4. Although in the foregoing experiment the application of ammonium sulfate before flooding gave the best results for rice production, it has been observed in other experiments that if irrigation was delayed more than a week after the application of ammonium sulfate, the yield of rice was less than that obtained when application was made after flooding. The reason for this reduced yield is believed to be due to nitrification of the added ammonium-nitrogen under the upland condition existing in the paddy soil prior to irrigation. After the field had been irrigated, the nitrate-nitrogen that was formed is lost through denitrification and leaching.

5. In the past the average Japanese farmer preferred concentrated organic nitrogenous fertilizers, such as soybean meal and fish meal, for rice production. Field experiments with these fertilizers have shown that, with the exception of applications for degraded paddy soils which will be discussed later, the effect on rice production is not superior to that of ammonium sulfate. When these organic fertilizers are broadcast on the water after flooding, difficulty is experienced in mixing such materials deeply and thoroughly in the soil of the furrow slice by the usual methods of harrowing practiced by farmers. Consequently, large losses of nitrogen occur through denitrification and the results are reflected in the yields. Data in Table 11 illustrates this point.

6. On the average, a rice crop contains, a total of 2.4 Kg of nitrogen in the grain and straw for every 100 Kg of brown rice harvested. With this information in mind, a study of the data in Table 2 shows that a large part of the applied nitrogen is not used by the rice plant. This is true not only for ammonium sulfate, but also for soybean meal.

C. Factors influencing nitrogen transformation in flooded paddy rice soils 22/

1. Temperature: 20/

a. The high summer temperatures accelerate the decomposition of organic matter in the soils, consequently, much ammonium nitrogen is produced. The results of an experiment shown in Table 12 illustrate this latter point very well. In this experiment a remarkably large amount of nitrogen was produced during the four days after the temperature was raised from 30° C to 40° C and maintained at the latter temperature.

b. The combined effects of high temperature and air-drying prior to flooding were investigated in one experiment. The results are shown in Table 13 and are summarized as follows:

(1) Production of ammonium-nitrogen in soil samples, incubated at temperatures of 26° C and 40° C, reached a maximum 14 days after flooding.

(2) More ammonium-nitrogen was produced where the samples were air-dried at both the low and high temperatures prior to flooding.

(3) Incubation at 40° C resulted in large amounts of ammonium-nitrogen being produced in both the air-dried and wet samples. Production of ammonium-nitrogen in wet samples incubated at 26° C was small.

2. Effect of mixing the soil of the upper portion of the furrow slice with the lower portion: 20/

a. During the early stages of the rice growing season, certain aerobic autotrophic micro-organisms, such as algae, flourish under the influence of the direct sunshine on the surface of the paddy fields. Thus, the uppermost layer, more specifically, the oxidized layer, of the flooded paddy soil is enriched with much easily decomposable organic matter composed of the cells of living and dead microorganisms. Some of the nitrogen assimilated by these microorganisms is believed to be fixed from gaseous nitrogen. During the course of the rice season, the soil of the oxidized layer is mixed or disturbed whenever cultivation is done. This mixing of the oxidized layer incorporates the easily decomposable organic matter into the reduced layer where it is quickly decomposed by the heterotrophic microorganisms. As a result, much ammonium-nitrogen is produced.

b. To illustrate the results of soil mixing during cultivation, as discussed in the previous paragraph, data from an experiment are presented in Table 14. In this experiment soil samples were taken during the period of rice growth at two depths of the furrow slice from two paddy fields at the Agricultural Experiment Station, Konosu, Saitama Prefecture. The results presented in Table 14 show that after 14 days of incubation the samples of the top layer (0-5 cm in depth), with soil from both the oxidized and reduced layers, contained more ammonium-nitrogen than the samples of the bottom layer (5-10 cm in depth), soil of the reduced layer only. The increases in ammonium-nitrogen in the top layer of samples from the two fields were 4.4 and 1.1 mg per 100 grams of dry soil. This corresponds to 22 Kg and 5.5 Kg of nitrogen per hectare, respectively for the top half of the furrow slice (0-5 cm). If it is supposed that these increased amounts are completely assimilated by the rice plant, ammonium-nitrogen produced from the easily decomposable organic matter of the oxidized layer merits serious consideration in practical rice culture.

