COMPREHENSIVE RESEARCH ON RICE

ANNUAL REPORT

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PROJECT TITLE: Nutritional and Environmental Factors Affecting High Yield Potential in California Rice

PROJECT LEADER AND PRINCIPAL UC INVESTIGATORS:

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LEVEL OF 1981 FUNDING: $20,000

OBJECTIVES AND EXPERIMENTS CONDUCTED IN LOCATION TO ACCOMPLISH OBJECTIVES:

1) To improve the fertilizer use efficiency of rice in California with emphasis on economics of fertilization, avoidance of adverse effects on crop performance and yield, pollution control and optimization of the yield of California rice varieties.

Large container greenhouse experiments were conducted with 15N-labeled fertilizers to study the nitrogen losses occurring from flooded rice when nitrogen fertilizer is applied at different rates, timing and methods of application. These experiments at UC Davis involved detailed laboratory chemical and isotopic analysis.

2) To determine the nutrient supplying capacity of California rice soils and the optimum use of fertilizers to enhance rice yields.

Five typical rice soils were collected from rice growing areas and were studied under greenhouse and laboratory conditions to measure the effect of flooding on several biological and physicochemical properties of California soils that are important to plant nutrition and growth. Two field experiments were conducted on rice variety x nitrogen interactions and separate field experiments investigated the benefits of nitrification inhibitors and slow-release nitrogen fertilizers.

3) To investigate physiological disorders in rice affecting seedling development, vegetative growth and rice yields.

Plant growth chamber experiments were conducted with the major California rice varieties to determine the effect of day/night temperatures on the growth and development of rice and upon temperature affected changes in rice soils. Graduate student research investigated the effects of water stress in irrigated rice.

4) To examine stand establishment problems in rice concerning germination, seedling emergence and stand establishment.

Field and greenhouse experiments were conducted with plant growth regulators, seed coating materials and plant nutrients concerning rice stand establishment.

OBJECTIVE 1

Fate of fertilizer nitrogen applied to flooded rice

The major mechanisms by which nitrogen is lost from flooded rice production have been studied in typical California rice production systems. Losses occur as a consequence of the nitrification of ammonium to nitrate nitrogen by autotrophic bacteria and subsequent biological and chemical denitrification. Volatilization of ammonia from surface applications of ammoniacal fertilizer sources is also a significant means of nitrogen loss. Fertilizer nitrogen may also be temporarily unavailable to plants through microbial immobilization as well as chemical immobilization with various soil organic components and inter-lattice fixation of ammonium ions by certain clay minerals.

To further identify the losses of nitrogen from flooded rice soils and to increase nitrogen-use efficiency by rice, a greenhouse experiment in 40 gallon steel drums was established. These treatments were to provide additional detail on the effect of rate, timing and method of nitrogen application on nitrogen use efficiency. Treatments involved rates of ^{15}N-labeled fertilizer to supply 0, 60, 120, and 180 kg N/ha applied to dry soil pre-flood, with split applications of 120 kg N/ha of which 90 kg N/ha was applied pre-flood and an additional 30 kg N/ha applied at either mid-tillering, maximum tillering or the panicle initiation stage and a treatment where 120 kg N/ha was applied in 4 split applications.

Nitrogen uptake by the crop and nitrogen transformations occurring in the soil are to be measured both chemically and isotopically, but there has not been sufficient time since completion of the experiment for this data to be collected. A technical report will be prepared on the completion of this study, which requires growing a second crop to measure residual nitrogen remaining in the soil and the portion available to subsequent rice crops.

To date only yield data from the experiment are available. These data are shown in Table 1.

Plant Analysis as a Diagnostic Tool in Fertilization

Plant analysis as an aid in diagnosing the nutritional status of rice, is based on the principle of limiting factors and critical nutrient concentrations. The technique has proven useful for researchers, agricultural consultants and farmers who desire to exercise a high level of rice management skills to maximize crop yields. Proper methods of sampling, sample preparation and chemical analysis must be followed if data obtained are to be useful for interpretation.

Field experiments have been conducted during the past three years where correlative data has been collected on the relationship between total leaf nitrogen at mid-tillering, maximum tillering, panicle initiation, flag leaf stage and final grain yields. Data for the 1981 experiments have not yet been compiled for computer analysis and the data are not yet complete. Previous years data show that a statistically significant positive correlation exists between the nitrogen content of the rice Y-leaf and grain yields. Correlation coefficients vary somewhat with variety and time of sampling but occur in the range of 0.44** and 0.93*. There has been no significant variety by Y-leaf N interaction, except for variety L201 which has a significantly lower critical N concentration than the short and medium grain varieties to produce near maximum yields. Critical values described here are estimated by identifying the N concentration in the Y-leaf associated with 90 percent of maximum grain yield.

Typical varietal x yield correlation and regression values from field experiments are shown below.

Variety	Time	Correlation (R^2)	Yield x N Regression Equations
Calrose 76	Mid-tiller	.86	$Y = 10945 + 5913(X) - 270\ (X^2)$
M7	"	.82	$Y = -22648 + 11905(X) - 1082(X^2)$
M5	"	.67	$Y = -54030 + 29097(X) - 3342(X^2)$
M301	"	.69	$Y = 11387 - 5482(X) - 1151(X^2)$
Calrose 76	Panicle initiation	.88	$Y = -31978 +22816(X) -3052(X^2)$
M7	"	.84	$Y = -38906 + 27133(X) - 3779(X^2)$
M5	"	.79	$Y = -37440 + 27340(X) - 3982(^2)$
M301	"	.84	$Y = -28205 + 20357(X) - 2674(^2)$
Calrose 76	Flag Leaf stafe	.89	$Y = -33096 + 27853(X) - 4452(X^2)$
M7	"	.87	$Y = -22032 + 18875(X) - 2817(X^2)$
M5	"	.73	$Y = -43407 + 33562(X) - 5319(X^2)$
M301	"	.76	$Y = -2625 + 2913(X) - 379(X^2)$

The tentative critical nitrogen, phosphorus and potassium plant tissue values for short and medium grain California rice varieties are shown in Table 2.

Two variety x N experiments were conducted during 1981 to develop information on newly released California rice varieties. Plant analysis samples were taken from trials at UC-Davis and at the McKnight Ranch in Butte County. Yield data from these experiments are reported in the following tables, but plant analysis data has not yet been correlated with yield response (Tables 3 and 4).

Nitrogen Mineralization and Transformations From Green Manure Crops

Mr. M. P. Westcott, Graduate Student, is researching the use of green manure crops as a nitrogen fertilizer source for rice. In this research an evaluation of organic nitrogen is being made in contrast with commercial fertilizer in terms of availability to the crop and various nitrogen transformations occurring in soils which affect nitrogen use efficiency.

A field experiment was established to supply measured amounts of nitrogen from vetch, ammonium sulfate and factorial combinations of selected treatments. Microplots were established within whole plots with $^{15}(NH_4)_2SO_4$-labeled fertilizer (5.35% atom excess) and ^{15}N-labeled vetch (3.32% atom excess) to monitor nitrogen fertilizer uptake and various nitrogen transformation which occur in the soil. Soil transformations are concerned with mineralization of organic nitrogen and the fate of nitrogen in extractable-exchangeable forms, the clay-fixed ammonia, and organically bound forms.

The collection of data from the field experiment and subsequent laboratory experiments are not complete, but the following tentative results are available:

1) The rice grain yield response from green manure nitrogen was lower than the response from comparable fertilizer nitrogen. Apparently the mineralization of the green manure did not provide the same quantity of available nitrogen to the crop fertilized as did ammonium sulfate fertilizer. Crop response to combinations of fertilizer N and vetch N are shown in figure 1.

2) The amounts of available nitrogen (extractable and exchangeable) in the soil indicate that fertilizer nitrogen provided significantly more nitrogen than vetch during the first 45 days after flooding, after which all available nitrogen was slowly released. Figures 2a and 2b show the levels of nitrogen in the soil throughout the growing season for selected treatments (Figure 2).

3) A comparison between inorganic and organic nitrogen sources indicates that there were only small differences in the patterns of nitrogen uptake by the crop. The relative contribution of the ^{15}N-labeled fertilizer to plant nitrogen uptake is shown in Figure 3. Lines E and F allow a direct comparison between the fertilizer and green manure nitrogen sources.

4) Preliminary data suggest that the supply of available soil nitrogen in the soil up until 45 days of the flooding, exerted a greater influence on grain yield than the supply of nitrogen available after this time. Since rice obtains about 75-80% of its total nitrogen from soil sources, the contribution of the green manure and fertilizer nitrogen is most important during the early growth stages. Figure 4 shows the correlation between available soil nitrogen at 30 days after flooding and final grain yields.

Effect of Slow Release Nitrogen Sources on Yield of Rice

Sulfur-coated urea has been prepared by the National Fertilizer Development Center as a slow release nitrogen source for crops which may be grown where nitrogen losses from the soil are inordinately high. An experiment comparing sulfur-coated urea (SCU-25) with commercial fertilizer urea was conducted at the UC-Davis Rice Facility. Rates of 60, 90, 120 and 150 pounds N/acre from each source were compared on rice grown in a flush-drain-flood rice cultural system. The rice after fertilization and planting was flush irrigated 3 times over 42 days before permanent flood was applied. At harvest time, grain yields were determined by harvesting the individual treatments. Yield data from the nitrogen source comparison are given in Table 5.

Significant differences in rice yield were obtained from use of the two nitrogen sources, sulfur-coated urea being significantly better than commercial urea. The average yield of combined urea nitrogen rates was 3,355 kg/ha, while SCU-25 produced an average of 6,700 kg/ha with combined rates of nitrogen.

Simultaneous with the establishment of the field experiment, nylon bags (7 x 30 cm) were filled with soil and loaded with two sources of sulfur-coated urea, SCU-11 and SCU-25. The SCU-11 has a slower dissolution rate than SCU-11. The bags were buried in the soil in plots containing the SCU-fertilizer and were subsequently treatly like the field experiment described above Filled nylon bags were removed just prior to permanent flooding and at 14-day intervals after flooding to measure the recovery of nitrogen from the sulfur-coated urea material. Sulfur-coated urea in the nylon bags was segregated and dissolution values calculated by the following equation.

$$\text{Recovery (\%)} = \frac{\text{Ave. wgt. of recovered granules} \times \text{\%N in original sample} \times .90}{2.59}$$

$$100 - \text{Recovery \%} = \text{\% Dissolution}$$

The dissolution values obtained for the two SCU sources are reported below:

Sampling date	Percent recovery of Sulfur-coated urea formulation SCU-25	SCU-11
Pre-permanent flood	32.5%	55.5%
June 25	28.0	53.5
July 8	20.6	52.5
July 23	16.5	33.6
August 6	7.5	27.1
August 21	6.0	21.3

Evidence suggests that SCU-11 would probably have been a more effective formulation for rice based on its release of nitrogen over a longer period of time. Only 6% remained of the SCU-25 material at the end of the experiment compared with 21.3% of the SCU-11 remaining. Where nitrogen losses are severe, conservation can be achieved with SCU fertilizer materials.

