

**CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)**

FINAL REPORT

Project Title: **DEVELOPMENT OF A LEAF COLOR CHART FOR
CALIFORNIA RICE VARIETIES**

Project Number: 01-0510

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with a no-cost extension to September 30, 2004.

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Executive Summary

The rice plant transitions through the most nitrogen sensitive growth stages within a few days. Therefore fertility management decisions must frequently be made for numerous large fields in a short period of time. Tissue sampling and subsequent lab analysis may not provide the needed information in a time effective manner. Furthermore, rice is grown under anaerobic soil conditions, thus rendering in-field tissue nitrate tests inapplicable.

To address the need for a real time nitrogen management tool, the authors initiated a project in 1998 to develop a leaf color chart (LCC) to estimate leaf nitrogen content in rice based on leaf color. Spectral data were used to fabricate a color chart consisting of eight acrylic plates (color cells) that accurately represents actual leaf color. Regression analysis of initial testing results relating leaf nitrogen to color revealed correlation coefficients ranging from 0.91 to 0.96 for the tested varieties. University of California and a commodity board funded the development and initial production costs. The overall objective was of this project the further development and adoption of the LCC, a low-cost real-time nitrogen management tool for rice in California.

Controlled replicated studies, area wide sampling, and grower generated information produced linear LCC calibration functions that predicted leaf N with a high degree of accuracy. R^2 values for the three calibration methods were 0.86, 0.87, and 0.81, respectively when data was pooled across varieties. The regression fitted equations were similar in slope (0.385, 0.426, and 0.433, respectively) and intercept (1.15, 1.01, and 0.85, respectively). Calibration equations varied somewhat between individual varieties. The single leaf technique of predicting leaf N proved to be more accurate than the whole field technique. Fertility management decisions would be better serve if based on results from the single leaf method. The whole technique is recommended to ascertain what portion of a field requires closely scrutiny with regard to plant nitrogen status.

The LCC was initially distributed to California rice growers and pest control advisors as part of a cooperative project. Individuals who agreed to participate in the on-farm phase of the calibration effort were provided an LCC and complete set of instructions free of charge. Project personnel supported the participants through organized training and demonstration events, on-farm consultations, and by telephone. The LCC was made available to the agricultural community at large upon request in 2003. All individuals requesting an LCC received one free of charge. To date over 400 LCC's have been distributed.

Outreach and education was continually pursued throughout the project. Twenty meetings of various sizes addressing aspects of the LCC were held during the contractual period. Project personnel delivered over 60 personalized on-farm consultations. Over 5400 project related contacts were logged during the project. Feedback from growers and PCA's indicated a fairly high acceptance rate of the LCC as a tool for nitrogen management.

Introduction

Precise fertility management of large acreage of rice necessitates a reliable real-time measure of leaf nitrogen. Research on rice and other plant species (1) demonstrated that leaf reflectance spectra predicts leaf nitrogen concentration. However, the instrumentation used to measure color is not suitable for on-farm use, and predictive reflectance wavelengths were frequently outside the visible range. Hand held chlorophyll meters (e.g., Model SPAD-1504, Minolta Ltd.), in contrast, can be used to estimate leaf nitrogen (2). These instruments are costly and require extensive sampling to accurately calibrate before they are useful. Another approach is to use leaf color directly as a predictor of leaf nitrogen. Noteworthy, the chlorophyll meter measures light transmitted through the leaf. Therefore its accuracy is influenced by leaf thickness, which can vary with a single leaf and influenced by production variables. A leaf color chart, in contrast, measures reflected light and therefore is independent of leaf thickness. A leaf color chart that allows the grower to match the color of a rice leaf (or field) to a series of colored panels was developed in Japan (Fujihari Ltd.). This chart is not readily available, and more importantly the color cells do not accurately match the leaf color of California public rice varieties (3).

To address the need for a real time nitrogen management tool, a project was initiated in 1998 to develop a leaf color chart (LCC, Figure 1) to estimate leaf nitrogen content in rice based on leaf color. Eight public varieties of rice were grown under a range of preplant applied nitrogen levels. Sample leaves at panicle initiation were harvested from all varieties and total nitrogen content chemically determined. The reflectance characteristics were measured with a spectrophotometer (Model 3700D, Minolta Ltd.) and described in three-dimensional color space using L*, a*, and b* designations of lightness, red to green scale, and blue to yellow scale, respectively. All colors in the visible spectrum can be described using L*, a*, b* color space (4), unlike other color systems, such as RGB, where only a subset of possible colors can be numerically quantified. Spectral reflectance characteristics of the individual leaves from the controlled experiment were recorded over the visible spectrum (400 to 700 nm) in 10 nm increments. Individual color cells and corresponding leaf samples for the LCC were incrementally partitioned across the range of b+ values (18 to 56) to produce 8 color cells (Figure 2). Spectral data were used to fabricate acrylic plates (color cells) representative of leaf color. The spectral characteristics of the color cells were tested repeatedly to ensure that leaf color was accurately described. Quality standards were met by evaluating color and color differences. Finished chips were then reevaluated for color quality, again using a spectrophotometer.

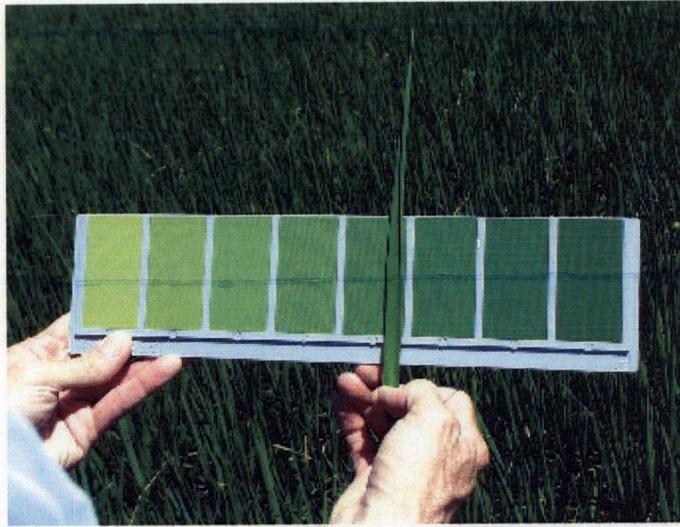


Figure 1. The University of California leaf color chart (LCC) predicts leaf N based on color.

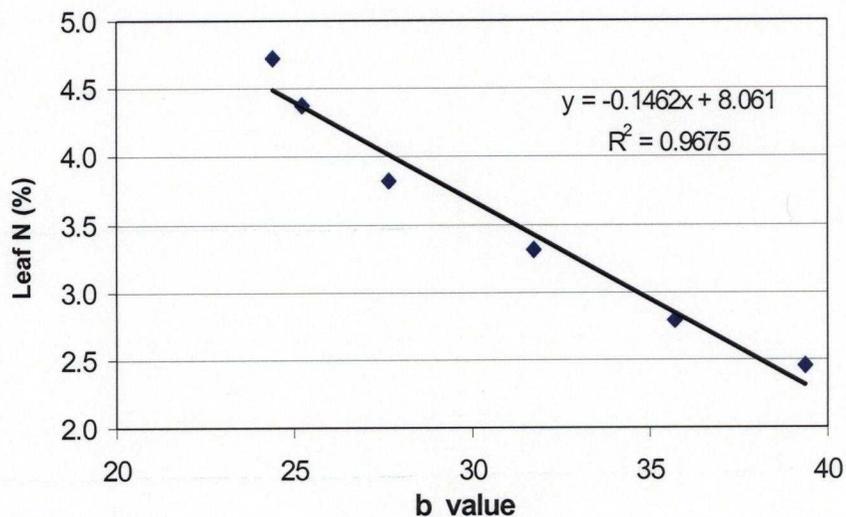


Figure 2. Relationship between b+ value and leaf N (%) in six medium and long grain California rice varieties. Each data point represents the average of 180 sampled leaves.

Special Qualities of the LCC. The LCC is constructed of high temperature acrylic plastic capable of withstanding temperatures of 180° F. The pigmentation in color cells is photo-stable. No measurable color change occurred following six months of continuous exposure to direct sunlight. Additionally, the LCC is linear. In that the incremental change in color and the associated tissue nitrogen is uniform between color cells. Thus, a user can effectively extrapolate between cells should a leaf be darker than one cell and

lighter than the adjacent one. Furthermore by design, the LCC color cells and the associated predicted nitrogen levels are highly correlated with the chlorophyll meter ($R^2 = 0.92$). Therefore, the LCC can easily be integrated into an existing fertility management system based on the chlorophyll meter.

The nitrogen status of rice at specific growth stages may be used for estimating supplemental nitrogen requirements and yield potential. Nitrogen status in the 'Y' leaf varies throughout the life cycle of rice (Figure 3). Because of this variability in leaf nitrogen it is essential that plants be sampled at a consistent growth stage for nitrogen management. Time of sampling must be based on the actual plant growth stage, not days after planting. Days after planting to panicle initiation, for example, may vary between years due to weather. Estimating tissue N status at critical points of the plant's life cycle can greatly improve the economics of rice production. The rice plant transitions through the most nitrogen sensitive growth stages within a few days. Therefore fertility management decisions must frequently be made for numerous large fields in a short period of time. Tissue sampling and subsequent lab analysis may not provide the needed information in a time effective manner. Additionally, rice is cultivated in an anaerobic, reduced soil environment. Consequently, quick tests for tissue nitrogen, such as petiole nitrate, are not applicable to rice where nitrogen is taken up as ammonia.

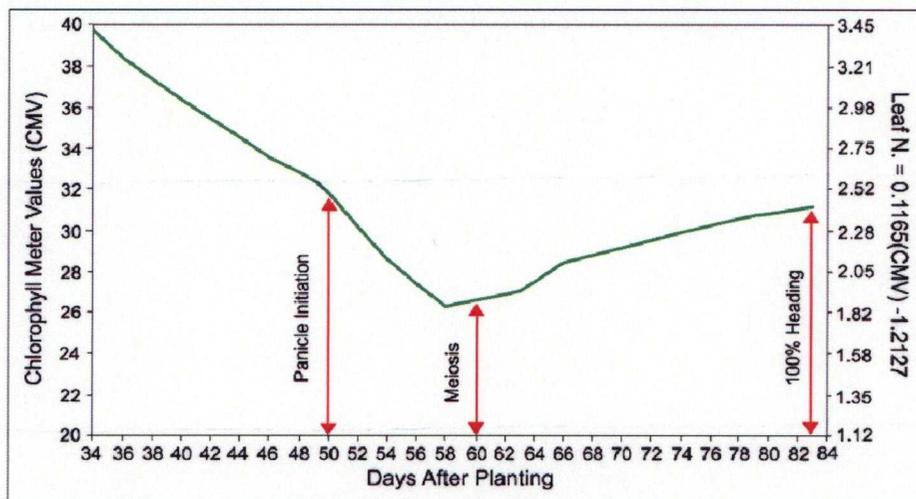


Figure 3. Seasonal variation in N content of the 'Y' leaf in short grain rice variety, Mutters and Eckert, 2000.

Furthermore, the LCC is a means to introduce key aspects of site specific management to growers' via a low-cost diagnostic tool. FREP supported research demonstrated that the improved economic and fertility use efficiency are possible by employing specific management strategies (5). The economic advantage is maximized in those crops (e.g. rice) where there is relatively large economic penalty for both under and over fertilization. Excessive nitrogen may induce sterile florets, promote fungal disease, diminish grain quality, and produce excessive soil nitrate run-off. Given that many growers apply mid-season fertilizer to their fields, the LCC enables them to more

accurately predict necessary application rates at the sub-field level if desired. Also, a more precise application of nitrogen fertilizer based on plant need and location in the field using the LCC is one means of improving fertilizer use efficiency which is particularly relevant the recent increase in fertilizer costs.

