 8	81. 0	96. 1	95. 7	(1)	49. 0	78. 4	93. 8	101. 7	102. 0	--------
1959	71. 8	67. 0	71. 4	61. 7	66. 3	(1)	38. 3	69. 7	88. 1	102. 0	108. 9	--------
Mississippi:												
Brooksville:												
1956	54. 5	47. 1	--------	54. 8	43. 1	8. 2	36. 1	40. 5	61. 8	62. 9	62. 6	--------
1957	68. 2	63. 6	--------	69. 3	67. 1	(1)	41. 9	74. 3	81. 2	90. 3	88. 0	--------
1959[3]	32. 4	27. 7	--------	29. 1	27. 4	(1)	21. 8	31. 4	53. 1	--------	78. 3	--------
Poplarville:												
1956	78. 5	--------	59. 2	76. 7	63. 9	9. 1	33. 7	71. 9	75. 0	85. 8	88. 5	--------
1957	36. 7	--------	38. 4	36. 6	38. 1	5. 9	21. 2	37. 8	42. 5	41. 7	43. 8	--------
1958	40. 6	--------	42. 1	45. 8	38. 4	(1)	13. 5	40. 6	64. 8	75. 0	68. 1	--------
1959[3]	15. 9	--------	16. 8	7. 2	15. 4	(1)	6. 7	39. 4	57. 4	--------	75. 4	--------

	Fall-applied nitrogen from various sources at 90 pounds per acre						0	30	60	90	120	240
Georgia:												
Tifton: [2]												
1958 [4]	66. 5	86. 6	--------	89. 6	75. 5	18. 5	64. 9	83. 4	103. 5	112. 5	108. 5	--------
1959	50. 6	56. 3	--------	51. 4	54. 9	(1)	48. 8	66. 3	77. 3	80. 2	[5] 85. 1	--------
Watkinsville: [3]												
1957	76. 7	71. 3	78. 4	75. 7	64. 3	(1)	39. 3	71. 9	90. 7	101. 9	99. 3	102. 0
1958	67. 2	67. 8	75. 9	64. 8	69. 7	5. 2	33. 0	66. 4	78. 6	92. 2	107. 8	102. 0
1959	80. 9	74. 0	87. 5	75. 1	60. 8	--------	19. 7	44. 6	82. 2	100. 1	113. 2	138. 1

[1] Not significant.
[2] Irrigated.
[3] Fall-applied nitrogen at 75 pounds per acre.
[4] Fall-applied nitrogen at 120 pounds per acre.
[5] 180 pounds per acre.

TABLE 3.—*Estimated amounts of percolating water between application of nitrogen in the fall and planting of corn the next spring and average relative effectiveness of the fall-applied nitrogen on corn yields at various locations in Alabama, Georgia, and Mississippi, 1955–59*

Location, soil type, and year	Rainfall	Runoff water	Evapotranspiration [1]	Estimated percolation	Average relative effectiveness of fall-applied nitrogen from all sources
Alabama:					
Belle Mina, Decatur clay loam:	*Inches*	*Inches*	*Inches*	*Inches*	*Percent*
1955	26.7				25
1957	28.2				30
1959	17.2				84
Prattville, Greenville fine sandy loam:					
1955	20.6				62
1957	16.5				34
1959	18.5				86
Thorsby, Greenville sandy loam:					
1956	28.9	1.2	8.2	19.5	70
1958	15.2	.4	8.2	6.6	89
1959	17.2	.5	5.1	11.6	48
Georgia:					
Tifton, Tifton sandy loam:					
1958	23.6	.9	11.3	11.4	18
1959	24.5	.1	11.9	12.5	7
Watkinsville, Cecil sandy loam:					
1957	19.3	4.4	7.5	7.4	39
1958	28.7	.1	10.0	18.6	45
1959	10.9	.2	5.1	5.6	59
Mississippi:					
Brooksville, Houston clay:					
1956	15.5	6.5	5.0	4.0	49
1957	30.1	6.3	8.1	15.7	43
1959	15.3	6.6	6.6	2.1	43
Poplarville, Ruston sandy loam:					
1956	18.0	5.3	7.2	5.5	61
1957	13.3	.6	6.6	6.1	49
1958	19.4	3.5	7.1	8.8	52
1959	18.3	.7	7.4	10.2	16

[1] Calculated from average daily maximum evapotranspiration rates (*18*).

