Masters Theses 1911 - February 2014

1931

The effect of some forms of nitrogen on the growth and nitrogen content of wheat and rice plants

Guy. Thelin
University of Massachusetts Amherst

Thelin, Guy., "The effect of some forms of nitrogen on the growth and nitrogen content of wheat and rice plants" (1931). *Masters Theses 1911 - February 2014*. 2029.
https://doi.org/10.7275/6871642

The Effect of Some Forms of Nitrogen on the Growth and Nitrogen Content of Wheat and Rice Plants

Guy Thelin

834

The Effect of Some Forms of Nitrogen on the Growth and Nitrogen Content of Wheat and Rice Plants

by

Guy Thelin

Thesis Submitted for the Degree of

Master of Science

Department of Agronomy

Massachusetts State College
Amherst, Massachusetts

1931

Average number of culms of rice and wheat produced with different forms of nitrogen.

Nitrogen Carrier	RICE			WHEAT		
	1st Stage	2nd Stage	3rd Stage	1st Stage	2nd Stage	3rd Stage
Check - No Nitrogen	1.03	1.03	1.03	1.78	1.30	1.25
Sodium Nitrate	1.67	1.50	1.61	3.52	3.23	3.00
Ammonium Sulphate	2.17	2.86	1.93	2.52	2.24	2.17
Sodium Nitrate 1 part Ammonium Sulphate 3 parts	2.13	2.57	2.19	3.37	3.10	2.50
Sodium Nitrate 2 parts Ammonium Sulphate 2 parts	2.28	2.37	2.74	3.23	3.50	2.40
Sodium Nitrate 3 parts Ammonium Sulphate 1 part	2.07	2.57	2.53	3.33	3.31	3.50
Urea	1.87	3.14	----	3.57	3.76	3.67

CONTENTS

Introduction

Since the dawn of research in plant science plant physiologists and agronomists have been interested in the problems of plant nutrition. The problem of the assimilation of nitrogen by economic plants continues to be one of the chief problems to occupy the attention of many investigators engaged in agronomic research. For the agronomist, the fertilizer manufacturer, and the practical farmer, the question of the effect of different forms of nitrogen on plant growth has for many years been of primary importance in the intelligent study and use of nitrogenous fertilizers. With the increasing production of the synthetic forms of nitrogen compounds this question has assumed more interest and importance.

It is known that plants are able to assimilate nitrogen from either inorganic or organic sources. From early investigations on the assimilation of nitrogen from various inorganic salts, it has generally been conceded that nitrogen in the nitrate form is the best form for higher plants. The lowland rice plant, however, is the exception to this assumption in that it prefers nitrogen in the ammonium form. A few investigators have

observed that a combination of the nitrate with ammonium nitrogen gives increased growth and vigor to growing plants. This has also been substantiated by some very recent investigations (30).

Since the comparative value of different forms of nitrogen absorbed by plants is usually determined by the total yield of dry matter, their effect on growth is of utmost importance. But nitrogen assimilation depends also on the amount and character of the nitrogen content of the plant. It is known, for example, that some plants may accumulate nitrogen by absorption, which they are not able to assimilate. This phase of the problem has here-tofore received but little consideration.

The author has been privileged to serve for several years in China, where rice and wheat are the most important two crops of the people, and is therefore especially interested in the problem as it affects these two plants.

Scope of Thesis

This thesis deals with the study of the effect of some forms of nitrogen on the growth and nitrogen content of rice and wheat plants. Both organic and inorganic forms were used, urea as the source of the former, and ammonium sulphate, and sodium nitrate as sources of the latter. Combinations of ammonium sulphate and sodium nitrate in different proportions were also used. Dry weights of plants were obtained, and determinations of total, nitric and ammonic nitrogen made. Data were secured also on changes in the reaction of the nutrient solution, number of plant culms and general growth conditions.

The dry matter produced, amount and character of nitrogen absorbed, character of growth and behavior of the plant, have been used as criteria of assimilation of the different nitrogen forms used.

Methods and Procedure

In these investigations with solution cultures, Vintula rice, an early maturing variety of lowland rice furnished by the United States Department of Agriculture and grown last year at the Federal Agricultural Experiment Station located at Crowley, Louisiana, and Marquis wheat were used. The seed samples were treated with Semesan disinfectant and later submerged in tap water at room temperature for several hours. Then the seeds were drained free of water and allowed to sprout. As soon as the sprouts appeared they were placed upon a paraffined bobbinet, which was stretched tightly over the mouth of a four gallon crock. The water in the crock which came to the surface of the bobbinet, was replenished with fresh water from time to time. These jars were placed in the greenhouse and were subjected to the same degree of temperature, humidity and light.

When the seedlings were eight to ten centimeters in height, uniform vigorous seedlings were selected and inserted into large paraffined corks which were a trifle smaller than the mouths of one quart fruit preserving jars, similar to the manner employed by Tottingham (49). Each cork contained six plants. These

corks were inserted into thin iron plates and jars enclosed after the manner described by Beaumont and Larsinos (4). The following mineral nutrient solution, a modification of Crone's, which has given good results with cereal plants, grasses and tobacco, was used:

$CaHPO_4.2H_2O$ ------- 0.0022 mol.

$CaSO_4.2H_2O$ -------- 0.0052 mol.

$MgSO_4.7H_2O$ -------- 0.0114 mol.

KCl -------------- 0.0075 mol.

Since the nutrient solutions were changed twice weekly only one fourth full strength was used during the early stages of growth and later increased to half strength (5). To the one-fourth full strength mineral nutrient solution manganese sulphate and boric acid were added at the rate of one part per million of manganese and boron respectively, and 0.0278 mol. nitrate of soda or other nitrogen materials or combinations of materials having an equivalent amount of nitrogen in every case. The stock solutions of nitrogen materials were prepared each week and tests showed that there was no deterioration in any of these solutions. The stock solutions were made from Baker's C.P. salts and distilled water, but nitrogen free tap water was used in preparing the complete nutrient solution for plant use. The source of iron was ferric

potassium tartrate first used at the rate of five milliliters of a 0,1 per cent solution. This was found sufficient for the young wheat plants but insufficient for rice. Consequently, the amount was five milliliters of a 0.5 per cent solution.

The freshly prepared nutrient solution has a reaction value of pH 6.4 to 6.6. Once each week the reactions of the used nutrient solutions were determined colorimetrically in order to observe the reaction changes of the various nitrogen carriers.

The following series of nitrogen materials were used:

1. Urea
2. Nitrate of soda
3. Ammonium sulphate
4. Combination of one part nitric nitrogen from sodium nitrate and three parts ammonic nitrogen from ammonium sulphate.
5. Combination of equal parts of nitric and ammonic nitrogen from sodium nitrate and ammonium sulphate, respectively.
6. Combination of three parts nitric nitrogen from sodium nitrate and one part ammonic nitrogen from ammonium sulphate.

To this was added a no nitrogen lot for control. Five replications of six plants each were made of each lot

in order to provide a sufficient number of plants for satisfactory results. There were three series each of wheat and rice, one for each stage of growth studied.

These cultures were grown in the greenhouse under nearly uniform conditions of light, humidity and temperature, but tap water at room temperature was used in making up the renewed nutrient solutions for the young rice plants.

The three series of plants were harvested at intervals of approximately one month, two months, and three months, respectively and condition of plants recorded. These harvested plants were placed immediately into a oven and thoroughly dried at a temperature of sixty degrees centigrade. When thoroughly dry they were weighed and weights of tops and roots recorded separately.

The analyses for inorganic nitric nitrogen and ammonic nitrogen was made according to the method of Session (42) and Sessions and Shive (41) except that the dried material was used instead of the plant extracts. The dried plants were ground to pass a 20 mesh sieve or finer and then placed in a ball mill for two and a half to three hours, after which time most of the material would pass thru a 100 mesh sieve. Only the finer material was used in the inorganic nitrogen determinations. Total nitrogen was determined by Mr. P. H. Smith of the Massachusetts Agricultural Experiment Station.

Review of Literature

Rice

Kellner (22), in 1884, found in pot experiments that ammonium salts produced better growth during the early development of rice plants but during later growth nitrates proved more effective. In the paddy soils of Japan Kellner (23) also showed that ammonia is formed in rather large quantities while nitrate formation was very slow.

Nagaoka (31) in Japan concluded that ammonium sulphate and soy bean cake were more effective than nitrates with lowland rice. He found that the value of ammonium sulphate and nitrate of soda stand in the ratio of 100 to 40. However, in his work on the manurial value of calcium cyanamid (32) his data show that nitrate of soda produced greater total yield than ammonium sulphate, but that these two forms were better than calcium cyanamid in pot experiments with transplanted plants of lowland or paddy rice.

Daikuhara and Imaseki (6) found that ammonium sulphate was more effective than either nitrate of soda or a combination of the two forms. With dry or upland rice, however, these two forms proved to be about of equal value.

In Hawaiian field trials Kelly (24) showed that applications of ammonium sulphate produced considerable increases in yields of straw and grain. Applications made before planting produced better yields compared with applications at intervals of growth. Nitrate of soda was ineffective in either case. In pot experiments with soil cultures nitrates were ineffective until near the heading period of rice. Soy bean cake, a common form of fertilizer in the Orient, produced very good growth, but ammonium sulphate was the most effective and produced not only greater height of plants but increased tillering over the nitrate cultures. The applications of nitrates in sand cultures showed very unhealthy and stunted growth, where as applications of ammonium sulphate produced healthy normal growth.

Gile and Carrero (13) in Porto Rico in their investigations on the problem of assimilation of iron by rice concluded that ferrous sulphate, ferric chloride, and ferric tartrate afforded sufficient iron in acid and neutral solutions, but only ferric tartrate furnished sufficient iron in alkaline solutions. Those plants grown in acid solutions contained the highest percentages of iron. Nutrient solutions supplied with 0.008 gram of iron per liter produced much better growth than with 0.002 grams of iron per liter. They concluded that rice is not

particularly sensitive to the reaction of the nutrient solutions except as the reaction influenced the availability of the iron. They also found that there was no assimilation of colloidal iron by rice plants (14).

Gile and Carrero (15) found in their work on the absorption of nutrients as affected by the number of roots supplied with the nutrient solution, that plants with all their roots in the nutrient solution absorbed the maximum total amount of the elements, and the fewer the number of roots the smaller the total amount absorbed; that the amount of the element absorbed per gram of roots increased greatly as the number of the roots in the nutrient solution diminished.

Using the triangular method of varying salt proportions with solution, sand, and soil cultures Trelease and Paulina (50) studied the effect of the addition of varying amounts of ammonium and nitrate salts on the growth of rice. They found that there was a direct relation of high yields of straw and grain to high proportions of nitrogenous salts in fertilizer mixtures. The best cultures of ammonium sulphate, ammonium nitrate, sodium nitrate, calcium nitrate, gave yields of 9.6, 6.5, 3.2, and 3.0 times, respectively, that of the control cultures The ammonium form of nitrogen was superior

to the nitrate form in every case.

Espino (10) in 1920 studied the salt requirements of young rice plants in which he grew lowland rice in various combinations of salt solutions during the three weeks period following germination. These studies, he states, "Involve experimental data on the growth of the rice plants in three different types of solutions: 3-salt solution type I comprising, besides a trace of ferric phosphate, the three salts monopotassium phosphate, calcium nitrate, and magnesium sulphate; 4-salt solution type A comprising, besides a trace of ferric phosphate, the three salts just mentioned together with ammonium sulphate; and 4-salt solution type B comprising, besides a trace of ferric phosphate, the four salts monopotassium phosphate, monocalcium phosphate, magnesium sulphate, and ammonium sulphate. Each type was studied with reference to a large number of different sets of salt proportions and several different total concentrations." These types were arranged on the basis of molecular proportions and not osmotic proportions. He concluded that no 3-salt type I set of proportions gave good growth, but excellent growth was obtained with proper sets of the 4-salt type A solutions, which indicate that plants require the ammonium ion. Espino further concludes that the most promising solution for rice plants will have

about 0.002 grams molecule per liter of all salts, with the salts being present in about the following proportions:

Monopotassium phosphate one part,

Ammonium sulphate one and one half parts,

Calcium nitrate one and one half parts, and

Magnesium sulphate four parts.

This seems to indicate that not only is the ammonium ion required but also the nitrate ion for the growth of rice plants.