Nutrient Transformation in California Soils Affecting Rice Nutrition

Flooded soils undergo important physicochemical changes which markedly influence the supply of available nutrients for the rice crop. In flooded soils the processes that control soil fertility are pH, Eh, Ec, ionic strength, sorption and desortpion, ion exchange, chemical kinetics, mineral equilibria and microbial by-products. Each soil undergoes changes which are characteristic of specific soil properties and their effects on rice nutrition are highly interactive. Since the transformations occurring in California rice soils have not be characterized, five major rice soils were examined in a flooded condition as a means of predicting rice crop nutritional behavior. Meyers clay, Willous clay, Stockton clay, Sacramento clay and San Joaquin loam were examined in this study. Changes in soil pH, Eh, extractable, P Fe and Mn were examined in addition to rates of ammonification of soil organice matter to available N.

Evidence present in figures 1a-b-c-d and e show the dynamic changes which occur from the time a soil is flooded until 60 days after flooding. Figures 1a and b show that pH values of the alkaline soils initially decrease on flooding, but may increase in pH with time. Evidence exists that among sodic soils that sodium bicarbonates and carbonates formed under flooded conditions may cause pH-increases of at least one pH unit. Redox potential is a measure of the intensity of oxidation or reduction. The soils examined showed an initial decrease in Eh but an increase after about 30 days of flooding and finally achieving a steady state.

Patterns of ammonia formation show increasing ammonia formation up to about 30 days after which the release rate becomes fairly stable. The addition of straw generally had a depressive effect on ammonia formation, but its release was continuous over the period of the experimentation.

Extractable phosphorus generally increased after flooding and the addition of straw slightly increased availability in some of the rice soils investigated. Available phosphorus did not show dramatic changes in availability 30 days after flooding. Extractable iron and manganese increased markedly on flooding, reflecting the reduction of non-exchangeable iron and manganese to more soluble forms (Figures 1d and 1e).

The chemical kinetics show that soils low in ammonical nitrogen would likely produce better rice production when basal nitrogen is applied prior to flooding. Soils high in ammonia release may only require late nitrogen top-dressing. Phosphorus, iron and manganese availability improve with soil flooding, and flooding enhances the availability of these nutrients.

OBJECTIVE 3

Effects of temperature on the growth and development of rice

The effects of temperature on the growth and development of 10 California rice cultivars were determined in three controlled temperature growth chambers installed at the University of California-Davis. Three day-night temperature environments were maintained at 35 /20 C, 30 /15 C and 25 /10 C during the study with varieties M101, S201, M7, M9, T55, S-6, M301, M302, L201 and Calrose 76. For convenience in this report the effects of temperature are reported for (1) seedling growth, (2) vegetative stages from seedling to panicle initiation and (3) reproductive growth, from panicle initiation to flowering.

Seedling growth: There is general agreement that rice seeds germinate faster as water temperatures are increased from minimal value (about 15 C) to an optimum. Water temperatures of 25 C to 30 C are the most favorable under California conditions, with shoot growth most rapid at 86 F(?), but root elongation and anchorage best at about 25 C. Temperatures above 30 C increase the number of "floating seedlings" and make stand establishment difficult. Water temperatures exert more influence on root growth than air temperatures. The seedling response of 10 California rice varieties to different day and night temperatures are shown in Table 6.

Vegetative growth: Early and rapid tillering is important to good photosynthetic activity, to smother weeds and ultimately to produce an adequate number of panicles for optimum yield. Tillering ability, however, is not as important in California where 150 pounds seed/acre is sown as it is where lower seeding rates are used because the number of tillers per plant. Both the rate of tiller production and the length of the tillering (vegetative period) are affected by temperature. Higher air temperatures increase the rate of tiller production but the duration is shortened and the final number of tillers at harvest is reduced. Tillering ability is complex, however, and varieties are affected differently by temperature, light intensity and the carbohydrate metabolism of the plant.

The rate of leaf emergence increases with temperature over the range of 16 to 36 C and water temperature is most critical. At the lower temperature leaf elongation is restricted but succeeding leaves grow longer as temperatures are raised. Leaf respiration increases with temperature to at least 45 C, but photosynthesis is relatively insensitive to temperature, its main effects on net CO_2 exchange are the result of its effect on respiration rates. Low temperatures at night or during periods of low light intensity appear advantageous to vegetative development.

The effect of day/night temperature on vegetative development of 6 California rice varieties is shown in Table 7.

Nutrient uptake: Evidence is very clear that air and water temperatures influence the uptake of plant nutrients and the carbohydrate metabolism of rice. The concentration of mineral elements gradually increases with a rising temperature regime up to about 30 C day temperature and 25 C night temperature. The effect of water temperature on nutrient absorption differs among various nutrients. Phosphorus and zinc are the most strongly inhibited by low temperature (15 C) and inhibition usually decreases in the order of ammonium, sulfur, potassium, magnesium and calcium.

The concentration of total sugar and crude starch and the ratio of total available carbohydrate to nitrogen are usually higher at low temperature, but translocation is often inhibited. Delayed nutrient translocation delays plant development and grain formation.

Reproduction: The onset of floral initiation is marked by the transformation of the apical growing point into floral primordia and by the production of floral initials instead of axillary tillers. The rate of panicle initiation is accelerated by high temperatures and delayed at low temperatures. Low temperatures delay panicle initiation is accelerated by high temperatures and delayed at low temperatures. Low temperatures delay panicle exsertion more by slowing down the leafing process than by inhibiting panicle initiation. The optimum temperature range for panicle initiation is between 25 C and 30 C by day and about 20 C at night. After panicle initiation, the next most sensitive reproductive event is the meiotic stage of the pollen mother cells, a time about 10-14 days before heading. The critical temperature for this cold induced sterility is about 20 C. High temperatures, usually above 35 C delays heading, causes incomplete panicle exsertion, failure of anther dehiscence, desiccation of pollen grains resulting in spikelet sterility and poorly filled grain.

Grain development: For grain formation, the critical low temperature is in the range of 12-18 C. Translocation of carbohydrates to the developing grain is retarded at these low temperatures, but the ripening period is also lengthened with the net result a greater final accumulation of dry matter. Low temperature favors an increase in weight per grain but it also delays the ripening process. High temperatures during ripening 30 C reduce the capacity of the grain to act as a sink for assimilates, resulting in chalky and chalky-centered kernels and an increased thickening of the bran layer.

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Temperature variations during the growth of rice are irregular and are involved in a complex way with other environmental and plant factors. Temperature, through various interactions from sowing to panicle initiation, detrmine the number of pnaicles, the number of florets per unit area dn affect the maximum potential rice yield. Temperature conditions before panicle initiation and up until flowering determine heading dates and the proportion of florets which will produce seed. Adverse conditions before floral initiation cannot be overcome by favorable conditions afterwards. Where solar radiation is not a factor in grain ripening, as is the case in California, rice yield is negatively correlated with mean daily air temperature during the ripening period.

Soil temperature exerts a profound influence on chemical changes which occur in a Meyers clay soil. Figure 5 shows a composite effect of temperature and incubation time on changes in soil pH, partial pressure of CO_2, organic acid formation, denitrification, ammonification and iron reduction. All these factors are significantly influenced by soil temperature which in turn exert various effects on the growth and mineral nutrition of the rice plant.

The Effect of Water Stress on Rice Yield Components

The effects of moisture stress on rice has not been widely investigated except on rainfed upland situations. With increasing pressures to use agricultural irrigation more efficiently questions arise concerning the optimum irrigation schedule for irrigating rice and the consequences of moisture stress at the various growth stages of rice. Mr. E. M. Abdelmalik has studied the effect of moisture stress on the growth and yield components of a California rice variety. In this study at intervals of seven days, twelve soil moisture treatments were imposed beginning 47 days after transplanting and continuing to the end of the growing season. A constant soil moisture tension of 5.1 atmospheres was imposed at 12 different water stress intervals for the variety M101. At grain maturity, treated plants were harvested and evaluated for plant growth response and grain yield components.

Plant height was not as severely affected by water stress as other yield components. Vegetative dry weight yield was most affected when water stress was imposed during the mid-tillering to maximum tiller stage. Percent grain sterility did not follow a well-defined pattern and moisture stress during vegetative growth stages were not significantly affected by blanking. Maximum blanking occurred in when moisture stress occurred during the flowering-grain filling stage which also reduced the seed index. The overall effects of moisture stress on yield was highly significant. The greatest reduction in yield occurred when moisture stress developed from mid-tillering to the panicle initiation stage. Late season moisture stress, during grain filling had the least detrimental effect on rice yields. The yield contributing characters which were affected by water stress in a decreasing order are: (1) number of grains per panicle; (2) weight of grains per panicle; (3) number of panicles per pot and (4) number of tillers per pot. Table 9 shows the average rice yields and yield components affected by water stress at different stages of growth and Table 10 - the simple correlation coefficients of rice yields and yield components as affected by water stress.

OBJECTIVE 4

Plant Growth Regulation to Improve Rice Production

A variety of plant growth regulators were investigated during 1981 which are designed to improve the biological efficiency of rice. Surfactant materials have been investigated in seed soaking to enhance the germination and seedling growth of rice. A material designated SRS appears to offer some promise but will require further field verification.

Three plant growth regulators have been investigated during 1981, but some growth and yield data are still incomplete for reporting due to the late 1981 rice harvest. Combinations of gibberellic acid, 6 benzyladenine, 1-cysteine and folic acids have been investigated with apparent responses in growth and rice yields.

Partial results of the gibberellic acid (GA) and 6 benzyladenine (6 BA) experiment, where all combinations of 10 and 20 ppm of material were spray applied to rice at two weeks before panicle intiaiton, at panicle initiation and two weeks after panicle initiation reveal that statistically significant rice yield increases were obtained by the treatments. Plant growth, heading and maturity were affected by combinations of GA and 6BA at concentrations of 20 ppm.

