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# Availability of Ammoniacal Nitrogen to Lowland Rice as Influenced by Fertilizer Placement[1]

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SYNOPSIS

Sub-surface (drilled) placement of ammonium nitrogen produced better growth and yields of lowland rice than similar nitrogen applied on the soil surface (broadcast). Nitrogen content of rice plants and percentage recovery of the applied nitrogen also increased. Ammonium nitrogen drilled 2 to 4 inches into the soil, where reducing conditions developed 3 to 5 days after flooding, remained in the soil and was available to lowland rice. Surface nitrogen, applied by broadcast methods, did not promote the best growth of rice. Losses of surface applied nitrogen apparently occurred through processes of nitrification and subsequently denitrification.

RICE grown under continuous submergence of water has consistently produced better vegetative growth and higher grain yields when fertilized with ammonium rather than nitrate nitrogen. The superiority of ammonium nitrogen has been variously attributed to its specific requirement and preferential absorption by rice. It has also been stated that it is not so readily leached, converted to nitrite nitrogen, or denitrified when applied to the soil. Ample evidence from water culture experiments shows, however, that rice is able to assimilate both ammonium and nitrate nitrogen. The occurrence of toxicity from nitrite nitrogen under field conditions has largely been discounted. Evidence now available indicates that the principal difference between the two nitrogen forms is in their retention and subsequent availability under submerged soil conditions. Ammonium nitrogen placed beneath the soil surface before flooding does not undergo transformation after submergence and is better retained and available to rice. Nitrate nitrogen present in submerged soils is denitrified and is lost from the soil as free nitrogen gas.

The physico-chemical properties of submerged soils, which are known to exert a great influence on the availability of nitrogen for rice, were first elucidated by Pearsall and Mortimer (4, 5, 6). individually and together. Working with naturally submerged soils and lake muds, they showed that measurable differences in aerobism (oxidation) and anaerobism (reduction) exist between a very thin layer of soil at the soil-water line and the soil immediately beneath. Aerated water maintained the oxygen content of the surface oxidative layer, which they characterized as having oxidation-reduction potentials exceeding 350 millivolts at pH 5.0, and contained oxidation products such as nitrate, sulfate, and ferric ions (6). Immediately beneath the surface oxidizing layer the potentials were characteristically below 350 millivolts, and reduction products of ammonium, sulfide, and ferrous ions were present. The occurrence and differentiation of oxidation and reduction layers in submerged rice soils have been confirmed by others (2, 3, 8). Japanese research, summarized by Shiori and Tanada (8) and Mitsui (3), places special emphasis on the differentiation of oxidation-reduction layers in submerged soils in respect to the transformations of nitrogen that occur therein. Nitrification of ammonium nitrogen was found to occur in the oxidizing layer by the action of autotrophic organisms. Nitrite or nitrate nitrogen produced in the oxidizing layer was denitrified by microbial and chemical processes as it passed through the reducing layer. Losses of nitrogen by this mechanism varied with the source of nitrogen used, time and method of application, and the soil physico-chemical conditions. These studies have led to the practice of deep plowing of ammonium nitrogen before flooding as

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well as ball placement shortly after transplanting for the fertilization of rice (1, 2, 3, 8).

Fertilization of rice is common in California, and until 1953 fertilizer was applied either broadcast on the soil surface before flooding, or more commonly, in the water by airplane after seeding.

This study reports the effects of different methods of applying ammonium nitrogen fertilizer for lowland rice. Fertilizer applications were made in relation to the occurrence of differentiated oxidation and reduction layers; their influence on the growth, nitrogen uptake, and yield of rice was determined.