Jacobson (17) found that eighty per cent of the total nitrogen of the culture solution was removed by the 100 day old rice plants during three days of the experiment in which the hydrogen ion reaction was observed. The pH values of the nutrient solutions changed from an average initial acidity of pH 5.0 to pH 3.0 after growing the plants for one three day period. This increase in the hydrogen ion concentration was more marked after photosynthesis had ceased indicating that the carbon-dioxide given off by the roots was absorbed by the cultural solution.

In his experiments on the nutritive values of different salts of ammonia, Palisoc (34) found, in using Espino's method of salt solutions, that ammonium nitrate was the best, ammonium sulphate second, and ammonium

phosphate was the poorest of all the ammonium salts used. The latter produced a physiological injury characterized by the drying of the tips of the leaves of the young plants. He also found that a nutrient solution composed of one part monopotassium phosphate, four parts ammonium nitrate, two parts calcium nitrate, and four parts magnesium sulphate with a total concentration of 0.00275 gram molecule per liter was better than Espino's best 4-salt solution.

The relation of sodium nitrate, ammonium sulphate, and green manure to the development of chlorosis in rice with soil cultures was studied by Metzger and Janssen (27). They found that chlorosis in rice, occurred in most cases before pH 6.0 was reached, was apparently due to the lack of available nitrogen, which was overcome as ammonification progressed in the submerged soils except where organic matter was in abundance. Spraying ferrous sulphate on the leaves of chlorotic plants or the addition of ferric citrate to the flood water failed to correct the condition.

In their investigations on the transformation of nitrogen in rice soils Janssen and Metzger (19) used soil cultures treated with sodium nitrate, ammonium sulphate, and soy beans as green manure, under unflooded and submerged, cropped and uncropped conditions.

Their results show that the nitrate content of the soil was never significant in any of the tests. In the cultures treated with ammonium sulphate it was observed that there was a decided decrease in ammonia content and a corresponding increase of nitrates for the unflooded soils. In the submerged series the ammonia decreased and at the same time nitrates also decreased to the extent as to be practically insignificant in amount. A comparison of cropped with uncropped cultures show that nitrates were reduced in the flooded soils by cropping. In those cultures treated with sodium nitrate the submerged soils show that the amount of nitrates decreased to a trace in the two-month period, while there was no significant amount of ammonia formed. In the unflooded soils the reduction of the nitrates was not as marked. The green manure treatments of the submerged soils showed a steady increase in ammonia but very small amounts of nitrates at any time. In the unflooded soils there was an increase followed with a decrease in the ammonia content but the nitrate content increased during the two month period. Janssen and Metzger conclude that ammonia is superior to nitrates as fertilizers either in the form of ammonium sulphate or green manure, but that

rice plants do assimilate nitrates to a considerable extent in the case of dry soils.

Bartholomew (2) found that the nitrogenous fertilizers may be divided according to their effect on the hydrogen-ion concentration under anaerobic conditions into three groups:

1. Acid producing - such as ammonium sulphate, Leunasalpeter, ammophos, and urea.
2. Alkaline producing - such as sodium nitrate, calcium nitrate, and calcium cyanamid.
3. Practically non-reacting - such as cottonseed meal and blood meal.

He concluded that the changes in hydrogen ion concentration under the conditions of the investigations in which rice was the crop used, were due largely to assimilation of the nitrogen by plants and bacteria, altho some changes may be due to the liberation of elemental nitrogen. He states that "Failure to control changes in hydrogen-ion concentration in studies concerning the availability of nitrogenous fertilizers may lead to erroneous interpretations of results."

In another series of investigations Bartholomew (3) studied the availability of nitrogen fertilizers to rice in sand cultures. He states that "nitrogen

whether in nitrate, organic, or ammonia form seems to be readily available for rice if other growth factors such as reaction, temperature, and light are maintained uniform for all treatments." He found that the efficiency of the following nitrogen compounds compared with ammonium sulphate as 100 to be: Leunasalpeter 96%, a mixture of cottonseed meal and ammonium sulphate 96%, urea 92%, nitrate of soda 89.5%, blood meal 87%, ammonium phosphate 84.5%, calcium cyanamid 69.5%, a mixture of cottonseed meal and nitrate of soda 66%, cottonseed meal 61.5%, and calcium nitrate 59%. Nitrogen was lost from all forms of nitrogen, whether it was in the ammonia, nitrate, or organic form, but there were greater amounts lost from the nitrates and organic nitrogen compounds. Denitrification took place so rapidly that the nitrate content was insignificant.

Several investigators, Loew and Sawa (25), Aso (1), and Nagooka (31) have observed that manganese has a beneficial influence on the rice plant on paddy soils of Japan.

Gericke (11), using seven types of solutions in which one element was deficient and a complete nutrient solution of all types, found that rice plants, comparable to those grown under field conditions, could be grown

successfully without the use of ammonium salts. Boron and manganese at the rate of one part per million, and ferric tartrate as the source of iron, were used. The solutions were composed of equal fractional mole concentrations and had an osmotic value equal to one atmosphere of pressure. Plants were grown for four weeks in complete nutrient solution and then at intervals of two weeks were transferred to solutions in which one element was lacking in order to study the salt requirement of the rice plant. No element was exhausted except iron and no solutions were renewed.

This indicates that the rice plant has a low absorptive capacity for iron. He also found that the rice plants utilized larger amounts of potassium and nitrogen indicating that these two ions are apparently paired. Gericke states that, "The apparent greater need of rice for these elements, both as to quantity required and as to the length of time they need to be available, reduces the factors which markedly affect the growth of rice in nutrient solutions, to the conditions that control the availability of iron, nitrogen, and potassium."

Wheat

Hutchinson and Miller (16) grew wheat plants in sterile sand and water cultures with ammonium sulphate as the source of nitrogen. They found that with sterile water cultures the growth of the plants was slow and the root growth very poor. The sterile cultures with ammonium sulphate and mineral solution which were inoculated with nitrifying organisms proved far superior in yield of dry matter and total nitrogen in crop but contained a smaller percentage of nitrogen in the dry matter. They concluded that wheat plants showed a decided preference for nitrogen in the form of nitrate.

Using the triangle system of molecular salt proportions with salts of KH_2PO_4, $Ca(NO_3)_2$, and $MgSO_4$, in sand cultures with wheat Sewell (43) obtained maximum grain yields with high molecular proportions of nitrogen and low phosphorus and potassium salts proportion or with low nitrogen and high phosphorus and potassium salt proportions.

Davidson and LeClerc (7), from field experiments, found that the presence of sodium nitrate in the soil at the early stages of growth stimulated the vegetative growth of the wheat crop and resulted in greater yields. Applications of sodium nitrate at the time of heading did not affect the vegetative growth, but gave a better quality of grain judging from its appearance and protein content.

No noticeable effect was observed on the crop when applications of sodium nitrate were made at the time the grain was in the milk stage. They also observed that applications of the nitrate at heading stage increased the protein content of the straw, and at the first stage the yield of straw and grain was increased.

Davidson (8) from the results of later field experiments concludes that "The effectiveness of nitrates in increasing yields decreases consistently as the time of their application approaches the stage of heading." And "The effectiveness of nitrates in increasing the protein content of the grain increases as their effectiveness in increasing the yield decreases."

In a study of factors affecting the nitrogen content of wheat and the changes that occur during the development of wheat Olsen (33) states that the percentage of nitrogen in the plant proper decreases with the continuous growth of the plant. He shows that the nitrogen percentage of the kernel decreases with the progressive development and increased weight of the kernel when grown under field conditions. If conditions are favorable for normal development, all the excess nitrogen in the different parts of the plant will be moved upward and transferred into the kernel. Olsen also observed that phosphorus entered the grain simultaneously with nitrogen except in

the early stages of development.

Jacobson (18) observed the changes in hydrogen-ion concentration with Marquis wheat plants 97 days old which were placed in cultural solutions with molecular proportions distributed in one eighths. He found that the pH value increased from 3.9 to 6.3 during the first twelve hours after which the reaction remained fairly constant for the 72 hour period of observation. The nitrogen concentration decreased from 85 to 24 parts per million of nitrate nitrogen, a loss of nearly 72 percent of the total nitrogen during the first twelve hour period. Only a trace of nitrogen was found at the end of the 36 hour period.

Tarr and Noble (48) grew seedlings of wheat, corn and soybeans in nutrient solutions of different hydrogen ion concentrations of constant values ranging from pH 3 to 8. Maximum growth of wheat seedlings occurred when the hydrogen-ion concentration was maintained at approximately pH 4. No harmful effects were noted at lesser concentrations altho chlorosis appeared in the solutions which had pH values of 6 or more due to the insolubility of the iron.

Jones and Shive (21) used insoluble ferric phosphate and soluble ferrous sulphate as sources of iron in Shive's three salt solution, R_5C_2 of 1.75 atmosphere (44), in which Marquis wheat was grown. The iron was supplied in

amounts varying from 0.01 milligram to 5.00 milligrams per liter of solution. The solutions were renewed twice weekly for a period of ninety days. In the ferric phosphate series more or less chlorosis appeared which could be easily remedied by the use of ferrous sulphate. There was no chlorosis in the ferrous sulphate series but toxic effects were apparent at higher concentrations. The highest yield of plants in the ferric phosphate series occurred with 2.00 milligrams of iron per liter of solution and in the ferrous sulphate series with 0.75 milligram of iron per liter of solution. This shows that not only the form of iron but the availability and amount is of utmost importance for good plant growth.

Marsh and Shive (26) used four forms of iron in their studies on the relation of the growth of soybeans to the amount and form of iron in several types of solutions. They concluded that ferric tartrate was the most efficient of the four forms.

With six types of salt solution cultures, Gericke (12) grew wheat seedlings successfully for four weeks, by rotating the plant in daily succession from a one-salt solution to another within each type. He found that seedlings grown one day in KNO_3 solution, the second day placed in $MgHPO_4$ solution, and the third in $CaSO_4$, were

almost as large as those grown in the complete nutrient solution of all types. He observed that larger plants were produced in those types of solutions in which $MgHPO_4$ and KNO_3 were included. He states that if a nutrient solution is a poor medium for plant growth because of a larger proportion of one ion, it should be improved by the addition of some other ion of opposite charge, even though this be added in the form of a salt that would also add more of the iron already in excess."

Assimilation of Ammonic and Nitric Nitrogen

In experiments with wheat, rice, mustard, corn, and flax plants grown in liquid cultures under conditions which excluded nitrification, Pantanelli and Severini (35) concluded that ammonic nitrogen has a coefficient of utilization for the formation of organic nitrogenous compounds superior to that of nitrate nitrogen. They (36) further conclude "That ammoniacal nitrogen has a potential nutritive value for plants superior to that of nitrates, but the full expression of that higher value is conditioned upon (1) slow absorption of the ammonium cation by the roots, (2) about equal absorption of the corresponding anion,and (3) the possession of a nutritive value by the anion itself."

Hutchinson and Miller (16) after carefully reviewing much of the literature relative to investigations on the assimilation of ammonia by plants summarized the results in these words: "The results of Griffiths and Mazé seem to prove conclusively that beans and maize assimilate ammonium salts as readily as nitrates. The same may be said of Kossowitsch's experiments with peas, for although sterilization was imperfectly maintained, nitrifying organisms were completely excluded. Breal's

results may also be considered to establish the utilization of ammonia (by Poa annua). The results obtained by Pitsch, Müntz, Gerloch and Vogel, and Krüger indicate that various plants employed are able to grow in absence of nitrate - not with absolute certainty as regards Muntz's experiments - but fail to prove that ammonia was the sole source of nitrogen."

Prianischnikov (39) critically reviews the literature on the comparative value of ammonia, nitrate, and nitrogen as nutrients for higher plants. One of the important factors is physiological acidity caused by the absorption of the ammonium ion of ammonium salts. In his experiments in which physiological acidity or initial alkalinity are correctly set aside by neutralization he found that the plant is able to take up ammonia quicker and convert it into organic materials, than occurs by the addition of nitrates. In experiments with constantly changing nutrient solutions he states that "We share fully the opinion that the increase of ammonia in the solution, itself in a neutral form, may not exceed certain limits without injury to the plant and that the limits for ammonia are lower than for nitrates. Using ammonium nitrate as the source for nitrogen he found that plants absorbed the ammonium ion quicker than the nitrate ion and that the salt was physiologically acid

and increased the utilization of difficultly soluble phosphates by plants. He also found that ammonium bicarbonate, under nearly neutral condition by passing carbon dioxide through the solution, to be the best form for introducing ammonia to plants.