PUBLICATIONS OR REPORTS

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4. Kuo, S. and D. S. Mikkelsen. 1981. The effects of straw and sulfate amendments on sulfide production in two flooded soils. Soil Science 132, No. 5.

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CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS

1. Nitrogen transformations in flooded rice that lead to losses and reduced crop nitrogen use efficiency include direct ammonia volatilization from the soil/water, losses directly from the plant plants as gaseous ammonia, nitrification-denitrification losses and immobilization by crop residues. Fertilizer nitrogen applied preflood reduces losses to a minimum with California rice cropping practices.

2. Tentative critical nutrient values have been developed for the new, short statured short and medium grain California rice varieties. Long grain varieties have a lower plant leaf N critical value and will require separate standards.

3. Slow release, sulfur coated urea materials significantly conserve nitrogen and increase nitrogen use efficiency under conditions of flush-drain-flood rice management.

4. Green manure crops such as vetch, labeled with isotopic ^{15}N did not release nitrogen to the crop as quickly as fertilizer nitrogen. After 45 days from flooding rice soil levels of extractable-exchangeable ammonium drop to very low values. Soil nitrogen contributions are most significant during the last 100 days of rice culture in California.

5. Rice production in California is significantly affected by day and night temperature variables during the growing season. Effects on seedling development, vegetative and reproductive growth were studied in controlled plant growth chambers.

Table 1. Effect of rate, timing and method of nitrogen application on crop performance.

Treatment (Kg N/ha)				Crop Yield Responses		
Preplant	Mid-till	Max Till	P.I.	Straw	Roots	Grain
0	0	0	0	18.7	4.9	23.3
60	0	0	0	74.9	24.0	139.4
120	0	0	0	119.4	44.3	153.0
180	0	0	0	114.1	20.6	173.7
90	30	0	0	94.2	29.0	144.0
90	0	30	0	85.4	20.7	158.1
90	0	0	30	112.7	35.8	138.1
30	30	30	30	79.6	17.6	122.3

Table 2. Plant Issue Analysis - Medium and Short Grain Varieties[1]

Plant growth stage	Total N[2]		Extractable PO -P[2]		Extractable K[2]	
	Critical	Adequate	Critical	Adequate	Critical	Adequate
Mid-tillering	3.8-4.0	4.0-4.8	1000	1000-1800	1.4	1.4-2.8
Maximum tillering	3.4-3.6	3.6-4.2	1000	1000-1800	1.2	1.2-2.4
Panicle Initiation	3.0-3.2	3.2-3.6	800	800-1800	1.0	1.2-2.4
Flag Leaf	2.6-2.8	2.8-3.2	800	800-1800	1.0	1.2-2.2

[1]Tentative critical values (January 1981)

[2]Analysis on dry weight basis of most recently matured leaves for Kjeldahl N, 2% HAc extractable PO_4-P and K.

Table 3. Grain Yield (14% moisture) for variety x nitrogen trial (Butte Co., 1981)

Fertilization Rate LDS N/AC	Variety S6	S201	M301	M302	M9	L201	Nitrogen Mean
0	5621	5679	6192	5407	5420	5426	5624 B
69	9206	9838	9844	8775	9325	9672	9443 A
102	8756	10096	9449	9143	9149	10384	9443 A
135	8727	10145	9560	9544	9876	10950	9784 A
153	8575	10400	8734	9133	9254	11186	9547 A
186	8674	9458	8987	9054	8558	10498	9205 A
Variety mean	8243 D	9269 B	8794 C	8509 CD	8597 C	9686 A	

Means with the same letter are not statistically different at .05% level
N rate means LSD .05 = 973 Kg/ha; (.01) = 1385 Kg/ha
Variety means LSD .05 = 285 Kg/ha; (.01) = 380 Kg/ha
N x V LSD .05 = 692 Kg/ha; (.01) = 931 Kg/ha

Table 4. Grain Yield (14% moisture) for variety x nitrogen trial (Rice Facility - UCD, 1981)

Fertilization Rate LBS N/AC	S6	S201	Variety M301	M302	M9	L201	Nitrogen Mean
	----------	----------	----------	kg/ha	----------	----------	
0	2606	2581	2932	3130	2797	2879	2821 D
60	4457	5052	4732	4729	5280	5172	4904 C
90	5262	6141	5942	5723	6016	6122	5867 CB
120	5380	6878	6849	5899	6433	6783	6370 BA
150	6108	7734	7327	7045	6847	7329	7065 A
Variety mean	4763 C	5677 A	5556 AB	5305 B	5474 AB	5657 A	

Means with the same letter have no significant differences at 5% level.
N rate means LSD (.05) = 978 LSD (.01) = 1370
Variety means LSD (.05) = 314 LSD (.01) = 417

Table 5. Grain Yield at 14% moisture of urea, and sulfur-coated urea at different N rates (Rice Facility, 1981).

Fertilization rate #N/AC	Urea	SCU	Nitrogen rate means
		kg/ha	
60	3100	5462	4281 B
90	3311	6244	4778 BA
120	3410	7310	5360 A
150	3598	7784	5691 A
Treatment means	3355 A	6700 B	

Means with the same letter has no significant difference at 5% level.
Treatment means LSD (.05) = 695, LSD (.01) = 946
N rate means LSD (.05) = 983, LSD (.01) = 1339

Table 6. Effect of day/night temperature on seeding development of California rice varieties.

Variety	Shoot length (mm)			Root length (mm)			Dry matter (g/25 plants)		
	25/10	30/15	35/20°C	25/10	30/15	35/20°C	25/10	30/15	35/20°C
M101	82.2	198.9	218.5	64.0	89.9	89.4	.147	.564	.570
S201	108.8	197.1	207.5	71.4	73.4	86.9	.203	.490	.626
M7	93.3	186.2	178.1	70.8	81.4	78.7	.168	.542	.539
T55	90.9	193.9	185.1	68.9	73.7	86.8	.167	.448	.490
S6	98.4	212.9	199.7	63.6	84.8	74.6	.139	.539	.529
M301	104.2	241.2	206.6	69.8	80.4	82.8	.179	.627	.583
M302	66.5	164.5	15.4	60.5	70.9	69.2	.133	.474	.339
CAL 76	114.3	198.4	203.3	62.5	74.7	73.1	.157	.613	.486
L201	119.6	214.1	210.5	68.5	93.7	84.0	.201	.584	.608
Average	88.0	204.8	196.3	67.6	82.2	80.8	.169	.555	.535

Table 7. Effects of day/night temperature on vegetative growth of California rice varieties.

Variety	Shoot length (mm) 25/10	30/15	35/20°C	Root length (mm) 25/10	30/15	35/20°C
M101	419.3	598.8	717.2	4.13	6.75	6.0
M9	363.6	570.2	623.5	3.19	8.38	4.75
M301	366.4	592.0	639.8	3.13	6.38	3.82
M302	372.4	581.1	662.5	3.88	7.06	5.56
S201	412.9	586.6	662.2	4.00	7.19	5.69
S6	491.2	663.5	757.4	3.69	7.63	5.38
Average	404.3	598.7	677.1	3.67	7.23	5.20

Table 8. Mean values for some rice yield components as affected by moisture stress at different stages of growth and development.

Time of water stress (days from transplanting)	Sterility (%)	Vegetative dry wt. gm/pot	Plant height cm
47	10.70	32.5	84.70
54	7.53	47.4	79.80
61	5.23	69.8	94.50
68	3.95	87.6	100.72
75	14.98	82.7	104.25
82	12.60	73.1	110.90
89	10.78	87.2	108.33
96	12.28	103.3	116.85
103	12.68	84.6	111.58
110	10.25	75.2	114.35
117	9.38	98.0	112.40
124	7.35	92.4	116.45
PLSD (0.05)	N.S.	20.6	5.75
PLSD (0.01)	N.S.	27.7	7.71

Table 9. Mean values for rice yields and yield components as affected by water stress at different stages of growth and development. PLSD (0.05, (0.01) are the protected least significant difference between treatments means at (0.05) and (0.01) significance level respectively.

Time of water stress (days from transplanting)	Grain yield gm/pot (14% H_2O)	Number of tillers/pot	Number of panicles/pot	Number of grains/panicle	100 grain wt. gm	Weight of grains/panicle gm
47	30.8	19.75	18.50	73.9	2.612	1.995
54	29.4	24.75	21.50	71.3	2.513	1.812
61	54.1	30.50	28.75	88.1	2.400	2.127
68	72.1	39.50	33.25	123.6	2.287	2.862
75	133.7	47.25	46.25	193.3	2.263	4.330
82	138.6	38.75	38.25	197.6	2.300	4.645
89	172.8	47.75	49.00	183. 3	2.312	4.370
96	170.8	48.75	48.50	188.7	2.387	4.595
103	157.1	39.75	40.50	183.2	2.512	4.530
110	134.2	34.00	33.50	193.8	2.500	4.887
117	172.2	43.75	45.25	213.8	2.462	5.355
124	140.4	39.00	38.5	191.5	.525	4.795
PLSD (0.05)	28.7	9.34	9.43	26.3	0.181	0.558
PLSD (0.01)	38.6	12.54	12.66	35.3	0.243	0.749

Table 10. Simple correlation coefficients (r), matrix of different combinations of rice yield and yield components as affected by moisture stress at different stages of growth. N.S. = not significant, * and ** are significant at 5% and 1% levels, respectively.

	Number of tillers/pot	Number of panicles/pot	Number of grains/panicle	100-grain wt. gm.	Weight of grains/panicle	Vegetative material/dry wt/gm pot	Plant height cm	Sterility %
Grain yield gm/pot	0.810**	0.874**	0.897**	-0.242 N.S.	0.893**	0.742**	0.823**	0.280 N.S.
Number of tillers/pot		0.946**	0.667**	-0.527**	0.599**	0.871*	0.644**	0.240 N.S.
Number of			0.727**	-0.490**	0.667**	0.857**	0.666**	0.368*
Number of grains/panicle				-0.272 N.S.	0.980**	0.633**	0.847**	0.263 N.S.
100-grain wt. gm					-0.103 N.S.	-0.432**	-0.135 N.S.	-0.238 N.S.
Weight of grains/panicle gm						0.587**	0.872**	0.174 N.S.
Vegetative material dry wt/pot gm							0.697**	0.149 N.S.
Plant height cm								0.001 N.S.

