termine the effect of cold water on the growth and development of the rice plant. These studies will include research on the inheritance of reaction to cold water.

Studies were conducted in 1961, near Willows, Glenn County, in a field irrigated with water from the Sacramento River at about 60°F. The effects of the cold water on the time from seeding to seedling emergence, heading, and ripening were determined by comparison with the same varieties grown at the Rice Experiment Station, Biggs, with irrigation water from 70° to 75°F. The results for seven varieties are shown in table 2.

Twenty-five rice varieties and hybrid lines were evaluated in 1962 for reaction to low water temperature. These tests were conducted in replicated field trials near Willows and in water-bath experiments at Beltsville, Maryland. A summary of data for eight varieties is presented in table 3.

Sixty-six Caloro plants were harvested in 1962 from two fields on the Wilfred Carrier ranch near Glenn, Glenn County. These plants were growing in checks adjacent to the canal transporting cold water. This location has a consistent history of cold-water damage. The plants were selected from the top several checks adjacent to the intake. Seed from each plant was divided into two lots so that each selection could be grown in single drilled rows and in single water-seeded rows in 1963. Where there was enough seed for evaluating response to cold water in water bath experiments, samples were sent to Beltsville.

TABLE 3. REACTION OF RICE VARIETIES TO LOW WATER TEMPERATURES IN A FIELD EXPERIMENT NEAR WILLOWS, CALIFORNIA, AND IN LABORATORY EXPERIMENTS AT BELTSVILLE, MARYLAND, 1962

Variety	Field Trials					Water-bath studies Beltsville	
	Time from sowing to emergence	Emergence[1] index (E)	Emergence[1] index (V)	Plants[2] at maturity	Floret sterility	Length of longest leaf	Comparison with Caloro
	days			number	per cent	Cm	per cent
Caloro	26	3.0	2.5	36.2	85.8	6.88	100
Calif. 489A1-7	27	2.8	3.2	25.2	80.0	5.61	81.5
Colusa	28	3.0	3.0	36.8	29.1	6.81	98.9
C.I. 9425-2	32	1.2	1.5	5.5	100.0	4.09	59.4
Sel. 2400	32	1.2	1.5	9.5	68.6	5.31	77.1
P.I. 226162	25	3.2	3.5	37.0	89.4	5.96	86.6
P.I. 175020	26	2.8	2.8	24.2	32.1	7.94	115.4
C.I. 8851-1	29	2.2	2.8	15.5	33.0	5.41	58.6

[1] Emergence index. 1 = Very poor. (E) = Relative speed.
5 = Very good. (V) = General vigor, leaf position, and root development.
[2] 180 seed sown in 3-ft. × 3-ft. plots.

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Nitrogen Fertilization of RICE *in California*

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CALIFORNIA'S RICE CROP, produced on land continuously flooded during the growing season, usually requires nitrogen fertilization for optimum production. Average yields are increased about 40% by nitrogen applications, but in some instances exceed 150%. The Japonica varieties, Caloro, Colusa or "1600," and Calrose—grown almost exclusively in California—require annual fertilization and receive an average of 80 lbs actual nitrogen per acre. Nitrogen is sometimes not required on new land or where a good leguminous green manure crop is turned into the soil. Generally, nitrogen is the only plant nutrient needed, but in some areas phosphorus is also required for optimum production.

The efficiency of nitrogen utilization depends on the fertilizer source and time and method of fertilizer application. Varietal effects are also important since yield capability is dependent upon genetic and agronomic factors. Among the major California water-sown rice varieties, Colusa is most responsive to fertilization but it lacks straw strength and resistance to lodging in some years. Calrose and Caloro are less responsive to high fertility levels but produce higher yields under low fertility conditions and have better resistance to lodging.

Nitrogen fertilization increased grain yields of Colusa by increasing both the size and number of seeds per panicle. This is reflected in a decreased grain/straw ratio as nitrogen fertilization is increased within reasonable limits. Grain yields obtained with the varieties Caloro and Calrose are accompanied by increased straw production, including increased tiller numbers and more panicles per plant, but not necessarily larger panicles.