Prianischnikov shows that nitrites in weak solutions constitute a good source of nitrogen for higher plants. But an increase of the hydrogen-ion concentration of the solution increases the injurious effect of the nitrite and causes the appearance of ammonia in the solution and accompanies the toxic action of the nitrites on plant growth. A deficiency of carbohydrates increases the sensitiveness of plants to nitrites.

Using the method of flowing solutions in sand culture with constant pH values, Bikusser (9) found that nitrate nitrogen is superior at pH 5.5, but with pH 7.0 ammonia is superior, that the calcium content is always lower with ammonia than with nitrites or nitrates with corn as the plant indicator. Results also indicate that increases in the hydrogen-ion concentration also increases the ash content of the plant regardless of the form of nitrogen used.

In the case of sugar beets the sulphate of ammonia at pH 7.0 was more effective than at pH 5.5. He suggests that in order to compare the effect of ammonia with that

of nitrates it is necessary to have a higher concentration of magnesium, calcium, and potassium in the nutrient solution for ammonia, because ammonia hinders the absorption of these basic elements.

Pirschle (37) compared flowing culture solutions with constant pH values with cultures which were not changed and found that calcium nitrate was superior to sulphate of ammonia with the unchanged cultures. But with flowing cultures sulphate of ammonia proved superior to calcium nitrate at pH 6.0 but inferior at pH 4.5 and 7.5.

In another investigation Pirschle (38) found that corn and peas were able to absorb nitrogen from urea as well in sterile as in non-sterile cultures. This capacity of the plants to decompose urea to ammonium carbonate is due to the enzyme urease. He states that ammonium carbonate is formed, before the nitrogen from urea is absorbed, is proved by an increase of pH in the culture solution with urea.

The carbohydrate content of the plant plays an important role in the assimilation of ammonia. Prianischnikov observed that the higher the carbohydrate content of the plant the more ammonic nitrogen can be absorbed by the plants, and the ammonia is quickly transformed by the plants to amids under formation of asparagin and glutamin.

The results and observations of Nevius (28) show that the effect of ammonium salts of strong acids is dependant on the hydrogen-ion concentration of the culture solution. In neutral to alkaline reactions the ammonium salts cause an apparent toxic effect. The harmful influence of ammonium salts increases with ammonium concentration and decreasing hydrogen-ion concentration. Other unfavorable factors, such as light deficiency, iron deficiency, and so forth causes an increase in the toxic effect of the ammonium salts. The ammonium salts, however, are as effective as the alkaline nitrates with the range of pH 5.3 to 5.6. If the pH value of the culture solution does not fall below 3.6 all injuries, which are observed in the presence of ammonium salts, are to be ascribed not to physiological acidity but to their basic constituent.

From a series of experiments with the corn plant Nevius (29) shows that when ammonia salts of strong acids are presented to the corn plant as sources of nitrogen, the basic constituent of these salts disappears from the solution with increasing speed in direct proportion as the pH value of the solution increases. His results show that the reaction is one of the most important factors which determines to what extent the nitrogen of ammonia salts is absorbed by the roots, and

that the dependence of the nitrogen absorption stands in causative connection with the degree of the hydrolytic dissociation of the ammonia salt in the culture solution. The formation of asparagin, within the plant, upon the absorption of nitrogen from ammonium salts, according to Mevius, is now assumed to be a stage of detoxication of ammonia. The corn plants are able to counteract the toxicity of the penetrated ammonia by organic acids, the amino acids and its amides. He states that the NH_4 nitrogen penetrates into the root cells as NH_3 molecules and probably as NH_4-OH molecules are there neutralized by organic acids. The production of the organic acids is stimulated by the penetrated ammonia and these acids can originate only in carbon metabolism. Mevius concludes that the ammonium nitrate salt is physiologically amphoteric. The physiological acidity, which appears under conditions favorable for carbon assimilation, can be changed to physiological alkalinity by a considerable decrease of the illumination; that the ammonium nitrogen absorption in the presence of ammonium nitrate as a source of nitrogen has to run independently from the nitrate nitrogen absorption.

Results of the investigations by Jones and Skinner(20) on the absorption of nitrogen from culture solutions show that in the case of soy bean plants both forms of nitrogen are absorbed. At the three weeks period of growth much larger quantities of the NH_4+ form than the NO_3- form was used, but at the five weeks period of growth the reverse condition was manifested. With corn plants the results indicate that absolute absorption of nitrogen in the NH_4+ form took place at a uniform rate, but that the absorption of nitrogen as NO_3- is affected by age, vigor, and growth rate of the plant.

Shive(45) of the New Jersey Experiment Station, working on the absorption of NH_4+ and NO_3- forms of nitrogen with several species of plants, found that there was a high absorption rate of NH_4+ form of nitrogen during the early growth phases and relatively very low absorption rate during the late growth phases; that there was a low absorption rate of NO_3- form of nitrogen during the early growth phases and a gradual upward slope during the late growth phases. In the case of oats, however, the NH_4+ absorption abruptly increases at the tillering state and the NO_3- absorption decreases indicating athat young active growing tissue demands the NH_4+ form of nitrogen. He also found that the total absorption rate, when the two forms of nitrogen are present, increased gradually until

the reproduction phase of development. Later (46) he found that during the mature development and seed forming phase the nitrate form was absorbed the more rapidly.

He states (47) that the "Results of this investigation clearly show that nitrogen absorbed by the plant as NH_4+ is much more closely associated with the synthesis of organic nitrogen compounds by the plant than is the absorption as NO_3-. This is indicated by the fact that culture solutions with relatively high proportions of nitrogen as NH_4+ and low proportions of NO_3- invariably produced plants which were high in both soluble and total organic nitrogen." When the proportions were reversed plants were found to be low in soluble and total organic nitrogen. During later stages of growth high proportions of NH_4+ nitrogen in cultures showed accumulation of NH_4+ in tissues of older plants. "This becomes so pronounced in the plants grown in culture solutions with relatively high proportions of NH_4+ and low proportions of NO_3- that toxicity results and the growth rates are markedly retarded during the later stages of development, while during the early stages of growth these solutions invariably produced better plants than did those with low proportions of NH_4+ and high proportions of NO_3- but otherwise the same."

Above 25°C any changes in temperature caused very little variation upon the hourly absorption rates of ni-

trogen in the form of NH_4^+ and NO_3^- but below 25°C the absorption rate of the NH_4^+ ion was much more affected than that of the NO_3^- ion.

In a series of experiments with corn, cotton, and wheat seedlings grown in solution, sand, and soil cultures with various amounts of NH_4-nitrogen, NO_3-nitrogen, and the two forms in combination Naftel (30) studied the absorption of nitrogen at different stages of growth. He states that all experiments gave similar results. Only the work on cotton is reported. His results show that NH_4-nitrogen was absorbed in larger amounts than NO_3-nitrogen by the young seedlings until they were three to five weeks old, after which time more NO_3-nitrogen was used. Large amounts of both forms were absorbed by the plants when four to eight weeks old. The absorption of the NH_4-nitrogen increased as the acidity of the culture solution decreased. Nitrate nitrogen absorption, however, was only slightly affected by the reaction of the nutrient solution. Greatest growth and fruiting, and greatest total nitrogen absorption occurred when both forms of nitrogen were present in the cultures.

Naftel also presents data which indicate that the nitrogen in the seed is available to the sprouts and young seedlings in the ammonium form.

Discussion of Results

Rice

During the first few days following the placing of seedlings in nutrient solutions, in which the weather was cloudy, it was noted that the rice seedlings became light green in color. Later the condition of the seedlings revealed marked symptoms of chlorosis especially marked in the seedlings receiving the organic nitrogen from urea. The iron supply was immediately increased from 5 cc. of a 0.1% solution of ferric potassium tartrate such as used on the wheat cultures, to an equal amount of a 0.5% solution. The control cultures were first to respond followed by the combined nitrogen cultures. The cultures receiving nitrogen from ammonium sulphate as well as those receiving nitrate nitrogen responded slowly, but the solutions containing urea never recovered from this chlorotic condition.

The two series of rice seedlings which were placed in solution on March 20, received 5 cc. of a 0.5% solution of ferric potassium tartrate as the source of iron, grew very well. Only the urea and nitrate of soda cultures showed slight symptoms of chlorosis as indicated by the slightly lighter green color of the younger growing leaves. The older leaves were of normal green color.

The leaves of the other cultures receiving nitrogen from ammonium sulfate alone or in combination with nitrate of soda showed a dark green color characteristic of plants receiving nitrogen in the ammonium form.

The plants supplied with urea did not grow as well as the plants which received other forms of nitrogen. Due to the hydrolysis of urea during hot weather it was necessary to change the treatment of these cultures. Throughout the remainder of the experiments these plants were placed into a solution of urea for one day and then into the mineral nutrient solution the second day similar to the method described by Gericke (12). The plants were lighter green in color which was especially manifested on the younger leaves. The roots were of a normal healthy straw color.

The plants receiving nitrates altho they did not grow as well as those supplied with urea during the first stage were larger and more erect during later growth. The leaves were more erect and slightly darker in color compared with plants supplied with urea. Root growth appeared to be normal.

The plants grown with ammonium salts alone or combined with nitrates were normal in top growth during the first two months except for the striking dark green color of the leaves. The roots, however, were darker in color

and shorter in proportion to the ammonic nitrogen presented to the plants. The plants receiving only ammonium salts showed slight deterioration in the development of the young roots. The tips of the white roots developing from the crown darkened in color and later became brown. This condition became more marked when the nitrogen supply was doubled during the third month of growth. At this time the top growth was checked and the plants showed a weakened condition as indicated by the drooping of the leaves. This character of growth is well illustrated by plates I and II.

The leaves of the control cultures were apparently of normal color, but the roots were very long and thin indicating nitrogen deficiency.

The data on hydrogen ion concentration are recorded in tables 1, 2 and 3. The nitrate nitrogen cultures show a definite increase in pH values toward alkalinity. On the other hand the cultures receiving ammonium salts show decreasing pH values from the initial range of pH 6.4 6o 6.6. This was most noticeable in the solutiony shich contained only ammonium sulphates. The cultures supplied with both the salts of ammonia and nitrate were slightly lower in hydrogen ion concentration. This indicates that there was greater absorption of the ammonium ion than the nitrate ion in these solutions.

Plate I. Rice Plants, approximately two months old, in the second stage of growth.

1. Control
2. Urea
3. $NaNO_3$
4. $(NH_4)_2SO_4$
5. $NaNO_3$ -----) $(NH_4)_2SO_4$--) With a ratio of 1:3 parts of nitrogen
6. $NaNO_3$ -----) $(NH_4)_2SO_4$--) " " ratio of 2:2 parts of nitrogen
7. $NaNO_3$ -----) $(NH_4)_2SO_4$--) " " ratio of 1:3 parts of nitrogen

Plate II. Rice Plants, two months and twenty-three days old, in the third stage of growth.

1. Control
2. Urea
3. $NaNO_3$
4. $(NH_4)_2SO_4$
5. $NaNO_3$ ------) With a ratio of 1:3 parts
   $(NH_4)_2SO_4$--) of nitrogen.
6. $NaNO_3$ ------) With a ratio of 2:2 parts
   $(NH_4)_2SO_4$--) of nitrogen
7. $NaNO_3$ ------) With a ratio of 3:1 parts
   $(NH_4)_2SO_4$--) of nitrogen

The number of plant culms is indicative of the response of the plant to its nutrient environment. From the data given in table 4 it is noted that the control cultures which were supplied with no nitrogen produced slightly more than one culm per plant. It is evident that the plants which received combined nitrogen and compare favorably with ammonium sulphate in the first stage of growth, are superior to the nitrates at all stages of growth in the number of plant culms produced. These plants also produced a larger number of plant culms at the second and third stage of growth than the plants which received only ammonium sulphate. The plants supplied with organic nitrogen produced more culms than the plants which grew in the presence of sodium nitrate at the first stage. The data also reveal that this group in the second stage of growth produced the largest number of culms.

The yields in dry matter produced by the various forms of nitrogen supplied to the plants are given in tables 5, 6, and 7. It can be seen that the differences between the means in table 5 are not significant except in the case of control and nitrate of soda groups which are very low. From this data it appears that the rice seedlings are able to assimilate nitric nitrogen as well as organic nitrogen but prefers the latter to the former.