The overall objective was to introduce and promote the adoption of the LCC, a real time nitrogen tool for rice. Specific objectives were to:

- 1.) Refine the chart calibration algorithms for multiple varieties across location;
- 2.) Improve the use and sampling techniques for single leaf and whole field nitrogen determination;
- 3.) Promote the adoption and proper use of the LCC through a series of field meetings and workshops training growers and PCA's.

Materials and Methods

The general schedule of project events is outlined below. Although the original term of the contract expired on December 31, 2003, an extension was requested so that the results of the project could be disseminated to the agricultural community during the winter and spring of 2004.

Year 1 – 2002

- Winter
 - Present currently available information about LCC at UCCE meetings
 - Solicited grower participation for on-farm calibration
- Summer
 - Nitrogen by variety experiment (controlled calibration study)
 - Valley wide leaf sampling and calibration by UC personnel
 - Grower collected leaf samples and calibration
 - Evaluated adequate and excessive leaf N levels
 - Outreach and education: field days and on-farm consultations

Year 2 – 2003

- Winter
 - Grower outreach and education: UCCE meetings and workshops
 - Distribution of LCC to growers and agricultural professionals
- Summer
 - Split N controlled studies
 - Whole field calibration of LCC
 - Outreach and education: field days and on-farm consultations

Year 3 – 2004

- Results disseminated to growers at UCCE meetings and workshops

- Updated single leaf and whole field calibrations for LCC
- LCC and instructions distributed free of charge upon request
- Results from controlled studies
- Provide in-field assistance to growers during the growing season

Objective 1. Refine the chart calibration algorithms for multiple varieties across location.

This objective was addressed using a three phase approach: controlled studies, sampling multiple locations across the rice growing region, and cooperators provided tissue samples with corresponding LCC values. The logic was to first, develop an expanded calibration for the LCC based on multiple varieties under carefully controlled conditions. Secondly, the broad area sampling of rice fields with known varieties provided a means to validate experimental results across a range of production conditions. And lastly, it was crucial to confirm the reliability of the LCC when used by a highly varied audience. In that, all data prior to this aspect of the project had been gathered by UC personnel intimately familiar with the LCC. By analyzing samples submitted by growers, we were able to ascertain the utility of the LCC when used by a range of clientele and determine the degree of training that might be needed before the LCC could be fully integrated into the on-farm management.

Controlled Studies. Experimental sites were used to address Objectives 1 and 2. Eight public rice varieties (M-202, M-205, M-103, S-201, L-204, L-205, Calhikari, and Calmati) were grown under six nitrogen levels (0, 40, 80, 120, 160, and 200 lb/a) at two on-farm locations in 2002 and 2003 located in Butte and Colusa counties. Nitrogen treatments were applied prior to planting. Preplant nitrogen was applied as ammonium sulfate with a precision applicator (Clampco Inc, Hollister, CA) in a prepared seed bed. The varieties were hand-sown at a seeding rate equivalent to 150 pounds per acre of seed into a replicated experiment in a two-factor randomized complete block design in collaborating growers' fields. Individual experimental plot size was 10 X 20 feet. Foundation seed for each variety was provided by the California Rice Experiment Station, Biggs, CA. Field preparation and management followed standard grower practices. Bolero at 3.7 lb ai/ac was applied 5 days after seeding (5 DAS) for grass control and Shark at 8 oz/ac 7 DAS was used for broadleaf and sedge weed control. An application of Quadris at 10 oz/ac was made to the whole field including the plots.

For all field experiments, plant growth and development was recorded throughout the growing season. Leaf sampling for the calibration phase of the project began at the onset of tillering and continued through panicle initiation (onset of the reproductive phase). Observations relating leaf color according to the LCC to tissue nitrogen at the single leaf ('Y' leaf) and whole canopy levels were taken at mid-tillering (~ 40 days after planting, depending on variety) and panicle initiation (~60 days after planting). For single leaf measurements, 20-30 recently expanded leaves corresponding to the range of LCC panels were harvested and will be subsequently analyzed for total nitrogen (DANR Laboratory, UCD). The replicated study was harvested with an experimental plot combine (SWECO, Sutter, CA) and yields standardized to 14% moisture content. Final rice height, lodging,

grain moisture, and yield data were recorded. JMP software from SAS Institute was used to generate the ANOVA, curve fitting, and regression analysis.

Calibration of the Leaf Color Chart. Regression equations related leaf color chart readings in the field to lab results of leaf N (%) for both the single leaf and whole field methods of using the color chart. Leaf color was used as the Y-variable and regressed onto leaf N, which was treated as a fixed X-variable because the variance in leaf N (calculated from duplicate lab tests on the same sample) was estimated to be much lower than the variance in the leaf color variable. Curve fitting then, minimized the squared deviations in leaf color for a given level of leaf N, and produced linear or quadratic equations of best fit. Curves fit separately for each variety were compared and then varieties were grouped together and fitted to a single curve if their regression lines lay within a 95% confidence band of each other.

For each case, the best fit regression equation that gave leaf color in terms of leaf N was solved for leaf N in terms of leaf color. These prediction equations were entered as formulas in a spreadsheet cell that calculates a predicted leaf N(%) for any value of leaf color. Note that since linear regressions always predict the mean of the Y-variable for the mean of the X-variable the agreement of actual and predicted leaf N provide a check on the equation. Prediction equations were then used to generate leaf N values that correspond to leaf color panel numbers that span the range of applicability of the equation.

Determine Adequate and Excessive Levels of Leaf N. To augment the use of the LCC to manage plant N during the growing season, data were gathered to determine ‘adequate’ and ‘excessive’ levels of leaf N in selected varieties. Real time leaf N levels as determined by the LCC, for example, require knowledge of the growth stage appropriate optimal N levels. An “excessive” level of leaf N was defined as the level at which yield began to decrease. For the varieties that tolerated excessive fertilization without a decrease in yield, the highest values of leaf N observed were taken to be the excessive value. For this reason, the levels of excessive leaf N as defined here may be higher than other estimates. Clearly, in an economic sense, any nitrogen level above adequate is wasteful, and therefore could be defined as “excessive”.

Adequate and excessive values of leaf N observed at mid-tiller and panicle initiation stages were determined by detailed examination of the yield response curves for each variety. An “adequate” level of leaf N was defined as the level above which yield did not increase further. The selection of the inflection points where the slope of the curve changed was facilitated by the “smoothing spline fit” feature of the JMP program. The flexibility of a curve fit made up of different polynomials in different sections is controlled by the parameter that enables the user to adjust the curvature of the fitted curve for clearest indication of adequate levels. Even with this tool, however, the choices involved uncertainty in some cases. Therefore, in an effort to improve upon the estimates from leaf N alone, plots of yield response versus single leaf and whole field color, and rice height and cover variables were also used to obtain independent estimates of adequate and excessive levels of these variables. Although the critical values of these

variables could be used in the field directly (data not shown), they were used here to provide several independent estimates of the adequate and excessive values of leaf N. Leaf color values were transformed to leaf N values by the equations derived above.

Grower Participation. Grower involvement in the field testing of the LCC was solicited at the annual UC Cooperative Extension rice growers meetings in January 2002. Winter meetings were held at four locations around the Sacramento Valley and had a total attendance of around 500. Growers were invited to participate in the 2002 valley-wide field testing of the LCC.

Cooperating growers were sought through personal contact, educational meetings, UCCE, Rice Research Board, and California Rice Commission newsletters. Approximately 1000 growers were reached through newsletter mailings. All participants received a LCC (free of charge) and complete set of written instructions (Figure 4).



Figure 4. Leaf color chart, protective sleeve, and instruction sheet provided to rice growers and pest control advisors free of charge.

Over 160 individuals participated in the study (see Appendix B). Growers and PCA's that signed the 'Participation Sign-up' sheet were mailed an instruction sheet describing the project (see Appendix C). Sampling instructions, tissue air-drying procedures, and a representative set of sample bags were provided. Growers were ask to provide 20-30 individual, recently expanded leaves corresponding to the each color cell. Participant growers supplied 61 samples consisting of 20-30 individual, recently expanded leaves corresponding to the each color cell. Samples received by mail or picked up during on-

farm visits will be catalogued by location, variety, and growth stage. Pertinent cultural practices that could affect results (e.g. application of triclopyr a few days before sampling) were noted. The grower matched as many cells as practical in a given field. Air dried leaf tissue samples will be submitted to the UC DANR Laboratory for analysis.

Multiple Location Sampling. UC staff collected leaf samples from fields throughout the valley in 2002. Samples were taken from 86 fields in 8 counties. The 20-30 of the most recently expanded leaves were harvested and the corresponding color value according to the LCC recorded. Five samples were taken from each visited field and analyzed separately. The variety, growth stage, and location were recorded. Leaf samples were oven dried at 60 C and submitted to the DANR Laboratory for total N analysis.

Objective 2. Improve the use and sampling techniques for single leaf and whole field nitrogen determination.

Whole field calibration of the LCC required a more extensive sampling protocol. Canopy color in rice is a function of the top two to three leaves (7). Consequently, the color of the field is actually a function of the human eye integrating the combine color of the upper canopy. Since the chlorophyll content of a leaf changes with age it is probable that the color of the leaves will differ accordingly. Moreover, the position of the individual leaves in the canopy will influence their relative contribution to overall canopy color. In the controlled studies, individual plots were evaluated for overall color and assigned a color cell value.

Extensive leaf sampling of the canopy was conducted at several growth stages (tillering, panicle initiation, pollen meiosis, and boot) for developing single leaf and whole field calibration of the LCC. Leaves from the top 3 leaf positions were harvested and dried. For the whole field methods, nitrogen levels in top three leaves at the various growth stages and their associated color will be processed using regression analysis to determine the relative contribution of each leaf to the over all color of the field. The result will be a unique whole field calibration based on canopy characteristic.

Split Nitrogen Study.

In 2003, a split N application experiment was also conducted. The purpose of the experiments was to determine the incremental response in terms of tissue N concentration at discrete stages of growth to various rates of midseason N application. This is an important aspect of mid season N management using the LCC for real time N management. Increasingly, growers apply mid-season applications of N to rice fields. The standard varieties M-205 and M-202 were grown at a range of preplant N levels and then top dressed at tillering and/or panicle initiation (Table 1). The split application of nitrogen was applied by hand using ammonium sulfate when the plants began to tiller and reached panicle initiation about 60 days after planting. Results were compared to those from the nitrogen by variety trial.

Total N and the values given under treatment are N rates in lbN/ac at the preplant, mid-tiller (MT), and panicle initiation (PI) stages. Both sites were seeded by airplane at the rate of 150 lb seed/acre. Regiment (14 g/ac at 25 DAS) and a tank mix of SuperWham (4 qt/ac) and Grandstand (4 oz/ac) at 38 DAS was applied at the Colusa site to control weeds. Weeds were controlled at the Butte site with Bolero (3.7 lb ai/ac at 5 DAS) and Shark (8 oz/ac at 7 DAS). Sampling of Y leaves for leaf N analysis, evaluations of leaf color, and applications of ammonium sulfate for the split treatments were made at 40 DAS for the mid-tiller stage, 47 DAS for the PI stage, and 54 DAS for the sampling one week after PI. Other data on rice height, density, cover, heading dates, and lodging, were also recorded. All leaf samples were submitted to the DANR Laboratory, UCD for analysis of total N, P, and K. All plots were harvested with the UCD plot harvester which gave yield and grain moisture.