Fall-applied nitrogen, regardless of source, for 1955–59 averaged 49 percent as effective as spring-applied nitrogen. This large loss in effectiveness from the offseason use of nitrogen indicates that fall application in the Southeast is impracticable, as was predicted by Nelson and Uhland (*14*).

No source of nitrogen was consistently superior or inferior to any other. However, within locations there were occasional differences among sources in some years that failed to show up in others. For example, fall-applied ammonium sulfate was poorer than most other sources at Thorsby in 1956 and at Prattville in 1957, but in all other years and locations it was as effective as the other sources. Sodium nitrate usually compared favorably with ammonium nitrate or ammonium sulfate. Although urea was surface applied on corn-crop residues, it was consistently among the most effective materials used at Belle Mina, Prattville, and Thorsby. It was poorer than other sources in only 5 of the 21 year-location tests. Apparently the large losses of ammonia found by Volk (*19*) from urea applied in this way did not occur in these experiments. Anhydrous ammonia was poorer than other sources in four year-location tests, but accuracy of metering it was severely limited by available application equipment. Thus, comparisons between locations must be made with reservation, since different equipment was used in each State.

Although fall-applied nitrogen averaged only 49 percent as effective as spring-applied nitrogen, the data in table 3 show that in some years the residual effect was very high and in others it was negligible. For example, at Prattville it ranged from 34 percent in 1957 to 86 percent in 1959, and at Poplarville from 16 percent in 1959 to 61 percent in 1956.

The data in table 3 also show that these variations cannot be explained by differences in winter rainfall and consequent losses by erosion and leaching. For example, the variations in effectiveness cited for 1956 and 1959 at Poplarville occurred in 2 years of equal rainfall. Other similar inconsistencies are apparent from the data presented. It is also obvious that fall-applied nitrogen was much more effective at some locations than at others. Inasmuch as winter rainfall does not explain these variations in location, soil texture would be the next most logical factor to examine.

The following data from table 3 when rearranged by soil type show no clear relationship between surface-soil texture and the effectiveness of fall-applied nitrogen:

Soil type	*Average relative effectiveness of fall-applied nitrogen from all sources* [1]
	Percent
Greenville sandy loam	69
Greenville fine sandy loam	61
Cecil sandy loam	48
Decatur clay loam	46
Houston clay	45
Ruston sandy loam	45
Tifton sandy loam	13

[1] Based on 3-year averages, except for Ruston sandy loam (4-yr. av.) and Tifton sandy loam (2-yr. av.).

The highest and lowest values were found on sandy loam, whereas finer textured soils fall apparently at random between the extremes. Furthermore, the differences cannot be explained by variations in permeability of the subsoils. For example, although the Houston clay is plastic throughout the profile, the nitrogen effectiveness was considerably poorer than for the Greenville sandy loam, which has a permeable clay B horizon.

Measurements of runoff (table 3) were made at some test locations to estimate actual percolation better. It is acknowledged that use of average daily evapotranspiration does not allow for individual year variations, nor does it represent true average losses where no plant cover is present. Also, antecedent rainfall would introduce some variation in moisture content of the profile at the start of the measurement period. Since there was no plant cover during the winter following fall application, the estimates of percolation are conservative. The results in table 3 show no clearly defined relationship between percolation and the effectiveness of the fall-applied nitrogen. For example, at Thorsby in 1956 and 1959 the estimated percolation was 19.5 and 11.6 inches, respectively, whereas the relative nitrogen effectiveness was 70 percent and 48 percent for these 2 years.

Obviously other factors overshadowed the effect of percolating water per se on nitrogen effectiveness. It seems probable that volatilization and runoff losses may have been contributing factors. No direct measurement of volatilized nitrogen was attempted in these experiments. However, soluble nitrogen was determined in the runoff water between the application of nitrogen in the fall and the planting of corn the following spring. The results were as follows:

Soil type and year	*Losses of nitrogen in runoff water*
Houston clay:	*Pounds per acre*
1956	22.5
1957	32.9+
1959	23.5
Ruston sandy loam:	
1956	6.2
1957	2.3
1958	11.3
1959	2.0

They can be used only as an indication of losses of applied nitrogen, since no measurements were made on unfertilized plots.