In the second stages of growth according to table 6 it is noted that there is a progressive increase in total yield which is in direct proportion as the amount of nitric/Nitrogen increases/in the combined nitrogen cultures. The yields of the sodium nitrate and urea groups show that these forms of nitrogen are not as effective as those grown with ammonium sulphate. The plants grown with the combined nitrate and ammonium salts produced the highest total yield as expressed in dry weight, indicating that this form is the most effective.

The results for the third stage as recorded in table 7 show somewhat different results. At this period the plants received twice as much nitrogen as during the two preceeding periods. Since the yields of sodium nitrate are greater than the ammonium sulphate and the 3 to 1 proportion it may be assumed that the concentration of ammonium salts was too high for good growth. The growth of the ammonium sulphate group was checked, the leaves began to droop indicating a weakened condition, the roots became brown, slimy and decomposed. These symptoms indicate that ammonium salts at this concentration are toxic to rice plants. The yields of the 3 to 1 proportion of the combined nitric and ammonic nitrogen cultures show that the nitrogen in this proportion is the most effective for growing rice.

As stated previously in the intooduction plants are able to absorb either orgnnic or inorganic forms of ni-

trogen, but may not be able to assimilate all of the accumulated nitrogen in the plant. This is clearly indicated by the data in tables 8, 9, and 10. Considering the nitrogen fractions at the first stage of growth it was found that the amounts of ammonic ar nitrate nitrogen increase in proportion as the amounts presented to the plants in the form of ammonium or nitrate salts are increased. The plants which were grown with sodium nitrate contained the largest amount of tosal inorganic nitrogen. The amounts of organic as well as total nitrogen increased from nitrate of soda, urea, to ammonium sulphate respectively, in direct proportion as the amounts of ammonium salts were increased. This shows that the ammonium form of nitrogen is more effective than the nitrate or organic sources of nitrogen for young rice seedling..

The data given in table 9 show that the plants grown with ammonium sulphate contained the smallest amount of inorganic nitrogen, the control excepted, and produced the largest amount of total organic nitrogen. The superiority of urea over nitrate of soda is also evident. But those plants receiving combined inorganic nitrogen contained more organic and total nitrogen than those plants grown with nitrate of soda or urea.

That the amount of nitrogen presented to the plants during the third month was considerably increased is-

indicated by the data in table 10 which show large amounts of inorganic or unassimilated nitrogen for the six groups of plants. Under these conditions ammonium sulphate compares favorably with nitrate of soda, but the plants grown with the combined inorganic nitrogen contain the larger amounts of inorganic, organic, and total nitrogen.

Wheat

The wheat seedlings during the first month of growth received only 5 cc. of 0.1% solution of ferric potassium tartrate as the source of iron and showed no chlorosis. If wheat and rice plants can be compared it is very evident that the rice plants manifest a greater need for available iron.

The plants grown with organic nitrogen were normal in every respect until the urea hydrolized during the second month of growth. Decomposition was noticed upon the lower portion of roots. This decomposed protein was cut away and the plants during the remainder of the experiment were treated as described above for rice seedlings. Under these severe conditions the growth during the third month was checked.

The plants supplied with nitrates grew normally and vigorously from the beginning of the experiment but the growth was somewhat uneven during the latter part of the growing period. The color of the leaves was normal and healthy. The roots were of the characteristic grayish white color until fungi appeared during late growth. The plants in this group and in two of the groups receiving the combined inorganic nitrogen were the only plants

to head (see plate III).

The plants supplied with ammonium sulphate did not grow well after the first few days. Later the following symptoms appeared. The tips of some of the leaves twisted and dried up. The lower leaves dried up, died, and then turned yellow. The upper leaves lacked the turgor characteristic of plants receiving nitrates. The roots turned from a grayish white to a dark brown, became slimy and decomposed. New roots appeared near the crown. A few days later these in turn changed in a manner similar to the initial root system, and fungous growth appeared. Other new roots appeared and these slowly deteriorated until finally the plants died. These symptoms indicate toxicity and are similar to those described by Beaumont (5) for toxicity in tobacco plants. The growing leaves of this group oa plants had a very dark green color which appeared to be characteristic of all the plants receiving ammonium sulphate as the source of nitrogen.

The plants supplied with both forms of inorganic nitrogen grew better at first than those which received only one form of nitrogen. Then the symptoms, such as described above, appeared on those plants which received the largest proportion of ammonium salts and there followed by the plants with lesser proportions of ammonium salts. This condition is clearly pictured in plate III.

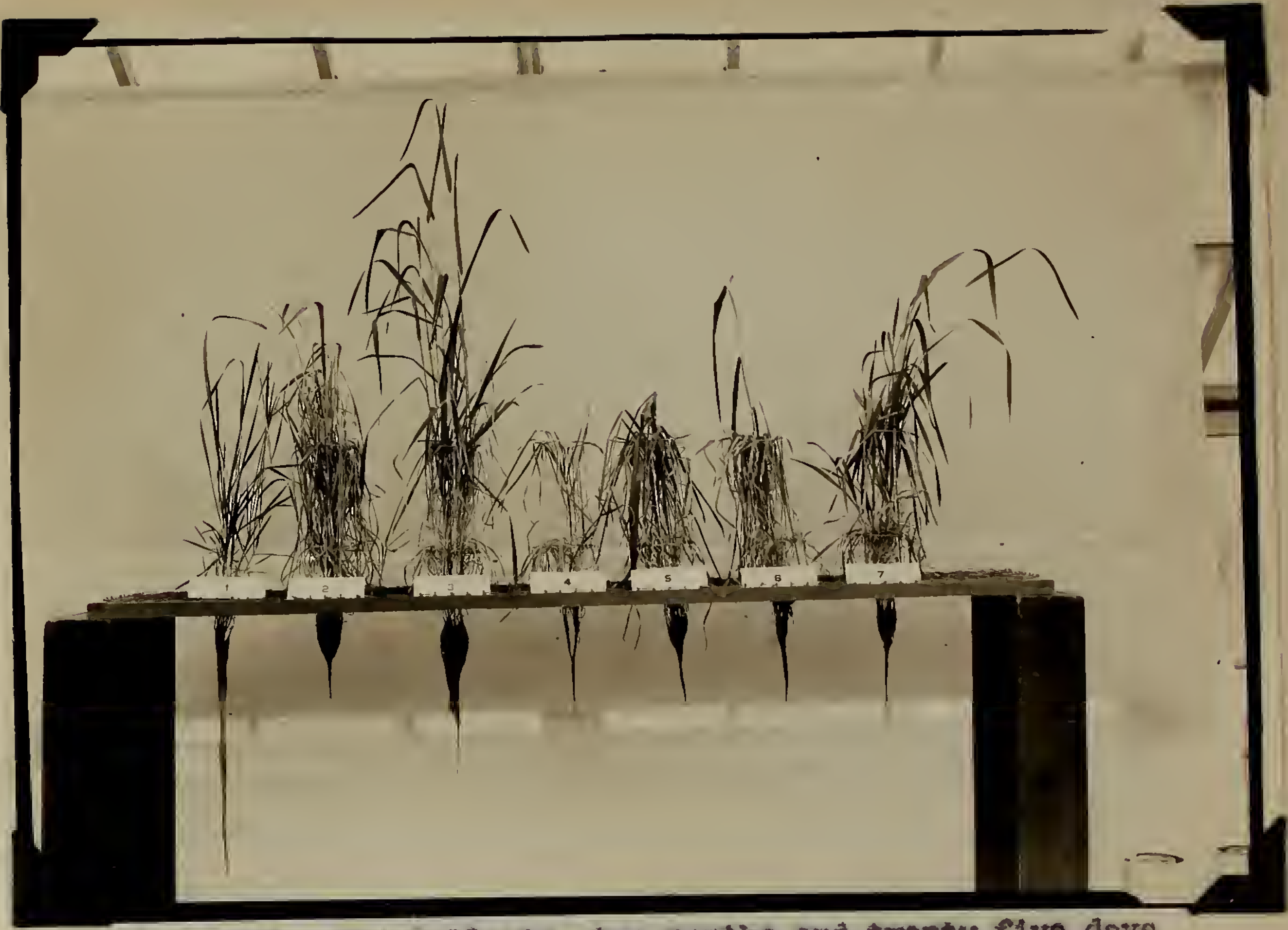

Plate III. Wheat Plants, two months and twenty five days old, in the third stage of growth.

1. Control
2. Urea
3. $NaNO_3$
4. $(NH_4)_2SO_4$
5. $NaNO_3$ -----) $(NH_4)_2SO_4$--) With a ratio of 1:3 parts of nitrogen.
6. $NaNO_3$ -----) $(NH_4)_2SO_4$--) With a ratio of 2:2 parts of nitrogen
7. $NaNO_3$ -----) $(NH_4)_2SO_4$--) With a ratio of 3:1 parts of nitrogen

The plants supplied with the 3 to 1 proportion of nitrates and ammonium salts grew very vigorously throughout the period of the experiment, but the plants were not as erect as those supplied with nitrates.

The data on the hydrogen ion reaction as presented in tables 11, 12, and 13 indicate changes which are similar to those which occureed with rice plants, but the pH values of the combined nitrogen and the ammonium sulphate cultures are not as low. This may indicate preferential absorption of the nitrate ion.

The effect of the various forms of nitrogen upon the production of plant culms is brought oub by the data in table 14. It is observed that the number of culms from plants supplied with ammonium sulphate is decidely less than from plants receiving any other form of nitrogen. The plants grown with urea produced the maximum number of culms. The number of culms from plants supplied with sodium nitrate compares favorably with those grown with different proportions of combined nitrogen in the first and second stages of growth and is greater than the 1 to 3 and 2 to 2 proportions of the third stage. The 3 to 1 ratio produced the second largest number of plant culms.

From the data on yields of dry matter as shown in tables 15, 16, and 17 the means of the dry weights of the

plants produced by the various sources of nitrogen are statistically significant. The yields of the combined nitrogen cultures increased progressively as the ratio of nitric nitrogen to ammonic nitrogen increased. The three to one proportion gave the largest return during the first and third stages of growth and the ammonium sulphate lot gave the smallest yield of plants in every case, except the control culture of the first stage. This relationship holds also for the dry weights of roots and tops. The urea source of nitrogen was more effective than nitrate of soda in dry matter produced.

In table 16 the yields from urea were the largest with nitrate of soda next. But in table 17 the 3 to 1 proportion of combined nitrogen gave the largest yield followed by nitrate of soda. The outstanding fact presented by these data is the very poor yields from the ammonium sulphate cultures indicating that ammonium sulphate as the sole source of nitrogen is decidely ineffective.

The amounts of ammonic nitrogen contained in the plant increased in proportion as the amounts presented to the plants are increased is shown from the data on the nitrogen fractions in tables 18, 19, and 20. This relationship is also true for nitric nitrogen except for the 3 to 1 proportion where the amount is a trifle

higher in the first stage and much higher in the third stage of growth. The amounts of inorganic nitrogen for the urea and control cultures is very small as would be expected. A comparison of the amounts of ammonic nitrogen with nitric nitrogen in table 18 indicates that the ammonium form is assimilated in larger amounts than the nitric nitrogen. These data also show that the greatest amount of organic nitrogen was produced during the first stage of growth. The largest amounts of inorganic nitrogen were found in the wheat plants at the third stage of growth, amounting to more than forty percent of the total nitrogen content. Another striking fact is the amount of ammonic nitrogen present as shown in tables 19 and 20 which closely correlates with the degree of toxicity manifested by plants from these respective groups.

Summary and Conclusions

This thesis gives the results of an investigation on the effect of some forms of nitrogen on the growth and nittogen content of rice and wheat plants grown in solution cultures. The salts used as sources of nitrogen were urea, sodium nitrate, and ammonium sulphate. Combinations of sodium nitrate and ammonium sulphate were also used in three differ nt proportions of nitrogen. These three proportions of nitric to ammonic nitrogen were in the ratio of 1 to 3, 2 to 2, and 3 to 1 respectively. The Vintula variety of lowland rice and Marquis wheat were grown in a modified Crone's nutrient solution. Each culture contained six plants and the cultures were replicated five times. Control cultures which received no nitrogen were also grown. The cultural solutions were renewed twice weekly. Data were secured on the hydrogen ion concentration, number of plant culms, yield in dry matter of tops, roots, and total plant material for three states of growth, which were approximately one month, two months, three months in duration. Analyses of the nitrogen fractions were made on the dry materialand the amounts of ammonic,

nitric and total nitrogen determined.