## MATERIALS AND METHODS

Field experiments were conducted at the Rice Experiment Station (Biggs, California) over a 3-year period to study the effect of methods of fertilizer application for lowland rice. The experiments were established on a Stockton clay soil, pH 5.1, in alternate fallow with rice. A randomized block design with four replications of all treatments was used, both with and without separating levees in different years. No effect from separating levees was observed. Ammonium sulfate applied at a rate to supply 30 pounds actual nitrogen per acre (30 N) was used as the nitrogen source, and the following treatments were made:

1. Check—no fertilizer.
2. Ammonium sulfate (30 N) broadcast in the water after flooding and seeding.
3. Ammonium sulfate (30 N) broadcast on a firm, dry seedbed before flooding.
4. Ammonium sulfate (30 N) broadcast on a firm, dry seedbed and mixed by discing into the top 4 inches of soil before flooding.
5. Ammonium sulfate (30 N) drilled 4 inches deep in bands 12 inches apart.

The experimental areas were uniformly seeded with rice, variety Caloro, after applying the fertilizer treatments. Except for the treatments broadcast in the water, all fertilizer was applied just before flooding. Water was applied as soon as practicable after the fertilizer applications to minimize nitrification of the ammonium nitrogen in the seedbed. The plots were submerged slowly to prevent movement of seed and fertilizer. The soil was submerged to a depth of 6 inches until the crop was nearly mature.

Measurements of the oxidation-reduction potential in the submerged soil were made every second day for a 14-day period after flooding during 1953. These were made to establish the rate of development and depth differentiation of the oxidation-reduction layer. Oxidation-reduction measurements were determined at depths of 0.5 cm. and 5 cms. ($\pm$ 0.5 cm.) with permanently seated electrodes. Platinum electrodes as described by Quispel (7), with a portable vacuum-tube potentiometer using a saturated calomel electrode as reference, were used for the Eh measurements.

Random plant samples were taken from a measured area in each treatment at 12- to 14-day intervals during the growth of the rice. The plant material, with roots removed, was dried in a forced-air oven at 70° C., weighed, and prepared for chemical analyses. Total nitrogen content of the plant material was determined by the Kjeldahl method.

Yields of rough rice were adjusted to a 14% moisture basis.

During 1955, off-station plots were established to evaluate broadcast and drilled ammonium nitrogen fertilizer applications under a wide range of soil conditions. The soil types Genevera clay, Plaza silty clay, Willows clay, and Rocklin clay were used. These represent a wide range of soils typically used for rice production in California. A randomized block design with four replications of each treatment was used at each location. Ammonium sulfate to supply 40 and 60 pounds actual nitrogen per acre was applied both with and without phosphate. Nitrogen effects are reported from only the *(1)* broadcast on the dry seedbed prior to flooding and *(2)* drilling to a depth of 2 to 4 inches in bands 12 inches apart treatments.

Yields of rough rice were determined from harvested quadrats. All yield data have been adjusted to a 14% moisture basis.

## RESULTS AND DISCUSSION

### Influence of Flooding

Data representing the mean oxidation-reduction potential status of Stockton clay at depths of 0.5 cm. and 5.0 cms. ($\pm$ 0.5 cm.), during a 14-day period after flooding, are given in figure 1. The mean oxidation-reduction potentials

