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RELATIVE EFFICIENCIES OF VARIOUS NITROGENOUS FERTILIZERS FOR PRODUCTION OF RICE[1]

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THE need for chemical nitrogen in rice production was probably never more acute throughout the world than today. Hunger and starvation are rampant among great masses of peoples many of whom are in rice-growing sections. In the oriental countries, in particular, there is insistent demand for industrial construction, including mechanical equipment for nitrogen fixation. It is not always known what form of nitrogen is best suited to local conditions from the combined industrial and agricultural standpoints. Similar problems face Americans who export nitrogen for rice culture and those who are responsible for allocation of shipments of these products. It is particularly desirable at this time to examine the scant agronomic data that have been published on the problem of the less conventional forms of nitrogen fertilizers for rice.

Ammonium sulfate is the standard mineral nitrogen fertilizer for lowland (irrigated) rice. It is used in nearly all parts of the world where it is available. Other nitrogen carriers, such as nitrates, urea, cyanamid, and organics, are also used, frequently with inferior results, but sometimes they give better crop yields than does ammonium sulfate.

Studies have indicated that the lowland rice plant utilizes ammonia nitrogen more effectively than nitrate nitrogen. The work of Nagoaka in Japan (11),[3] Trelease and Paulina in the Philippines (17), and Kelley in Hawaii (7, 8) is essentially in accord in indicating superiority of ammonia nitrogen over the nitrate form. Frequently, however, results in both pot and in field experiments have been out of harmony with this general rule. This is to be expected for hundred of varieties of rice are grown on more than 200 million acres, under varied soil and climatic conditions and by numerous cultural and irrigation practices The efficiency of nitrate nitrogen is frequently rated at about 65 as compared to the ammonia form taken as 100. Experiments conducted in water and sand cultures indicate that the rice plant can utilize either form of nitrogen, but that the ammonia form is taken up more readily. After any form of nitrogen, including nitrate, becomes a part of the plant tissues, it is retained readily.

Urea, or ammonium nitrate, frequently can be produced more economically than can ammonium sulfate, due to varying natural resources particularly a cheap supply of sulphuric acid or calcium sulfate. The purpose of the present paper is to examine experimental

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[3]Figures in parenthesis refer to "Literature Cited", p. 752.

work throughout the world in which comparisons have been made of the efficiencies of some of the newer forms of fixed nitrogen, such as urea and ammonium nitrate, in relation to ammonium sulfate. It involves also a general comparison of nitrate versus ammonia nitrogen, with some information regarding the use of organic forms of this element. In order to have a clear picture of the contrasting efficiencies of various forms of nitrogen under different conditions and in different parts of the world, it is desirable briefly to review certain featurs of rice culture.

AGRICULTURAL PRACTICE WITH RICE

GENERAL FARM PRACTICE

Some of the agricultural practices and the conditions under which fertilizers must ordinarily be applied to rice are given below: (a) Land on which rice is grown is submerged during most of the growing season, leaving little opportunity for absorption of nutrients under conditions of good aeration; (b) some soils are subject to severe leaching while others have such impervious subsoils (or have developed such effective plowpans) that water losses are small; (c) a plentiful supply of organic matter is beneficial for good rice production and definite steps are frequently taken to provide such materials by means of legume and other crops, animal manures, and human refuse from cities; (d) the need for other nutrients such as potassium, phosphorus, or sulfur varies widely with the character of the soil. Often experimental results with additions of nitrogen alone are not satisfactory because of acute shortages of other plant nutrients in the soil. (e) The mode of seeding and fertilizing the rice crop is also an important factor influencing the efficiency of nitrogen carriers. When nitrogen compounds are added to soil before, or at seeding, and the soil is allowed to remain in a moist condition the plants absorb a considerable part of the added nitrogen. Good results may be obtained from nitrates under these conditions. (f) Cyanamid is often toxic to seeds during germination. Its use may, therefore, be inadvisable when fertilization is done at seeding time, but it may give good results when added at a later period such as after the rice seedlings are well established or transplanted.

THE NEED FOR NITROGEN

The response of rice to nitrogen fertilization varies widely in different countries and in different parts of the same country. In the continental United States soils used for rice production are, for the most part, not too well supplied with available nitrogen. But the yield increase from nitrogen applications seldom exceeds 30%. In many parts of the Orient, experimental plots frequently show more than 100% increase in rice yields over a relatively low base level, when suitable nitrogenous fertilizer is used. Large increases in yield are usually obtained in countries such as India, China, Burma, and Japan where large acreages of rice are grown but even in these countries marked exceptions to the general rule occur.