The conclusions may be summarized as follows:

1. Observations indicate that rice plants have a higher requirement for avaiaable iron than wheat plants.
2. The absorption of nitrogen in the nitrate and organic forms increased the pH values of the nutrient solutions.
2. The absorption of nitrogen in the ammonium form decreased the pH values of the nutrient solutions.
4. The absorption of nitrogen from solutions containing different proportions of nitrate and ammonium salts decreased the pH values of the nutrient solutions, but this decrease was slightly less than the pH values of the solutions which received only ammonium salts. In case of wheat plants these valueswere comparatively higher.
5. If the character of growth, the number of plant culms produced, and the yield of dry matter produced, may be considered as criteria, then ammonium sulphate was more effective than nitrate of soda or urea for rice plants, during the first and second stages of growth. In the third state in which the concentration of ammonium salts was doubled nitrate of soda proved more effective.than ammonium or the 1 to 3 proportion of combined nitrogen except in the number of plant

culms produced. For wheat urea and nitrate of soda proved more effective than ammonium sulphate at every stage of growth. The 3 to 1 proportion of ammonic and nitric nitrogen produced the largest yield of rice at all three stages of growth. This combination also produced the largest yield of wheat during the first and third stages of growth but was surpassed by urea and nitrate of soda at the second state of growth.

6. Ammonium sulphate produced symptoms of toxicity on wheat plants during first stage of growth, which effect was cumulative through the second and third stages at which times it became pronounced. The 1:3 and 2:2 combinations also showed symptoms of toxicity in proportion to the amounts of ammonium salts present. The growth of rice in the third state was depressed by the increased concentration of the ammonium salts.

7. In general the amounts of inorganic nitrogen in the plant increased in direct proportion as the amounts in the initial nutrient solutions for both rice and wheat were increased.

8. The ammonium salts produced the greatest amount of organic and total nitrogen with normal rice plants. With wheat plants the combined salts of ammonium sulphate and ~~medium~~ sodium nitrate produced the greatest amount of organic and total nitrogen during the first two stages of growth. The 1 to 3 combination produced the largest amount of organic

and total nitrogen in the third stage.

9. When the concentration of the supplied salts was doubled the greatest amount of organic and total nitrogen came from the combined nitrogen cultures for both rice and wheat plant.

Bibliography

1. Aso, K.
   On the physiological influence of manganese compounds on plants. Bul. Col. of Agr. Japan 6:13103. 1902.

2. Bartholomew, R. P.
   Effect on soil reaction of nitrogenous fertilizers under anaerobic conditions of rice production. Jour. A,. Soc. Agron. 20:1305-15. 1928.

3. ________
   The availability of nitrogenous fertilizers to rice. Soil Science 28:85-104. 1929.

4. Beaumont, A. B., and Larsinos, G. J.
   Water culture technic for studies in tobacco nutrition. Jour. Am. Soc. Agron. 21:150-155. 1929.

5. Beaumont, A. B.
   Toxicity of ammonium compounds for tobacco. To be published in the proceedings of the International Soil Congress. 1931.

6. Daikuhara, G., and Imaseki, T.
   On the behavior of nitrates to paddy soils. Bul. Imp. Cent. Agr. Exp. Station Japan 1:1-36. 1907.

7. Davidson, Jehiel, and LeClerc, J. A.
   Effect of sodium nitrate applied at different stages of growth on the yield, composition, and quality of wheat. Jour. Am. Soc. Agron. 9:145-154. 1917.

8. Davidson, Jehiel
The effect of nitrates applied at different stages of growth on the yield, composition and quality of wheat. Jour. Am. Soc. Agron. 14:118-122. 1922.

9. Dikussar, I. G.
Die Wirkung des Ammoniumsalfats und des Salpeters auf die Entwicklung von Zuckürriben und Mais in Abhängigkeit von der chemischen Zusammensetzung der Nährlösung. Landw Jahrb 72:79 1930.

10. Espino, R. B.
Some aspects of the salt requirement of young rice plants. Philippine Mag. and Jour. of Sc. 15:455-523.

11. Gericke, W. F.
Plant food requirement of rice. Soil Science 29:208-219 1930.

12. ________
On physiological balance in nutrient solutions for plant cultures. Am. Jour. of Botany 9:180-182. 1922.

13. Gile, P. L., and Carrero, J. O.
Absorption of nutrients as affected by the number of roots supplied with the nutrient. Jour. Agr. Res. 9:73-95. 1917.

14. ________
Assimilation of Colloidal iron by rice. Jour. Agr. Res. 3:205-10. 1914.

15. ________
Assimilation of iron by rice from certain nutrient solutions. Jour. Agr. Res. 7:503-528. 1914.

16. Hutchinson, H. B., and Miller, N. H.
The direct assimilation of ammonium salts by plants.
Jour. Agr. Sc. 3:179-194. 1909.

17. Jacobson, H. G. M.
Changes in hydrogen ion concentration in nutrient
solutions: in cultures with rice. Jour. Am. Soc.
Agron. 17:583-86. 1925.

18. ______
Changes in hydrogen ion concentration in nutrient
solutions: in cultures with wheat. Jour. Am. Soc.
Agron. 17:577-583. 1925.

19. Janssen, George, and Metzger, W. H.
Transformation of nitrogen in rice soil. Jour. Am.
Soc. Agron. 20:459-76.

20. Jones, C. D., and Skinner, E. E.
Absorption of nitrogen from culture solutions by
plants. New Jersey Agr. Exp. Report - 1926 pp.
260-365. 1926.

21. Jones, Linus, H., and Shive, John W.
The effect of ammonium sulphate upon plants in nu-
trient solutions supplied with ferric phosphate and
ferrous sulphate as sources of iron. Jour. Agr.
Res. 21:701-728. 1921.

22. Kellner, O.
Agricultur chemische Studiern über dis Rescultur.
Landw Vers. Stat. 30:18-32. 1884.

23. Kellner., Kozai, Y., Mori, Y., and Nagaoka, M.
Manuring experiments with paddy rice. Col. Agr.
Tokyo Imp. Univ. 1:No. 9 pp. 1-49.

24. Kelly, W. P.
The assimilation of nitrogen by rice. Hawaiian Agr. Exp. Sta. Bul. 24. 1911.

25. Loew, O., and Sawa, S.
On the action of manganese compounds on plants. Bul. Col. Agr. Japan 5:161. 1902-03.

26. Marsh, R. P., and Shive, J. W.
Adjustment of iron supply to requirement of soybeans in solution cultures. Bot. Gaz. 79:1-27. 1925.

27. Metzger, W. H., and Janssen.
Relation of sodium nitrate and certain other nitrogen carriers to the development of chlorosis in rice. Jour. Agr. Res. 37:589-602. 1928.

28. Mevius, Walter
Die Wirkung der Ammoniumsalze in ihrer Abhangizkeit von der Wasserstoffionenkonzentration. Planta 6:379-455. 1928.

29. ______
Die Wirkung der Ammoniumsalze in ihrer Abhangizkeit von der Wasserstoffionenkonzentration. Planta 9:1- 1928.

30. Naftel, James A.
The absorption of ammonium and nitrate nitrogen by various plants in different stages of growth. Jour. Am. Soc. Agron. 23:142-158. 1931.

31. Nagoaka, M.
On the behavior of the rice plant to nitrate and ammonium salts. Bul. Col. Agr. Tokyo Imp. Univ. 6:285-334. 1904.

32. ________ On the manurial value of calcium cyanamid. Bul. Col. Agr. Tokyo Imp. Univ. 6:135-136. 1904.

33. Olson, George A.
A study of the factors affecting nitrogen content of wheat and the changes that occur during the development of wheat. Jour. Agr. Res. 24:939-955. 1923.

34. Palisoc, E.
Comparative nutritive values of different salts of ammonium. Phillippine Agr. 17:37-43. 1928.

35. Pantanelli, E. and Severini, G.
Some experiments on the utilization of ammonium salts by green plants. Staz. Sper. Cegr. Ital 43:pp. 449-544 cited in Exp. Sta. Rec. 22:223. 1910.

36. ________ Further experiments on the utilization of ammonium salts by green plants. Staz. Sper. Agr. Ital. 44: No. 11 & 12 pp. 873-908 cited in E. S. Record 27;634. 1911.

37. Pirschle, K.
Assimilation des Harnstoffs durch höhere Pflanze Biochemische Zeitschr 212:466. 1929.

38. ________ Nitrate und Ammonsalze als Stickstoffquellen für höhere Pflanzen bei Konstanter Wasserstoffionenkonzentration. Planta 9:84. 1929.

39. Prianischnikov, D. N.
Ammoniak, Nitrate and Nitrite als Stickstoffquellen fur hohere pflanzen. In Ergebrnisse der Bilogie, Ester Band 407-444 Julius Springer, Berlin (translation). 1926.

40. ______
Zur Frage der Ammoniakernahrung der hoheren Pflanzen. Biochemische Zeittschr 207:341- 1929.

41. Sessions, A. C., and Shive, J. W.
A method for the determination of inorganic nitrogen in plant extracts. Plant Physiol. 3:499-511. 1928.

42. Sessions, A. C.
A method for the determination of inorganic nitrogen in dried plant tissue. Soil Sc. 29:285-9. 1930.

43. Sewell, M. C.
Relation of the molecular proportions in the nutrient solution to the growth of wheat. Jour. Agr. Res. 28:387-93. 1924.

44. Shive, John, W.
A study of physiological balance in nutrient media. Physiol. Res. 1:327-397. 1915.

45. ______
Report of Dept. of Plant Physiology. New Jersey Agr. Exp. Sta. Rpt. 1927-pp. 31. 1927.

46. ______
Report of Dept. of Plant Physiology. New Jersey Agr. Exp. Sta. Rpt. 1928 p. 58. 1928.

47. ______
Report of Dept. of Plant Physiology. New Jersey Agr. Exp. Sta. Rpt. 1929-p. 45. 1929.

48. Tarr, L. W., and Noble, S. C.
The effect of hydrogen ion concentration upon the growth of seedlings. Del. Agr. Exp. Sta. Bul. 131. 1922.

49. Tottingham, W. E.
A quantitative chemical and physiological study of nutrient solutions for plant cultures. Physiol. Researches 1:No. 4-133-245. 1914.

50. Trelease, P. F., and Paulino P.
The effect on the growth of rice of the addition of ammonium and nitrate salts to soil cultures. Philippine Agr. 8:293-313. 1920.

Table I.

Hydrogen Ion Reaction

Rice. I.

First Stage

Date	Urea		$NaNO_3$		$(NH_4)_2SO_4$		$NaNO_3$-1 $(NH_4)_2SO_4$-3		$NaNO_3$-2 $(NH_4)_2SO_4$-2		$NaNO_3$-3 $(NH_4)_2SO_4$-1		Control	
	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode
3/23/31	7.6-7.6	7.6	6.6-6.6	6.6	6.2-6.4	6.4	6.5-6.5	6.5	6.4-6.4	6.4	6.4-6.4	6.4	6.6-6.6	6.6
3/30/31			6.7-6.8	6.8	6.2-6.2	6.2	6.4-6.4	6.4	6.4-6.5	6.4	6.4-6.4	6.4	6.6-6.7	6.6
4/8/31			6.8-6.8	6.8	5.6-6.0	6.0	5.8-6.2	6.2	5.8-6.2	6.2	6.0-6.2	6.0	6.6-6.6	6.6
4/13/31			6.4-6.4	6.4	5.0-5.0	5.0	5.2-5.2	5.2	4.6-4.8	4.8	4.8-5.2	5.0	6.4-6.4	6.4

Table II.

Hydrogen Ion Reaction

Rice. II.