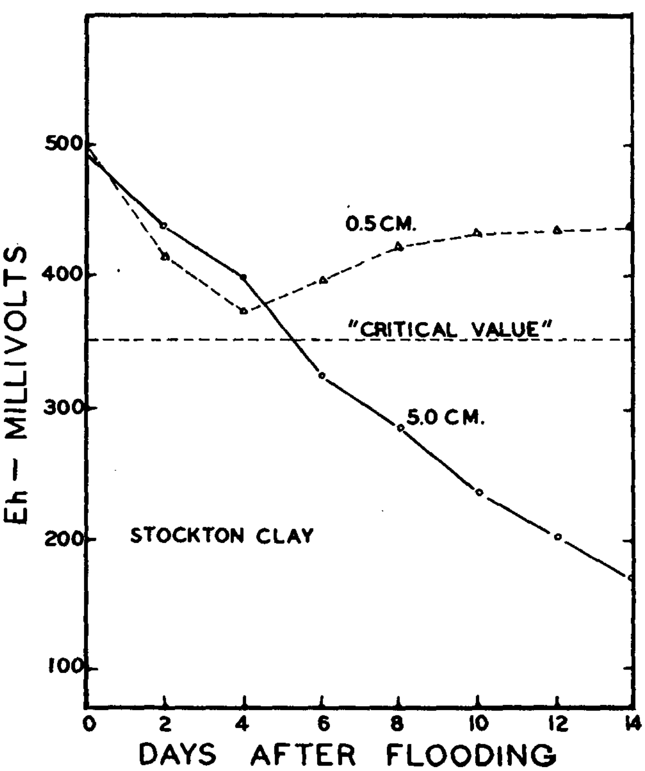


FIG. 1.—Mean oxidation-reduction potentials ($E_5$) of Stockton clay at depths of 0.5 and 5.0 cm. ($\pm$0.5 cm.) during a 14-day period after flooding. Critical value from Pearsall (6).

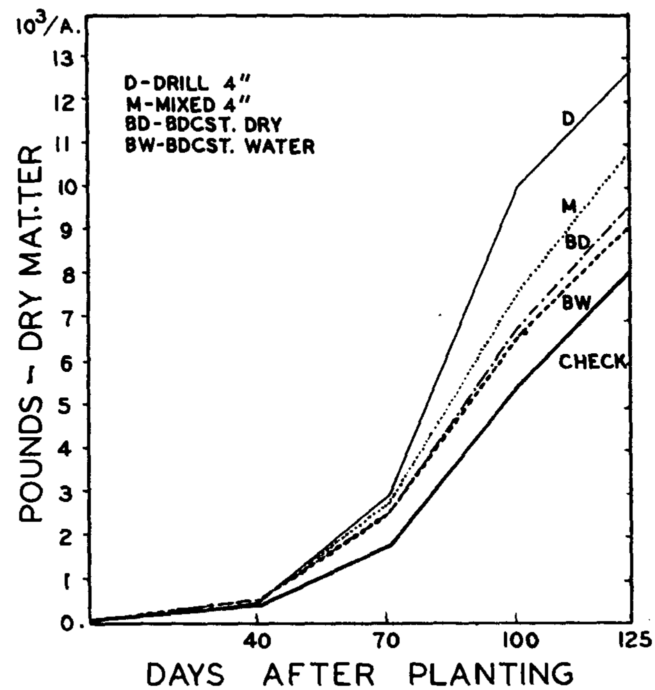


FIG. 2.—Mean accumulative dry-matter production of Caloro rice as affected by method of nitrogen application.

were corrected to pH 5.0 which approximates the average soil reaction at this experimental site. The potentials in the surface (0.5 cm.) layer varied from an initial value of 497 millivolts to 373 millivolts 4 days after flooding. Thereafter the potential increased slowly for 6 days when an equilibrium value near 434 millivolts was established. At the 5.0-cm. depth, the average potential declined gradually after flooding from 493 millivolts to 167 millivolts after 14 days. Using the potential value of 350 millivolts as the boundary between the oxidation and reduction layers, reducing conditions were established about 5 days after flooding. This layer remained in a condition of reduction thereafter.

The methods of fertilizer application used in these experiments provide for distinguishing not only surface and sub-surface nitrogen applications, but also appropriate combinations of each. Ammonium sulfate broadcast into the water would be partially dissolved in the flood water or held in the surface mud of the oxidizing layer. Fertilizer broadcast on the dry seedbed before flooding, may remain on the surface, or it may be partially distributed in the plow layer, depending upon the seedbed condition. Fertilizer mixed into the top 4 inches would exist largely under reducing conditions after flooding, while drilled applications should be entirely in the reduction layer.