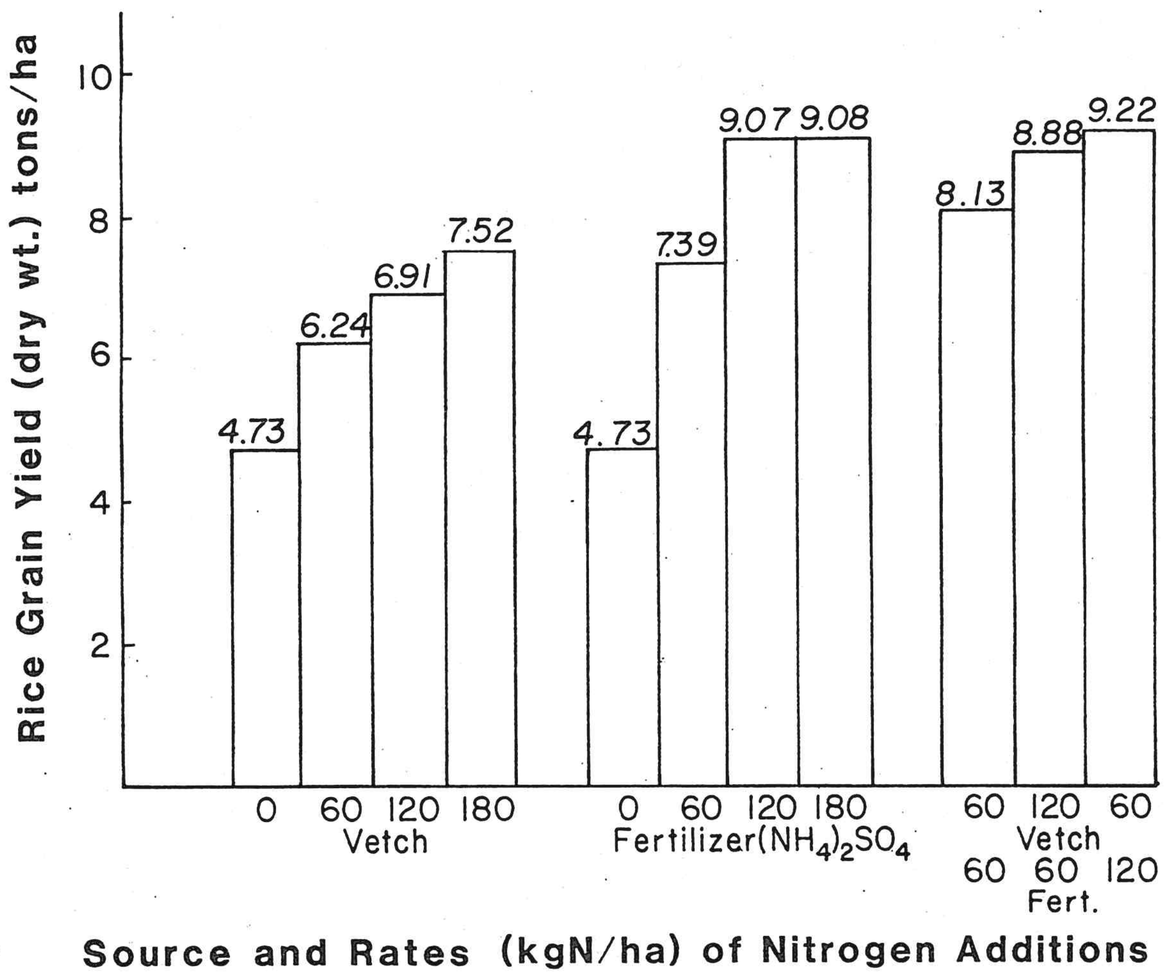

FIGURE 1. Grain yield of rice with nitrogen additions as vetch and ammonium sulfate at various rates and combinations.

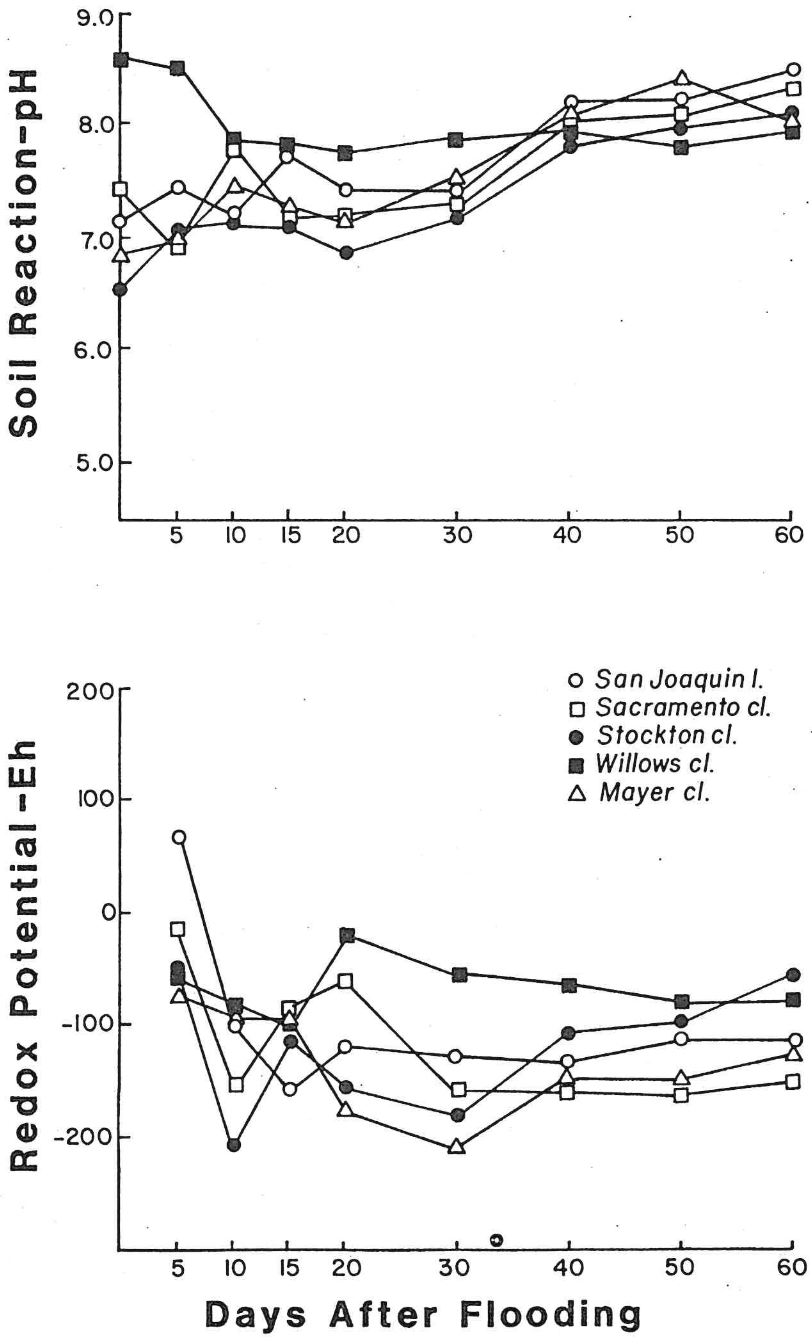

FIGURE 1a. Effect of flooding on the pH and Eh of selected California soils.

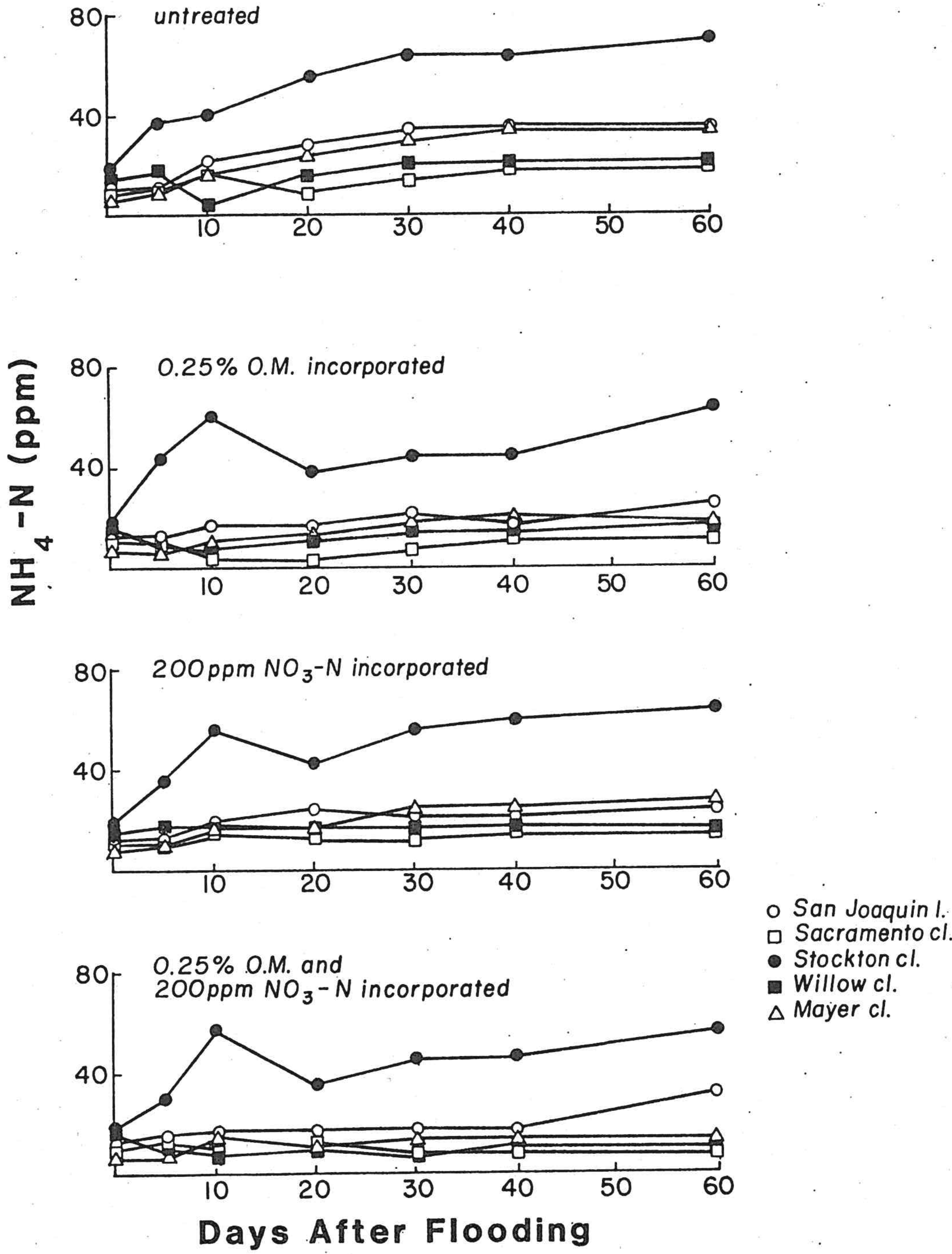

FIGURE 1b. Effect of flooding on the rates of ammonification of selected California soils, with and without added organic matter.