Table 1. Assigned treatments for the split N application study. Treatments were applied at preplant, tillering (MT), and/or panicle initiation (PI). For example, the treatment 33-33-33 refers to 33 lb/a N applied at preplant, MT and PI.

Total N	Split	Treatment
0	None	0-0-0
100	None	100-0-0
100	MT	67-33-0
100	PI	67-0-33
100	MT/PI	33-33-33
125	None	125-0-0
150	None	150-0-0
150	MT	100-50-0
150	PI	100-0-50
150	MT/PI	50-50-50
175	None	175-0-0
200	None	200-0-0
200	MT	100-100-0
200	PI	100-0-100
200	MT/PI	100-50-50

Objective 3. Promote the adoption and proper use of the LCC through a series of field meetings and workshops training growers and PCA's. The outreach phase of the project focused on grower training, in-field assistance, and the distribution of the LCC.

Development and maintenance of a LCC grower database. The second phase of grower involvement was the integration of the color chart into on-farm nitrogen management. A database of participating growers was developed that includes contact and production information. The database was used to assist with data interpretation and for mailing

updated information (e.g. multi-variety calibration table) to growers that use the LCC. During the second of the project free color charts were sent to all that requested one. Thus the first year distribution was to those that signed up to participate in the on-farm leaf sampling exercise; the second year was to the rice community in general.

Growers were advised that the predicted N values are based on currently available data. Although it is reliable, it should be considered a work in progress and subject to minor modifications depending on the outcome of the current experiments. Upon completion of the current FREP funded study, a final calibration table was developed based on data from all years.

On-farm visits. Project personnel made numerous on-farm visits to assist with sampling and provide instruction during late June and July when plants were transitioning into the reproductive stage (a critical time for nitrogen management). Project personnel could be reached by telephone or email and were available to assist with sampling or answer questions.

Field days. Field meetings were conducted at 2 locations in 2002, 2003, and 2004 to provide instruction in the use of the LCC and on proper sampling protocol. Handouts with useful information were available. Meeting dates and times were widely advertised via newsletters and local media. All meetings were open to the public and conducted in compliance with the University of California's affirmative action policy.

Field days were conducted prior to 'leaf sampling season' to ensure that the LCC is properly used and to clarify sampling protocol needed for the study. Meetings were held at four locations in the Sacramento Valley. Sign-up sheets at the meetings were used to generate a mailing list of active participants. LCC users were advised of developments and updated materials (e.g. new calibration tables) available by mail.

Annual meetings. Experimental results were presented at the annual Cooperative Extension rice grower meetings. Four Cooperative Extension sponsored meetings were held in February 2002 and January 2003 and 2004 in Yuba City, Colusa, Glenn, and Gridley, CA. Growers were invited and encouraged to participate in the Valley wide project.

Rice Production Workshops. All day workshops at two locations were conducted in 2002 and 2003 and one location in San Joaquin County in 2004. The use of the LCC in N management was an integral part of the Fertility Management section. All attendees received a 12 chapter production manual, which included a discussion of the LCC and its use.

Newsletters. Information and updates of the project were included in the periodic CE newsletters that were circulated throughout the Sacramento Valley. Information was also included on the UC Rice Web page.

Results and Discussion

Nitrogen X Variety Trial: Calibration of the LCC for selected varieties

The principle objective of the controlled study was to refine the calibration of the LCC across a range of varieties. However as a matter of course yield data was also recorded (Table 2). Among the varieties tested, on average M-206 was the apparent highest yielding variety although there was no significant difference in yield between top three producing varieties. The most striking was the relatively low rates of N at which the highest yields were observed. Growers typically apply between 125 and 170 lb/a N depending on the operation. In this case, for example, M-206 produced the highest yields at 100 lb/a. Cropping history and straw management practices apparently contribute substantially to the inherent soil fertility. Long term and more recent on-farm studies conducted by UC scientists demonstrated that N can be reduced by 25% without affecting yields (8). The zero N treatments produced between 4577 and 5825 lb/a, which is evidence of the residual N fertility present in the soil. Importantly, the LCC estimates the leaf N that is present, irrespective of the amount actually applied. The optimal N fertility levels to ensure good production at a given location does not affect the accuracy of the LCC. The yields of the test varieties were comparable to previous results (3). Thus plant productivity was assumed to be representative of the individual varieties and therefore a good test population for the calibration of the LCC.

Table 2. Ranked yields across location by variety at optimum and zero nitrogen rates in 2002.

Variety	Optimum			Zero N		
	N Rate	Yield (lb/ac)	Rank	Rate	Yield (lb/ac)	Rank
M206	100	8405	1	0	5825	2
M205	100	8209	2	0	5257	4
S102	50	8007	3	0	6294	1
M202	50	7802	4	0	5657	3
M104	100	6998	5	0	4862	5
M402	50	6110	6	0	4577	6
Mean		7589			5412	
LSD(0.05)		413			515	
CV(%)		6.8			7.4	

The confidence bands were used to determine whether a quadratic fit was significantly better than a linear fit for the same variety group and stage (data not shown). However, in most cases a linear fit was sufficient (Figure 5). A linear fit as determined by confidence bands adequately described the relationship between the single leaf color and percent leaf N at two stages of growth. These variety groups, based on similar

relationships of leaf color to leaf N, are the same groups that might be expected from similar yield responses. The LCC predicted leaf N with a greater degree of confidence at panicle initiation as compared to readings taken at mid tiller (Table 3). Regressions for mid-tiller (40 days after seeding, DAS) stage was significantly different in all variety groups. The time difference between the mid-tiller sampling and the PI sampling appeared to cause larger differences in the relationship between leaf color and leaf N than the difference between variety groups. For greatest precision, the calibration equation specific for stage, variety, and method (single leaf of whole field) should be used. Equations for all varieties and stages are presented at the bottom of Tables 3 that are useful as a general approximation, but results in somewhat lower R-Square values (e.g. at PI $R^2 = 0.86$). Nonetheless given the need to adapt the LCC to wide range of varieties and to keep the interpretation of results straight forward, the across variety regression curve was used to generate the single leaf calibration curve that is included on the back of the LCC.

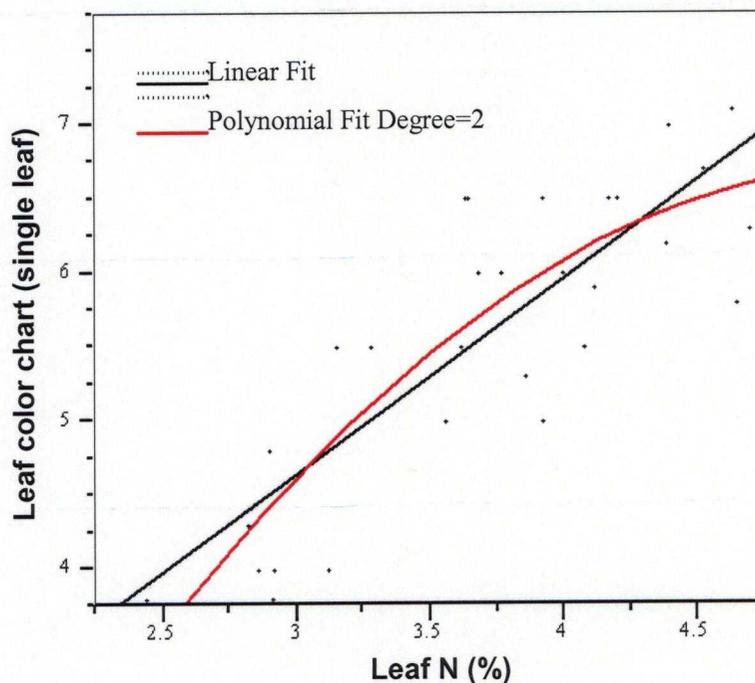


Figure 5. Single leaf color regression onto leaf N(%) for M402/S104 variety group at mid-tiller stage. Since quadratic fit lies within 95% confidence band of linear regression line it is not a significantly better fit. (See Table 3 for linear equation, R-Sq = 0.86).

Table 3. Determination of leaf N from single leaf color at mid-tiller and panicle initiation stages for each variety: equations of best fit, applicable range, leaf N(%) calculation.

Variety	Stage	Fitted equation of Leaf Color vs Leaf N(%) Prediction equation	R-Square	LCC Range
M205	MidTlr	$N = 0.344 * LCC + 0.925$	0.76	$1.3 \leq LCC \leq 3.7$
M206	PI	$N = 0.420 * LCC + 1.01$	0.91	$1.4 \leq LCC \leq 4.4$
	Both Stages	$N = 0.430 * LCC + 0.869$	0.66	$1.3 \leq LCC \leq 4.3$
M202 S102	MidTlr	$N = 0.377 * LCC + 1.289$	0.79	$1.7 \leq LCC \leq 4.3$
	PI	$N = 0.376 * LCC + 0.883$	0.88	$1.3 \leq LCC \leq 3.9$
	Both Stages	$N = 0.380 * LCC + 0.730$	0.72	$1.1 \leq LCC \leq 3.8$
M402 M104	MidTlr	$N = 0.365 * LCC + 1.045$	0.86	$1.4 \leq LCC \leq 4.0$
	PI	$N = 0.416 * LCC + 1.11$	0.90	$1.6 \leq LCC \leq 4.4$
	Both Stages	$N = 0.395 * LCC + 0.933$	0.76	$1.3 \leq LCC \leq 4.1$
All Varieties	MidTlr	$N = 0.437 * LCC + 0.983$	0.70	$1.4 \leq LCC \leq 4.5$
	PI	$N = 0.385 * LCC + 1.15$	0.86	$1.5 \leq LCC \leq 4.2$
	Both Stages	$N = 0.432 * LCC + 1.2079$	0.66	$1.6 \leq LCC \leq 4.7$

Adequate and Excessive levels of leaf N

Adequate and excessive values of leaf N observed at mid-tiller and panicle initiation stages were determined by detailed examination of the yield response curves for each variety. An "adequate" level of leaf N was defined as the level above which yield did not increase further. That is, the point at which the yield response curve began to flatten or peak. An "excessive" level of leaf N was defined as the level at which yield began to decrease. Adequate and excessive leaf N for M-206, M-205, and M-104 were 3.6 to 4.8, 3.6 to 4.2, and 3.4 to 4.7, respectively (Figure 6). M-205 exhibited the greatest sensitivity in terms of yield to leaf N levels. Optimal yields for M-205 occurred within a narrow range (0.6 %) as compared to M-104 (1.3%). Results imply that greater care must be taken in the N management of M-205 to ensure productivity. The sensitivity of yield to tissue N levels underscores the utility of the LCC for real time N management. In that fertilization decision are better served by leaf analysis and growth stage rather than routine or days after planting. Moreover, these decisions must be made within a narrow range of plant development which may not be possible using conventional laboratory tissue analysis because of the potential time delays.