Losses from the Ruston sandy loam averaged less than 6 percent of the nitrogen applied. However, with the Houston clay about 26 percent of the applied nitrogen was found in the runoff. In neither soil was nitrogen loss related to total runoff. These data suggest that runoff losses of surface-applied nitrogen could be appreciable on soils with low infiltration rates, particularly when intensive rainfall occurs soon after application. They also indicate that the unexpectedly low effectiveness of the fall-applied nitrogen on Houston clay can be at least partly explained by runoff losses.

Total rainfall and amount of percolation may have less effect on leaching than their distribution with respect to temperature. For example, it can be rationalized that rapid microbial immobilizaton of the fall-applied nitrogen in 3 to 4 tons of corn-crop residues (roots and stover) occurs in the Southeast during the normally mild weather of the late fall and early winter. Since activity would be reduced with cooler weather in December, completion of the cycle back to nitrates would be interrupted. However, a week or so of warm weather occasionally occurs during the December–March period, when microbial activity could increase, with the mineralization of some nitrogen.

The vulnerable periods for leaching then would be (1) immediately after application, (2) after unseasonably warm weather during the winter, and (3) early in the spring after temperatures remain above 40° F. and before the new crop has reached the stage of rapid nitrogen uptake.

Rainfall in amount and intensity to cause leaching during these critical periods should be more effective in removing applied nitrogen from the profile than similar amounts at other times. Sufficient data are not available from the naturally occurring combinations of rainfall and temperature experienced thus far to test this hypothesis.

It is further recognized that crop-residue management can have a bearing on residual nitrogen, both on that in the crop residues and that in inorganic form in the soil. This factor could not be studied, and the practice of leaving stover on the soil surface in these experiments is considered to be optimum conservation management.

Ammonium nitrate applied in the spring increased average corn yields as follows:

Ammonium nitrate applied	*Increase in corn yields*
Pounds per acre	*Bushels per acre*
50	29.4
100	42.7
150	47.7

These results indicate returns of 1 bushel of corn per acre for each 1.7, 2.3, and 3.1 pounds of nitrogen, respectively, at the three application rates. These are average responses under the diverse conditions of 21 year-location tests.

Yield Response of Subsequent Crops to Residual Nitrogen From Both Fall and Spring Applications

As a general average, fall-applied nitrogen fertilizers increased yields of small grains following the first-year corn crop by only about 490 pounds of dry forage per acre. Carryover to the second corn crop, which was planted about 18 months after the fertilizers were applied, was negligible. This lack of response to residual nitrogen would be expected in view of the nitrogen removal by two preceding crops in addition to losses in other ways.

However, the spring applications of nitrogen as ammonium nitrate had relatively high residual effects on small-grain forage yields over a period of 16 months on all soils, as shown in table 4. The intermediate rates had small carryover effects. However, when 200 pounds of nitrogen had been applied in the spring, average dry-forage yields of small grain seeded the following fall were increased by 1,600 pounds per acre. This additional fall and winter growth could substantially contribute to the farm forage supply by simply utilizing the leftover nitrogen from well-fertilized corn.

There were also marked residual effects of the spring-applied nitrogen on yields of the corn crop following the small-grain crop. Table 4 shows an average increase of 19 bushels at the 200-pound original application. Although average carryover effects of the intermediate rates were small, large yield increases were consistently made on the Cecil sandy loam from both the 50- and 100-pound rates.

Table 4.—*Residual effects of nitrogen as ammonium nitrate applied to corn plots in spring on (1) small grain seeded the following fall and (2) second corn crop planted 1 year later on various soils without additional nitrogen*

OVEN-DRY SMALL-GRAIN FORAGE

Nitrogen applied to preceding corn plots (pounds per acre)	Yields per acre on—							Average [2]
	Decatur clay loam	Greenville fine sandy loam	Greenville sandy loam	Tifton sandy loam	Cecil sandy loam [1]	Houston clay	Ruston sandy loam	
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
0	471	------	1,093	1,251	560	1,026	666	792
50	955	------	1,221	1,420	650	938	1,014	983
100	1,320	------	1,720	1,660	1,150	1,334	1,351	1,392
200	2,217	------	2,601	------	2,800	1,771	2,573	2,392