### Effects of Method of Application

The 3-year mean accumulative dry-matter production of rice at 4 stages of growth, as affected by different methods of nitrogen application, is shown in figure 2. Samples were harvested at 12- to 14-day intervals but are reported here at 40 days (period of pre-tillering), 70 days (tillering stage), 100 days (pre-heading stage), and after 125 days (head emergence).

Vegetative development of rice during the first 14 to 21 days was markedly stimulated by broadcast nitrogen applications. Surface nitrogen stimulated the early growth of seedling rice and promoted quicker emergence from the water. After approximately 21 days, the treatment receiving broadcast nitrogen became progressively poorer in growth, and the plants' original deep-green color gradually changed to pale green and finally yellow. The effect of drilled nitrogen was not evident for about 21 days, and the early growth on this treatment was not significantly different from the unfertilized rice. Analysis of variance at 40 days showed no significant differences in dry-matter production as affected by treatment.

Seventy days after planting, dry-matter production was significantly better where drilled nitrogen was applied. The increased dry-matter production was 66.5% better than the check, while fertilizer treatments that were broadcast in water, broadcast dry, and mixed into the surface soil gave 39.4, 46.4, and 49.8% more dry matter, respectively. All fertilizer treatments were significantly better than the control.

At 100 days, dry-matter production was nearly the same in both broadcast treatments, with 21.0 and 21.5% more dry matter than the check treatment. The fertilizer treatments mixed into the surface soil and drilled were each significantly better, with 53.4 and 84.3% increases in dry-matter production, respectively.

When sampled at 125 days, while the rice was heading but not completely mature, the treatments broadcast in water and applied on dry soil were about equal, with 13.6 and 13.8% more dry matter than the check, respectively. Dry-matter production from fertilizer mixed in the surface soil was significantly better than the broadcast treatments but poorer than the drilled treatments.

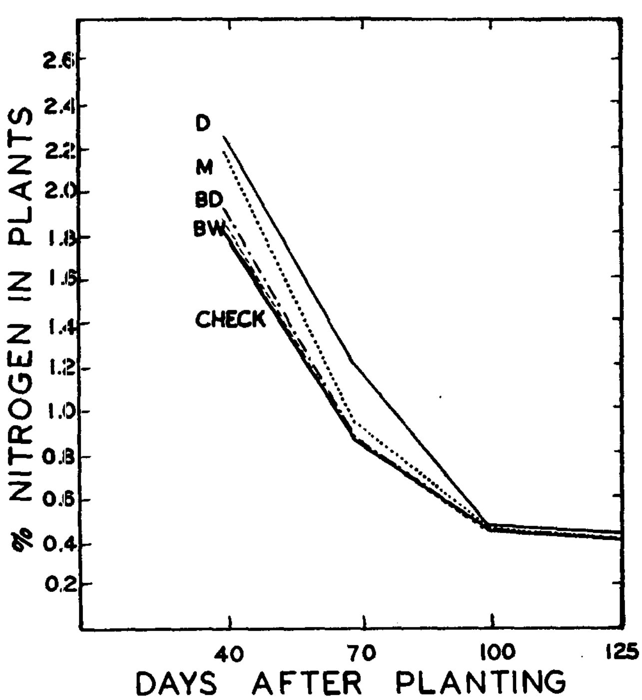


FIG. 3.—Percent nitrogen composition of Caloro rice as affected by method of nitrogen application.