FORMS OF NITROGEN AVAILABLE

Nitrogenous fertilizers of commerce fall into three general classes: (a) ammonia or ammonium compounds, (b) nitrates, and (c) natural organics. The first group also includes urea and cyanamid that form ammonia readily in the soil. Nitrates have long had a prominent place in world commerce. Recently, ammonium nitrate, which contains both ammonia and nitrate nitrogen, has come into prominence. Natural organics are widely used in the Orient.

EXPERIMENTS WITH NITROGENOUS FERTILIZERS FOR RICE

In the United States, rice is produced commercially in Arkansas, California, Louisiana, and Texas. Important experiments with nitrogen fertilizers have been carried out in each of these states. Other rice-producing countries of the world have conducted fertilizer experiments, some of which have been reported in available literature. A large part of the information by which the practices of farmers in most Oriental countries are guided appears, however, to come from long experience rather than from the results of formal experiments. Field experiments have been reported from some of these countries over a period of a good many years. Some of the work done 30 to 40 years ago was not laid out according to modern expermental design, but it appears to have led to conclusions that have, in general, stood the test of time.

Many factors contribute to the variability of rice yields on field plots. Differences in stands, weed control, and methods of harvesting are factors responsible for rather wide difference. In an experimental field, the conventional harvesting machinery used may be well suited to certain plots while on others the plants may be lodged with the result that varying quantities of grain are left in the field. Another factor is irregular maturity. A fertilizer application may change the date of maturity by a few days either way. A hot wind, or other adverse climatic factors, may produce shrivelled grain on plots in one state of maturity and not affect that in another plot in a slightly different stage of maturity. All of this means that the variation associated with yields on rice plots may be as great as, or greater than, that occuring in other crops.

EXPERIMENTS IN CONTINENTAL UNITED STATES

Experiments with rice culture have been carried on at the Biggs Rice Field Station in California for more than 30 years. During the earlier years of these experiments, careful attention was given to the influence of various factors on rice production. Among the more important of these factors are preparation of seedbed, date of seeding, varietal differences, time and depth of submergence, weed control, annual versus alternate season cropping, and basic fertilization practice. The Stockton clay adobe soil of this station is presumably neutral to mildly alkaline in reaction.

In 1932, a series of experiments involving nitrogen fertilization applied at three rates, 20, 30, and 40 pounds of nitrogen per acre, was inaugurated. In organizing these experiments, account was taken of the vast background of local and general information accumulated at the station (6). The principal commercial variety, Caloro, was used, seeded at a favorable date and the land was submerged continuously until the plots were drained just prior to harvest. This system of irrigation successfully controls barnyard grass, the most troublesome weed in rice fields of Caifornia (3).

A summary of the results for the 1932–36 period previously published are expressed graphically in Figs. 1 and 2 (3) and results for the 1938–42 period are shown in Fig. 3.

A statistical analysis of the data for the first period (1932–36) leads to the following conclusions:

1. In only one year (1935) was there a significant difference due to the kinds of nitrogenous compounds used. In considering the experiment as a whole, however, certain of the nitrogenous compounds differed from others in their effects in most years.

2. The rate of applications of the nitrogenous material had more effect on yields than did the type of nitrogen carrier used.

3. As might be expected, average yields for various years are significantly different.

4. Significant differences due to rate of application were obtained in 1932, 1934, and 1936.

5. The soil used for this work was variable.

Results for 1938–42 on these same plots are shown graphically in Fig. 3.

Analysis of the data for the second period (1938–42) leads to the same conclusions stated above except that in no year was there a significant difference between the various nitrogen carriers. Also, it became more evident that seasonal variations exert more influence on the yield than do the nitrogenous materials used.

A series of experiments comparing ammonium sulfate with ammonium nitrate in one year shows a small superiority of the former over the latter. But conclusions drawn from results for a single year are scarcely justified.