SECOND CORN CROP

Nitrogen applied to preceding corn plots (pounds per acre)	Decatur clay loam	Greenville fine sandy loam	Greenville sandy loam	Tifton sandy loam	Cecil sandy loam [1]	Houston clay	Ruston sandy loam	Average [2]
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
0	9	13	26	------	26	24	------	20
50	11	15	28	------	36	25	------	23
100	12	17	30	------	49	29	------	27
200	24	20	38	------	65	46	------	39

[1] For small-grain forage, yields calculated by plotting data obtained at 0, 60, 120, and 240 pounds of nitrogen per acre and interpolating for 50, 100, and 200 pounds per acre; for second corn crop, yields calculated by plotting data for nitrogen rates actually used.

[2] Based on 16 and 10 year-location tests for small-grain forage and second corn crop, respectively.

Assuming that 2 pounds of fertilizer nitrogen are required to produce a bushel of corn, the average residual value of the 100-pound rate to the second corn crop on this soil would be 46 pounds of nitrogen—an impressive figure to the farmer. The apparent inconsistency in magnitude of residual effects from fall- and spring-applied nitrogen is probably due to the return of appreciable amounts of the spring-applied nitrogen to the soil in the crop residues.

Nitrogen Uptake and Recovery

Nitrogen uptake was measured in the first corn crop, the following winter crop of small grain, and in some instances the second corn crop. These crops were grown successively over a period of approximately 24 months after the fall nitrogen applications and 16 months after the spring applications. Recovery of applied nitrogen was calculated on the basis of differences in crop uptake between the unfertilized and fertilized plots.

The results are presented in tables 5 and 6. As shown in table 6, only about one-third of the fall-applied nitrogen was recovered on an average by the first corn crop as compared with 55 percent from the nearest rate of ammonium nitrate applied in the spring. With the exception of urea, the average recoveries from the various nitrogen sources were almost identical, ranging from 32 to 36 percent. The average recoveries for ammonium sulfate and anhydrous ammonia are not strictly comparable with those for the other sources, because these two materials were not tested on Ruston and Houston soils, where recoveries were generally low. Recoveries from urea tended to be lower than from other sources, but averaged 28 percent, even though the method of application used certainly would have favored volatilization loss of anhydrous ammonia from this source (*20*). The overall recovery of the fall-applied nitrogen was about 62 percent of that of the equivalent spring application rate. This gives a higher relative effectiveness than the 49-percent figure based on yield response.

Average recoveries of spring-applied nitrogen by the first corn crop (table 6) decreased from 60 percent at the lowest rate to 40 percent at the highest rate. It is recognized that inability to include the nitrogen contained in roots introduces an error here. However, by conservative estimates of root nitrogen content, at least 30 percent of the applied nitrogen did not contribute to the requirements of this crop. Furthermore, considerable crop-absorbed nitrogen was returned to the soil in the corn stover, amounting to about 50 pounds per acre at the higher rates of fertilization. This means that, even though complete loss of the leftover applied nitrogen is assumed, there should be an appreciable carryover from the crop-residue nitrogen returned to the soil.

Residual-nitrogen uptake from the spring applications to corn plots was measured in a fall-seeded small-grain crop and a second corn crop in selected tests. These results are presented in table 7. Although the tests do not permit differentiation between leftover applied nitrogen and crop-residue nitrogen, appreciable additional amounts of nitrogen were recovered by each crop. On the Cecil sandy loam, for

TABLE 5.—*Nitrogen uptake per acre by first corn crop in grain plus stover after fall and spring applications of nitrogen on various soils, 1955–59*