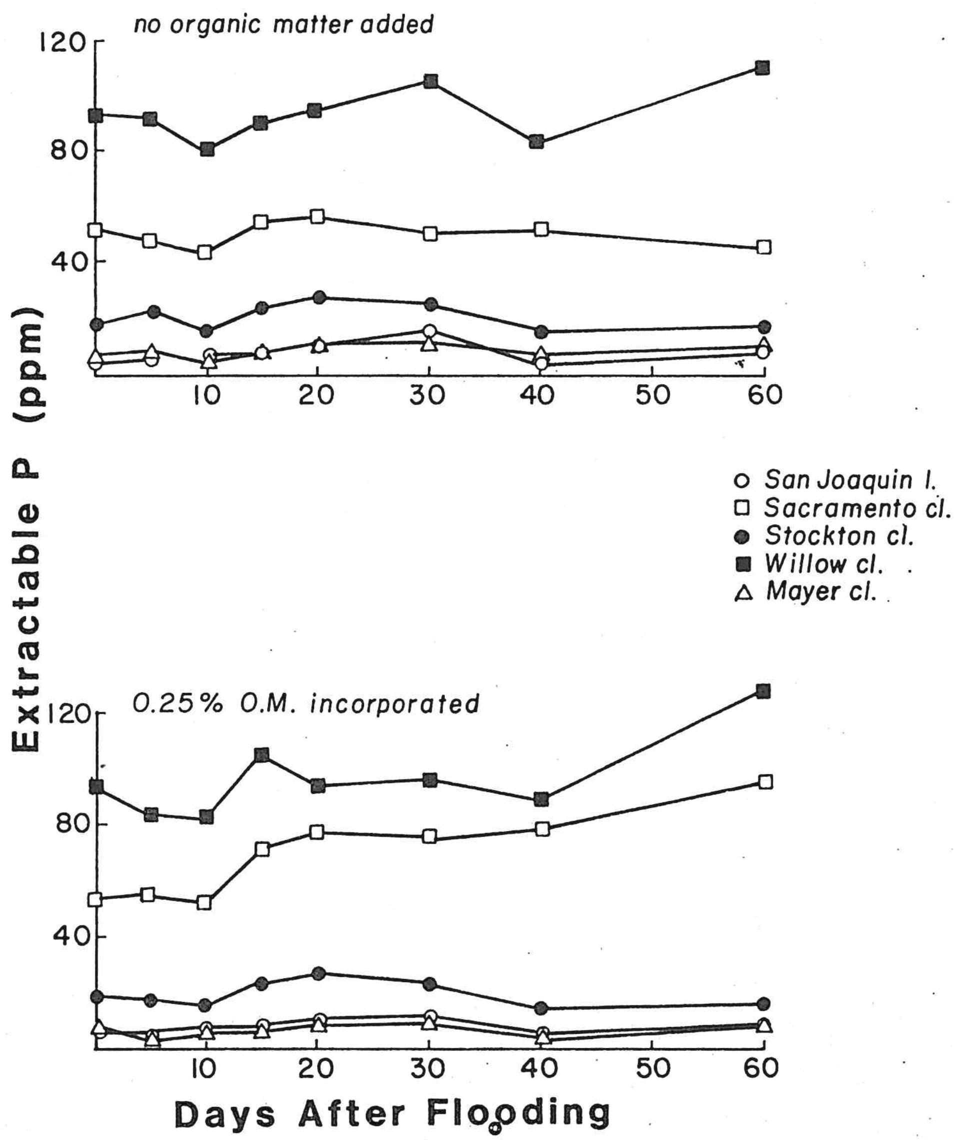

FIGURE 1c. Effect of flooding on the phosphorus extractable from selected California soils, with and without added organic matter.

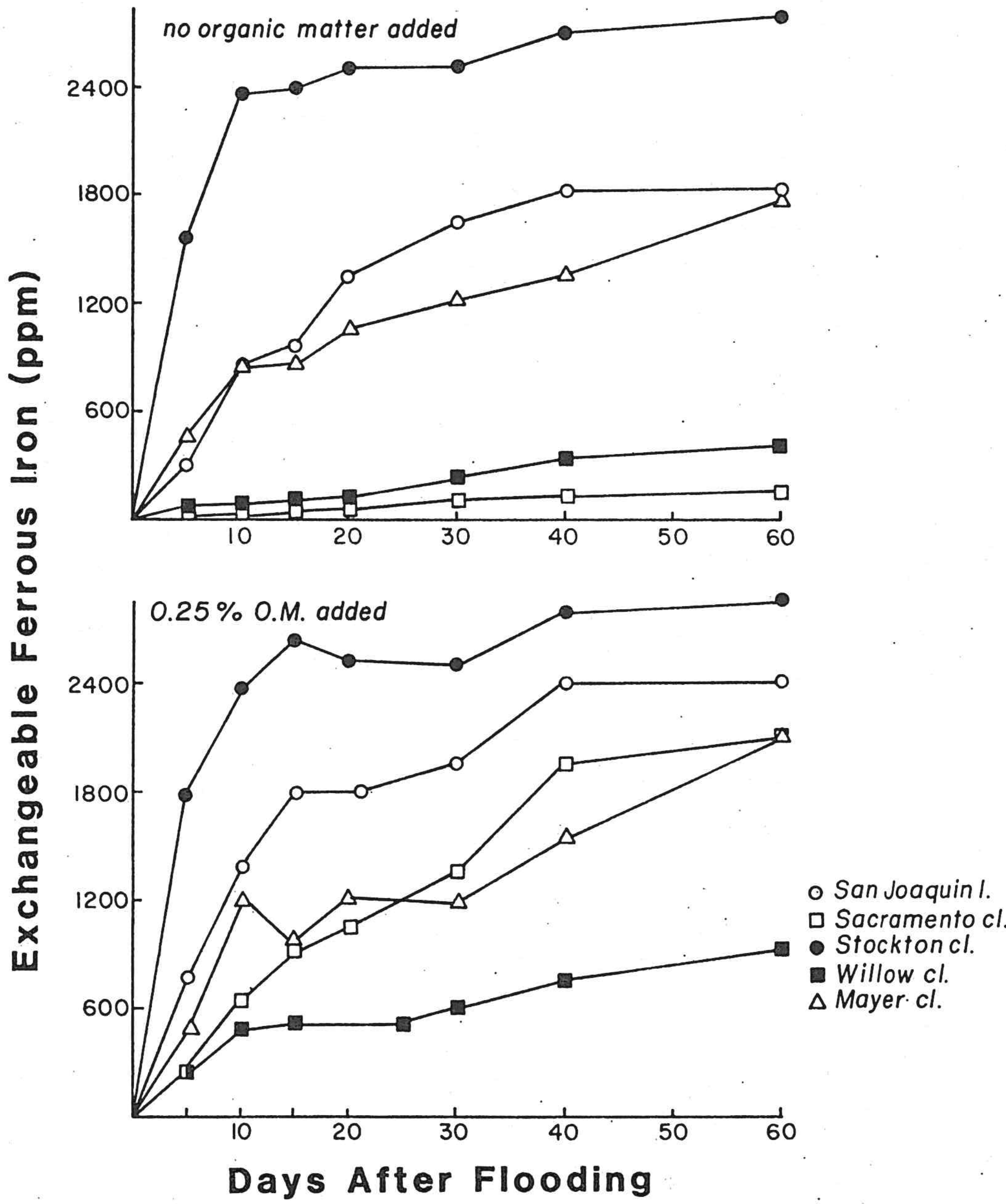

FIGURE 1d. Effect of flooding on the extractable ferrous iron from selected California soils, with and without added organic matter.

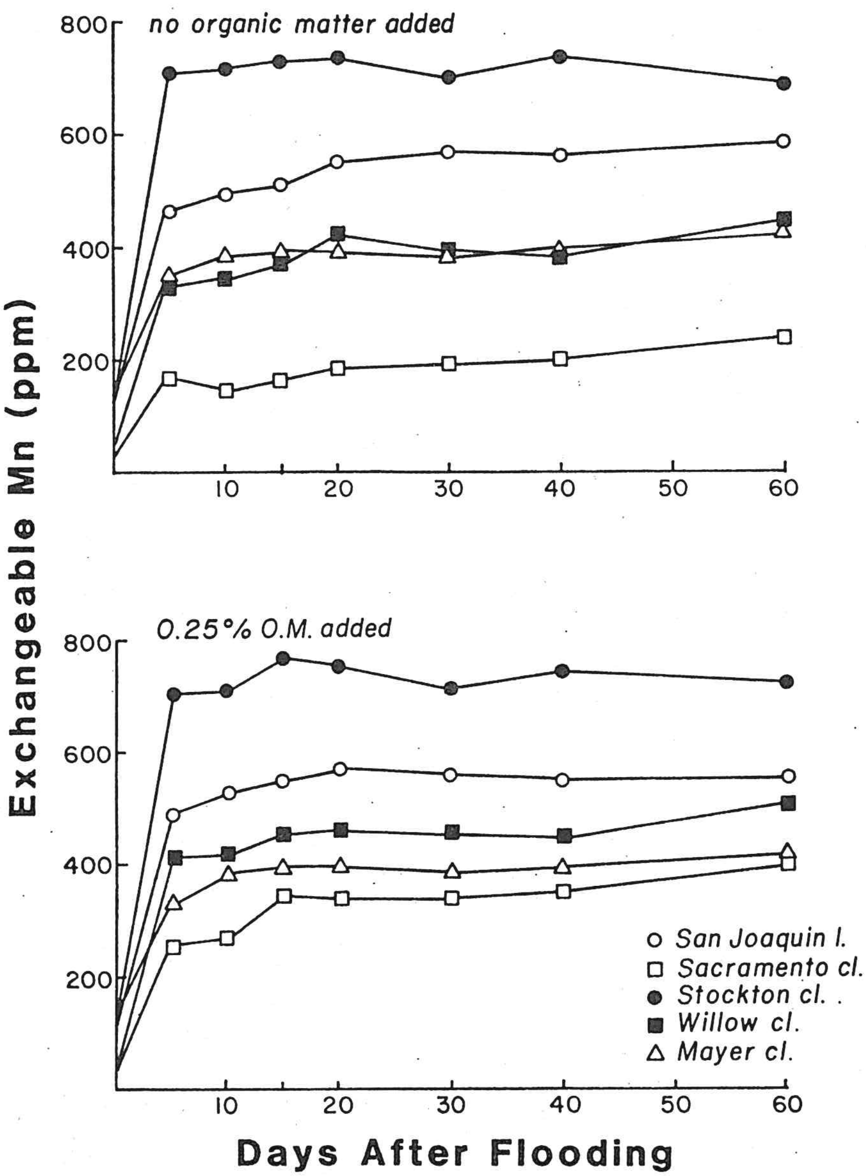

FIGURE 1e. Effect of flooding on the extractable manganese from selected California soils, with and without added organic matter.