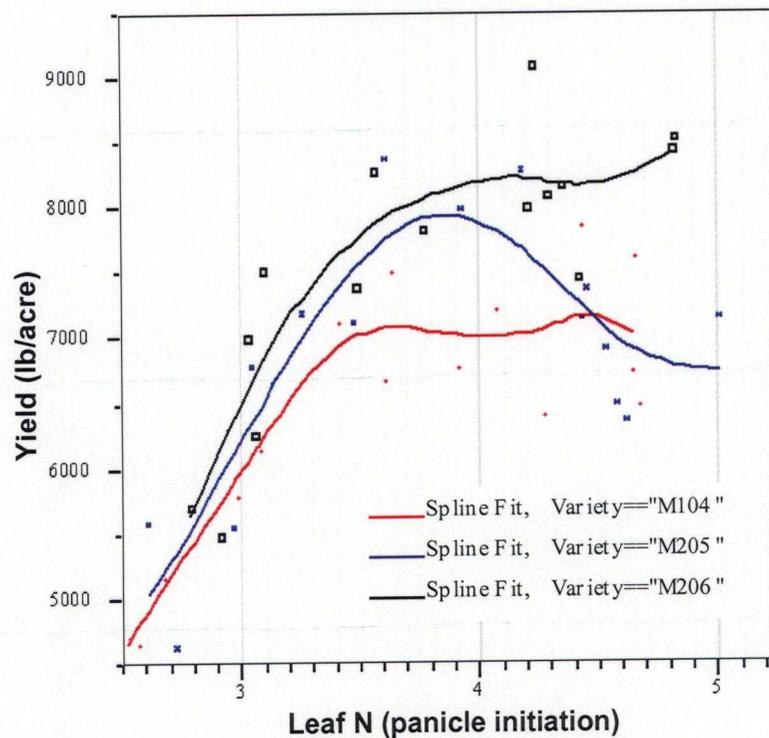


Figure 6. Adequate and excessive leaf N values for M206, M205 and M104.

For the varieties that tolerated excessive fertilization without a decrease in yield, the highest values of leaf N observed were taken to be the excessive value (Figure 7). Yields

of M-202 were stable over a range of leaf N of 1.5% (3.2 to 4.7%). It was the least sensitive variety to changes beyond adequate leaf N among the varieties tested. Adequate levels for S-102 and M-402 were 2.9 and 3.1 percent, respectively. In a fashion comparable to M-205, the yields of M-402 dramatically declined once leaf N exceeded 3.6 percent at panicle initiation. The small difference in adequate and excessive leaf N for varieties M205 and M402 emphasizes that just a slight over fertilization of these varieties may decrease yield.

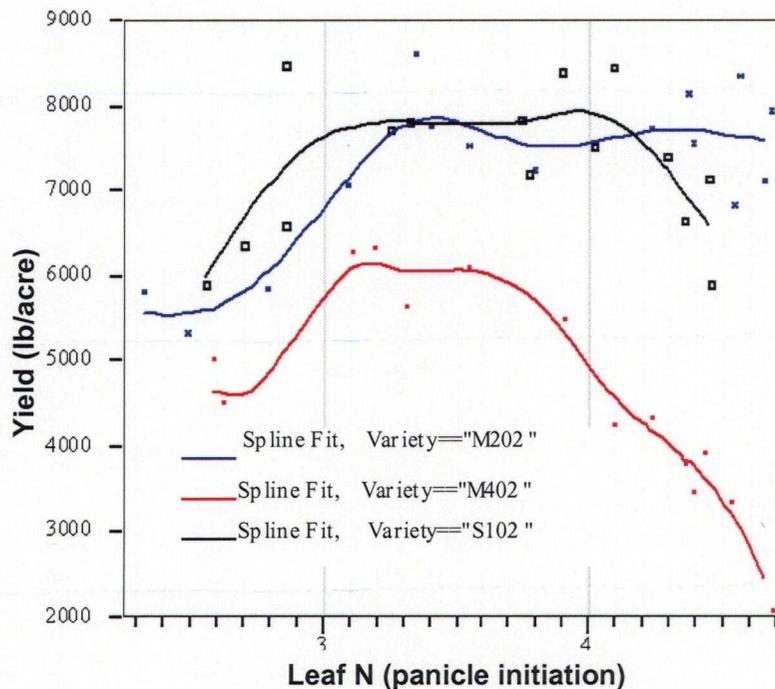


Figure 7. Adequate and excessive values for M202, S102 and M402.

Adequate and excessive heights were transformed to corresponding adequate and excessive values of leaf N using highly correlated linear regression equations (Figure 8). Coefficients of determination relating plant height to leaf N were 0.90 for M202, 0.93 for S102, and 0.94 for M402. Adequate and excessive values read from this plot were 24" and 30" for both M202 and S102 and 20.5" and 24" for M402, respectively. Although the critical values of these variables could be used in the field directly (data not shown), they were used here to provide several independent estimates of the adequate and excessive values of leaf N. Leaf color values were transformed to leaf N values by the equations derived above (Tables 3). Rice height and cover variables were correlated very highly with leaf N and were transformed by appropriate regressions for each variety and stage (see Figure 9 for example).

On average, yield was most sensitive to leaf N at mid tiller as compared to PI as indicated by the smaller range (Table 4). M-104 was the least sensitive to over fertilization at mid tiller and M-402 was the most likely to exhibit a yield loss with excessive levels of leaf N as indicated by the difference between excessive and adequate levels. M-206, M-104, M-202, and S-102 were less sensitive to over fertilization at PI as compared to mid tiller.

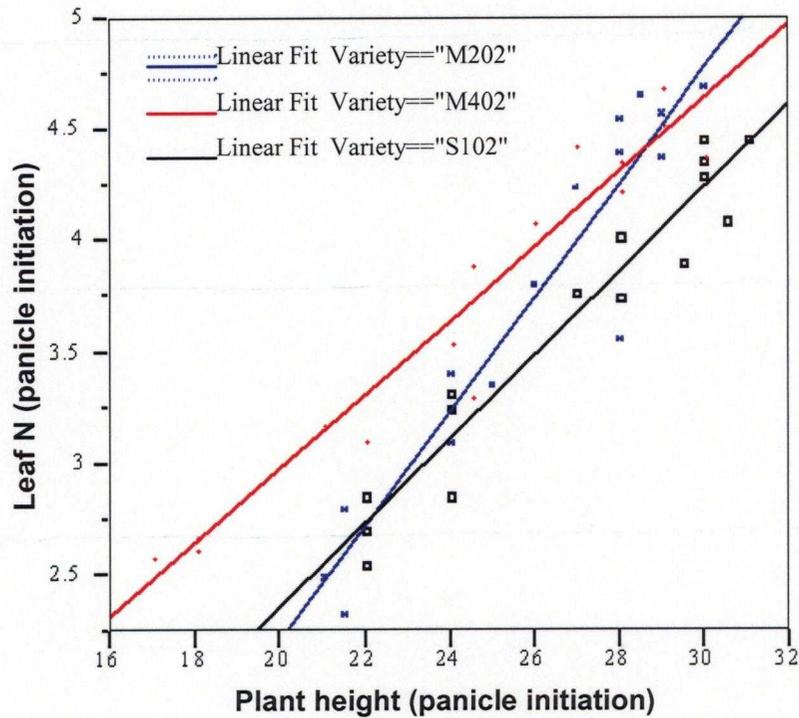


Figure 8. Adequate and excessive heights were transformed to corresponding adequate and excessive values of leaf N using highly correlated linear regression equations.

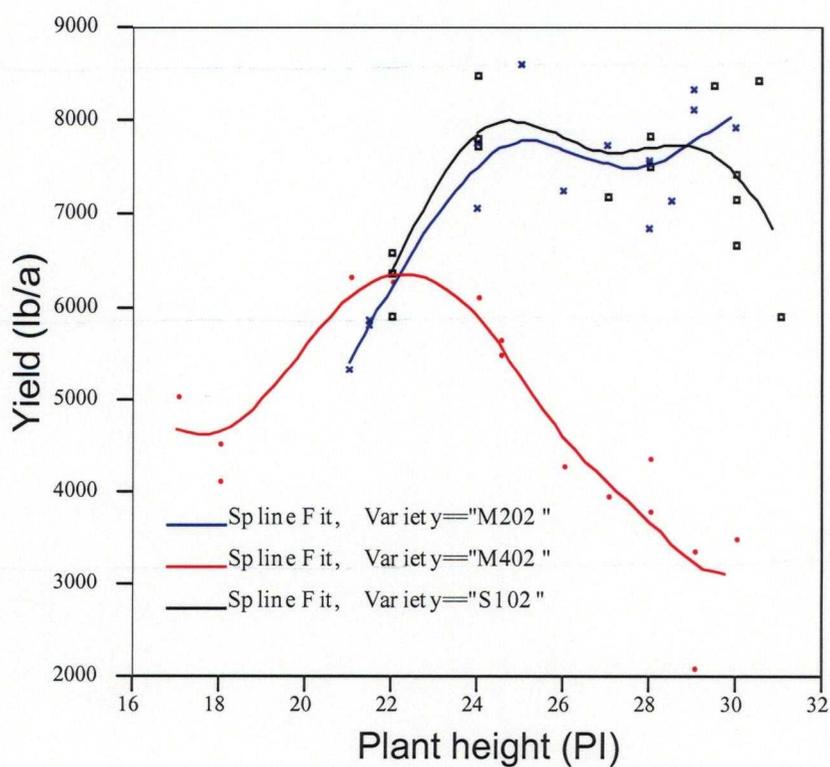


Figure 9. Adequate and excessive values read from this plot were 24" and 30" for both M202 and S102 and 20.5" and 24" for M402, respectively.

Table 4. Adequate and excessive values of leaf nitrogen (%) at mid tiller and panicle initiation stages for six varieties of rice in 2004.

Variety	Leaf Nitrogen (%)					
	Mid-Tiller Stage			Panicle Initiation Stage		
	Adequate	Excessive	Exc - Adq	Adequate	Excessive	Exc - Adq
M206	4.1	5.0	0.9	3.7	4.8	1.2
M205	3.8	4.5	0.7	3.7	4.4	0.7
M104	3.8	5.0	1.2	3.5	4.7	1.2
M202	3.6	4.6	0.9	3.0	4.7	1.6
S102	3.4	4.2	0.8	3.0	4.2	1.1
M402	3.5	4.0	0.5	3.1	3.7	0.6
Mean	3.7	4.5	0.8	3.3	4.4	1.1
Chart	4.0	4.6	0.6	3.2	3.6	0.4

Valley Wide Multi-location Sampling and Calibration

UC staff collected samples from 86 fields in 8 counties in Sacramento Valley. Data from valley sampling pooled across location and variety indicated a strong linear relationship between the LCC and leaf N (Figure 10). There were no discernible differences in the accuracy of the LCC between varieties (data not shown). One calibration curve describes the relationship between the LCC and tissue N for all varieties. Interestingly, the slope of the regression line is similar to one derived from the grower provided pooled samples, 0.426 and 0.443 (Table 6), respectively. The zero intercept differed between the two afore mentioned functions by only 0.16 %. The good agreement between the two calibration methods points to the reliability of LCC to ascertain real time plant nitrogen status across a wide range of growing conditions.

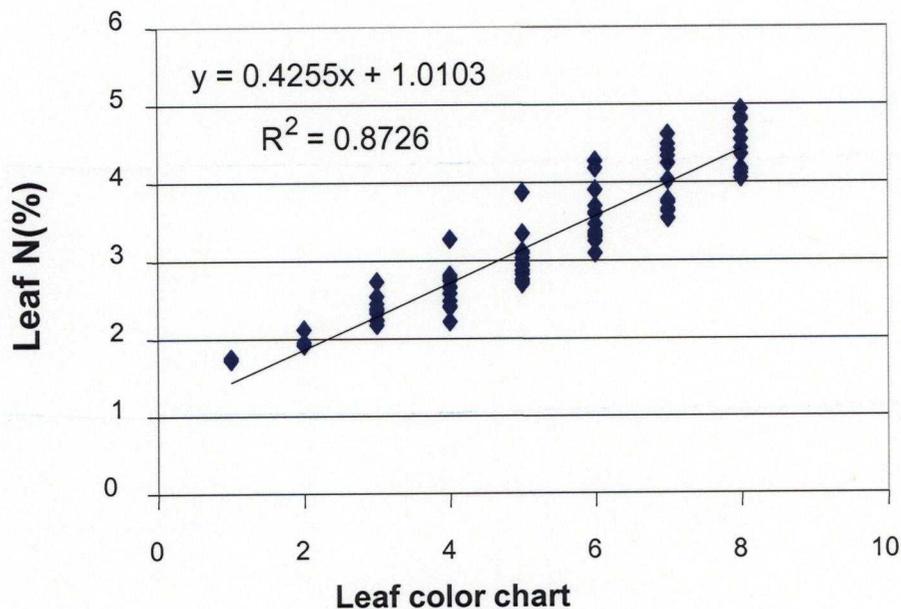


Figure 10. Leaf nitrogen (%) as a function of LCC values for rice leaves at panicle initiation for nine varieties collected in the Sacramento Valley in 2003. N = 86.