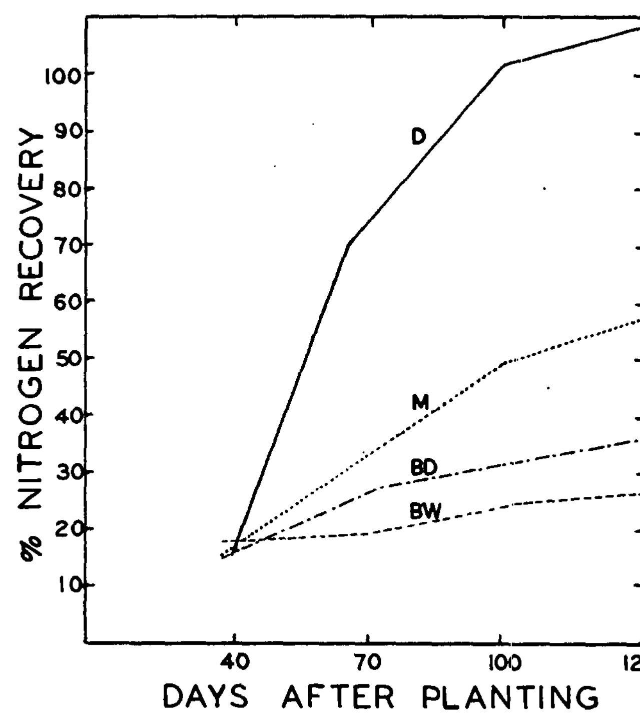


FIG. 4.—Percent recovery of applied nitrogen as affected by method of nitrogen application.

## Nitrogen Composition and Percent Recovery

Whole-plant samples, except roots, were analysed for their total nitrogen content. These values and the percent recovery of applied nitrogen based on yield and plant nitrogen content are shown in figures 3 and 4. In the pre-tillering samples at 40 days, the nitrogen content of the plants was increased significantly by ammonium nitrogen fertilizer mixed or drilled into the soil. No significant differences exist between the check and the broadcast treatments. The percent recovery of fertilizer nitrogen was greater, however, in the treatments broadcast in water and applied on dry soil but not significantly different from the treatment mixed into the soil. These surface treatments provided more readily available nitrogen for seedling plants, which stimulated seedling growth and increased the rate of nitrogen uptake.

Percentage of nitrogen content at 70 days (tillering stage) was significantly higher in the drilled treatment than in any other. The greater availability of drilled nitrogen at this later date and its stimulatory effect on growth enabled the plants to recover 70.9% of the fertilizer nitrogen applied. No significant differences in either nitrogen content or nitrogen recovery occurred in the other treatments.

Nitrogen composition of rice plants at 100 days (pre-heading) was not significantly affected by the method of nitrogen application. Considerable differences in the recovery of applied nitrogen are evident, however. At this sampling 101.4% of the applied nitrogen was recovered in the drilled treatment as compared with 47.5% where the fertilizer was mixed in the surface 4 inches. Approximately one-fourth of the applied nitrogen was recovered where the fertilizer was broadcast.

Recovery of nitrogen at 125 days (heading) was most efficient, 107.6%, from drilled fertilizer. Recovery of fertilizer mixed in the surface 4 inches was 55.4 and 33.5 and 25.4%, respectively, when the fertilizer was applied broadcast on the soil or into the water. No significant differences in nitrogen content of the rice plants were found at this sampling.

## Rice Yields

Yield data of paddy rice from the fertilizer placement treatments for the period 1953–1955 are shown in table 1. Rice yields have been converted into index values with unfertilized rice equal to 100. Drilled nitrogen consistently produced significantly higher yields than any other treatment. The average effect of 4-inch placement was to increase yields about 37% over unfertilized rice. Fertilizer nitrogen mixed into the seedbed produced good results but is significantly poorer than drilled nitrogen. Surface-applied nitrogen is generally poorer than treatments mixing the nitrogen into the seedbed. The effect of dry broadcast treatments may depend upon the condition of the seedbed. A coarse, dry, open seedbed (as is desirable for rice) may allow the nitrogen to penetrate so deep that discing or mixing the fertilizer into the seedbed becomes unnecessary. Yield data from these trials show the poor performance of fertilizer broadcast into water. Nitrification and subsequent denitrification reactions bring about serious losses of nitrogen, resulting in poor rice yields.