Second Stage

Date	Urea		$NaNO_3$		$(NH_4)_2SO_4$		$NaNO_3$-1 $(NH_4)_2SO_4$-3		$NaNO_3$-2 $(NH_4)_2SO_4$-2		$NaNO_3$-3 $(NH_4)_2SO_4$-1		Control	
	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode
3/23/31	7.6-7.6	7.6	6.6-6.6	6.6	6.2-6.4	6.4	6.5-6.5	6.5	6.4-6.4	6.4	6.4-6.4	6.4	6.6-6.6	6.6
3/30/31	---	---	6.6-6.6	6.6	6.2-6.2	6.2	6.3-6.3	6.3	6.4-6.4	6.4	6.4-6.4	6.4	6.4-6.4	6.4
4/6/31	---	---	6.6-6.8	6.8	5.6-6.0	5.8	6.0-6.0	6.0	6.2-6.4	6.2	6.2-6.4	6.2	6.6-6.6	6.6
4/13/31	---	---	6.8-6.8	6.8	4.0-4.8	4.4	4.6-5.2	4.8	4.6-5.4	5.2	5.2-5.4	5.4	6.4-6.5	6.5
4/20/31	---	---	6.7-6.8	6.7	3.9-5.0	4.0	4.0-4.4	4.0	4.4-5.2	4.4	4.2-5.2	4.4	6.4-6.6	6.5
4/27/31	---	---	7.0-7.0	7.0	4.2-5.0	4.4	4.6-5.4	5.0	5.6-5.8	5.6	5.8-6.0	6.0	6.6-6.6	6.6
5/4/31	---	---	6.6-6.8	6.6	3.8-3.8	3.8	3.8-4.6	4.2	4.4-4.8	4.4	4.8-5.4	5.4	6.6-6.6	6.6

Table III.

Hydrogen Ion Reaction
Rice. III.

Third Stage

Date	Urea		$NaNO_3$		$(NH_4)_2SO_4$		$NaNO_3$-1 $(NH_4)_2SO_4$-3		$NaNO_3$-2 $(NH_4)_2SO_4$-2		$NaNO_3$-3 $(NH_4)_2SO_4$-1		Control	
	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode
2/27/31	6.4-6.6	6.5	6.4-6.5	6.4	6.6-6.6	6.6	6.6-6.6	6.6	6.6-6.6	6.6	6.6-6.6	6.6	6.6-6.6	6.6
3/2/31	6.7-6.8	6.8	6.6-6.6	6.6	6.4-6.5	6.4	6.5-6.5	6.5	6.5-6.5	6.5	6.4-6.6	6.4	6.4-6.5	6.4
3/6/31	6.8-7.0	6.8	6.6-6.6	6.6	6.2-6.4	6.4	6.4-6.4	6.4	6.4-6.4	6.4	6.4-6.4	6.4	6.6-6.6	6.6
3/9/31	6.8-6.8	6.8	6.6-6.6	6.6	6.4-6.4	6.4	6.4-6.4	6.4	6.4-6.4	6.4	6.4-6.4	6.4	6.4-6.4	6.4
3/13/31	7.0-7.4	7.2	6.6-6.8	6.6	6.4-6.6	6.4	6.4-6.4	6.4	6.4-6.4	6.4	6.4-6.6	6.4	6.4-6.5	6.6
3/18/31	7.4-7.6	7.6	6.8-6.8	6.8	6.4-6.6	6.4	6.2-6.6	6.6	6.4-6.5	6.4	6.4-6.4	6.4	6.6-6.6	6.6
3/23/31	7.6-7.6	7.6	6.6-6.6	6.6	6.6-6.6	6.6	6.2-6.4	6.4	5.6-5.8	5.8	5.8-6.0	5.8	6.4-6.4	6.4
3/30/31	---	---	6.6-6.6	6.6	5.4-6.6	6.6	5.2-6.2	5.2	5.0-5.2	5.2	5.0-5.4	5.2	6.4-6.4	6.4
4/7/31	---	---	6.5-6.6	6.6	4.0-5.4	4.2	4.0-5.8	4.8	4.2-5.2	4.2	4.4-5.2	4.6	6.6-6.6	6.6
4/13/31	---	---	6.4-6.4	6.4	3.8-4.8	3.8	3.8-4.2	4.2	3.8-4.4	3.8	3.8-5.0	4.4	6.4-6.4	6.4
4/20/31	---	---	6.8-6.8	6.8	4.4-5.4	5.2	4.6-5.6	5.2	4.0-6.0	4.0	4.2-5.2	5.2	6.6-6.8	6.6
4/27/31	---	---	6.6-7.0	6.8	4.1-6.6	4.1	5.8-6.4	6.0	6.0-6.8	6.4	6.2-6.8	6.4	6.8-6.9	6.9
5/4/31	---	---	6.7-7.0	6.8	3.8-5.4	3.8	5.0-5.8	5.6	5.8-6.0	5.8	5.8-6.6	6.4	6.6-6.8	6.6
5/11/31	---	---	6.6-6.8	6.6	5.6-6.6	5.6	5.8-6.4	6.4	5.8-6.2	6.2	5.4-6.4	6.0	6.6-6.8	6.8
5/18/31	---	---	7.0-7.2	7.0	4.2-5.4	4.2	5.4-5.6	5.4	5.4-5.8	5.4	5.6-6.2	6.0	6.6-6.8	6.6
5/23/31	---	---	6.4-6.4	6.4	4.8-4.8	4.8	5.0-5.2	5.2	5.2-5.4	5.2	5.2-5.4	5.4	6.4-6.4	6.4

Table IV.

Number of Culms
Rice

Source of Nitrogen	First Stage			Second Stage			Third Stage		
	Number of Plants	Total Number of Culms	Average per Plant	Number of Plants	Total Number of Culms	Average per Plant	Number of Plants	Total Number of Culms	Average per Plant
Urea	30	56	1.866	29	91	3.137	---	---	---
$NaNO_3$	30	50	1.666	28	42	1.500	28	45	1.607
$(NH_4)_2SO_4$	30	65	2.166	28	64	2.285	27	52	1.925
$NaNO_3$ - 1) $(NH_4)_2SO_4$ - 3)	29	62	2.134	28	72	2.571	26	57	2.192
$NaNO_3$ - 2) $(NH_4)_2SO_4$ - 2)	30	66	2.280	30	71	2.366	23	63	2.739
$NaNO_3$ - 3) $(NH_4)_2SO_4$ - 1)	29	60	2.069	28	72	2.571	28	71	2.532
Control	30	31	1.033	30	31	1.033	29	30	1.034

Table V. Rice Harvest - First Stage

	Tops	Roots	Total
Urea	0.5835 gm.	0.2395 gm.	.8230
	0.5070 "	0.2070 "	.7140
	0.6200 "	0.2270 "	.8470
	0.5755 "	0.2030 "	.7785
	0.6120 "	0.2570 "	.8690
Total	2.8980	1.1335	4.0315
	.580	Mean = .8063 ± .015	
$NaNO_3$ Sod nit	0.3035 gm.	.227 0.1230 gm.	.4265
	0.4600 "	0.1895 "	.6495
	0.4685 "	0.2450 "	.7135
	0.3305 "	0.1685 "	.4990
	0.2430 "	0.1400 "	.3830
Total	1.8105	.9660	2.6765
	.362	.193 Mean = .5353 ± .032	?
$(NH_4)_2SO_4$ ammon sul	0.5995 gm.	0.1710 gm.	.7705
	0.5485 "	0.1735 "	.7220
	0.5840 "	0.1810 "	.7650
	0.6965 "	0.1575 "	.8540
	0.6985 "	0.1750 "	.8735
Total	3.1270	.8580	3.9850
	.625	.172 Mean = .7976 ± .015	
$NaNO_3$-1 pt.) $(NH_4)_2SO_4$-3 pts)	0.6485 gm.	0.2135 gm.	.8620
	0.5185 "	0.1460 "	.6645
	0.5595 "	0.1690 "	.7285
	0.6650 "	0.2065 "	.8715
	0.5685 "	0.1695 "	.7380
Total	2.9600	.181 .9045	3.8645
	.592	Mean = .7729 ± .043	
$NaNO_3$-2 pts) $(NH_4)_2SO_4$-2 pts)	0.4540 gm.	0.1545 gm.	.6085
	0.7360 "	0.2215 "	.9575
	0.6580 "	0.2060 "	.8640
	0.5320 "	0.1905 "	.7225
	0.7395 "	0.2475 "	.9870
Total	3.1195	1.0200	4.1395
	.624	.204 Mean = .8279 ± .043	
$NaNO_3$-3 pts) $(NH_4)_2SO_4$-1 pt.)	0.5170 gm.	0.2060 gm.	.7230
	0.7950 "	0.2195 "	1.0145
	0.6590 "	0.2255 "	.8845
	0.5250 "	0.1775 "	.7025
	0.7015 "	0.2110 "	.9125
Total	3.1975	1.0395	4.237
	[illegible]	.208 Mean = .8474 ± .049	
Check - No N	0.2790 gm.	0.1870 gm.	.4610
	0.2620 "	0.1930 "	.4550
	0.2725 "	0.1560 "	.4285
	0.2835 "	0.1730 "	.4565
	0.3405 "	0.1965 "	.5370
Total	1.4375	.9055	2.3380
	.288	.181 Mean = .4676 ± .011	

Table VI. Rice Harvest - Second Stage

	Tops	Roots	Total
Urea	1.9516 gm.	0.5381 gm.	2.4897
	1.9330 "	0.4946 "	2.4276
	2.2933 "	0.6368 "	2.9301
	1.2036 "	0.3903 "	1.5939
	3.2767 "	0.8488 "	4.1255
Total	10.6582	2.9086	13.5668
	2.132	.572	Mean = 2.7134 ± .248
$NaNO_3$	3.2919 gm.	0.9936 gm.	4.2855
	1.7888 "	0.5553 "	2.3441
	2.1661 "	0.6370 "	2.8031
	1.5430 "	0.4921 "	2.0351
	2.7672 "	0.8335 "	3.6007
Total	11.5570	3.5115	15.0685
	2.311	.702	Mean = 3.0137 ± .248
$(NH_4)_2SO_4$	2.9700 gm.	0.5516 gm.	3.5216
	2.7875 "	0.6114 "	3.3989
	2.9711 "	0.7224 "	3.6935
	2.29130 "	0.5812 "	3.4942
	3.4448 "	0.7600 "	4.2048
Total	15.0864	3.2266	18.3130
	3.017	.645	Mean = 3.6626 ± .086
$NaNO_3$- 1 pt.) $(NH_4)_2SO_4$-3 pts)	3.2974 gm.	0.5835 gm.	3.8809
	2.5957 "	0.4924 "	3.0881
	2.2437 "	0.4260 "	2.6697
	3.3650 "	0.6719 "	4.0369
	3.7601 "	0.7960 "	4.5561
Total	15.2619	2.9698	18.2317
	3.052	.594	Mean = 3.6463 ± .204
$NaNO_3$ - 2 pts) $(NH_4)_2SO_4$ - 2 pts)	3.5077 gm.	0.6256 gm.	4.1333
	2.9260 "	0.5634 "	3.4894
	3.2606 "	0.5254 "	3.7860
	3.5025 "	0.6247 "	4.1272
	3.9023 "	0.9211 "	4.8234
Total	17.0991	3.2602	20.3598
	3.420	.652	Mean = 4.0719 ± .138
$NaNO_3$ - 3 pts) $(NH_4)_2SO_4$ - 1 pt.)	5.4748 gm.	1.0484 gm.	6.5232
	3.9075 "	0.8600 "	4.7675
	3.1937 "	0.7153 "	3.9090
	3.3708 "	0.6437 "	4.0145
	4.4897 "	0.9662 "	5.4559
Total	20.4365	4.2336	24.6701
	4.087	.847	Mean = 4.9340 ± .292
Check - No N	1.2131 gm.	0.8492 gm.	2.0623
	1.1487 "	0.7388 "	1.8875
	1.1050 "	0.7062 "	1.8112
	0.9392 "	0.6637 "	1.6029
	1.0308 "	0.7290 "	1.7598
Total	5.4368	3.6869	9.1237
	1.087	.737	Mean = 1.8247 ± .044

Table VII. Rice Harvest - Third Stage

	Tops	Roots	Total
$NaNO_3$	5.7115 gm.	1.5275 gm.	7.2340
	5.6805 "	1.3624 "	7.0429
	6.3454 "	1.7256 "	8.0710
	2.4934 "	0.7268 "	3.2202
	4.9457 "	1.6388 "	6.5845
Total	25.1765	6.9811	32.1576
	5.035	1.39[illegible]	Mean = 6.4315 ± .503
$(NH_4)_2SO_4$	5.3480 gm.	1.0930 gm.	6.4410
	5.4740 "	1.0988 "	6.5728
	4.1107 "	0.9992 "	5.1099
	1.2000 "	0.2610 "	1.4610
	0.9862 "	0.2924 "	1.2786
Total	17.1189	3.7444	20.8633
	3.424	.749	Mean = 4.1727 ± .705
$NaNO_3$-1 pt.) $(NH_4)_2SO_4$-3 pts)	3.4504 gm.	0.4526 gm.	3.9030
	2.7610 "	0.4126 "	3.1736
	6.4250 "	1.1480 "	7.5730
	1.4672 "	0.2786 "	1.7458
	2.8287 "	0.5536 "	3.3823
Total	16.9323	2.8454	19.7777
	3.386	.569	Mean = 3.9555 ± .583
$NaNO_3$-2 pts) $(NH_4)_2SO_4$-2 pts)	7.7390 gm.	1.0311 gm.	8.7701
	7.6883 "	1.0690 "	8.7573
	7.5532 "	1.0014 "	8.5546
	2.0654 "	0.3900 "	2.4554
	5.3300 "	0.7340 "	6.0640
Total	30.3759	4.2255	34.6014
	6.075	.845	Mean = 6.9203 ± .738
$NaNO_3$-3 pts) $(NH_4)_2SO_4$-1 pt.)	10.2400 gm.	1.3332 gm.	11.5732
	6.9435 "	0.8350 "	7.7785
	7.7490 "	1.0122 "	8.7612
	6.7140 "	1.1196 "	7.8336
	10.9060 "	1.4000 "	12.3060
Total	42.5525	5.7000	48.2525
	8.511	1.140	Mean = 9.6505 ± .576
Control	1.6358 gm.	0.8956 gm.	2.5314
	1.3413 "	0.6563 "	1.9976
	1.1710 "	0.5082 "	1.6792
	1.2133 "	0.6830 "	1.8963
	1.1253 "	0.5364 "	1.6617
Total	6.4867	3.2795	9.7662
	1.247	.656	Mean = 1.9532 ± .095

Table VIII.