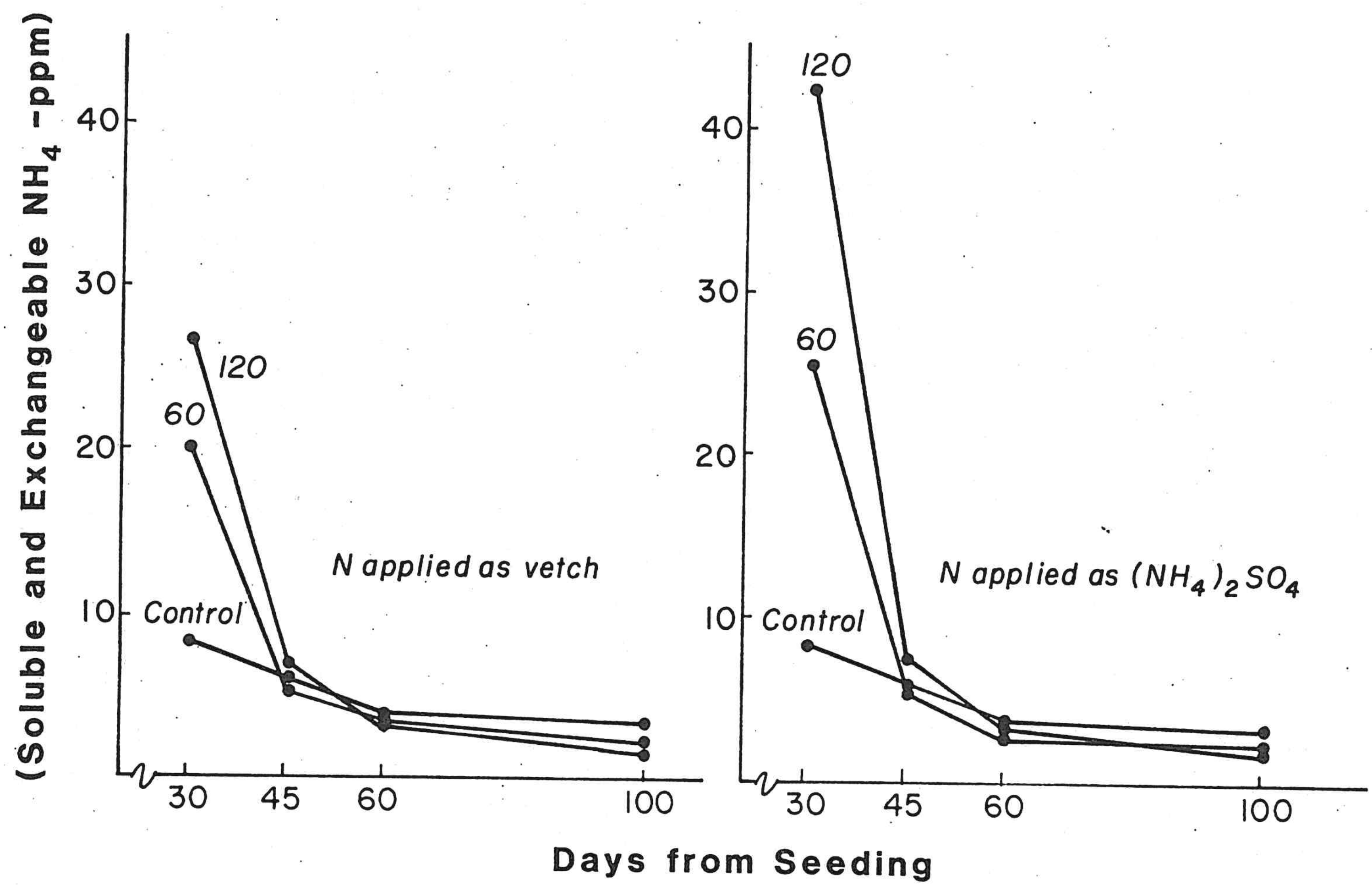

FIGURE 2a and 2b. Available soil nitrogen as affected by rate and source of nitrogen addition as determined at different growth stages.

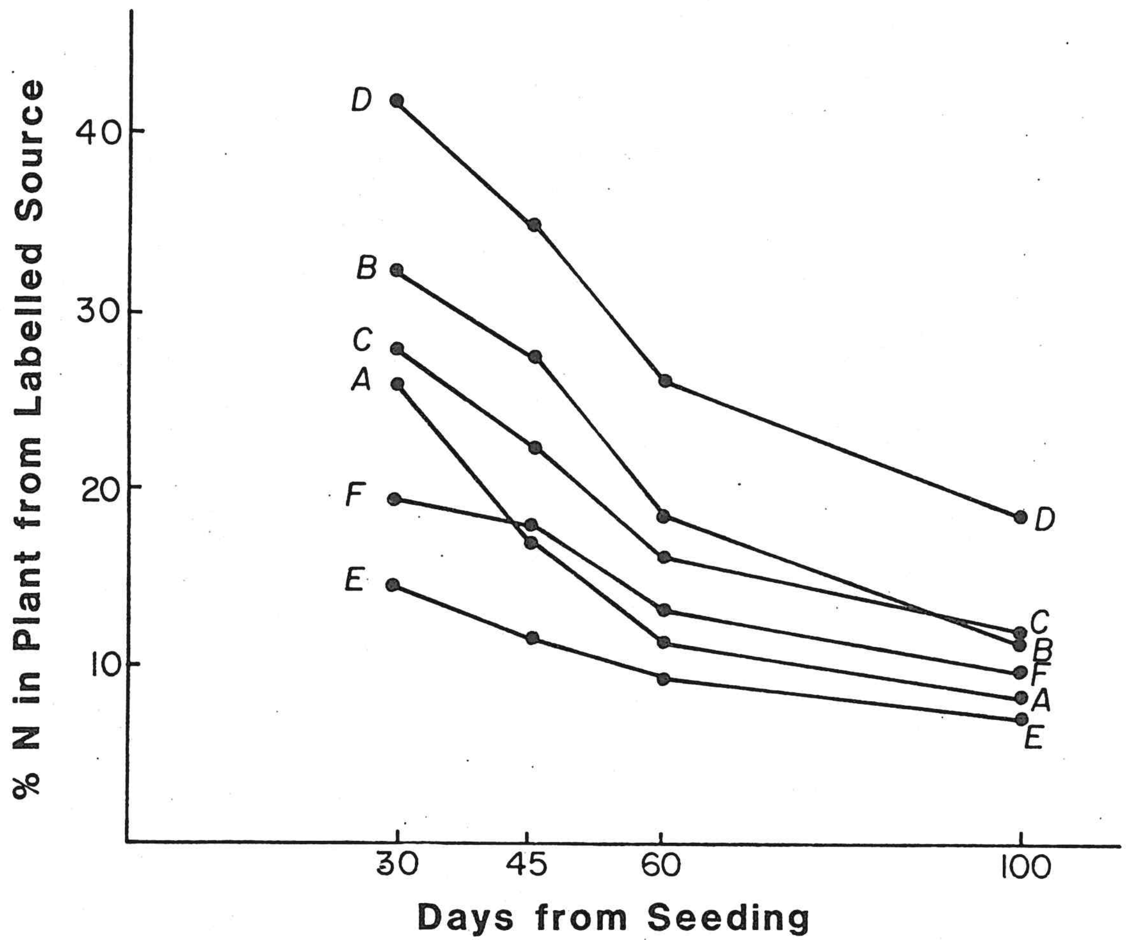

FIGURE 3. Contribution of added nitrogen sources to uptake of nitrogen by rice at different growth stages.