Most of the many fertilizer studies were conducted with the Caloro variety which occupies a major portion of the planted acreage of California. In typical California lowland rice soils, oxidative conditions exist after flooding in the surface 0.5 cm. At a depth of 5.0 cm, reducing conditions develop about five days after flooding has occurred. The inorganic nitrogen present in the oxidative layer is transformed into nitrates which move into the reducing layer, where most of it is lost later through denitrification.

Application methods

Field experiments designed to evaluate different methods of nitrogen application under the conditions described have been conducted over a period of four years. Typical clay rice soils with impeded drainage were used in the experiments.

Drilled nitrogen consistently produced higher yields . . .

Original treatments used when the experiment began were modified after two years and some new combinations were added. Ammonium sulfate was applied at 150 and 300 pounds per acre depending upon the fertility of the soil. These nitrogen rates were below optimum levels to allow a critical evaluation of the methods of nitrogen application. The treatments and methods of nitrogen application included:

1. Ammonium sulfate broadcast in the water after flooding and seeding.
2. Ammonium sulfate broadcast on the dry seedbed before flooding.
3. Ammonium sulfate broadcast on the dry seedbed and mixed by disking into the top 4 inches of soil before flooding.
4. Ammonium sulfate drilled 2 inches deep in bands 12 inches apart before flooding.
5. Same as (4) except drilled 4 inches deep.

The yield response of rice to different methods of nitrogen application is shown in table 1. Rice yields were converted into index values with unfertilized rice equal to 100. In these experiments the drilled nitrogen treatments consistently produced higher yields than any other method of application. The average effect of the 2- and 4-inch placement was to increase yields about 40% over unfertilized rice and 33% over the nitrogen broadcast in the water. Differences of 60% were obtained between applications broadcast on the dry seedbed as compared with drilled nitrogen applications. These larger increases are usually obtained where the seedbed is fine and firm, retaining nearly all of the broadcast fertilizer at the soil surface.

Experiments to determine the influence of drill row spacing on yields were conducted using a drilled nitrogen placement depth of 2 inches with drill row widths of 6, 9, 12, and 18 inches. While significant yield responses were obtained with nitrogen applications, no significant differences in paddy rice were obtained in spacings up to 18 inches between drill rows. However, observations while the rice was emerging from the water and at the tillering stage indicated that although final yields were not affected, the close, drill row spacings did result in faster seedling establishment.

The time of soil nitrogen applications can be an important factor in final rice yield. It has been established that nitrification will take place if ammonium nitrogen is drilled into a warm, moist, aerated seedbed much prior to flooding. Measurements of the rate of nitrification have shown that as much as 60% of the ammonium nitrogen can be converted within seven days under warm spring soil temperatures. An 87% conversion can occur by the fifteenth day and the transformation is almost complete in typical rice soils within 21 days. Because the nitrate-nitrogen produced is ultimately lost to the crop after flooding, the time interval between application and subsequent flooding should be as short as practicable.

Split applications of nitrogen with part applied as a basal application at planting and the balance as a top-dressing during the period of earliest head formation have proven effective in some regions of the world. Benefits have varied, however, in respect to varieties, growth duration, soil and climatic conditions.

Japonica rice grown in California has three periods of maximum nitrogen requirement. One occurs about 35 to 50 days after planting when the number of tillers and tillers that will bear heads is determined. A second period of high nitrogen requirement occurs about 65 to 75 days after planting when tillering slows down, and the internodes of the stem begin to elongate. This is commonly called the "jointing stage" and is the period during which the number of grains per head is determined. The third period exists at the heading stage, 90 to 110 days after planting, when the head emerges from the boot. Supplementary nitrogen will benefit yields only when applied during the first two periods, however. If applied too late, nitrogen will stimulate excessive vegetative development, delay maturity and frequently induces excessive lodging.

Experiments were conducted at five locations on three different soil types to determine if split applications of nitrogen

SUMMARY

Japonica rice is grown in the Central Valley of California primarily on dense clay soils under continuous flooding. Nitrogen is usually insufficient in these soils for optimum rice production, and nitrogen fertilization increases average yields about 40%. In some instances, nitrogen and phosphorus together are essential for optimum yields. Potash and other nutrient elements are usually adequate.