Rice experiments in Texas have been conducted on Lake Charles and Crowley clay soils. The former soil is presumably neutral to mildly acid in reaction and the latter mildly to moderately acid in the virgin condition. Extensive background information has been obtained through experiments conducted since 1909. The factors studied are similar to those listed in the discussion of work in California. A two-year comparison of four nitrogen carriers gave average relative efficiencies as follows: Ammonium sulfate 100, uramon 100, nitrate of soda 98, cyanamid 88. The no-nitrogen plots, which rated 82, gave an average yield of 2,272 pounds of rice per acre (20). The soil used was apparently of fairly good productivity and the highest yield increase due to nitrogen application was about 22%.

The Louisiana Agricultural Experiment Station has conducted pot and field experiments concerned with rice culture (5, 15, 19).

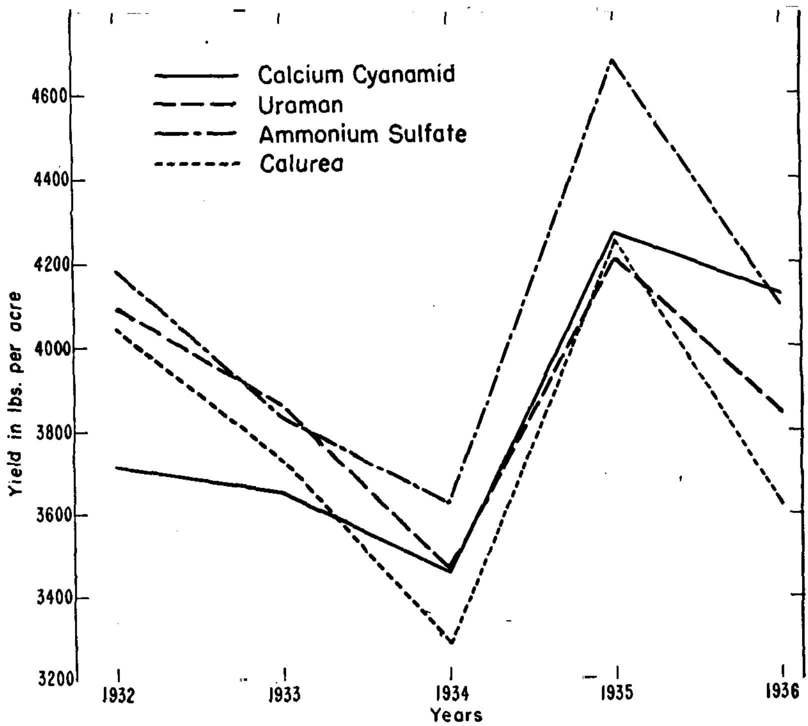

FIG. 1.—Yields of rice as influenced by different forms of nitrogen applied at equal rates (30 pounds per acre).

The Rice Experiment Station is located on Crowley silty clay loam soil of gray color and in the virgin condition is presumably of mildly acid reaction. The soil of this station had been used for growing rice during a period of 40 years. The experiments in which different sources of nitrogen were compared were carried out in pots of soil taken from a rice plot. The pots were kept out-of-doors during the period of the test. Table 1 summarizes data obtained in the set of pot experiments indicated.

TABLE 1.—*Influence upon rice growth of ammonium sulfate and urea, with and without phosphate treatments, experiments conducted in 3-gallon pots of Crowley soil, Louisiana, 1935 (15).*

Fertilizer rate and grade and form of nitrogen used	Av. head yield, grams	Av. straw yield, grams	Relative head yield, av. check value = 100
Check, no treatment.	4.6	9.0	100
200 lbs. 8-0-0 (ammonium sulfate)	3.8	9.0	82
400 lbs. 8-0-0 (ammonium sulfate)	3.5	9.3	76
200 lbs. 8-0-0 (urea)	4.7	11.2	102
400 lbs. 8-0-0 (urea)	6.0	9.0	130
400 lbs. 8-8-0 (urea-superphos)	6.1	12.0	132
400 lbs. 8-8-0 (urea-ammophos) . . .	5.8	11.3	126