Grower Field Testing and Collaboration

In an effort to field test the LCC under 'real world' conditions collaborating growers were sought at meetings and through newsletters. Over 165 growers signed up to participate in the study (Appendix B). Thirty nine participating growers mailed in 61 samples consisting of 20-30 individual, recently expanded leaves corresponding to the each color cell from across the Sacramento Valley. Leaf samples represented 7 varieties of rice. The LCC predicted leaf N with a high degree of accuracy for all varieties tested by the growers (Table 5).

The accuracy of the LCC when used by participating growers compared favorably to results obtained from the controlled experiments (Table 3). The lower R^2 value for the pooled data could be attributed in part to difference in varieties. Previous work (3) demonstrated that there were slight but statistically insignificant variations in the calibration curves between varieties. Admittedly a limited number of samples were available for some varieties. However, based on this sample population of clientele the LCC is readily adaptable to different varieties across a range of growing conditions.

Table 5. Correlation analysis describing the relation between leaf N content predicted by the leaf color chart used by growers and percent leaf N as determined by laboratory analysis for selected varieties of rice. Samples were taken at panicle initiation.

Variety	Regression equation	R2	N
Akitakomachi	$Y = 0.432X + 0.891$	0.891	2
Arborio	$Y = 0.427X + 1.236$	0.948	2
M-104	$Y = 0.389X + 0.956$	0.842	3
M-202	$Y = 0.483X + 0.920$	0.920	18
M-205	$Y = 0.581X + 0.471$	0.940	15
M-206	$Y = 0.413X + 0.865$	0.837	11
M-401	$Y = 0.442X + 0.769$	0.885	8
All varieties combined	$Y = 0.443X + 0.846$	0.812	61

Split N Study

Whole Field Calibration

A split N application experiment was conducted to ascertain the accuracy of estimating leaf N using a whole field method (WF) and substantiate adequate levels of leaf N as determined in the 2002 experiments. WF predicted less N content than did the single leaf (SL) method (Figure 11). At mid-tiller stage mean of WF color (4.84) was 0.74 color panels less than SL color (5.58). At PI stage mean WF color (4.31) was 1.72 color panels less than SL color (6.03). The relationship was a parallel over the range of the LCC. Although leaf color measured by the whole field method correlated rather well with the single leaf method at each stage ($R-Sq = 0.67$ and 0.74 at mid-tiller and PI stages, respectively), the differences from 40 to 57 DAS were initially puzzling; whole field color grew lighter while single leaf color became darker. Since whole field color

readings were lighter than single leaf color, the calibrated leaf N values were lower for the same leaf color panel by about 1%. This is contrary to the pre-project calibration. It is not surprising that the whole field method would predict lower values since the color of the field is an integration of all visible leaves, some of which are older.

Regression analysis demonstrated that the WF method was most accurate at PI for all varieties tested (Table 6). Coefficients of determination ranged from 0.63 at mid tiller for M-202, M-205, M206, and S-102 to 0.81 at PI for M-402 and M-104. In all cases the regression fit was stronger at PI than at mid tiller. Pooling the varieties showed that WF leaf color accounted for 75 percent of the observed variation in leaf N. Interestingly when the relative contribution of individual leaves by position was determined by multi-regression analysis the second position leaf was the most significant contributor. The equation of the fitted model was:

$$\text{WF} = -0.0290 - 0.3017 * \text{Leaf 1} + 0.9202 * \text{Leaf 2} + 0.0482 * \text{Leaf 3} + 1.1503 * \text{composite}$$

where $R^2 = 75.02$ and $P = 0.001$.

The highest P-value on the independent variables is 0.9093 belonging to Leaf 3 (Table 7). Since the P-value is greater than 0.10, Leaf 3 is not statistically significantly at the 90% confidence level. Therefore it can be removed from the model. This concurs with previous research demonstrating that canopy color is dominated by Leaf 1 and Leaf 2 (6).

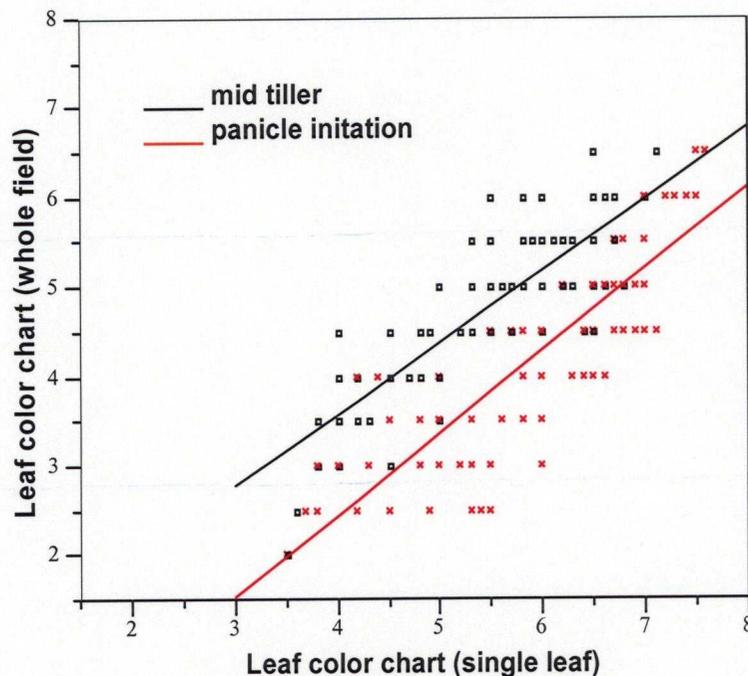


Figure 11. Whole field leaf color method versus the single leaf color method.

The SL method is recommended for final determination of leaf N status when making fertility management decisions. However, the WF technique provides useful tool for identifying parts of the field that are under fertilized and requiring closer inspection. It also provides growers with a means to remotely delineated portions of a field that would benefit from site specific management practices.

Table 6. Determination of leaf nitrogen from whole field color value at mid-tiller (MidTlr) and panicle initiation (PI) stages for each variety: equations of best fit, range of applicability and leaf N (%) calculation.

Variety	Stage	Fitted equation of Leaf Color vs Leaf N(%)	R-Square	LCC
		Prediction equation		Range
M205	MidTlr	$N = 0.472 * LCC + 0.796$	0.63	$1.3 \leq LCC \leq 4.6$
M206				
S102				
M202	PI	$N = 0.425 * LCC + 0.736$	0.79	$1.2 \leq LCC \leq 4.1$
	Both	$N = 0.328 * LCC + 0.851$	0.66	$1.1 \leq LCC \leq 3.7$
M402	MidTlr	$N = 0.347 * LCC + 0.814$	0.67	$1.1 \leq LCC \leq 3.8$
M104				
	PI	$N = 0.519 * LCC + 0.816$	0.81	$1.3 \leq LCC \leq 5.0$
	Both	$N = 0.542 * LCC + 0.779$	0.76	$1.3 \leq LCC \leq 5.1$
All Var.	MidTlr	$N = 0.484 * LCC + 1.4328$	0.58	$1.9 \leq LCC \leq 5.3$
	PI	$N = 0.485 * LCC + 0.754$	0.75	$1.2 \leq LCC \leq 4.6$
	Both Stages	$N = 0.402 * LCC + 0.832$	0.65	$1.2 \leq LCC \leq 4.0$

Table 7. Multiple regression analysis describing the relative contribution of leaf canopy position to whole field color as determined by the leaf color chart.

Dependent variable: LCC whole field

Parameter	Estimate	SE	T statistic	P-value
Constant	-0.028999	0.28586	-0.101406	0.9195
Leaf 1	-0.301722	0.39813	-0.757842	0.4506
Leaf 2	0.920242	0.49764	1.8492	0.0679
Leaf 3	0.048207	0.42204	0.114225	0.9093
Composite	1.1503	0.28320	4.06173	0.0001

Analysis of Variance

Source	Sum of Squares	DF	Mean Sq	F-ratio	P-value
Model	114.267	4	28.5666	120.60	0.0000
Residual	20.1334	85	0.236864		

Total (corr.) 134.40 89
 R-squared = 85.0189 percent
 R-squared (adjusted for DF) = 84.3148
 Standard error of estimate = 0.486687
 Mean absolute error = 0.380676
 Durbin-Watson statistic = 0.696935 (P=0.0000)

Adequate Levels of Leaf N

Increasing levels of N delayed plant development. Days to 50% heading increased in a linear fashion for both M-202 and M-205 (Figure 12). M-205 was consistently 5 days later than M-202 irrespective of the N level. Four N treatments produced comparably the highest yields (Figure 13). The single application treatments of 125 and 150 lb/a preplant produced 10100 and 10300 lb/a, respectively, in contrast to the 2002 study where the highest yields were observed at 100 N lb/a. Both the 125 and 150 treatments displayed 50 percent lodging. The apparent advantage to split applications of N in this study was a reduction in lodging. A high incidence of lodgings can lead to uneven ripening and loss in quality. Confirming findings from 2002, adequate levels of leaf N ranged between 3.3 and 3.6 percent at PI (Figure 14).

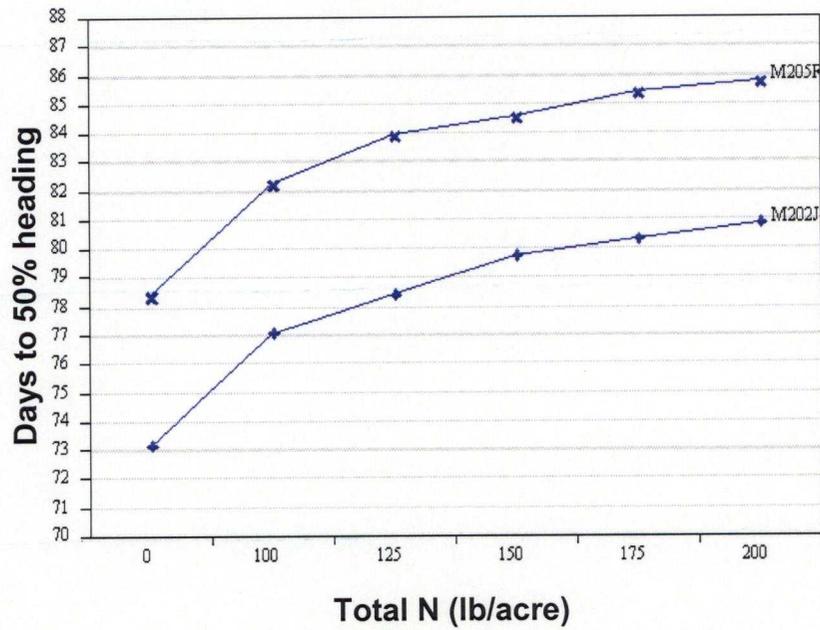


Figure 12. Days required to reach 50% heading for M-202 and M-205 at different levels of applied N.