Table 1.—Effect of method of application of ammonium sulphate (30 pounds actual N) on yield of rice on Stockton clay.

| Fertilizer treatment | Rice yield index | | | |
|---|---|---|---|---|
| | 1953 | 1954 | 1955 | Average |
| Check | 100 | 100 | 100 | 100 |
| Broadcast in water (30 N) | 106 | 111 | — | 108 |
| Broadcast dry seedbed (30 N) | 122 | 118 | 118 | 119 |
| Broadcast dry and disced (30 N) | — | 132 | 118 | 125 |
| Drilled 4" deep (30 N) | 142 | 137 | 133 | 137 |

During 1955 additional replicated experiments with fertilizer placement treatments were conducted on some major rice-producing soils. Ammonium sulfate was used to supply 40 and 60 pounds actual nitrogen per acre. The nitrogen source, broadcast on the dry seedbed before flooding, was compared with drilled application of nitrogen and nitrogen-phosphorus materials. The results of the nitrogen treatments are given in table 2. These yields are reported as pounds of paddy rice produced per acre, corrected to a 14% moisture basis.

At all locations where nitrogen fertilizer responses were obtained, drilled applications were better than the same quantity broadcast in both total dry-matter production (data not reported) as well as paddy rice yields. Only during the early stage of growth, when the rice first emerged from the water, was the broadcast treatments superior. Within 2 to 3 weeks after emergence, the superiority of the drilled fertilizer was manifest. The average yield increases of paddy rice fertilized with 40 pounds actual nitrogen were 44 and 69% respectively for the broadcast and drilled plots yield increases were 71 and 105% respectively for broadcast and drilled treatments at the 60-pound actual nitrogen level.

## SUMMARY

Different methods of ammonium nitrogen application were studied as they influence the vegetative growth, nitrogen uptake, and yield of lowland rice. The method of application is related to the development of distinct layers of oxidation and reduction which develop in flooded soils and to the nature of nitrogen transformation which occurs.

In a typical lowland rice soil, oxidative conditions exist in the surface 0.5 cm. of soil after flooding. Autotrophic organisms in this layer bring about the nitrification of surface-applied ammonium fertilizer. Beneath the thin surface oxidizing layer and at a depth of 5.0 cm., reducing conditions develop about 5 days after flooding the soil. Nitrate nitrogen, which develops in the oxidation layer and moves into the reducing layer, is largely lost through denitrification. Ammonium nitrogen drilled into the soil to a depth of 2 to 4 inches before flooding, and where

Table 2.—Effect of rate and method of ammonium sulphate application on yield of rice.

| Fertilizer | Rice yields on various soil types | | | | |
|---|---|---|---|---|---|
| | Genevera clay | Plaza silty clay | Willows clay | Rocklin clay | Average yield index |
| | lbs./A. | lbs./A. | lbs./A. | lbs./A. | |
| Check | 2523 | 1808 | 2228 | 1427 | 100 |
| 40 N-Broadcast | 3442 | 2614 | 2779 | 2452 | 144 |
| 40 N-Drill | 4108 | 2975 | 3277 | 2908 | 169 |
| 60 N-Broadcast | 3975 | 2675 | 3145 | 3360 | 171 |
| 60 N-Drilled | 5703 | 3022 | 3966 | 3540 | 205 |
| LSD (.05) | 640 | 508 | 605 | 393 | |

reducing conditions develop after flooding, provides good retention and availability of nitrogen for lowland rice. Ammonium nitrogen broadcast on the dry seedbed, or broadcast and then mixed into the surface soil prior to flooding, or broadcast in the water after flooding was significantly poorer than drilling.

Drilled applications of ammonium sulfate produced better vegetative growth as measured by dry-matter production. The nitrogen content of the plant material was increased at all stages of growth except during the maturation stage, and yields of paddy rice were increased. Mixing broadcast ammonium sulfate into the surface soil, thereby incorporating part of the nitrogen into the reducing layer, gave better growth and rice yields than when material was left on the soil surface or broadcast in the water.

On several important California rice soils, drilled applications of ammonium sulfate were significantly better than the same quantity of nitrogen broadcast on the dry seedbed.

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