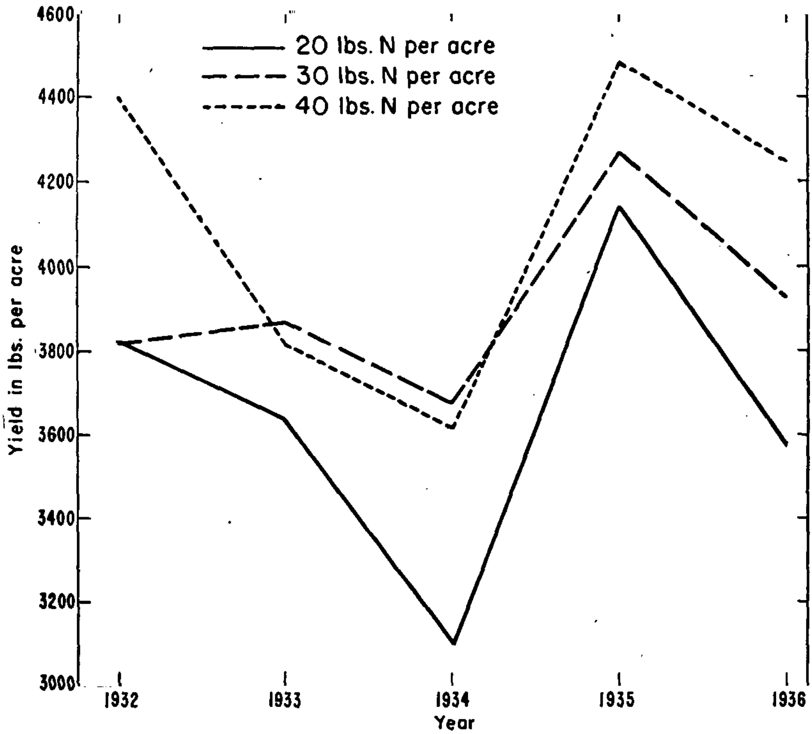

FIG. 2.—Yield of rice as influenced by rate of application of nitrogen over a 5-year period.

In this experiment the response of rice plants to nitrogen in the form of ammonium sulfate is in sharp contrast to the response from urea. Ammonium sulfate has a tendency to produce an immediate small increase in the soil acidity. It appears that plant growth in the pots may have been retarded by acidity in this experiment. Such action is seldom sufficient to be detrimental immediately to rice growing in the field. The markedly beneficial effects from urea tend to make this explanation seem plausible since urea splits chemically to produce ammonia and this tends to give an immediate alkaline effect. The alkalinity thus produced should persist for a considerable period since ammonia is not readily nitrified under the anaerobic conditions of lowland rice culture.

Rice fertilization has been given an important place in the work of the Arkansas Experiment Station (9, 10, 13, 14). The results of experiments conducted on two farms in Arkansas are given in Table 2.

It is apparent from the above data that the responses obtained from each of the three nitrogen carriers are highly variable. The yields on the Wallworth farm are far above average for Arkansas. The results with nitrate of soda on the Cox farm are not in accord with those commonly reported for this material.

TABLE 2.—*Effect of different sources of nitrogen on rice production in bushels per acre at two farms in Arkansas, rate of application 20.5 pounds of nitrogen per acre (14).*

Nitrogen source	Wallworth Farm		Cox Farm		
	1938	1939	1938	1939	1940
Check—none	78.9	73.3	27.5	52.7	38.8
Ammonium sulfate	90.4*	76.2	33.9*	60.1	49.3*
Nitrate of soda	79.9	75.5	37.6*	76.9*	64.9*
Cyanamid	93.8*	70.1	37.7*	59.9*	55.4*

*Significant above 5% level.

Recently, experiments have been initiated in which ammonium nitrate is used as one of the nitrogen carriers, the results of which