Soil type and year	Fall-applied nitrogen from various sources at 100 pounds per acre						Spring-applied nitrogen as ammonium nitrate at pounds shown per acre				
	None (check)	Ammonium nitrate	Ammonium sulfate	Anhydrous ammonia	Sodium nitrate	Urea	0	50	100	150	200
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Decatur clay loam,[1] 1955	49	69	69	69	65	69	49	49	75	------	70
Greenville sandy loam:											
1956	78	105	98	114	124	112	78	103	122	148	150
1957	91	108	106	118	110	101	91	111	120	123	129
1958	60	135	130	111	141	124	60	109	155	187	202
1959	46	84	81	77	78	73	46	80	114	134	152
Houston clay:											
1956	34	54	------	------	------	------	34	45	56	72	79
1957	56	96	80	------	97	96	56	92	109	142	153
1958	40	------	------	------	------	------	40	49	83	100	130
1959 [2]	26	40	44	------	37	34	26	40	59	------	116
Ruston sandy loam:											
1956	31	77	------	47	82	52	31	69	78	99	106
1957	25	54	------	47	47	46	25	43	63	68	72
1958	19	60	------	57	64	43	19	55	83	102	98
1959 [2]	10	21	------	26	9	16	9	42	61	------	111
							0	60	90	120	240
Tifton sandy loam: [3]											
1958	82	78	95	------	115	94	82	113	124	120	------
1959	59	70	77	------	71	63	59	96	132	148	------
Cecil sandy loam: [3]											
1956	80	138	128	103	136	134	80	125	128	149	174
1957	36	71	71	78	75	70	36	85	115	112	127
1958	50	71	77	92	66	79	50	87	109	135	137
1959	23	71	69	74	61	54	23	69	87	104	165

[1] Nitrogen uptake in grain only. [2] Fall-applied nitrogen at 75 pounds per acre. [3] Fall-applied nitrogen at 90 pounds per acre.

TABLE 6.—*Nitrogen recovery per acre by first corn crop in grain plus stover after fall and spring applications of nitrogen on various soils, 1956–59* [1]

Soil type	Fall-applied nitrogen from various sources at 100 pounds per acre [2]						Spring-applied nitrogen as ammonium nitrate at pounds shown per acre			
	Ammonium nitrate	Ammonium sulfate	Anhydrous ammonia	Sodium nitrate	Urea	Average	50	100	150	200
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Greenville sandy loam	40	35	38	45	34	38	64	61	53	45
Houston clay	30	24	---	28	26	27	35	38	41	37
Ruston sandy loam	33	---	24	30	19	27	63	50	43	38
Tifton sandy loam [3]	8	18	---	29	9	---	70	57	32	---
Cecil sandy loam [3]	45	44	44	41	41	44	73	69	64	38
Average [4]	34	32	35	36	28	---	60	55	48	40

[1] Based on 4-year averages, except 2-year average for Tifton sandy loam.
[2] 90 pounds per acre on Tifton and Cecil soils.
[3] For spring-applied nitrogen, results calculated by plotting recoveries at rates actually used.
[4] For spring-applied nitrogen, based on 16 year-location tests.

TABLE 7.—*Nitrogen uptake and recovery per acre by fall-seeded small-grain and second corn crops from spring applications of ammonium nitrate to preceding corn plots on various soils*

SMALL-GRAIN CROP—OAT FORAGE

Nitrogen applied to preceding corn plots (pounds per acre)	Nitrogen uptake on—				Average[2]	Nitrogen recovery
	Greenville sandy loam	Cecil sandy loam[1]	Houston clay	Ruston sandy loam		
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Percent*
0	7	5	15	8	9	----------
50	9	8	16	13	12	6
100	13	16	21	16	16	7
200	35	46	29	33	34	13

SECOND CORN CROP—GRAIN PLUS STOVER

Nitrogen applied to preceding corn plots (pounds per acre)	Greenville sandy loam	Cecil sandy loam[1]	Houston clay	Ruston sandy loam	Average[2]	Nitrogen recovery
0	30	25	22	--------	26	----------
50	33	34	24	--------	32	12
100	36	43	27	--------	39	13
200	61	63	47	--------	60	17

[1] Calculated by plotting data for nitrogen rates actually used.
[2] Based on 11 and 7 year-location tests for small-grain and second corn crops, respectively.

example, the average uptake per acre by the second crop from the original 200-pound application was 38 pounds more nitrogen. Assuming 50-percent efficiency of applied nitrogen, this is equivalent to a 76-pound application of fertilizer nitrogen to the second corn crop.