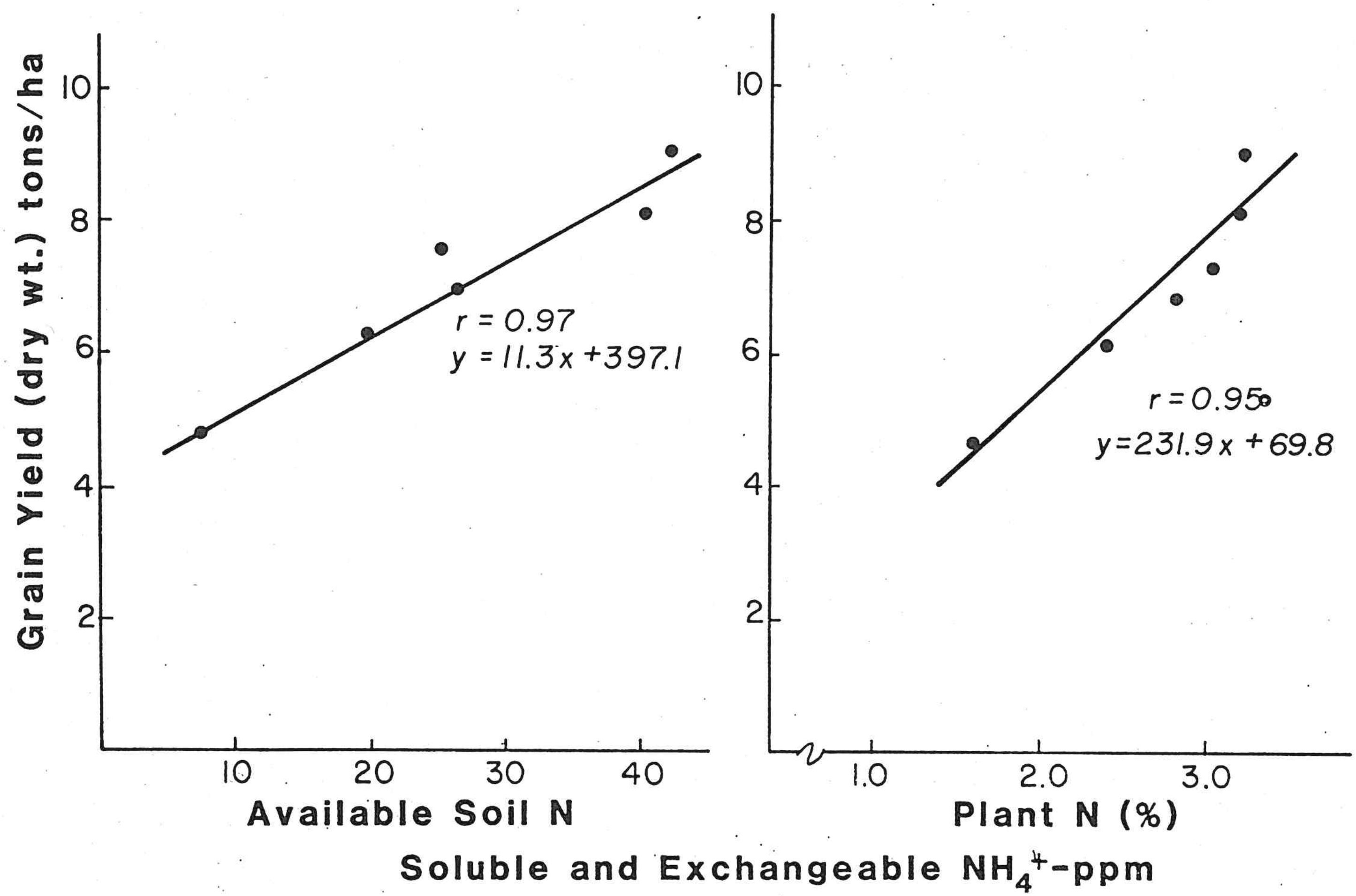

FIGURE 4a and 4b. Relationship between available soil nitrogen and plant nitrogen 30 days after planting and at harvest time.

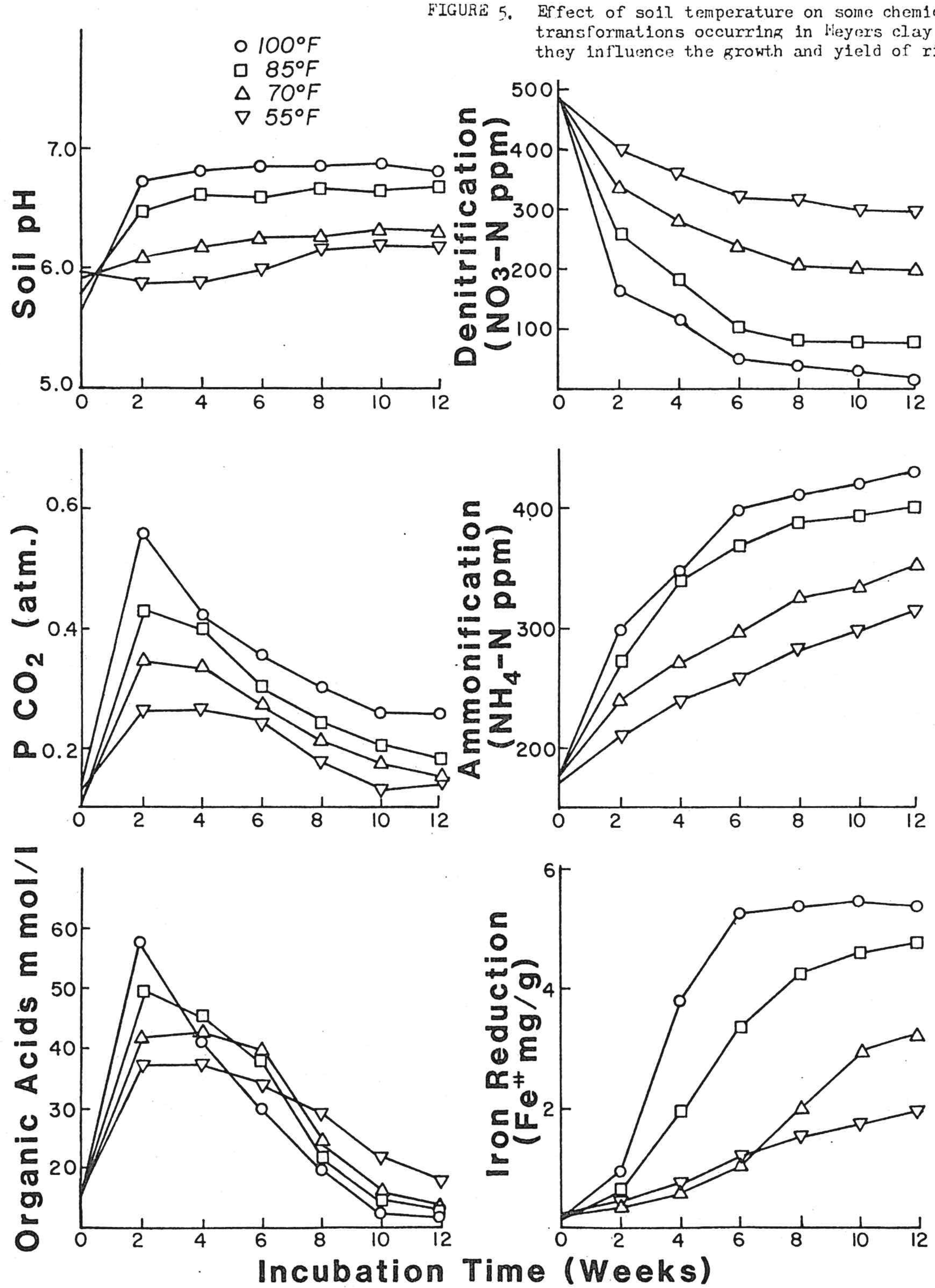

FIGURE 5. Effect of soil temperature on some chemical transformations occurring in Meyers clay as they influence the growth and yield of rice.

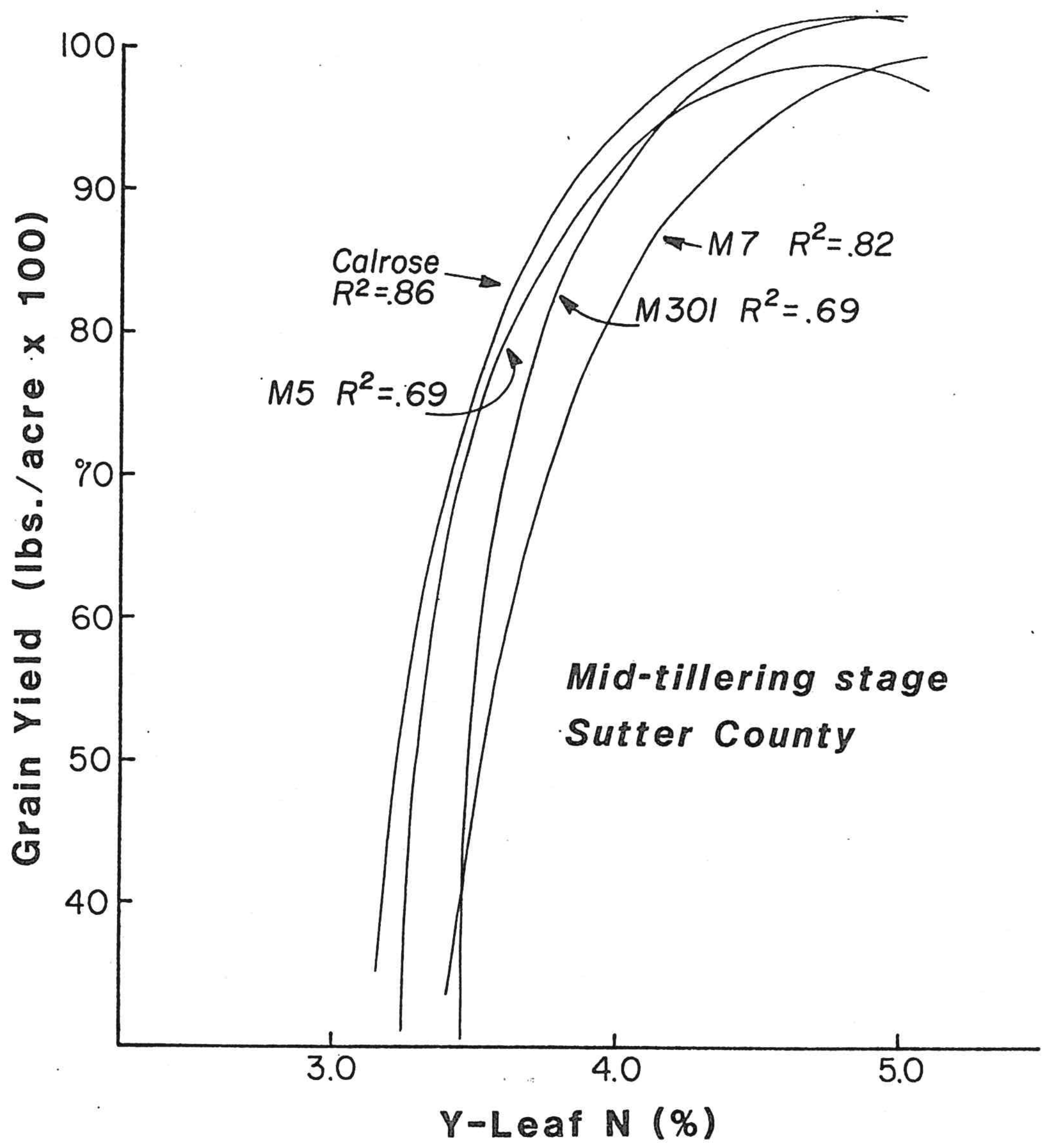

FIGURE 6. Relationships between "Y-leaf" nitrogen at the mid-tillering stage and grain yield in Sutter County trial.