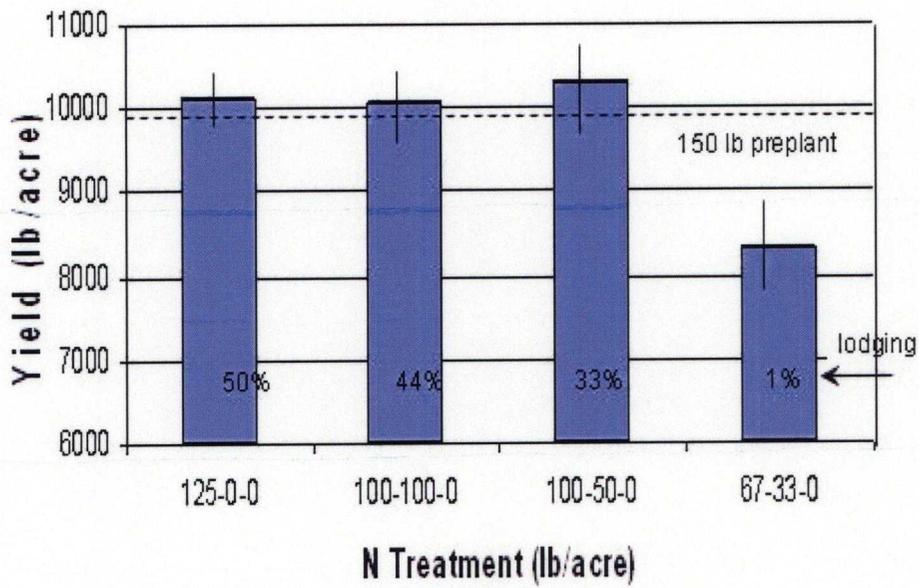


Figure 13. Maximum yields and associated rates and timing of N application.

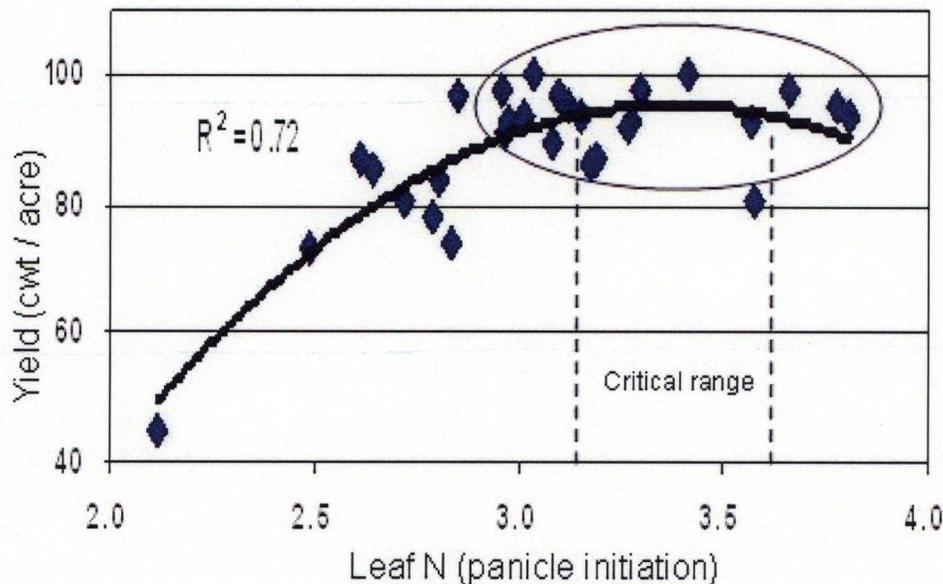


Figure 14. Yield as a function of leaf N at panicle initiation. Pooled across varieties M-202 and M-205.

The calibrations were not affected by split fertilizer applications. Perhaps the most important result from all three trials, was the finding that the relationship of leaf N to leaf color was highly dependent upon stage and was dependent upon variety to a lesser degree. Also, the single leaf method is strongly recommended over the whole field method.

Outreach and Education

Outreach and education was a primary objective throughout the study. Project personnel engaged growers and pest control advisors throughout the year. In the winter months numerous UCCE sponsored educational meetings included information related to the LCC. During the summer months we consulted with agricultural professional in the field both on a one to one basis and at UCCE sponsored field days. The number of people contacted by this project is an exemplary of Cooperative Extension's ability to effectively convey information in a timely manner to a large audience.

Results from the controlled study were used to develop an updated calibration curve for the LCC. The adjusted linear calibration model ($Y = 0.385 \text{ LCC} + 1.15$) was developed by pooling all single leaf results from the FREP studies. Unlike the previous iteration, the single leaf applies to all varieties. Therefore the use of the LCC is simplified without compromising accuracy. Calibrations for individual varieties were also made available.

Additionally for the first time, a whole field calibration is possible. Notice that because for the contribution of the lower leaves in the canopy and their corresponding nitrogen levels, the whole method predicts lower nitrogen content. This will prove useful for rapidly evaluating a large area and offer guidance to farm managers where extensive sampling is required.

Specific outreach and education accomplishments are listed below.

1. Winter Meetings. Information from this study was presented at 12 different meetings, 4 in each year of the study 2002, 2003, and 2004. Total attendance for the 12 meetings was over 1200 people.
2. Rice Production Workshop. Five all day production workshops were conducted over the course of the project, two in 2002 and 2003 and one in 2004. The use of the LCC was fully integrated into the N management section of the workshop. Details on the LCC were provided as part of a 12 chapter production manual. Leaf color chart were made available by request to all participant through a sign-up sheet. LCC's were mailed to all that requested one free of charge. Combined attendance was over 400 people.
3. Summer Field Meetings. Two field meetings were held in each year. In 2002 and 2003, the meetings were held at the experimental sites. In 2004, the field days were held in participating growers fields. Combined attendance was 120 people.
4. Annual Rice Field Day. Informed growers about the LCC at the Rice Experiment Station Annual field day (August 2002) attended by over 600 people.
5. Newsletters. Periodic newsletters mailed through the local UCCE offices, the California Rice Commission, or the California Research Board (RRB) contained articles on the LCC. The combined mailing lists of the three organizations exceeds 2500 recipients.
6. Web Based Information. Information on the LCC is posted on the UC and RRB websites.
7. On-farm Visits. Project personnel were available upon request for personnel consultations during the growing season throughout the rice growing region of California. We made our office and mobile telephone numbers widely available through newsletters and group meetings. We visited farms in all 8 rice producing counties including San Joaquin County. Consultations with rice producers in Fresno County were conducted by telephone. Sixty four farm calls and numerous telephone consultations were made.
8. Grower Participation. 169 growers signed-up to participate in the on-farm calibration portion of the project. Growers were sent an LCC and complete of instruction on gathering and processing leaf samples. Farm visits mentioned in number 6 above commonly coincided with the leaf sampling period.
9. Mailing List. A mailing list of interested growers was compiled. New information such as updated calibration tables were mailed to the entire list on a periodic basis. Updated calibration tables will be provided in the form of an adhesive label that can be directly attached to the LCC for easy use. See Appendix D.

10. LCC Distribution. In addition to the 169 people that received a LCC in 2002, all new requests for an LCC were honored. This practice continues today. To date over 400 LCC's have been given to growers and PCAs in the California.
11. Scientific Meetings. Presentations were made at National Rice Technical Workgroup meetings, Little Rock 2002 and the Irrigated Rice Conference, Camboriu, Brazil, 2004.

Summary

A leaf color chart (LCC) consisting of 8 color cells representing the actual reflectance characteristics of rice leaves across a range of nitrogen levels and produced using University of California patented technology was evaluated for use in rice fields. Controlled replicated studies, area wide sampling, and grower generated information produced linear LCC calibration functions that predicted leaf N with a high degree of accuracy. R^2 for the three calibration methods were 0.86, 0.87, and 0.81, respectively when data was pooled across varieties. The regression fitted equations were similar in slope (0.385, 0.426, and 0.433, respectively) and intercept (1.15, 1.01, and 0.85, respectively). Calibration equations varied somewhat between individual varieties. The single leaf technique of predicting leaf N proved to be more accurate than the whole field technique. This was not surprising given the contribution of several layers of leaves to overall canopy color. While the whole technique is fairly reliable ($R^2 = 0.75$), it is recommended that it be used only to ascertain what portion of a field requires closer scrutiny with regard to plant nitrogen status. Fertility management decisions would be better serve if based on results from the single leaf method.

The LCC was initially distributed to California rice growers and pest control advisors as part of a cooperative project. Individuals who agreed to participate in the on-farm phase of the calibration effort were provided an LCC and complete set of instructions free of charge. One hundred and sixty nine LCC were mailed to participants. Project personnel supported the participants through organized training and demonstration events, on-farm consultations, and by telephone. The calibration curve resulting from this effort is discussed in the preceding paragraph. When results from the 2002 studies were presented during the UCCE sponsored winter meetings, the LCC was made available to the agricultural at large upon request. Sign up sheets were circulated at meetings held throughout the Sacramento Valley. All individuals requesting an LCC received one free of charge. Additionally an updated calibration table printed on a self-adhesive label was mailed to all previous users of the LCC. The label is easily attached to the back of the LCC. In all over 400 LCC's have been distributed to date.

Outreach and education was continually pursued throughout the project. Twenty meetings of various sizes addressing aspects of the LCC were held during the contractual period. Project personnel delivered over 60 personalized on-farm consultations. Over 5400 project related contacts were logged during the project. Feedback from growers and PCA's indicated a fairly high acceptance rate of the LCC as a tool for nitrogen management.

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Appendix A

Statistical Analysis of N X V trial

Nitrogen X variety ANOVA (Reps not sig.)

Response Yield (lb/ac)

Summary of Fit

RSquare	0.948311
RSquare Adj	0.920685
Root Mean Square Error	395.778
Mean of Response	6676.1
Observations (or Sum Wgts)	90

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	49	166681333	3401660	21.7164	
Error	40	6265609	156640		
C. Total	89	175766466			<.0001

Effect Tests

Source	Nparm	DF	DFDen	Sum of Squares	F Ratio	Prob > F	
Rep	2	2	8	370562	1.1828	0.3548	
N Rate	4	4	8	13800294	22.0255	0.0002	
Rep*N Rate&Random	15	8	40	2536240	2.0239	0.0681	Shrunk
Variety	5	5	10	36033462	46.0079	<.0001	
Rep*Variety&Random	18	10	40	2233531	1.4259	0.2044	Shrunk
Variety*N Rate	20	20	40	31117877	9.9329	<.0001	

Tests on Random effects refer to shrunken predictors rather than traditional estimates.