The combined residual effects of single applications at different rates as measured by nitrogen recovery in three successive crops are given in table 8. The percentage recovery of applied nitrogen by the fertilized crops decreased with increasing rate of application, but the opposite was true for the crops that followed. Thus, the difference in total recovery between the lowest and highest rates was only 7 percent. These data emphasize the possibilities for improving the utili-

TABLE 8.—*Recovery of nitrogen, applied at different rates in the spring, by the aboveground parts of three successive crops*[1]

Nitrogen rates (pounds per acre)	1st crop	2d crop	3d crop	Total
	Percent	*Percent*	*Percent*	*Percent*
50	59	6	12	77
100	55	7	13	75
200	40	13	17	70

[1] Average of 7 year-location tests.

zation of applied nitrogen fertilizer by considering the residual effects on the succeeding crop. They also accentuate the need for soil test procedures to estimate residual nitrogen.

Prediction of Residual Nitrogen

Soil profiles were sampled in March 1958 at 12-inch increments to a depth of 36 inches to study the accumulation of nitrogen applied the preceding fall. Samples were taken of Greenville, Cecil, and Ruston sandy loams from plots that had received fall applications of ammonium nitrate and from check plots. Analysis of these samples showed that a relatively large fraction of the fall-applied nitrogen had remained in nitrate form within the 12- to 36-inch depth over the winter, as indicated in table 9.[3] In fact, between 60 and 90 percent of the applied nitrogen was accounted for in this way, and this finding agrees reasonably well with the relative effectiveness as measured by yield.

TABLE 9.—*Overwinter accumulation of nitrate nitrogen in three soils from fall applications of ammonium nitrate, 1958*

Soil type and nitrogen rates (pounds per acre)	Nitrate nitrogen found per acre at depths (inches) shown			Total
	0–12	12–24	24–36	
	Pounds	*Pounds*	*Pounds*	*Pounds*
Greenville sandy loam:				
100	8.4	50.4	42.4	101.2
Check	2.4	4.0	4.0	10.4
Cecil sandy loam:				
90	9.6	25.2	51.6	86.4
Check	5.6	6.4	12.0	24.0
Ruston sandy loam:				
100	28.0	36.0	27.2	91.2
Check	10.0	8.0	8.0	26.0

The amount of nitrate nitrogen formed upon incubation of these soils at 55-percent relative humidity and 30° C. for 4 weeks did not differ appreciably with treatment. However, with the Cecil sandy loam, some of the fall-applied nitrogen was present in labile organic form. From these results it appears that a method for predicting carryover effects of offseason nitrogen applications could probably be based on simple nitrate measurements. Assigning properly weighted values to the nitrates found at various depths would probably be the most difficult part of such a procedure.

[3] Study by V. J. Kilmer, Plant Industry Station, Beltsville, Md.

SUMMARY

Nitrogen fertilizer broadcast in November or December on widely different soils at seven locations in Alabama, Georgia, and Mississippi during 1955–59 was only 49 percent as effective as nitrogen fertilizer applied the following spring when measured by corn yields. In terms of nitrogen recovered, the relative effectiveness was 62 percent.

There were no consistent differences among the five nitrogen sources applied in the fall as measured by corn yields, but nitrogen recovery tended to be lower from urea than from the other sources.

There were marked variations in the effectiveness of fall-applied nitrogen at different locations. However, these variations could not be explained on the basis of rainfall, estimated percolation, or soil texture. Thus, leaching does not appear to be the primary reason for the low relative effectiveness of fall-applied nitrogen.

Appreciable losses of nitrogen occurred in runoff from a fine-textured soil between application of nitrogen in the fall and planting of corn the next spring. Such losses from a sandy loam were negligible.

Recovery of spring-applied nitrogen by the fertilized crop decreased with increasing rate, amounting to little more than 50 percent at recommended rates of application. The economic implications of this low effectiveness emphasize the necessity for developing management practices to improve utilization of applied nitrogen by the fertilized crop.

Considerable residual effects of spring-applied nitrogen were found over a period of 16 months based on both yield and nitrogen uptake by the crops. Average uptakes of 25 and 34 pounds per acre of additional nitrogen were made by the second and third crops, respectively, from the 200-pound original application. This residual nitrogen produced average yield increases of 1,600 pounds of dry forage and 19 bushels of corn per acre. These results emphasize the economic importance of residual nitrogen and the need for soil test procedures for its estimation.

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