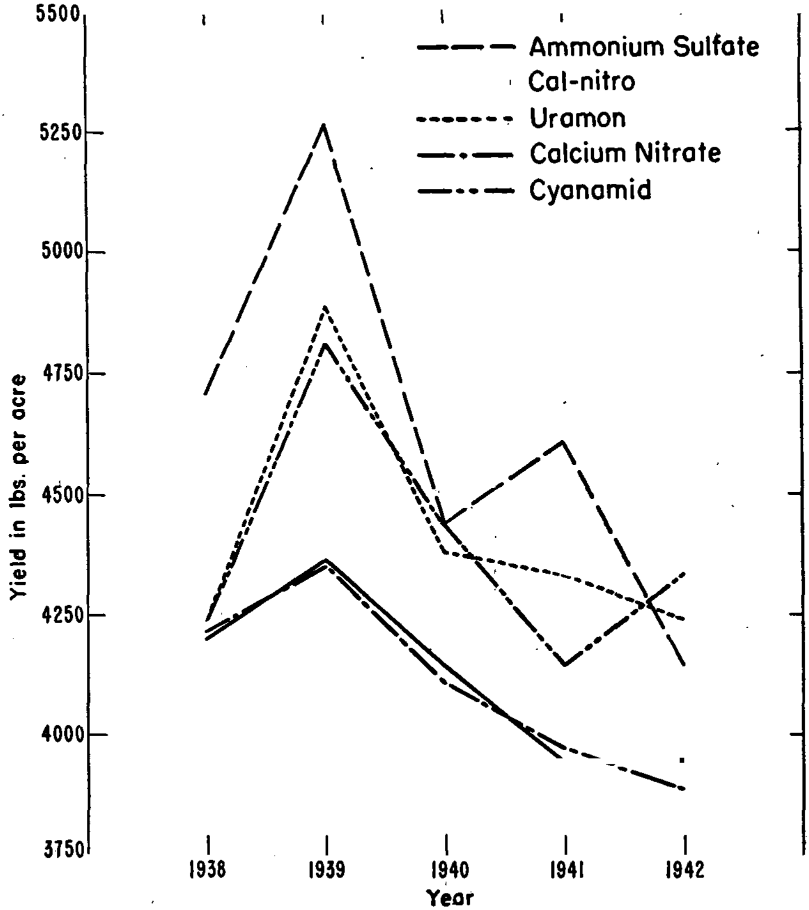

FIG. 3.—Effect of different nitrogen carriers, each at the rate of 30 pounds of nitrogen per acre, on rice yields over a 5-year period.

will be published later by the Arkansas Experiment Station. However, through the courtesy of L. C. Kapp, in charge of the experiments, we are able to present the results for 1944, shown in Tables 3 and 4.

TABLE 3.—*Summarized rice yield per acre from four nitrogenous materials applied to rice lands at two rates and for all periods of application at Rice Branch Experiment Station, Stuttgart, Ark., in 1944.*

Treatment rate per acre	Average acre increase in bushels from materials applied at all periods			
	Cyanamid	Ammonium nitrate	Chilean nitrate	Ammonium sulfate
41.0 pounds N	12.3	7.3	6.5	11.4
81.0 pounds N	16.0	10.7	12.1	15.0
All treatments*	14.2	9.0	9.3	13.2

*Average acre yields for applications in all periods of growth and at both rates of nitrogen addition.

The data of the Rice Branch Experiment Station in Arkansas are in harmony with the general results previously cited. Ammonia nitrogen tends to be more efficient than nitrate nitrogen for promoting the growth of rice, but nitrates give good response under certain conditions.

TABLE 4.—*Effect of nitrogenous fertilizers applied in furrow at plowing and also supplemented with equivalent nitrogen on dry soil before first watering on acre yields of rice at the Rice Branch Experimental Station, Stuttgart, Ark., in 1944.**

Fertilizer	Yields per acre, bu.	Increase over check, bu.	Increase over furrow, bu.
Checks	74.2	—	—
$NaNO_3$	80.6	6.4	—
NH_4NO_3	78.4	4.2	—
Cyanamid	80.9	6.7	—
$NaNO_3$†	86.5	12.3	5.9
NH_4NO_3†	87.8	13.6	9.4
Cyanamid	90.7	16.5	9.8

*Furrow application 4 to 6 inches deep; March 15, 1944.
†20.5 pounds of nitrogen per acre applied on furrow. Applied equivalent amounts before first watering on 6–8–44 on surface or dry soil supplementing furrow application. Zenith variety seeded at rate of 2 bushels per acre.

EXPERIMENTS IN OTHER REGIONS

The important features of rice fertilization in Hawaii were worked out more than 30 years ago (7, 8). More recently, much of the former rice land has been transferred to sugarcane culture and interest in rice is less marked than when the original experimental work was done. The experiments at the Hawaiian Experiment Station were concerned in part with the comparative effectiveness of nitrate versus ammonium nitrogen.

Nitrogen was applied at the rate of 70 pounds per acre either before seeding or in six applications during crop growth. When applied before seeding, sodium nitrate had about 65% of the efficiency of ammonium sulfate and when used in six applications the relative efficiency of the nitrate dropped to about 60%.

In the Philippines pot culture experiments were conducted, using different nitrogenous salts applied to a local clay loam soil in 19-liter containers (17). Combinations of nutrients were numerous and varied. An overall summary of relative efficiencies of three nitrogen salts in increasing grain yields is as follows: Ammonium sulfate = 100, ammonium nitrate = 71, sodium nitrate = 48. The rating for the no-nitrogen control was 23.