Effect Details

Rep

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
1	6735.0667	152.42739	6735.07
2	6804.3333	152.42739	6804.33
3	6488.9000	152.42739	6488.90

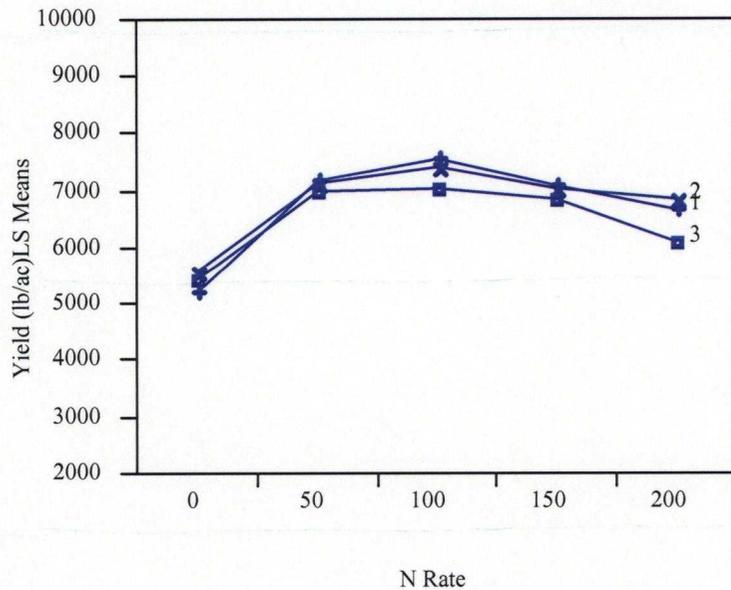
N Rate

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
0	5411.8889	169.69594	5411.89
50	7106.8333	169.69594	7106.83
100	7325.8333	169.69594	7325.83
150	6986.6111	169.69594	6986.61
200	6549.3333	169.69594	6549.33

Rep*N Rate&Random

LS Means Plot



Variety

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
M104	6473.9333	169.86889	6473.93
M202	7251.8000	169.86889	7251.80
M205	6863.3333	169.86889	6863.33
M206	7558.1333	169.86889	7558.13
M402	4612.8000	169.86889	4612.80
S102	7296.6000	169.86889	7296.60

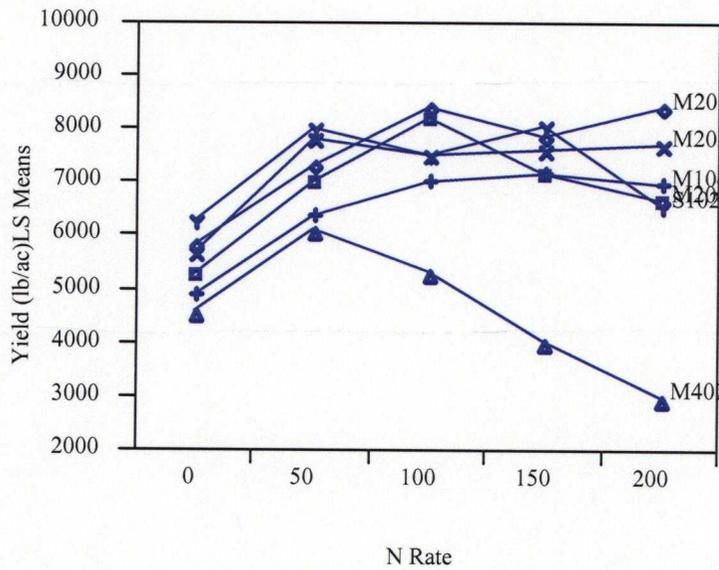
Variety*N Rate

Least Squares Means Table

Level	Least Sq Mean	Std Error
M104,0	4862.0000	291.06080
M104,50	6373.6667	291.06080
M104,100	6997.6667	291.06080
M104,150	7175.3333	291.06080
M104,200	6961.0000	291.06080
M202,0	5656.6667	291.06080
M202,50	7801.6667	291.06080
M202,100	7501.3333	291.06080
M202,150	7602.3333	291.06080
M202,200	7697.0000	291.06080
M205,0	5256.6667	291.06080
M205,50	7034.6667	291.06080
M205,100	8209.3333	291.06080
M205,150	7148.3333	291.06080
M205,200	6667.6667	291.06080
M206,0	5825.3333	291.06080
M206,50	7314.0000	291.06080
M206,100	8405.3333	291.06080
M206,150	7858.0000	291.06080
M206,200	8388.0000	291.06080
M402,0	4577.0000	291.06080

Level	Least Sq Mean	Std Error
M402,50	6109.6667	291.06080
M402,100	5320.6667	291.06080
M402,150	4052.6667	291.06080
M402,200	3004.0000	291.06080
S102,0	6293.6667	291.06080
S102,50	8007.3333	291.06080
S102,100	7520.6667	291.06080
S102,150	8083.0000	291.06080
S102,200	6578.3333	291.06080

LS Means Plot



Response Yield (lb/ac)

Summary of Fit

RSquare	0.268365
RSquare Adj	0.131793
Root Mean Square Error	1309.437
Mean of Response	6676.1
Observations (or Sum Wgts)	90

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	14	47169526	3369252	1.9650	
Error	75	128596940	1714626		Prob > F
C. Total	89	175766466			0.0324

Effect Tests

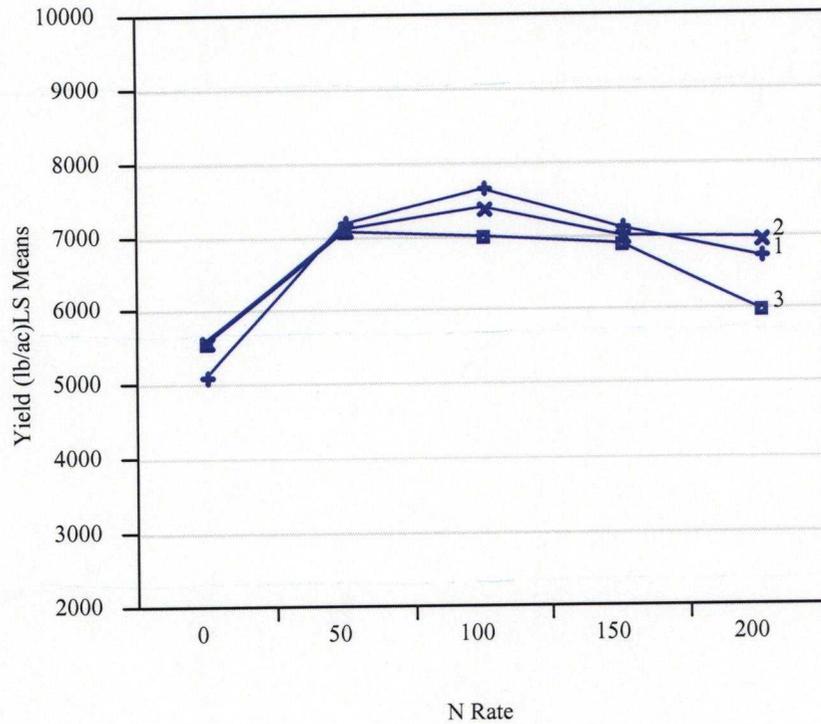
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Rep	2	2	1648941	0.4808	0.6202
N Rate	4	4	41731223	6.0846	0.0003
Rep*N Rate	8	8	3789362	0.2763	0.9718

Effect Details
Rep*N Rate

Least Squares Means Table

Level	Least Sq Mean	Std Error
1,0	5093.5000	534.57551
1,50	7161.5000	534.57551
1,100	7620.8333	534.57551
1,150	7093.0000	534.57551
1,200	6706.5000	534.57551
2,0	5588.5000	534.57551
2,50	7104.8333	534.57551
2,100	7369.8333	534.57551
2,150	6996.8333	534.57551
2,200	6961.6667	534.57551
3,0	5553.6667	534.57551
3,50	7054.1667	534.57551
3,100	6986.8333	534.57551
3,150	6870.0000	534.57551
3,200	5979.8333	534.57551

LS Means Plot



APPENDIX B

List of participating growers

Table B. List of participating growers.

First Name	Last Name	Street Address	City	State	Zip
Joe	Lauwenrijssen	6380 Hillgate Rd.	Arbuckle	CA	95912
Sharron	Wiggin	6590 Hillgate	Arbuckle	CA	95912
John	Scheimer	P.O. Box 248	Arbuckle	CA	95912
Bob	Wallace	P.O. Box 580	Arbuckle	CA	95912
William	Meredith	3747 Mary Lane	Auburn	CA	95602
Rodney	Jenkins	2971 Dos Rios Rd.	Biggs	CA	95917
Carl	Johnson	P.O. Box 306	Biggs	CA	95917
Kent	McKenzee	P.O. Box 306	Biggs	CA	95917
T&B Farm		P.O. Box 456	Biggs	CA	95917
Jerry	Southham	1749 Co. Rd. Y	Butte City	CA	95920
Walter	Ludy	P.O. Box 144	Butte City	CA	95920
NIH Farm		P.O. Box 67	Butte City	CA	95920
Muham	Hussain	P.O. Box 9	Butte City	CA	95920
Martin	Jones	1720 Bidwell Ave.	Chico	CA	95926
Brad	Wurlitzer	721 Sheridan Ave.	Chico	CA	95926
Lance	Tennis	P.O. Box 5491	Chico	CA	95927
John	Werner	4 Skymountain Circle	Chico	CA	95928
Ryan	Christy	105 Jay St.	Colusa	CA	95932
Toby	Leonard	1525 Rosewood Way	Colusa	CA	95932
John	Brown	2070 Wescott Rd.	Colusa	CA	95932
David	Jarrett	3278 Arena Dr.	Colusa	CA	95932
Punch	Haskell	3437 Grover Ave.	Colusa	CA	95932
Jim	Pingrey	944 Ninth St.	Colusa	CA	95932
Alan	Deaner	P.O. Box 1212	Colusa	CA	95932
Kathy	Yerxa	P.O. Box 209	Colusa	CA	95932
Jeff	Moresco	P.O. Box 292	Colusa	CA	95932
Derrick	Ash	P.O. Box 296	Colusa	CA	95932
Arnold	Andreotti	P.O. Box 298	Colusa	CA	95932
J.R.	Galagher	P.O. Box 730	Colusa	CA	95932
Jim	Rogers	P.O. Box 850	Colusa	CA	95932
Bill	Prichard	2409 Madrid Ct.	Davis	CA	95616
Mat	Huston	3031 Ginaro Place	Davis	CA	95616
Stacey	Roberts	721 Falcon Ave.	Davis	CA	95616
Richard	Lewis	Dept. Of Entomology-Br	Davis	CA	95616
Pat	Mullen	P.O. Box 410	Des Arc	AR	72040
Fred	Stolp	2911 Grainland Rd.	Durham	CA	95938
Gene	Fenn	3555 Grainland Rd.	Durham	CA	95938
Lance	Benson	P.O. Box 1180	Durham	CA	95938
Frank	Heffren	P.O. Box 427	Durham	CA	95938
August	Boeger	P.O. Box 479	Durham	CA	95938
Mike	Perkins	P.O. Box 510	El Campo	TX	77437
Curtis	Sandbey	7509 Song Sparrow Way	Elk Grove	CA	95758
Steve	Hohn	13607 Campbell	Escalon	CA	95320
Bill	Sorrenti	14033 Steinegul	Escalon	CA	95320