3. Effect of soil temperature on the ammonium-nitrogen content of flooded paddy soil.

a. Generally speaking, the soil temperature of the furrow slice is influenced that of the surface water. At the beginning of the rice season the temperature of the surface water and the soil of the furrow slice are often as low as 20° C. At midsummer the temperatures of the water and the soil often rise as high as 40° C during the day. Since a high temperature of 40° C is known to increase the activity of heterotrophic microorganisms and inhibit the activity of nitrifying microorganisms, under a high temperature the differentiation of the oxidized layer in the flooded soil may be delayed and the loss of nitrogen through oxidation-reduction may be reduced. On the other hand, it is believed that a low temperature of 20° C delays decomposition of the soil organic matter, facilitates the formation of the oxidized layer in which nitrification occurs, and results in the loss of much nitrogen through denitrification.

b. Effect of low temperature. 19/

(1) In order to determine the effects of low temperature on nitrogen transformation in the upper layer of flooded paddy soils, an experiment was conducted using soil from paddy fieldsat the Agricultural Experiment Station, Konosu, Saitama Prefecture. Except for the check samples, the ammonium sulfate or soybean meal was added to the soil samples and incubated at 20° C. The results are given in Table 15.

(2) The data given in Table 15 show a marked decrease in ammonium-nitrogen. The decrease was especially great where the soil depth was shallow and the ratio of the thickness of the reduced layer to the thickness of the oxidized layer was small. Although the actual loss of nitrogen was not measured in this experiment, from the results of a previous experiment Table 6 using the same soil, incubating at 30° C, it was found that a decrease in the ammonium-nitrogen content was accompanied by a loss of nitrogen from the soil.

c. Effect of high temperature 22/

(1) Under flooded condition, high temperature promotes not only the decomposition of organic matter and the production of ammonium-nitrogen in paddy soil (Table 13), but it also tends to delay the decrease of ammonium-nitrogen. To investigate this effect on the ammonium-nitrogen content; an experiment was conducted using soil samples from two paddy fields at the Agricultural Experiment Station, Konosu, Saitama Prefecture. The results are presented in Table 16.

(2) The results tabulated in Table 16 show clearly that, in comparison to the lower temperature of 30° C, the high temperature of 40° C not only increases the production of ammonium-nitrogen but it also delayed the decrease of ammonium-nitrogen in the samples.

d. Effect of air-drying of the soil of the furrow slice before flooding.

(1) It has been shown earlier (Tables 5 and 13) that air-drying paddy soil prior to irrigation results in a great increase in ammonium-nitrogen production. The effect of this nitrogen transformation on rice production will be discussed in a later section of this report.

D. Fixation of free nitrogen in flooded paddy rice soils 27/

1. Many workers have claimed that certain blue-green algae (Nostoc) are able to assimilate gaseous nitrogen. According to the results of De 7/, nitrogen fixation by blue green algae in flooded paddy soil is highly probable. In a previous experiment it has been shown that the upper layer, probably the oxidized layer, of a flooded paddy soil usually becomes enriched with available nitrogen during the summer season. To prove definitely the phenomenon of fixation of gaseous nitrogen in flooded paddy soils, the following experiment was carried out using methods similar to those of De.