Nitrogen Fractions of Rice Plants

First Stage

Milligrams of Nitrogen per Gram of Material Air Dried at 60°-65°C.

Nitrogen Carrier	Inorganic Nitrogen		Total Inorganic Nitrogen	Organic Nitrogen	Total Nitrogen
	Ammonic Nitrogen	Nitric Nitrogen			
Urea	.611	.683	1.294	27.776	29.07
$NaNO_3$	.458	2.519	2.977	26.023	29.00
$(NH_4)_2SO_4$	1.686	.450	2.136	36.674	38.81
$NaNO_3$-N-1 part; $(NH_4)_2SO_4$-N-3 parts	1.218	.808	2.026	35.524	37.55
$NaNO_3$-N-2 parts; $(NH_4)_2SO_4$-N-2 parts	.773	1.323	2.096	34.544	36.64
$NaNO_3$-N-3 parts; $(NH_4)_2SO_4$-N-1 part	.398	1.510	1.908	34.032	35.94
Control-No Nitrogen	.562	.457	1.019	17.961	18.98

Table IX.

Nitrogen Fractions of Rice Plants

Second Stage

Milligrams of Nitrogen per Gram of Material Air Dried at 60°-65°C.

Nitrogen Carrier	Inorganic Nitrogen		Total Inorganic Nitrogen	Organic Nitrogen	Total Nitrogen
	Ammonic Nitrogen	Nitric Nitrogen			
Urea	1.053	1.122	2.175	33.115	36.29
$NaNO_3$	.298	3.171	3.369 (4)	30.251	33.62
$(NH_4)_2SO_4$	~~.211~~ 2.11	.991	~~1.102~~ 3.101	38.828	39.93
$NaNO_3$-N-1 part) $(NH_4)_2SO_4$-N-3 parts)	1.193	2.141	3.334	37.926	41.26
$NaNO_3$-N-2 parts) $(NH_4)_2SO_4$-N-2 parts)	.653	3.595	4.248	36.662	40.91
$NaNO_3$-N-3 parts) $(NH_4)_2SO_4$-N-3 parts)	.332	3.758	4.087	34.373	38.46
Control-No Nitrogen	.366	.584	.950	20.07	21.02

Table X.

Nitrogen Fractions of Rice Plants

Third Stage

Milligrams of Nitrogen per Gram of Material Air Dried at 60°-65°C.

Nitrogen Carrier	Inorganic Nitrogen		Total Inorganic Nitrogen	Organic Nitrogen	Total Nitrogen
	Ammonic Nitrogen	Nitric Nitrogen			
Urea	----	----	----	----	----
$NaNO_3$	.309	7.729	8.038	26.212	34.25
$(NH_4)_2SO_4$	7.596	2.541	10.~~407~~ 137	26.503	47.00
$NaNO_3$-N-1 part) $(NH_4)_2SO_4$-N-3 parts)	8.597	5.826	14.423	38.607	53.03
$NaNO_3$-N-2 parts) $(NH_4)_2SO_4$ -N-2 parts)	5.219	9.351	14.570	37.270	51.84
$NaNO_3$-N-3 parts) $(NH_4)_2SO_4$-N-1 part)	2.828	14.586	17.414	34.846	52.26
Control-No Nitrogen	.378	.916	1.294	20.916	22.21

Table XI.

Hydrogen Ion Reaction

Wheat. I.

First Stage

Date	Urea		$NaNO_3$		$(NH_4)_2SO_4$		$NaNO_3$-1 $(NH_4)_2SO_4$-3		$NaNO_3$-2 $(NH_4)_2SO_4$-2		$NaNO_3$-3 $(NH_4)_2SO_4$-1		Control	
	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode
2/21/31	6.8-7.2	6.8	6.8-7.0	7.0	6.6-6.6	6.6	6.4-6.6	6.6	6.6-6.8	6.6	6.6-6.8	6.8		
2/25/31	6.6-6.8	6.8	6.8-6.8	6.8	6.2-6.2	6.2	6.4-6.4	6.4	6.4-6.4	6.4	6.4-6.4	6.4		
2/28/31	6.4-6.4	6.4	6.6-6.6	6.6	5.2-6.0	5.2	5.4-5.4	5.4	5.2-5.2	5.2	5.2-5.2	5.2		5.4
3/3/31	6.6-6.6	6.6	6.6-6.8	6.6	5.2-5.2	5.2	5.8-5.8	5.8	5.8-5.8	5.8	5.6-5.6	5.6		6.0
3/6/31	6.6-6.6	6.6	6.8-6.8	6.8	4.6-4.7	4.6	5.2-5.4	5.4	5.2-5.4	5.4	5.2-5.4	5.2		6.2
2/10/31	6.6-6.6	6.6	6.6-6.7	6.7	4.7-5.0	5.0	5.4-5.8	5.6	5.2-5.8	5.4	5.6-6.0	5.8		6.4
3/14/31	6.4-6.5	6.5	6.5-6.8	6.6	4.0-4.0	4.0	6.0-6.2	6.2	6.2-6.2	6.2	6.4-6.4	6.4		6.2

Table XII.

Hydrogen Ion Reaction

Wheat. II.

Second Stage

Date	Urea		$NaNO_3$		$(NH_4)_2SO_4$		$NaNO_3$-1 $(NH_4)_2SO_4$-3		$NaNO_3$-2 $(NH_4)_2SO_4$-2		$NaNO_3$-3 $(NH_4)_2SO_4$-1		Control	
	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode
2/24/31	6.6-6.8	6.8	6.8-6.8	6.8	6.2-6.2	6.2	6.4-6.4	6.4	6.4-6.4	6.4	6.4-6.4	6.4		--
2/28/31	6.2-6.2	6.2	6.6-6.6	6.3	4.4-4.4	4.4	5.4-5.4	5.4	5.4-5.6	5.6	5.4-5.4	5.4	6.0-6.0	6.0
3/3/31	6.6-6.6	6.6	6.6-6.6	6.6	5.2-5.2	5.2	5.8-5.8	5.8	6.0-6.0	6.0	5.6-5.6	5.6	6.0-6.0	6.0
3/6/31	6.6-6.6	6.6	6.8-6.8	6.8	4.6-4.7	4.6	5.2-5.4	5.4	5.2-5.4	5.4	5.2-5.4	5.2	6.2-6.2	6.2
3/10/31	6.6-6.8	6.6	6.7-6.8	6.8	5.2-5.8	5.2	5.6-6.0	6.0	5.6-6.0	6.0	5.6-6.0	6.0	6.2-6.2	6.2
3/14/31	6.4-6.5	6.5	6.5-6.8	6.6	4.0-4.0	4.0	6.0-6.2	6.2	6.2-6.2	6.2	6.4-6.4	6.4	6.2-6.2	6.2
3/18/31	7.0-7.2	7.2	7.0-7.2	7.0	5.2-5.2	5.2	6.2-6.3	6.2	6.0-6.4	6.4	6.4-6.6	6.5	6.4-6.6	6.4
3/24/31	6.6-7.4	6.6	7.0-7.2	7.2	5.0-5.4	5.2	6.0-6.2	6.0	6.0-6.2	6.0	6.4-6.6	6.4	6.4-6.4	6.4
3/31/31	---	----	6.8-6.8	6.8	6.3-6.4	6.3	6.5-6.8	6.8	6.6-6.6	6.6	6.4-6.6	6.4	6.0-6.0	6.0
4/2/31	---	---	7.0-7.0	7.0	6.4-6.4	6.4	6.6-6.6	6.6	6.6-6.8	6.8	6.4-6.8	6.8	6.4-6.4	6.4

Table XIII.

Hydrogen Ion Reaction
Third Stage.

Date	Urea		$NaNO_3$		$(NH_4)_2SO_4$		$NaNO_3$-1 $(NH_4)_2SO_4$-3		$NaNO_3$-2 $(NH_4)_2SO_4$-2		$NaNO_3$-3 $(NH_4)_2SO_4$-1		Control	
	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mod
2/28/31	6.4-6.4	6.4	6.6-6.6	6.6	5.2-5.4	5.5	5.8-5.8	5.8	5.6-5.8	5.8	5.8-5.8	5.8		6.0
3/3/31	6.6-6.6	6.6	6.8-6.8	6.8	5.4-6.0	5.6	5.8-6.0	6.0	6.0-6.0	6.0	5.8-6.0	6.0		6.0
3/6/31	6.6-6.6	6.6	6.8-6.8	6.8	4.4-4.6	4.4	5.4-5.6	4.4	5.2-5.6	5.6	5.5-5.6	5.5		6.2
3/10/31	6.6-6.6	6.6	6.8-6.8	6.8	4.4-4.4	4.4	5.8-6.0	6.0	5.6-6.0	6.0	5.8-5.8	5.8		6.2
3/14/31	6.5-6.4	6.5	6.5-6.6	6.6	4.0-4.0	4.0	6.0-6.2	6.2	6.2-6.2	6.2	6.4-6.4	6.4		6.2
3/18/31	7.0-7.2	7.2	7.4-7.4	7.4	6.0-6.2	6.0	6.2-6.4	6.2	6.2-6.4	6.4	6.4-6.5	6.5		6.6
3/23/31	7.6-7.6	7.6	7.6-7.6	7.6	5.4-6.6	6.4	5.8-6.0	5.8	6.4-6.6	6.4	7.2-7.7	7.2		6.6
3/31/31	---	---	6.8-6.8	6.8	5.4-6.1	5.4	6.2-6.8	6.6	6.4-6.8	6.6	6.2-6.4	6.4		6.4
4/7/31	---	---	7.0-7.0	7.0	6.6-6.6	6.6	6.2-6.8	6.4	6.0-6.8	6.4	6.0-6.0	6.6		6.6
4/14/31	---	---	6.8-7.2	7.0	6.4-7.0	6.8	6.4-7.2	6.6	6.5-6.6	6.6	6.4-6.7	6.6		7.0
4/21/31	---	---	7.2-7.4	7.4	6.4-6.6	6.6	6.6-6.6	6.6	7.0-7.2	7.2	6.6-7.6	7.4		6.6

Table XIV.