Iris	Moffit	25744 E. Lone Tree Rd.	Escalon	CA	95320
Mike	Benedix	25888 E. Dobbs Rd.	Escalon	CA	95320
Rodney	Kromann Jr.	26089 E. Magnolia Ave.	Escalon	CA	95320
Greg	Jackson	925 Gina Ct.	Escalon	CA	95320
Herman	Doornenbal	P.O. Box 235	Escalon	CA	95320
Mike	Garcia	2403 Co. Rd. W	Glenn	CA	95943
Greg	Pylman	2586 Hwy. 45	Glenn	CA	95943
Craig	Boschi	2999 Co. Rd. VV	Glenn	CA	95943
Rick	Simson	7554 Rd. 35	Glenn	CA	95943
Lorenzo	Pope	7875 Co. Rd. 321/2	Glenn	CA	95943
Paul	Imle	Route 1 Box 30	Gonvick	MN	56644
Drew	Rudd	1117 Larkin Rd.	Gridley	CA	95948
Mike	Boeger	P.O. Box 364	Gridley	CA	95948
George	Sligar	P.O. Box 46	Gridley	CA	95948
Robert	King	P.O. Box 342	Gridley	CA	95948
Larry	Pires	7982 Kirkville Rd.	Knightslanding	CA	95645
Jerry	Whatley	7101 Gulf Highway	Lake Charles	LA	70607
Curt	Scilacci	6115 W. Wise Rd.	Lincoln	CA	95648
Nick	Greco	P.O. Box 273	Lincoln	CA	95648
Gary	Rudd	10875 N. Butte Rd.	Live Oak	CA	95953
Doug	Rudd	10879 N. Butte Rd.	Live Oak	CA	95953
Frank M.	Rosa	4796 Clark Rd.	Live Oak	CA	95953
Darin	Clark	4109 Mary Ave.	Marysville	CA	95901
William	Baggett	7605 Hwy 70	Marysville	CA	95901
Elloy	Mohella	9088 Shell Rd.	Marysville	CA	95901
Jim	Vierra	P.O. Box 130	Maxwell	CA	95955
Danny	Vierra	P.O. Box 130	Maxwell	CA	95955
Lemuel	Pearson	P.O. Box 192	Maxwell	CA	95955
George	Cain	P.O. Box 278	Maxwell	CA	95955
Steve	Dennis	P.O. Box 368	Maxwell	CA	95955
John	Pfyl	P.O. Box 455	Maxwell	CA	95955
Jack	DeWitt	P.O. Box 603	Maxwell	CA	95955
Joe	Richter	P.O. Box 664	Maxwell	CA	95955
Russel	Pearson	P.O. Box 89	Maxwell	CA	95955
Ed	Lang	12447 Moroni Rd.	Meridian	CA	95957
Lotfin	Kent	6315 Hwy. 17 South	Newport	AR	72112
Dave	Rolufs	1378 Marcum Rd.	Nicolaus	CA	95659
Mike	Daddow	1568 Marcum Rd.	Nicolaus	CA	95659
Jay	Bolton	3789 A Powerline	Nicolaus	CA	95659
Brett	Scheidel	P.O. Box 35	Nicolaus	CA	95659
Clay	Jacobson	3992 Cord U.	Orland	CA	95963
Dennis	Lindberg	1096 Middlehoff Ln.	Oroville	CA	95965
Tom	Donati	1908 Hwy. 70	Oroville	CA	95965
Justin	Olensk	1700 Majurra Dr.	Pleasant Grove	CA	95668
Kent	Brocker	1864 Weatlett Rd.	Pleasant Grove	CA	95668
Thomas	Cuquet	2244 Catlett Rd.	Pleasant Grove	CA	95688
Walt	Trevethan	2985 Catlett Rd.	Pleasant Grove	CA	95668
Brian	Van Dyke	4416 Pleasant Grove Rd.	Pleasant Grove	CA	95668
Kenji	Tokita	7235 Pacific Ave.	Pleasant Grove	CA	95668
Chris	McKenzie	P.O. Box 603	Pleasant Grove	CA	95668

Gary	VanDyke	P.O. Box 767	Pleasant Grove	CA	95668
Bruce	Lopes	699 Co. Rd. W	Princeton	CA	95970
Bill	Weller	7849 Co. Rd. 62	Princeton	CA	95970
John	Garner	P.O. Box 121	Princeton	CA	95970
Greg	Massa	P.O. Box 304	Princeton	CA	95970
Braly	Zumwalt	P.O. Box 35	Princeton	CA	95970
Brent	Owen	P.O. Box 2483	Redding	CA	96099
K.D.	Hawkins	P.O. Box 992483	Redding	CA	96099
Christine	Negm	5370 Church St.	Richvale	CA	95974
Steve	Rystrom	P.O. Box 342	Richvale	CA	95974
Nancy	Schleiger	P.O. Box 352	Richvale	CA	95974
Marty	Lund	1504 Pacific Ave.	Rio Oso	CA	95674
Rich	French	218 Pleasant Grove Rd.	Rio Oso	CA	95674
Steven	Mintz	218 Pleasant Grove Rd.	Rio Oso	CA	95674
	Demeter Corp	2591 W. Elkhorn Blv.	Rio Linda	CA	95673
Wally	DeWitt	3630 Miami St.	Sacramento	CA	95821
Jim	Sopwith	4850 Riego Rd.	Sacramento	CA	95836
Gale	Houser	5370 W. Riego Rd.	Sacramento	CA	95837
P.J.	Aiken	2245 W. Charter Way	Stockton	CA	95206
Dennis	Pelucca	P.O. Box 6992	Stockton	CA	95206
Albert	Giammecchini	2966 Beyer Ln.	Stockton	CA	95215
David	Giampaoli	9343 Pass Rd.	Sutter	CA	95911
Don	Boom	P.O. Box 364	Wheatland	CA	95692
Doug	Mayberry	P.O. Box 1390	Williams	CA	95987
Michael	Montz	6959 Co. Rd. 57	Willows	CA	95988
Maurice	Merrill	7397 Co. Rd. 41	Willows	CA	95988
Carl	Funke	7542 Co. Rd. 44	Willows	CA	95988
Roy	Newland	7754 Co. Rd. 44	Willows	CA	95988
Joel	Danley	853 Pacific Ave.	Willows	CA	95988
Donald	Cecil	P.O. Box 1303	Willows	CA	95988
Heath	Crowe	P.O. Box 1303	Willows	CA	95988
Roy	Holzappel	P.O. Box 1303	Willows	CA	95988
Gina	Taylor	P.O. Box 1303	Willows	CA	95988
Wayne	Montz	P.O. Box 1312	Willows	CA	95988
Rick	Rominger	23756 Co. Rd. 89	Winters	CA	95694
John	Miller	174448 Co. Rd. 97	Woodland	CA	95695
	Millsar Farms	17448 Co. Rd. 97	Woodland	CA	95695
Fritz	Durst	1769 Woodside Dr.	Woodland	CA	95695
Chris	O'Sullivan	25 Gibson Rd.	Woodland	CA	95695
Bill	Geer Jr.	3 Rancho Place	Woodland	CA	95695
Tim	Miramontes	37170 County Rd. 15	Woodland	CA	95695
Bill	Geer	704 Elm St.	Woodland	CA	95695
Jan	Blixen	825 W. Cross St.	Woodland	CA	95695
Ron	Lee	880 Notre Dame Dr.	Woodland	CA	95695
Ashley	Payne	P.O. Box 1813	Woodland	CA	95776
Chuck	Buckingha	P.O. Box 1818	Woodland	CA	95776
Kay	Siller	1453 Bogue Rd.	Yuba City	CA	95991
Ignacia	Ayala	1947 Harbor Town Dr.	Yuba City	CA	95991
Larry	Middleton	P.O. Box 625	Yuba City	CA	95991
Randall	Krehe	1021 Bogue Rd.	Yuba City	CA	95991

John	Munger	12755 Garden Hwy.	Yuba City	CA	95991
Alfred	Montna	12755 Garden Hwy.	Yuba City	CA	95991
Pete	Montna	2100 Everglade	Yuba City	CA	95991
Bill	Warnock	2996 Caminito Ave.	Yuba City	CA	95991
Doug	Boeger	494 Jones Rd.	Yuba City	CA	95991
Matt	Brugmann	1127 Yolanda Dr.	Yuba City	CA	95993
Jim	Mitchum	2120 Sanborn Road	Yuba City	CA	95993
Jake	Onstott	2120 W. Onstott Frtge.	Yuba City	CA	95993
Rick	Gerst	2274 Goldleaf Ct.	Yuba City	CA	95993
Brad	Krehe	3203 Oswald Rd.	Yuba City	CA	95993
Bob	Amarel Jr.	6368 S. Township	Yuba City	CA	95993
Eugene	Muzio	12500 E. Fairchild Rd.	Stockton	CA	95215
Mike	Juneh	1129 Cypress St.	Willows	CA	95988

Appendix C

Instruction sheet for leaf sample – picture of bags etc

LEAF COLOR CHART (LCC) CALIBRATION

June 2002

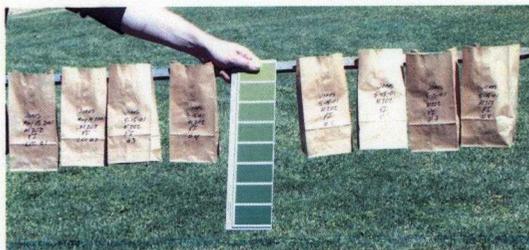
Dear Cooperator:

Based on experimental plots and several field surveys, the LCC accurately predicts leaf nitrogen content in rice. The next steps are to field test the LCC under grower conditions and develop a calibration table for multiple varieties. We need your help.

Enclosed is the LCC that you requested when you signed up to help with the field testing. Also included is an instruction sheet for using the LCC, 2 sets of sample bags, 2 sets of sample labels, and extra sample labels. We would appreciate as many sets of samples that you have time to collect. The procedure for sample collection and handling is outlined below.

Suggested materials:

Small paper bags
 Marking pen
 Tape or staple gun
 Wooden stake 4 - 5 feet long



We suggest taping the eight bags to the stick so the samples can be carried comfortably, one bag for each color panel.

Information needed on the sample bags:

Grower Name:	Ex: Tom Jones
Date of Collection:	7-15-01
Variety:	M202
Growth Stage:	PI
Days after Planting:	60 days
LCC Panel No.:	#6
Herbicides w/in last month:	Grandstand

Sample collection:

With the sun at your back, between 10 AM and 2 PM, select and pick Y leaves (most recently fully expanded leaf) from a plant, match the leaf to the closest individual color chip and place in the corresponding paper bag. Sometimes the leaves will not exactly match the color panels – Choose the panel that is the closest match. Approximately 25 leaves are needed for a reliable chemical analysis. Be sure to hold the LCC in such a way that surface reflection is minimized.

Most of your field will probably correspond to only 3 to 4 color panels. To sample for the

lighter and darker color panels, leaves can be taken around fertilizer skips and over lap areas. Match leaves to as many color chips as reasonably possible.

Sample handling after collection:

Samples need to air dry to preserve quality. Leaves exposed to direct sun will fade and loose quality quickly. A warm, dry, well-ventilated place (away from fertilizers) is best. Do not roll bags tightly at this stage since they will not dry out properly; bags left open will dry faster. Once samples are completely dry, close the bags and send to the following address:

University of California
Cooperative Extension
2279B Del Oro Ave.
Oroville, CA 95965

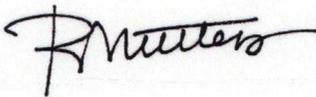
Attn: Cass Mutters

Thank you for your assistance. The combined efforts of growers across the rice-growing region should produce reliable calibrations for most varieties and locations. Results will be mailed directly to participants and made available throughout the industry through newsletters and grower meetings.

Minolta Chlorophyll Meter:

By design, the LCC relates very well to the chlorophyll meter (SPAD). If you plan to use the LCC in tandem with the meter, we have some variety specific information that may be helpful.

If you have any questions please contact Cass Mutters at 530-538-7201 or Jim Eckert at: 530-538-2090.



Farm Advisor
UC Cooperative Extension

Appendix D

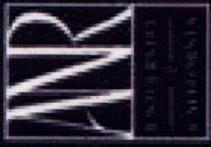
Self adhesive calibration label based results from current study that was mailed to all participating growers and pest control advisors. It was included in all subsequent requests for the LCC.

LEAF COLOR CHART

Single Leaf
% N =

Whole Field
% N =

1	2	3	4	5	6	7	8
1.5	1.9	2.3	2.7	3.1	3.5	3.8	4.2
0.9	1.3	1.7	2.1	2.5	3.0	3.4	3.8



Single Leaf Method: Match the most recently fully expanded leaf to the corresponding color panel. Determine the nitrogen level from the above table.
Whole Field Method: Hold the chart just below eye level at a comfortable distance. Match the color of the field to the corresponding color panel.
 The Leaf Color Chart estimates leaf nitrogen content at penicid initiation in rice. Use the chart at mid day in full sunlight with the sun at your back. Tilt the chart slightly to avoid glare. Do not store in direct sunlight.

Experimental Use Only