2. In order to minimize the unavoidable loss of soil nitrogen under flooded conditions, probably in the oxidized layer, the depth of the incubated soil was purposely made shallow. One virgin soil on Arakawa river alluvial soil and two paddy soils from the Agricultural Experiment Station, Konosu, Saitama Prefecture, were used in this experiment. Samples, each weighing 25 grams (air-dry), were placed in Erlenmeyer flasks of 300 cc capacity. Three series of treatments were conducted. No chemicals were added to the check series. To one series 0.5 grams of $CaCO_3$ were added, and to the other series 0.5 grams of $CaCO_3$ and 18.4 mg of KH_2PO_4 were added. The samples were flooded with 100 cc of distilled water and then were inoculated with the surface water from a paddy field at the Agricultural Experiment Station, Konosu. The flasks containing the soil samples were placed near a window in the light of the afternoon sun on 20 August 1942. After a few days blue-green algae were noted in the flasks. Their growth during the experiment was vigorous. Nostoc and Osillatoria were found to be most abundant. Total nitrogen in the flasks was determined before the experiment and approximately 50 days and 90 days after flooding.

3. The results of this experiment are given in Table 17. The data clearly show fixation of gaseous nitrogen in the samples to which $CaCO_3$ alone or $CaCO_3$ and KH_2PO_4 were added. The addition of $CaCO_3$ was very effective in promoting the fixation of nitrogen in the soil samples used in this experiment. The check samples of a fertile soil from a paddy field at the Agricultural Experiment Station, Konosu, which had received organic fertilizer each year (sample C),

showed a large loss of soil nitrogen.

4. Under actual field conditions at the Agricultural Experiment Station Konosu, investigations have shown that the uppermost layer of flooded paddy soil is enriched with the organic nitrogen of microorganisms even where no lime has been applied. The explanation of this enrichment probably is due to the fact that the plant nutrients in the surface water of the paddy fields is replenished daily by irrigation water and its reaction during the day becomes somewhat alkaline due to the assimilation of CO_2 during the photosynthetical activities of hydrophytes. During the night the surface water becomes acid as a result of the production of CO_2 from the respiratory processes of these plants and also of other soil organisms. Thus the pH of the surface water of a paddy field occasionally is even greater than pH 9 during a clear afternoon, and is near pH 6 early in the morning. This alkaline reaction of the surface water during the day enables certain blue-green algae to grow vigorously and assimilate gaseous nitrogen without the application of lime.

E. Eluviation in paddy rice soils under flooded conditions.

1. Profile of a well-drained paddy soil.

a. The furrow slice of a paddy soil corresponds to the A horizon of an upland soil. The soil of the furrow slice receives much inorganic and organic materials such as crop and weed residues, farm manures, and commercial fertilizers. These materials are regularly mixed into the soil by tillage practices. In addition, the soil is subjected yearly to alternate periods of flooding and drying. Flooding brings about reduced condition in the soil and percolation of water into the subsoil. Drying brings about oxidative conditions and little or no percolation. Thus, in a paddy soil, irrigation water is largely responsible for eluviation.

b. Beneath the furrow slice generally is a layer of about 5 cm in thickness which is referred to as the "plow-sole". This plow sole is a layer formed as a result of rice culture and is hardened and compacted by eluviated substances from the furrow slice. Before an upland field is converted to a paddy field, the furrow slice could well have been part of the A or B horizon. In a nature paddy soil the plow sole generally corresponds to the B_1 horizon except in the case of highly degraded paddy soil in which the plow sole appears to have been changed into the A_2 horizon. The plow sole usually is almost structureless. During the latter portion of the rice growing season, the rice plant distributes its root in this layer.

c. The subsoil which lies below the plow sole generally is the B_2 horizon. Except in sandy soils, its structure is usually prismatic or columner at its lower depth. Some of the substances which pass through the plow sole are deposited in its interstices and openings made by plant roots. As will be shown later, the subsoil usually is low in available nitrogen. Although under laboratory conditions some ammonium-nitrogen is formed through the drying and wetting effect, under actual field conditions little or no ammonium-nitrogen is formed during the irrigation season.

d. The gley horizon often is found in the lower portion of a paddy soil. That horizon will not be discussed any further in this report.

2. Characteristics of the B horizon of a well-drained paddy soil under flooded conditions: 22/