Consistently better vegetative growth and higher grain yields are obtained when rice is fertilized with ammonium rather than nitrate nitrogen. Evidence indicates that the two forms differ mainly in their retention and subsequent availability under submerged soil conditions. Ammonium nitrogen placed 2 to 4 inches beneath the dry soil surface, and just ahead of flooding, does not undergo significant transformation and is better retained and more available to rice. Nitrate nitrogen is not efficiently used since it is subject to denitrification under flooded conditions. Reductive conditions develop in these soils within three to five days after flooding.

Sub-surface (drilled) placement of ammonium nitrogen produced better growth and yields of rice than other methods of application. Average yield indices were: 142 when equal amounts of nitrogen were drilled 2 inches and 140 when drilled 4 inches deep before flooding; 126 when broadcast on the soil and disked; 121 when broadcast on dry soil; and 108 when broadcast into the water after flooding. The width of the fertilizer-drilled rows did not affect yields in spacings up to 18 inches, but earlier seedling responses were obtained with 6 and 12 inch spacings.

The most efficient use of nitrogen was obtained by drilling all of it into the dry seedbed ahead of flooding. Split applications of nitrogen with one half applied ahead of flooding and the balance applied as a top dressing in the water were occasionally equal, but seldom better than a single pre-flooding soil application. Supplementary nitrogen applied to correct deficiencies which develop can be broadcast into the water. Top-dressed nitrogen was utilized most efficiently if applied between 35 and 50 days after planting—the period of tiller development of the crop.

Fertilizer salts were easily compared in efficiency as nitrogen sources with near ideal placement of 2 to 4 inches, but ammonia solutions and anhydrous ammonia must be placed deeper in the soil to achieve satisfactory retention. Using the best placement procedures for each material, the relative efficiency of each (using ammonium sulfate as 100) was: ammonium chloride 97, cyanamide 92, urea 90, aqua ammonia (20% N) 85, anhydrous ammonia 83, and ammonium nitrate 57.

TABLE 1—EFFECT OF METHOD OF AMMONIUM SULFATE APPLICATION ON YIELD OF RICE

Method of fertilization*	Rice yield index				
	Expt. 1	Expt. 2	Expt. 3	Expt. 4	Average
Unfertilized	100	100	100	100	100
Nitrogen broadcast in water	106	111	...	...	108
Nitrogen broadcast dry seedbed	122	118	118	126	121
Nitrogen broadcast and disked	...	132	118	130	126
Nitrogen drilled 2" deep	...	...	140	143	142
Nitrogen drilled 4" deep	142	137	133	146	140

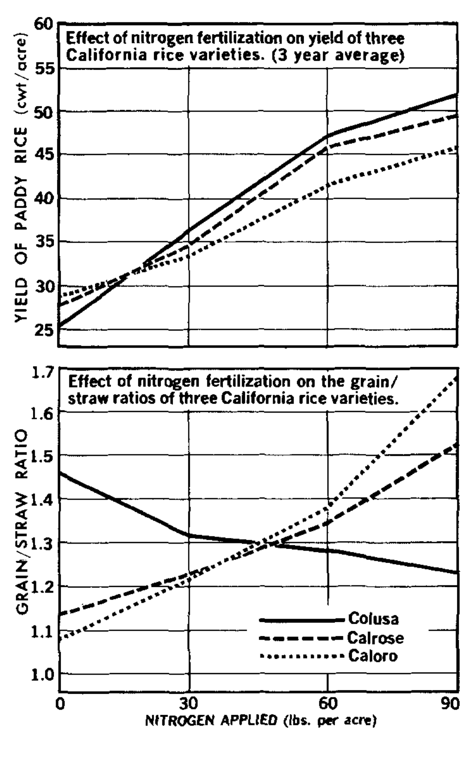
* Nitrogen applied as ammonium sulfate.