In China formal experiments with rice are few. A memorandum by Naifeng F. Chang, Chinese Technical Expert of UNRRA, was prepared under date of June 9, 1945. It sets forth certain recommendations ragarding the use of mineral nitrogen. A suggested program is as follows: 10 pounds of ammonium sulfate to the seedbed of about 1/10 acre that will furnish plants for 1 acre later; 60 pounds ammonium sulfate at transplanting; 40 pounds of ammonium nitrate as a top dressing about 20 days after transplanting.

A recent article published in Chinese and translated by Chang (1), states that in China nitrogen is the most deficient of the major plant food elements needed for rice production. Applications of ammonium sulfate have increased average rice yields slightly more than they have those of wheat.

Extensive experiments with rice culture have been carried on in Japan. Very few of the data from that country, however, have been made available to English readers. A book published in Japanese (12) summarizes some experimental results with rice in Japan. One set of experiments was conducted in "wood plots". In this series the following relative values for grain production were obtained with a uniform rate of nitrogen applied: Ammonium sulfate = 100, sodium nitrate = 49, soybean cake = 91.

Yamaguchi (21) conducted careful experiments with rice using sand, soil, and solution cultures. Ammonium sulfate, sodium nitrate, and urea were used as sources of nitrogen. The relative values of ammonium sulfate and urea vary with differences in culture medium, but in a well-buffered soil they tend to be of near equal value.

India, like other oriental countries with a warm climate, has a long record of rice production. Experimental work has been fairly elaborate in recent years.

In a series of 29 experiments in the Punjab region, one of the drier portions of India, a mixture of ammonium sulfate and sodium nitrate was superior to ammonium sulfate alone in six experiments, inferior in five, and approximately equal in the remainder. The relative efficiency of the mixture varied from place to place (2).

The Department of Agriculture of Burma has conducted many fertilizer experiments with rice (4, 16, 18). In some field tests, organic and inorganic nitrogenous materials have been added to the soil. Data for rice production in one of the experiments for the period 1926–31 are summarized thus: No nitrogen, 1,398 pounds; 40 pounds nitrogen as sodium nitrate, 1,412 pounds; and 40 pounds nitrogen as ammonium sulfate, 1,758 pounds per acre. Considered statistically, the odds in favor of beneficial results from nitrogen applications are 1.9:1 for sodium nitrate and 90:1 for ammonium sulfate. On another farm, experiments were conducted with urea at the rate of 20 pounds of nitrogen per acre. Four applications were used. The average yield of rice on the control plots was 1,870 pounds and on the urea-treated plots 2,130 pounds per acre. The results are comparable with those normally obtained from use of a like quantity of nitrogen as ammonium sulfate in sections where yields are low and nitrogen is deficient.

Ammonium sulfate is ordinarily the best nitrogenous fertilizer for rice. An overall view of nitrogen fertilization of rice throughout the world indicates that urea is often preferable to ammonium nitrate. This is especially true provided the cost per unit of nitrogen as urea does not greatly exceed that of ammonium nitrate. Moreover, indications are that nitrogen may often be fixed as cheaply in the form of urea as in ammonium nitrate in manufacturing plants of modern design.

SUMMARY

The data of this paper lead to the following conclusions:

1. Yields of rice are substantially increased in most parts of the world from additions of nitrogenous fertilizers, providing other nutrients are not the limiting factor.

2. The ammonia form of nitrogen is usually more efficient with lowland rice than the nitrate form, but there are exceptions.

3. Urea has only recently been used as a fertilizer for rice and experimental data with this nitrogen carrier are few. Compounds such as urea and cyanamid that form ammonia nitrogen, owe a part of their superiority over nitrates to retention by the soil. An indefinite part of the nitrate nitrogen is lost by leaching and the usefulness of this form may also be impaired through chemical reduction.

4. The slight superiority, or inferiority, of urea as compared to ammonium sulfate is probably related to the sulfur supply in the soil and to soil reaction.

5. Tests with ammonium nitrate have been conducted over a short period only. A fair supposition from the data at hand is that the ammonium portion of nitrogen present (one half of the total) is as good as the best of nitrogen carriers, while the nitrate portion rates with the nitrogen of nitrate of soda.

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