Number of Culms
Wheat

Source of Nitrogen	First Stage			Second Stage			Third Stage		
	Number of Plants	Total Number of Culms	Average per Plant	Number of Plants	Total Number of Culms	Average per Plant	Number of Plants	Total Number of Culms	Average per Plant
Urea	30	107	3.566	29	109	3.758	30	110	3.666
$NaNO_3$	29	102	3.517	30	97	3.233	30	90	3.000
$(NH_4)_2SO_4$	29	73	2.517	29	65	2.241	29	63	2.172
($NaNO_3$ - 1) $(NH_4)_2SO_4$ - 3)	30	101	3.366	29	90	3.103	30	75	2.500
$NaNO_3$ - 2) $(NH_4)_2SO_4$ - 2)	30	97	3.233	30	105	3.500	30	82	2.400
$NaNO_3$ - 3) $(NH_4)_2SO_4$ - 1)	30	100	3.333	29	96	3.310	30	105	3.500
Control	18	32	1.777	23	30	1.304	16	20	1.250

Table XV. Wheat Harvest - First Stage

	Tops	Roots	Total
Urea	1.5410 gm.	.4420 gm.	1.9830
	1.4750 "	.4180 "	1.8930
	1.5110 "	.3390 "	1.8500
	1.9570 "	.4980 "	2.4550
	1.6500 "	.3780 "	2.0280
Total	8.1340	2.0750	10.209
	1.627	.415	Mean = 2.0418 ± .068
$NaNO_3$	1.1630 gm.	.4000 gm.	1.5630
	1.3545 "	.4630 "	1.8175
	1.4000 "	.4765 "	1.8765
	1.5235 "	.5115 "	2.0350
	1.5010 "	.4925 "	1.9935
Total	6.9420	2.3435	9.2855
	1.388	.469	Mean = 1.8571 ± .052
$(NH_4)_2SO_4$	.8665 gm.	.2270 gm.	1.0935
	.9525 "	.2465 "	1.1990
	.9380 "	.2315 "	1.1695
	.9050 "	.2200 "	1.1250
	1.0045 "	.3300 "	1.3345
Total	4.6665	1.2550	5.9215
	.933	.251	Mean = 1.1843 ± .025
$NaNO_3$-1 pt.) $(NH_4)_2SO_4$-3 pts)	1.3070 gm.	.3970 gm.	1.7040
	1.3850 "	.3760 "	1.7610
	1.4845 "	.4300 "	1.9145
	1.3670 "	.3735 "	1.7405
	1.5850 "	.4445 "	2.0295
Total	7.1285	2.0210	9.1495
	1.426	.404	Mean = 1.8299 + .037
$NaNO_3$-2 pts) $(NH_4)_2SO_4$-2 pts)	1.4815 gm.	.4235 gm.	1.9100
	1.6670 "	.4190 "	2.0860
	1.5250 "	.4060 "	1.9310
	1.5290 "	.4000 "	1.9290
	1.7515 "	.5160 "	2.2675
Total	7.9540	2.1635	10.1235
	1.591	.434	Mean = 2.0247 ± .041
$NaNO_3$-3 pts) $(NH_4)_2SO_4$-1 pt.)	2.0955 gm.	.5375 gm.	2.6330
	1.9070 "	.4565 "	2.3635
	1.8270 "	.4830 "	2.3100
	1.7175 "	.4340 "	2.1515
	1.6695 "	.4640 "	2.1335
Total	9.2165	2.3750	11.5915
	1.843	.475	Mean = 2.3183 ± .054
Check - No N	.4760 gm.	.8290 gm.	1.3050
	.3750 "	.7315 "	1.1065
	.4300 "	.8165 "	1.2465
Total	1.2810	2.3770	3.6580
	.4270	.7923	Mean = 1.2193 ± .019

Table XVI . Wheat Harvest - Second Stage

	Tops	Roots	Total
Urea	7.7545 gm.	1.4930 gm.	9.2475
	6.9720 "	1.3935 "	8.3655
	5.1490 "	0.8900 "	6.0390
	6.4960 "	1.1190 "	7.6150
	6.1860 "	1.0040 "	7.1900
Total	32.5575	5.8995	38.4570
	6.512	*1.180* Mean = 7.6914	± .0325
$NaNO_3$	4.8305 gm.	1.0550 gm.	5.8855
	4.1770 "	1.0655 "	5.2425
	4.0900 "	1.1235 "	5.2135
	6.2510 "	1.4350 "	7.6860
	4.0540 "	0.8890 "	5.9430
Total	23.4025	6.5680	29.9705
	4.681	*1.314* Mean = 5.9941	± .271
$(NH_4)_2SO_4$	1.7480 gm.	0.3875 gm.	2.1355
	1.2765 "	0.2790 "	1.5555
	1.4685 "	0.3545 "	1.8230
	1.2360 "	0.2420 "	1.4780
	1.2090 "	0.3835 "	1.5925
Total	6.9380	1.6465	8.5845
	1.388	*.329* Mean = 1.7169	± .072
$NaNO_3$-1 pt.) $(NH_4)_2SO_4$-3 pts)	1.8005 gm.	0.4950 gm.	2.2955
	2.1920 "	0.6320 "	2.8240
	2.2495 "	0.6310 "	2.8305
	2.7880 "	0.5270 "	3.3150
	2.1680	0.4710 "	2.6390
Total	11.1980	2.7560	13.9540
	2.240	*.551* Mean = 2.7908	± .099
$NaNO_3$-2 pts) $(NH_4)_2SO_4$-2 pts)	4.2370 gm.	1.2035 gm.	5.4405
	2.3900 "	0.5230 "	2.9130
	2.5060 "	0.5580 "	3.0640
	3.8300 "	0.8675 "	4.6975
	3.2285 "	0.8860 "	4.1145
Total	16.1915	4.0380	20.2295
	3.238	*.808* Mean = 4.0459	± .290
$NaNO_3$-3 pts) $(NH_4)_2SO_4$-1 pt.)	4.4390 gm.	0.8915 gm.	5.3305
	3.5630 "	0.6670 "	4.2300
	2.8545 "	0.7895 "	3.6490
	2.7900 "	0.6990 "	3.4830
	3.4820 "	0.9655 "	4.4475
Total	17.1285	4.0125	21.1410
	3.426	*.803* Mean = 4.2282	± .198
Check - No N	0.9200 gm.	0.7525 gm.	1.6725
	0.9170 "	0.7685 "	1.6855
	0.9720 "	0.7080 "	1.6800
	0.8900 "	0.6050 "	1.4950
Total	3.6990	2.8340	6.5330
	.9247	Mean = 1.6333 *.7085*	± .023

Table XVII.

Wheat Harvest - Third Stage

	Tops	Roots	Total
Urea	2.9210 gm.	0.5236 gm.	3.4446
	4.0525 "	0.5760 "	4.6285
	10.4250 "	1.2156 "	11.6406
	3.4020 "	0.7090 "	4.1110
	4.6131 "	0.6060 "	5.2191
Total	25.4136	3.6302	29.6438
	5.083	.726 Mean = 5.8088	± .534
$NaNO_3$	3.0220 gm.	0.7700 gm.	3.7920
	8.1440 "	1.3370 "	9.4810
	6.9834 "	1.0730 "	8.0564
	10.5922 "	1.5382 "	12.1304
	3.9880 "	0.7876 "	4.7756
Total	32.7296	5.5058	38.2354
	6.546	1.101 Mean = 7.6471	± 1.263
$(NH_4)_2SO_4$	2.0880 gm.	0.3570 gm.	2.4450
	1.7842 "	0.3700 "	2.1542
	1.3270 "	0.2626 "	1.5896
	1.9855 "	0.3600 "	2.3455
	1.5326 "	0.3057 "	1.7383 - 1.8383
Total	8.7173	1.6553	10.2726 - 10.3726 ?
	1.743	.331 .411 Mean = 2.0545	± .101 2.074
$NaNO_3$-1 pt.) $(NH_4)_2SO_4$-3 pts)	4.4910 gm.	0.7176 gm.	5.2086
	5.2420 "	0.5873 "	5.8293
	3.5830 "	0.6175 "	4.2005
	3.6300 "	0.5378 "	4.1678
	2.1840 "	0.3290 "	2.5130
Total	19.1300	2.7892	21.9192
	3.826	.557 Mean = 4.3838	± .338
$NaNO_3$-2 pts) $(NH_4)_2SO_4$-2 pts)	4.3912 gm.	0.9196 gm.	5.3108
	4.1070 "	0.7508 "	4.8578
	5.8706 "	1.1070 "	6.9776
	7.3290 "	1.0635 "	8.3925
	6.6832 "	1.0529 "	7.7361
Total	28.3810	4.8938	33.2748
	5.676	.979 Mean = 6.6550	± .410
$NaNO_3$-3 pts) $(NH_4)_2SO_4$-1 pt.)	12.1000 gm.	1.4910 gm.	13.5910
	7.2580 "	0.9466 "	8.2046
	12.2308 "	1.2884 "	13.5192
	11.6520 "	1.2700 "	12.9220
	13.1590 "	1.8127 "	14.9717
Total	56.3998	6.8087	63.2085
	11.280	1.362 Mean = 12.6417	± .695
Check - No N	2.3220 gm.	0.8091 gm.	3.1311
	1.9242 "	0.8665 "	2.7907
	1.8861 "	0.7993 "	2.6854
	6.1323	2.4749	8.6072
	2.044	Mean = 2.8691	± .044
		.825	

Table XVIII. Nitrogen Fractions of Wheat Plants

First Stage

Milligrams of Nitrogen per Gram of Material Air Dried at 60°-65°C.

Nitrogen Carrier	Inorganic Nitrogen		Total Inorganic Nitrogen	Organic Nitrogen	Total Nitrogen
	Ammonic Nitrogen	Nitric Nitrogen			
Urea	.562	.551	1.113	41.487	42.59
$NaNO_3$	.227	5.903	6.130	36.880	43.01
$(NH_4)_2SO_4$	1.445	.810	2.255	40.475	42.73
$NaNO_3$-N-1 part, $(NH_4)_2SO_4$-N-3 parts	.610	3.474	4.065	45.535	49.60
$NaNO_3$-N-2 parts, $(NH_4)_2SO_4$-N-2 parts	.591	4.635	5.226	44.234	49.46
$NaNO_3$-N-3 parts, $(NH_4)_2SO_4$-N-1 part	.492	6.168	6.660	41.670	48.33
Control-No Nitrogen	.291	.206	.497	18.133	18.63

Table XIX.

Nitrogen Fractions of Wheat Plants

Second Stage

Milligrams of Nitrogen per Gram of Material Air Dried at 60°-65°C.

Nitrogen Carrier	Inorganic Nitrogen		Total Inorganic Nitrogen	Organic Nitrogen	Total Nitrogen
	Ammonic Nitrogen	Nitric Nitrogen			
Urea	.738	.882	1.620	33.620	35.24
$NaNO_3$	.445	11.110	11.555	28.305	39.86
$(NH_4)_2SO_4$	11.387	2.360	13.747	30.133	43.88
$NaNO_3$-N-1 part) $(NH_4)_2SO_4$-N-3 parts)	9.038	3.778	12.816	35.044	47.86
$NaNO_3$-N-2 parts) $(NH_4)_2SO_4$-N-2 parts)	3.262	6.780	10.042	37.868	47.91
$NaNO_3$-N- 3parts) $(NH_4)_2SO_4$-N-1 part)	1.360	8.950	10.310	35.040	45.25
Control -No Nitrogen	.275	2.856	3.131	20.549	23.68

Table XX.

Nitrogen Fractions of Wheat Plants

Third Stage

Milligrams of Nitrogen per Gram of Material Air Dried at 60°-65°C.

Nitrogen Carrier	Inorganic Nitrogen		Total Inorganic Nitrogen	Organic Nitrogen	Total Nitrogen
	Ammonic Nitrogen	Nitric Nitrogen			
Urea	.302	2.463	2.765	30.405	33.17
$NaNO_3$	.497	14.022	14.519	22.061	36.58
$(NH_4)_2SO_4$	13.569	4.999	18.568	26.632	45.25
$NaNO_3$-N-1 part) $(NH_4)_2SO_4$-N-3 parts)	15.063	6.193	21.256	35.204	56.46
$NaNO_3$-N-2 parts) $(NH_4)_2SO_4$-N-2 parts)	11.506	12.457	23.963	31.097	55.06
$NaNO_3$-N-3 parts) $(NH_4)_2SO_4$-N-1 part)	4.624	20.086	24.710	28.810	53.52
Control-No Nitrogen	.732	1.808	2.540	16.580	19.12

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the members of the Agronomy Department for their loyal support, suggestions and encouragement given while engaged with the work of this thesis. He especially acknowledges the advice and encouragement given by Dr. A. B. Beaumont under whose supervision the completion of the work was made possible, and the valuable assistance given by Mr. F. H. Smith of the Massachusetts Agricultural Experiment Station.

Approved by

Committee on Thesis.

Date ____________