TABLE 2—EFFECT OF SPLIT APPLICATIONS OF NITROGEN AND TIME OF APPLICATION

Method of application	Time (days)	Average paddy yields pounds/acre
Check (no fertilizer)		3202
All nitrogen drilled 2–4"	Pre-flooding	4795
All nitrogen broadcast	Pre-flooding	3842
½ nitrogen drilled; ½ broadcast	40 days after planting	4320
½ nitrogen drilled; ½ broadcast	47 days after planting	4684
½ nitrogen drilled; ½ broadcast	54 days after planting	4428
½ nitrogen drilled; ½ broadcast	61 days after planting	4610
½ nitrogen drilled; ½ broadcast	68 days after planting	4389
½ nitrogen drilled; ½ broadcast	75 days after planting	4108
½ nitrogen drilled; ½ broadcast	82 days after planting	4093

LSD(.05) = 526 pounds per acre.

were more efficiently utilized than a single basal application made prior to planting. Yield data presented in table 2 shows results of no fertilization as compared with treatments using: ammonium sulfate (150 and 300 pounds per acre, depending upon the site) drilled 2 to 4 inches deep prior to flooding; ammonium sulfate (same rates) broadcast on the dry seedbed prior to flooding; and ammonium sulfate, one-half of total application drilled 2 to 4 inches deep (same rates) and one-half applied as a top-dressing in water at approximately 7-day intervals between 40 and 82 days after planting.



Significant yield increases were obtained with all nitrogen fertilization treatments, but where all the nitrogen was drilled prior to flooding, results were significantly better than where it was broadcast. These experiments indicated there was no yield advantage, moreover, in splitting the nitrogen application. Yields were reduced if top-dressing applications were made later than 65 to 70 days after planting. Nitrogen top-dressed after this period delayed maturity, increased the danger of lodging and did not improve yields.

Rice can use either ammonium or nitrate sources of nitrogen, but the ammonium nitrogen is the only inorganic form that can be maintained in continuously flooded soils. The maintenance of ammonium nitrogen is dependent, however, upon proper time and method of fertilizer application as already discussed.

A number of different ammonium-nitrogen sources, including liquid, gaseous, and solid forms, are available for use. The dry materials can be used under a wider range of seedbed conditions and application methods than the liquid or gaseous materials, which contain volatile ammonia. For satisfactory retention, the liquid and gaseous types must be injected into the soil. However, the dry, cloddy seedbed most desirable for rice, sometimes makes retention and proper placement of volatile materials difficult.

TABLE 3—RELATIVE EFFICIENCY OF VARIOUS NITROGEN FERTILIZERS FOR LOWLAND RICE

Fertilizer source	Relative efficiency range
Ammonium sulfate	100
Ammonium chloride	97–100
Cyanamide	92–100
Urea	90–100
Aqua ammonia	85–100
Anhydrous ammonia	83–100
Ammonium nitrate	57–100

Studies of various ammonium nitrogen sources have been conducted on a wide variety of California soils over a number of years. Data from these experiments have been compiled and transformed into index values with ammonium sulfate as a standard equal to 100. A tabulation of nitrogen sources and their relative efficiency in increasing rice yields is shown in table 3.

Ammonium sulfate has consistently ranked among the best nitrogen sources for rice. Although not statistically better in all experiments, its performance has been a standard of comparison over a wide range of soils and cropping conditions. In recent years ammonium chloride has received attention but no significant differences between ammonium chloride and sulfate have been established in experiments conducted. Cyanamide has been an excellent source of nitrogen, but its use has been considerably reduced in recent years because of its higher cost and restricted supplies. Urea is a popular source because of its high analysis, but urea has not consistently performed well under all conditions. Because urea is subject to leaching before it is hydrolyzed to ammonium carbonate, it may be that its distribution pattern when drilled into the soil is not as favorable as ammonium sulfate. Aqua and anhydrous ammonia are also good nitrogen sources which suffer adversely because of application problems. Volatile ammonia-bearing materials must be drilled sufficiently deep to allow good retention in the soil. Under some conditions placement must be deeper than thought to obtain ideal retention for rice. Drilled ammonium sulfate is not better than aqua or anhydrous ammonia under some seedbed conditions, however.

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