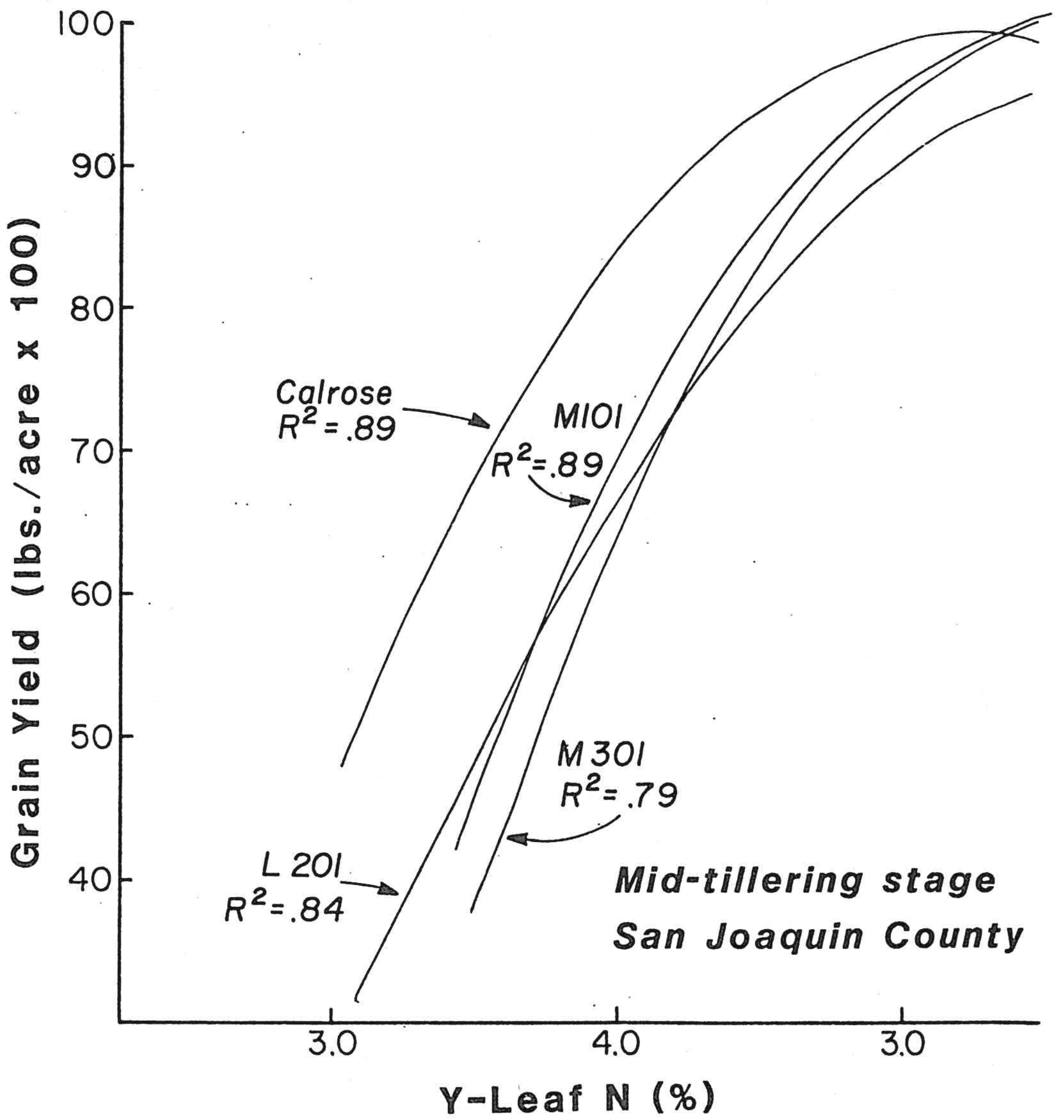

FIGURE 7. Relationships between "Y-leaf" nitrogen at the mid-tillering stage and grain yield in San Joaquin County trial.

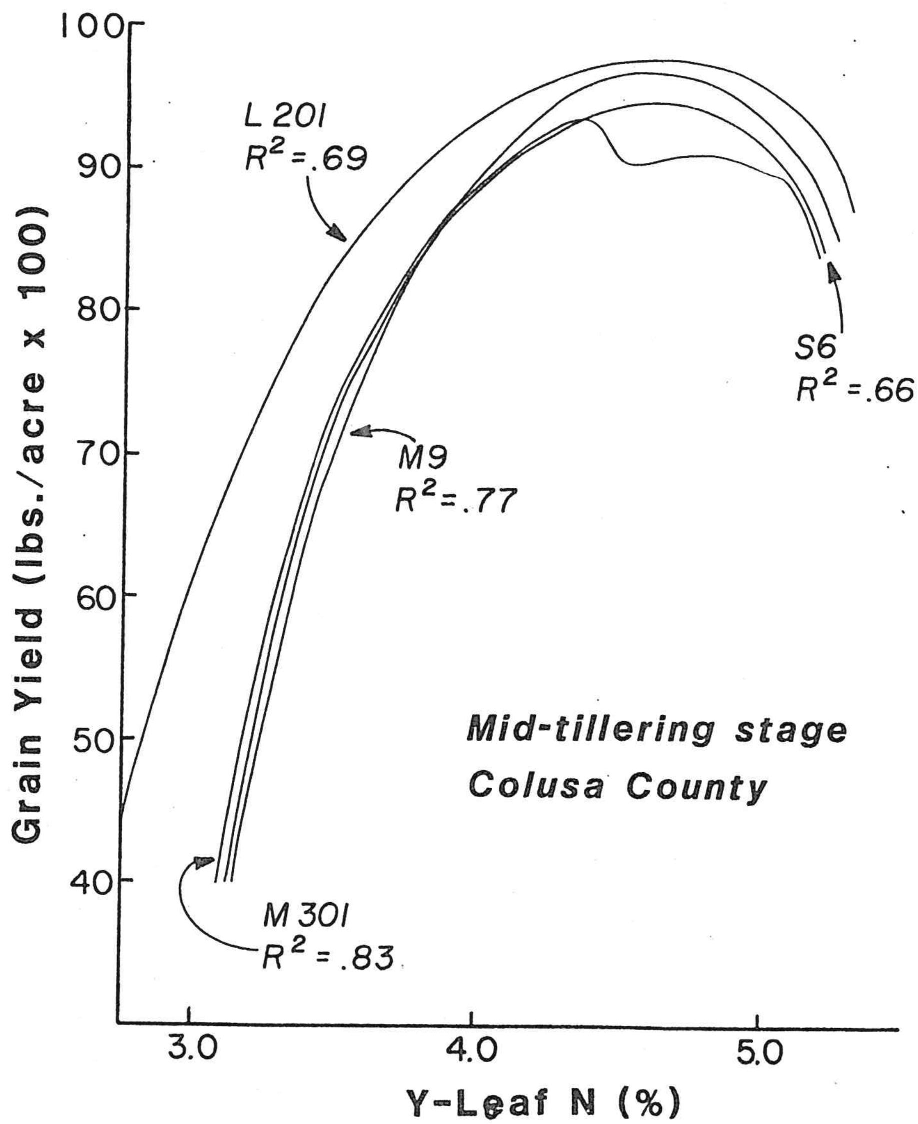

FIGURE 8. Relationship between "Y-leaf" nitrogen at the mid-tillering stage and grain yield in the Colusa County trial.

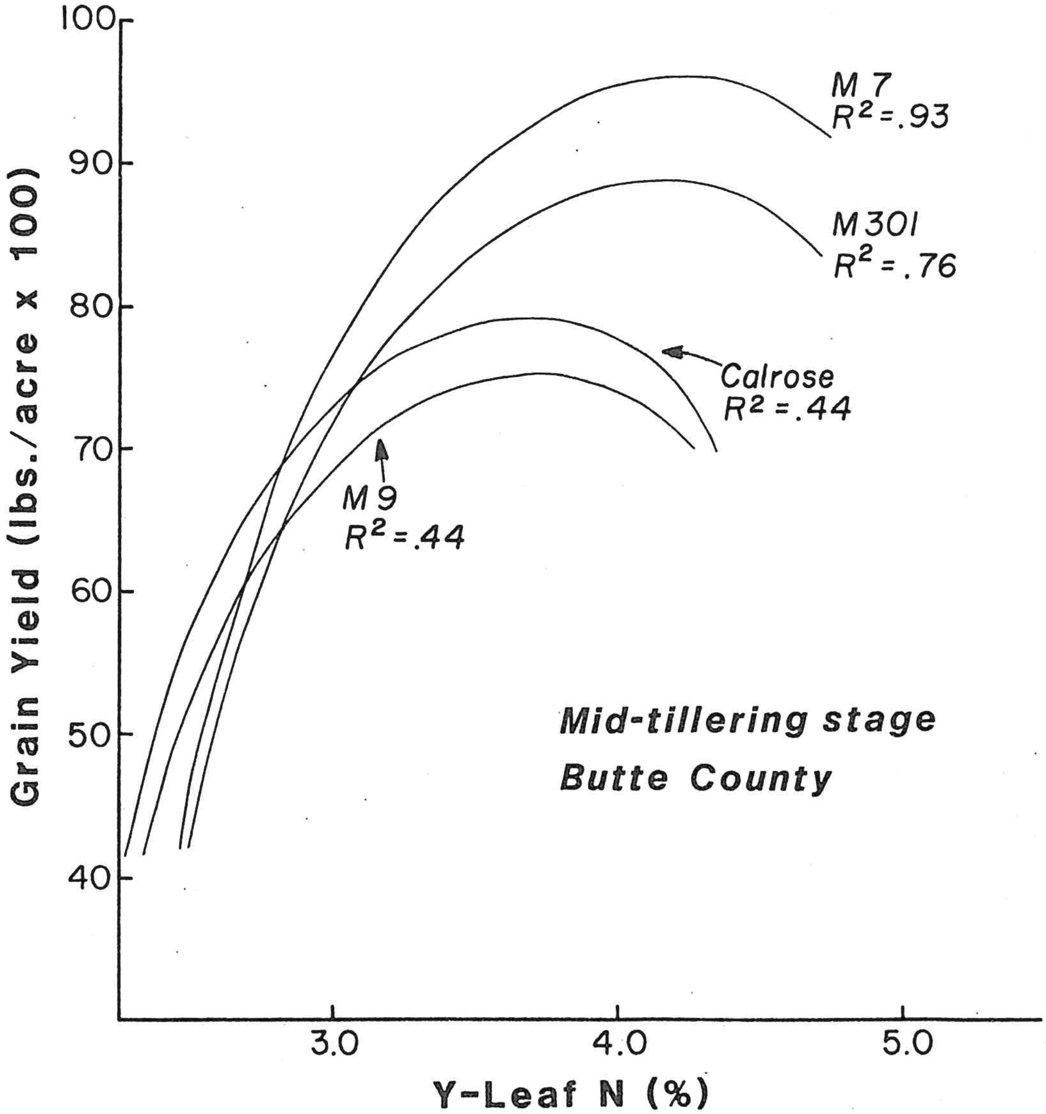

FIGURE 9. Relationships between "Y-leaf" nitrogen at the mid-tillering stage and grain yield in the Butte County trial.